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# A large-scale "experiment" to examine the effects of landscape context and habitat fragmentation on mammals

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**Abstract**

A large-scale "experiment" was undertaken in a 100 000 ha region of south-eastern Australia to examine the response of mammals to landscape context, habitat fragmentation and other factors. The investigation examined the presence and abundance of mammals in three broad categories of sites for which there were strong contrasts in the composition of the surrounding landscape:

- Large contiguous areas of *Eucalyptus* forest,
- Areas dominated by exotic plantation softwood Radiata Pine (*Pinus radiata*) trees, and
- Fragments of eucalypt forest surrounded by an extensive *P. radiata* plantation.

These sites provided the basis for assessing the effects of what we term "landscape context". Eighty-six fragments of remnant eucalypt forest of varying size, shape, isolation age and other attributes were selected by a stratified, randomization process. Forty sites were located in large contiguous areas of *Eucalyptus* forest and these were matched to the sites in the remnants on the basis of forest type, geology and climatic conditions. A further 40 sites were selected in areas dominated by *P. radiata* trees and these also were matched to sites in the remnants and those in large contiguous areas of native forest on the basis of geology and climatic conditions. Two major surveys sampled mammals in the study. Hairtubing (a technique for detecting animals from the analysis of fur collected in a small portable bait station) was utilized at all 166 sites selected in the study. Trapping and a combination of different types of hairtubing was then employed at a subset of 58 sites. Data from these surveys was used to investigate the response of mammals to landscape context, habitat fragmentation and other attributes. A sub-theme of the study was to assess the efficacy of different methods to count mammals. There were large differences in the effectiveness of the different field techniques. The best technique (best in the sense of counting most animals) varied between species, particularly in relation to body size. Trapping and smaller-sized hairtubes were superior for small mammals such as Brown Antechinus (*Antechinus stuartii*) and Bush Rat (*Rattus fuscipes*). Large hairtubes performed best in the detection of large mammals like the Common Wombat (*Vombatus ursinus*), Common and Mountain Brushtail Possums (*Trichosurus vulpecula* and *Trichosurus caninus*), and Swamp Wallaby (*Wallabia bicolor*). *W. bicolor* and *V. ursinus* showed no response to landscape context and were detected at similar rates in the remnants, sites in large contiguous areas of native forest and sites dominated by stands of *P. radiata*. *Trichosurus* spp. were recorded significantly less often in sites dominated by *P. radiata* trees. Landscape context effects for *R. fuscipes* and *A. stuartii* varied depending on the field methods employed to sample mammals. However, in general, *R. fuscipes* and *A. stuartii* were recorded significantly less frequently in *P. radiata* sites than sites in large contiguous areas of *Eucalyptus* forest or fragments of remnant eucalypt forest surrounded by the softwood plantation. An important finding of our work was that although some species were extremely rare in *P. radiata* stands, no significant differences were identified in mammal presence and abundance between sites located in large contiguous areas of *Eucalyptus* forest and sites in fragments of remnant eucalypt forest surrounded by the softwood plantation. This finding suggests that either: animals from potential population sources in contiguous eucalypt forest can move through the softwood plantation and colonise the remnants, or populations residing in the fragments of remnant eucalypt forest are large enough to resist local extinction. Softwood plantations are presently being expanded in south-eastern Australia, particularly on semi-cleared farmland that supports remnant fragments of native *Eucalyptus* forest and woodland. Our findings indicate that remnant native forest within plantations of exotic *P. radiata* trees are occupied by several species of native mammals even when these fragments are surrounded

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by extensive, largely unsuitable plantation forests that have been established for many decades. These fragments should *not* be cleared during efforts to expand the softwood plantation estate. Large remnants and those with particular habitat features such as a dense cover of vegetation should have priority for exemption from clearing. 

*Keywords:* Mammals; Landscape context; Habitat fragmentation; Sampling methods for mammals; Remnant vegetation; Plantation design; South-eastern Australia

## 1. Introduction

Forest landscapes around the world are undergoing major and rapid change (Noss and Cooperrider, 1994; Forman, 1996), particularly as a result of a range of human activities such as clearing (Graetz et al., 1995), forest harvesting operations (Harris, 1984; Kohm and Franklin, 1997; Lindenmayer et al., 1998) and the establishment of plantations or tree farms (State of the Environment Australia, 1996). The response of biodiversity to these changes has become a major focus of research in ecology (Hansson and Angelstam, 1991; Bennett, 1998). Such studies are particularly relevant in Australia where there has been widespread clearing of native forest and woodland in the 200 years since white settlement (Woodgate and Black, 1988). For example, more than 80 billion trees have been cleared in the Murray-Darling River Basin of south-eastern Australia alone (Walker et al., 1993). In addition, large areas that formerly supported native *Eucalyptus* forest have been replaced by plantations of exotic conifer trees (e.g. Radiata Pine, *Pinus radiata*) (Resource Assessment Commission, 1992).

The impacts of the loss of habitat can be magnified by the fragmentation of, and edge effects in, vegetation that remains (Temple and Cary, 1988). Indeed, many authors regard habitat loss and fragmentation as major factors contributing to the loss of biodiversity worldwide (e.g. Harris, 1984; Wilcove et al., 1986). Despite the widespread recognition of the importance of habitat loss and fragmentation, a better understanding of the response of biota is required (see reviews by Andren, 1994; Zuidema et al., 1996) to assess the effectiveness of strategies designed to mitigate the impacts of human activities on landscape change. Here we describe the results of a large-scale "experiment" in an extensively modified forest landscape near Tumut in south-eastern Australia (Fig. 1). The study examined the effects of fragmentation on populations of mammals, and it encompassed three broad types of sites:

- Sites dominated by extensive exotic softwood *P. radiata* trees.
- Sites in remnant fragments of native *Eucalyptus* forest of varying size and shape located within the boundaries (and thus surrounded by) the *P. radiata* plantation.
- Sites in large contiguous areas of native *Eucalyptus* forest.

For these three broad categories there were strong contrasts in the composition of the surrounding landscape (see Fig. 2). This provided the basis for assessing the effects of what we term "landscape context".

In addition to examining landscape context effects, a subsidiary aim of our work was to assess the response of mammals to other attributes of sites selected within "landscape context" categories including climatic conditions, the structure and floristic composition of the vegetation and the size, shape and spatial isolation of eucalypt fragments embedded within the *P. radiata* plantation. We also investigated the efficacy of methods used to count animals in our field studies. This was because any attempt to assess landscape context and fragmentation effects on mammals is conditional on the field data gathered and thus the techniques employed as part of counting protocols.

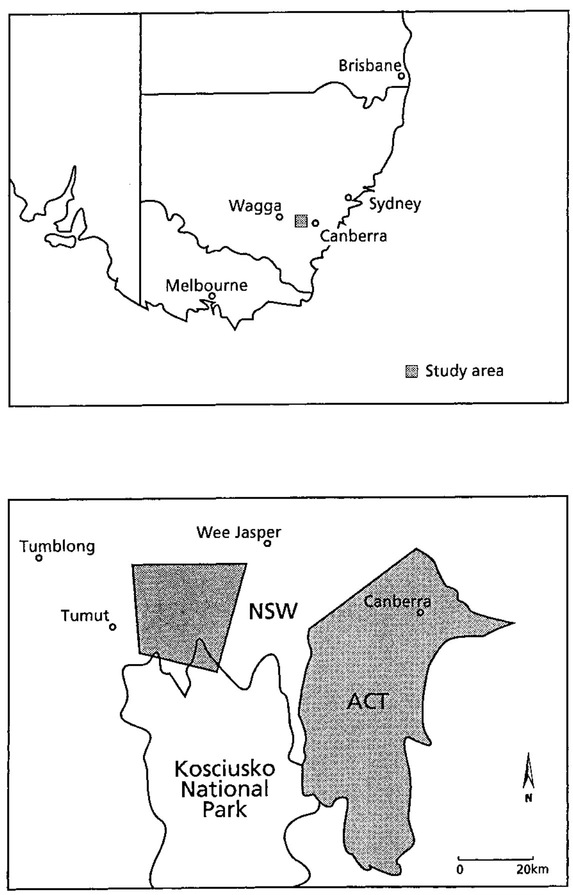



Fig. 1. The general location of area targeted for the fragmentation study at Tumut in southern NSW, south-eastern Australia.

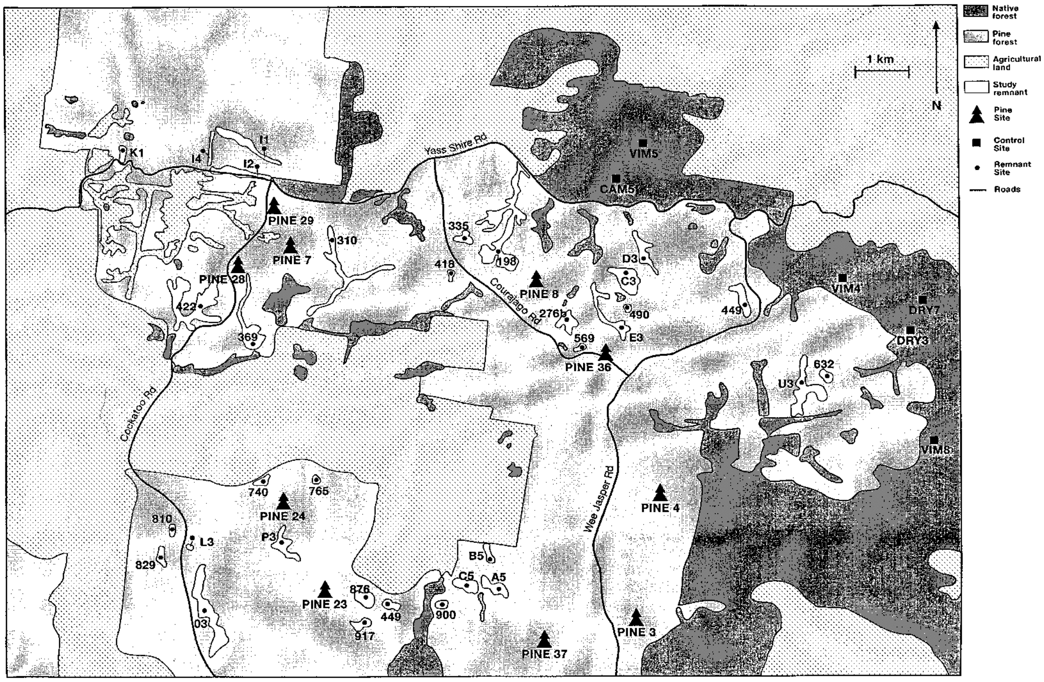



Fig. 2. The location of part of the study area at Tumut showing a subset of remnants, *P. radiata* sites and sites in large areas of native *Eucalyptus* forest. Sites in large areas of native *Eucalyptus* forest have codes such as CAM5, VIM8 or CAM5. Pine sites are denoted Pine 8, Pine 29, etc. Other numbers correspond to patches of native eucalypt forest.

## 2. Methods

### 2.1. Study area and study design

The study took place in the Tumut region of southern New South Wales (NSW), south-eastern Australia (Fig. 1). Our work focussed on forests in and around an extensive *P. radiata* plantation that began being established in the early 1930's. The plantation is called the Buccleuch State Forest and it contains approximately 45 000 ha of exotic conifers (State Forests of NSW unpublished data). Native *Eucalyptus* forest was cleared to establish the *P. radiata* plantation (Tyndale-Biscoe and Smith, 1969). A number of patches of the original forest were left uncleared within the boundaries of the plantation and these form one of the broad groups of sites (the remnants) we investigated. The remnants were exempt from clearing for a number of reasons including: the maintenance of water quality, conservation of representative examples of the original vegetation, unsuitability for plantation establishment, and the presence of large old forest that was difficult to clear. Remnant fragments of *Eucalyptus* forest within the plantation and the extensive areas of native vegetation surrounding the *P. radiata* plantation are dominated by a range of trees species including: Narrow-leaved Peppermint (*Eucalyptus radiata*), Mountain Swamp Gum (*Eucalyptus camphora*), Red Stringybark (*Eucalyptus macrorhynca*), Apple Box (*Eucalyptus bridgesdiana*), Ribbon Gum (*Eucalyptus viminalis*), and, Broad-leaved Peppermint (*Eucalyptus dives*). Understorey vegetation in these areas is comprised of trees such as Silver Wattle (*Acacia dealbata*), Broad-leaved Hickory Wattle (*Acacia falciformis*), Blackwood (*Acacia melanoxylon*) and Cherry Ballart (*Exocarpus cupressiformis*) as well as shrub species like Blanket Leaf (*Bedfordia arborescens*), *Cassinia* spp. and Mountain Tea Tree (*Leptospermum junipereum*) (Costermans, 1994).

Most importantly, extensive on-ground reconnaissance of the study region indicated that features of the areas cleared for softwood establishment (e.g. slope, aspect and topographic position) were also found in both the areas supporting remnant fragments of the original native forest and large areas of contiguous *Eucalyptus* forest beyond the boundaries of the *P. radiata* plantation. This information was used to match the environmental conditions of sites selected within the three broad landscape contexts. Our study employed a rigorous experimental design that was overlaid on the existing landscape characteristics created by human activities in the study region over the past 60 years.

### 2.2. The remnants

There are 192 areas of remnant *Eucalyptus* forest within the boundaries of the *P. radiata* plantation and they range in size (0.2–124 ha), shape (long and narrow [=strips] vs elliptical [=patches]), the time (10–65 years) since the surrounding *P. radiata* forest had been established (=remnant isolation period), and other characteristics. A sample of 86 of the 192 remnants was selected for detailed survey by a stratified and randomized process. Any given remnant was separated from another one by the surrounding *P. radiata* matrix. The 86 remnants encompassed four size classes, two shape classes, two ages of surrounding vegetation, and five groups based on dominant tree species. Table 1 shows the levels used for these variables. The selection procedure meant that as many combinations of remnants in these stratification classes were represented (and replicated where possible).

Sixty-three of the 86 remnants exceeded 3 ha in size. A randomly located 600 m long × 50 m wide site was established in these areas to guide mammal surveys. Flagging tape was used to mark the sites and also to delimit the 0, 100, 200, 300, 400, 500 and 600 m points along the site. The remaining 23 remnants selected for study were < 3 ha and the length of the transect used in these cases was scaled according to remnant size. Remnants 1–2 ha were allocated a 200 m long × 50 m wide site. A 400 m long × 50 m wide site was employed in those covering an area of 2–3 ha.

### 2.3. Pine sites and sites in large areas of contiguous forest

In addition to the 86 remnants, our study included 40 sites dominated by stands of *P. radiata* trees and a further 40 sites located within extensive areas of contiguous native *Eucalyptus* forest. These 80 sites varied in slope, aspect and topographic position. In the case of the *P. radiata* forest, the sites also covered a range of thinning ages, whereas within areas of contiguous native *Eucalyptus* forest, a suite of different forest types was sampled. For all 80 sites, a 600 m × 50 m wide transect (marked at 200 m intervals) was used as the standard sampling unit to count mammals. Fig. 2 shows some of the remnants, sites in stands of *P. radiata* and sites in large contiguous areas of eucalypt forest in part of our study area.

### 2.4. Cross-matching between sites with different landscape contexts

Regional environmental datasets for climate, vegetation cover and geology were used for cross-matching between the three broad types of sites characterised by different spatial contexts. This enabled sites in the remnants and those in contiguous areas of native *Eucalyptus* forest to be matched on the basis of climatic conditions, underlying geology, and dominant tree species. Similarly, sites in stands of *P. radiata* were matched to both the remnants and the contiguous areas of native *Eucalyptus* forest on the basis of climatic conditions and underlying geology. Further details of the procedures used to design our study are presented in Lindenmayer et al. (1997a).

### 2.5. Field methods for counting animals

Two techniques were used to count mammals in our study; aluminium box or Elliott trapping and hairtubing. Elliott traps were set along the flagged sampling transects. Lines of traps remained open for four consecutive nights. Each trapped animal was marked, weighed and sexed before release.

Hairtubing has been used in a number of studies of forest-dependent wildlife in Australia (Laidlaw and Wilson, 1989; Cherry et al., 1990). The method determines the presence of various species of mammals by attracting them to a tube that contains a bait (Suckling, 1978; Scotts and Craig, 1988). The bait is held within a closed chamber that prevents it being removed. Double-sided tape is fixed to the inside of most types of hairtubes. Fur from mammals that enter the tube adheres to the tape and is analysed to identify the species. Identification can be made by an assessment of the gross morphology of a hair sample as well as an examination of sections of individual hairs under a microscope (Brunner and Coman, 1974). A hairtube may be visited by a given animal more than once, and/or by several individuals and species (Scotts and Craig, 1988). The method can have some logistical advantages over other techniques like trapping because hairtubes do not need to be cleared each day allowing large numbers to be employed. However, the approach does *not* yield information on the identity, gender or age of a particular animal (Lindenmayer et al., 1994). It follows that it is not possible to determine the number of times a hairtube is visited by a given animal or the number of hairtubes visited by an individual.

Table 1
Levels of design variables used to stratify the remnant patches of native *Eucalyptus* forest embedded within an extensive plantation of *P. radiata* at Tumut in south-eastern Australia

| Design variable | Levels |
|---|---|
| Remnant size | 1–3 ha, 3–10 ha, 11–20 ha, > 20 ha |
| Remnant shape | Patch, strip |
| Age of surrounding vegetation | Old, young |
| Type of surrounding vegetation | Uniform, heterogeneous |
| Dominant tree species | *E. viminalis*, *E. radiata*, *E. camphora*, Dry [a], Other [b] |

[a] Dry sites are dominated by either *Eucalyptus dives*, *Eucalyptus macrorhynca* and/or *Eucalyptus bridgesdiana*.

[b] Other sites are dominated by either *Eucalyptus dalrympleana*, *Eucalyptus pauciflora*, and/or *Eucalyptus stellulata*.

Earlier investigations have indicated that different species of mammals are detected by different types of hairtubes (Lindenmayer et al., 1994). Given this, we used several types of hairtubes in this study:

- Small tubes with an entrance diameter of 32 mm (see Suckling, 1978; Lindenmayer et al., 1994). These were placed on the forest floor and also fixed to trees 2–3 m above the ground.
- A modified form of the small hairtube described above in which there were crympted depressions (= "dimples") along their length. These were limited to placements on the ground.
- Large tubes (entrance diameter = 105 mm). The design of the large tubes is described by Scotts and Craig (1988). The lack of suitable attachment points on the large tubes meant they were confined to positions on the forest floor.
- A new form of hairtube was devised for our investigation (Faunatech Pty). The "hair funnel" was a tapered device with a closed bait chamber at its narrowest end. The contact area for collecting samples of mammal hair in the funnel was a thin wafer insert on its upper wall that was lined with an industrial adhesive.

### 2.6. Field sampling

Field surveys of mammals were completed between January–February 1996 and again in January–February 1997. During the first survey, hair funnels were set out along the flagged transect lines that had been established at all 166 sites selected for study. A pair of hair funnels was set out at plots located at 100 m intervals along each transect line, giving a maximum of seven plots and 14 funnels per site. In the case of the 23 remnants of eucalypt forest smaller than 3 ha that were included in our experimental design, the number of plots varied according to the length of the flagged transect and thus the remnant size. At a given plot, one funnel was placed on the ground and the other attached to a tree or shrub 2–3 m above the forest floor. This protocol was followed in an attempt to detect both terrestrial mammals as well as scansorial and arboreal mammals (Lindenmayer et al., 1994). The funnels were left in place for seven days before they were retrieved and any hair samples inspected in the laboratory.

In the second major mammal survey (January–February 1997), 58 of the 166 sites were selected for intensive sampling; 41 in remnants, nine in large contiguous areas of native *Eucalyptus* forest, and eight dominated by stands of *P. radiata* forest. Sampling plots were established at 50 m intervals along the flagged transects at each site, giving a maximum of 13 plots per site. At each plot we installed:

- One Elliott aluminium box trap.
- One hair funnel on the forest floor.
- One large hairtube on the forest floor.
- One small hairtube without "dimples" on the ground.
- One small hairtube with "dimples" on the ground.

The length of time used to survey mammals at each plot in 1997 was identical to that used in 1996.

### 2.7. Site and landscape measurements

The major factor in our 'experiment' was the landscape spatial context (i.e. sites dominated by *P. radiata*, sites in eucalypt fragments, and sites in large contiguous areas of native *Eucalyptus* forest). In addition, other attributes of all 166 sites such as vegetation structure and plant species composition were measured and included as covariates in our statistical analyses (Table 2). Estimates of climate attributes also were derived for each of the 166 sites and these included measures such as annual mean temperature and precipitation, mean temperature for the hottest and coldest quarters, and precipitation of the wettest and driest quarters (Table 2). They were obtained by applying the computer-based climate prediction system BIOCLIM (Nix and Switzer, 1991).

Data were gathered for a subset of covariates relevant only to the 86 fragments of eucalypt forest embedded within the limits of the *P. radiata* plantation. These included the five variables used to stratify the selection of the remnants (size, shape, dominant tree species, age of surrounding forest, and variation in age the surrounding forest; see Table 1) as well as other measures such as perimeter to area ratio, a connectivity index and an isolation factor (Table 3). Further details of the range of attributes measured or derived for each site are provided by Lindenmayer et al. (1997a).

## 3. Results

### 3.1. General findings

A total of 17 species of mammals was detected by hairtubing and trapping: Mountain Brushtail Possum (*Trichosurus caninus*), Common Brushtail Possum (*Trichosurus vulpecula*), Sugar Glider (*Petaurus breviceps*), Bush Rat (*Rattus fuscipes*), Brown Antechinus (*Antechinus stuartii*), Black Rat (*Rattus rattus*), Dusky Antechinus (*Antechinus swainsonii*), Swamp Rat (*Rattus lutreolus*), House Mouse (*Mus musculus*), Common Wombat (*Vombatus ursinus*), Swamp Wallaby (*Wallabia bicolor*), Echidna (*Tachyglossus aculeatus*), Rabbit (*Oryctolagus cuniculus*), Red Fox (*Vulpes vulpes*), Feral Cat (*Felis catus*), Dingo and/or wild dog (*Canis familiaris dingo*), Feral Pig (*Sus scrofa*). The final five taxa

Table 2
Measures of the vegetation structure, plant species composition and climatic conditions recorded or derived for sites

| Variable | Description |
|---|---|
| *Plot measures* | |
| Dominant tree | The dominant species of trees in a remnant (identified from buds and fruits – see Costermans, 1994) |
| Stand basal area | Measured in $m^2$ per ha using a basal area wedge |
| Topography | The topographic position of a site, in one six categories: flat, gully, north-facing slope, east-facing slope, south-facing slope, and west-facing slope |
| Disturbance | Evidence of disturbance was recorded and classified as mining, grazing, fire, logging, other and none |
| Dieback index | Evidence of dieback among dominant trees was recorded (e.g. crown and/or lateral branch death) |
| Hollow trees | The abundance of trees with bayonet and branch hollows (*sensu* Jacobs, 1955) was recorded |
| Slope angle | The inclination of a plot measured using a clinometer |
| Bark index | The quantity of strips of decorticating bark peeling from the trunk and lateral branches of trees (see Lindenmayer et al., 1990) |
| Foliage depth | The depth of foliage from the top to the bottom of the largest tree crown in the plot (measured in m) |
| Rock index | A rock cover index was recorded for each plot as one of six classes: none, 1–5%, 5–15%, 15–30%, 30–60%, and >60% |
| Bracken index | The % cover of Austral Bracken (*Pterideum esculentum*) on the forest floor was recorded as one of six classes: none, 1–5%, 5–15%, 15–30%, 30–60%, and >60% |
| Ground cover | The % cover of the forest floor was assigned to one of six classes: none, 1–5%, 5–15%, 15–30%, 30–60%, and >60% |
| Number logs | The number of eucalypt and softwood logs in each diameter classes was recorded (10–20, 20–30, 30–40, 40–50 and >50 cm) |
| Windrows | The number of, and distance to, windrowed piles of logs remaining from the previous stand of *Eucalyptus* forest that was cleared and burnt to establish *P. radiata* trees was recorded. This measure was pertinent only to *P. radiata* sites |
| Dominant cover | The % cover of dominant trees was recorded as one of six classes: none, 1–5%, 5–15%, 15–30%, 30–60%, and >60% |
| Sub-dom. cover | The % cover of sub-dominant plants was recorded as one of six classes: none, 1–5%, 5–15%, 15–30%, 30–60%, and >60% |
| Shrub cover | The % cover of shrubs was recorded as one of six classes: none, 1–5%, 5–15%, 15–30%, 30–60%, and >60% |
| Grass index | The % cover of grass was recorded as one of six classes: none, 1–5%, 5–15%, 15–30%, 30–60%, and >60% |
| Litter depth | Ranked in four categories from none to high |
| Blackberry index | An index describing the prevalence of introduced *Rubus fruticosus* scored from none to 100% in six categories each of 20% intervals |
| Plant matrix | A two-way height and diameter matrix was completed for each plot. Each stem in the plot was assigned by one of five height and seven diameter classes. The height categories were 1–2, 2–4, 4–8, 8–16, 16–30, and >30 m. The diameter classes were: 1–5, 5–10, 10–20, 20–30, 30–40, 40–50, and >50 cm |
| *Measures summed across all plots* | |
| Invasion index | Index (0–5) of the extent of *P. radiata* wildling established along the transect (not relevant in *P. radiata* sites) |
| Pruning status | The stage in the silvicultural cycle of plantation *P. radiata* was recorded. The amount of pruning slash on the forest floor (e.g. lateral branches remaining from thinned trees) also was recorded. These data were relevant to *P. radiata* sites only |
| Geology | Predominant lithology derived from geological surveys and mapping completed for the Tumut region |
| Stream index | A measure of the "moistness" of a site calculated from information on the distance to a watercourse and stream order (*sensu* Strahler, 1957). The index was calculated by dividing the distance to the closest stream from the start of a given transect by the order of the stream. This was repeated from the mid and endpoint of each transect. The three values were then added to give a single overall number for the stream index |
| Eucalypt species | Number of different species of eucalypts recorded (summed across all plots) |
| Temperature indices | Annual mean temperature, Isothermality, Temperature seasonality (C of V), Maximum temperature of the hottest month, Minimum temperature of the coldest month, Temperature annual range, Mean temperature of wettest quarter, Mean temperature of the driest quarter, Mean temperature of the warmest quarter, Mean temperature of the coldest quarter. |
| Precipitation Indices | Annual precipitation, Precipitation of the wettest month, Precipitation of the driest month, Precipitation seasonality (C of V), Precipitation of the wettest quarter, Precipitation of the driest quarter, Precipitation of the warmest quarter, Precipitation of the coldest quarter |
| Radiation indices | Annual mean radiation, Highest periodly radiation, Lowest periodly radiation, Radiation seasonality (C of V), Radiation of the wettest quarter, Radiation of the driest quarter, Radiation of the warmest quarter, Radiation of the coldest quarter |
| Growth indices | Annual mean moisture index, Highest period moisture index, Lowest period moisture index, Moisture index seasonality (C of V), Mean moisture index of the highest quarter moisture index, Mean moisture index of the lowest quarter moisture index, Mean moisture index of the warmest quarter moisture index, Mean moisture index of the coldest quarter moisture index |

are mammals introduced to Australia (Wilson et al., 1992). *R. rattus* and *M. musculus* are also exotic species (Watts and Aslin, 1981).

Of the species of mammals recorded, only six were detected frequently enough to enable detailed data analyses: *V. ursinus*, *W. bicolor*, *R. fuscipes*, *A. stuartii*, *T. caninus* and *T. vulpecula*. As it is not possible to distinguish between hair samples *of T. caninus* and *T. vulpecula*, analyses have been made for both species combined (i.e. *Trichosurus* spp.).

Our study focussed around three key questions:

- Are there any landscape context effects on the presence of mammals?

Table 3
A description of variables gathered specifically for the 86 remnants of *Eucalyptus* forest surveyed for site at Tumut in southern NSW

| Variable | Description |
|---|---|
| Perimeter | The perimeter of each patch. Extracted from a G.I.S. database derived for the plantation and associated remnants |
| Perimeter: area ratio | The ratio of the area of a remnant to its perimeter |
| Distance to native forest | The distance (measured in metres) from the edge of a patch to the nearest large consolidated area (>1000 ha) of native *Eucalyptus* forest |
| Pine age | The age of the *P. radiata* forest surrounding a given patch and reflecting the number of years since the original native forest had been cleared and replaced by exotic conifer trees. Calculated from stand class maps developed for the plantation by State Forests of NSW |
| Surrounding vegetation | The type of vegetation surrounding a remnant was classified as "heterogenous" if there was marked variation (>20 years) in the ages of the adjacent *P. radiata* (such as a clearfall on one edge of a remnant and a mature stand on the other). The type of surrounding vegetation was "uniform" if the entire area of was comprised stands of *P. radiata* of broadly similar age (i.e. <20 years different in the age of extent *P. radiata* forest) |
| Isolation index | The average distance to the closest neighboring remnant in six equal zones surrounding each remnant |
| Connectivity | A measure used to indicate is a remnant was isolated from other areas of native forest (="discrete") or whether it was linked to other areas of eucalypt forest (="non-discrete") |

- Does the addition of covariates help explain some of the observed patterns in animal response?
- Are there differences between field sampling methods in the detection of mammals?

Analyses from field data gathered in 1996 and also in 1997 provide some answers to all but the last of these questions. We present data on detectability by different techniques first because subsequent interpretations of landscape context and other (covariate) effects are conditional on these results.

### 3.2. Method differences in the detection of mammals

Table 4 contains a summary of the number of sites where each of the five most species of mammals was detected by a given method. Cross-tabulations were used to compare detection rates of the different methods (Table 5). For a given species and a nominated pair of methods the cross-tabulations show:

- The number of sites where animals were detected by a given method but not the other method of the selected pair.
- The number of sites where the species was detected by both techniques.
- The total number of sites where the target species was detected by that combination of methods.
- The number of sites where the species remained undetected by the selected pair but was recorded by any other method.

*Trichosurus* spp., *W. bicolor* and *V. ursinus* are too large to be captured in aluminium box traps. Thus, comparisons between trapping and other methods were made only for *A. stuartii* and *R. fuscipes*.

Our analyses revealed large differences between methods in the detectability of different species of mammals. In the case of *Trichosurus* spp., the funnels produced more records than other methods (Tables 4 and 5). The highest number of co-detections on the same site by a pair of methods was recorded by a combination of funnels and large hairtubes. Conversely, dimpled hairtubes performed worst of the methods compared. There were more sites where *Trichosurus* spp. was *not* recorded when the dimpled hairtubes were one of a pair of combination of techniques examined (Table 5). Moreover, there were few instances of

Table 4
The number of sites where mammals were detected by each method for each species codes for columns are: D = Dimpled small hairtubes; F = hair funnels; L = large hairtubes; S = small hairtubes; T = Elliott traps. A dash (–) indicates that Elliott traps are too small to capture large species. The final column shows the total number of sites where a given species was detected by any method

| Species | Field sampling method | | | | | |
|---|---|---|---|---|---|---|
| | D | F | L | S | T | Total |
| *Trichosurus* spp | 6 | 16 | 14 | 14 | – | 26 |
| *A. stuartii* | 18 | 14 | 4 | 19 | 37 | 41 |
| *R. fuscipes* | 12 | 9 | 14 | 18 | 22 | 31 |
| *W. bicolor* | 7 | 10 | 20 | 8 | – | 25 |
| *V. ursinus* | 1 | 3 | 11 | 1 | – | 14 |

Table 5
Comparison of the number of plots where various species of mammals were detected by combinations of different field methods. The codes for the different methods are D = dimpled small hairtubes, F = hair funnel, S = small hairtubes, L = large hairtubes and T = trapping. Positive detection = y; n = no detection

*Trichosurus spp*

| | | S | n | y |
|---|---|---|---|---|
| D | F | L | n | y |
| n | n | n | 31 | 3 |
| n | n | y | 3 | 1 |
| n | y | n | 3 | 3 |
| n | y | y | 3 | 4 |
| y | n | n | 0 | 2 |
| y | n | y | 1 | 0 |
| y | y | n | 1 | 0 |
| y | y | y | 1 | 1 |

*A. stuartii*

| | | | T | n | y |
|---|---|---|---|---|---|
| D | F | L | S | n | y |
| n | n | n | n | 16 | 13 |
| n | n | n | y | 1 | 5 |
| n | n | y | n | 0 | 0 |
| n | n | y | y | 1 | 0 |
| n | y | n | n | 0 | 2 |
| n | y | n | y | 0 | 0 |
| n | y | y | n | 0 | 1 |
| n | y | y | y | 0 | 0 |
| y | n | n | n | 1 | 3 |
| y | n | n | y | 1 | 2 |
| y | n | y | n | 0 | 0 |
| y | n | y | y | 0 | 0 |
| y | y | n | n | 0 | 2 |
| y | y | n | y | 0 | 7 |
| y | y | y | n | 0 | 0 |
| y | y | y | y | 0 | 2 |

*W. bicolor*

| | | S | n | y |
|---|---|---|---|---|
| D | F | L | n | y |
| n | n | n | 32 | 2 |
| n | n | y | 9 | 1 |
| n | y | n | 0 | 0 |
| n | y | y | 3 | 3 |
| y | n | n | 2 | 0 |
| y | n | y | 0 | 1 |
| y | y | n | 1 | 0 |
| y | y | y | 2 | 1 |

*R. fuscipes*

| | | | T | n | y |
|---|---|---|---|---|---|
| D | F | L | S | n | y |
| n | n | n | n | 26 | 7 |
| n | n | n | y | 1 | 1 |
| n | n | y | n | 4 | 1 |
| n | n | y | y | 1 | 1 |
| n | y | n | n | 1 | 0 |
| n | y | n | y | 0 | 0 |
| n | y | y | n | 0 | 2 |
| n | y | y | y | 1 | 0 |
| y | n | n | n | 0 | 3 |
| y | n | n | y | 0 | 0 |
| y | n | y | n | 1 | 1 |
| y | n | y | y | 1 | 1 |
| y | y | n | n | 0 | 0 |
| y | y | n | y | 0 | 3 |
| y | y | y | n | 0 | 0 |
| y | y | y | y | 0 | 3 |

*V. ursinus*

| | | S | n | y |
|---|---|---|---|---|
| D | F | L | n | y |
| n | n | n | 43 | 0 |
| n | n | y | 10 | 0 |
| n | y | n | 2 | 0 |
| n | y | y | 1 | 3 |
| y | n | n | 0 | 1 |
| y | n | y | 0 | 0 |
| y | y | n | 0 | 0 |
| y | y | y | 0 | 0 |

conjoint detection on the same site when the dimpled hairtubes were compared with other methods.

*A. stuartii* was detected at more sites by trapping than other methods employed (Table 5). All combinations of techniques examined that did *not* include trapping were characterised by high counts for the "other" category; *viz*, the species was detected on many sites by a method/s other than the two being compared (Table 5). Thus, detections by other methods contributed very few additional positive site detections to those where *A. stuartii* was trapped. There were fewer detections of *A. stuartii* by the large hairtubes than other methods we examined (Tables 4 and 5). A combination of large hairtubes and funnels detected *A. stuartii* on only 15 of the total of 41 sites where the species was detected per se. In contrast, the small and dimpled hairtubes performed relatively well and the combination of these techniques with trapping resulted in low counts in the "other" category. The dimpled hairtubes and traps, and small hairtubes and traps, detected *A. stuartii* on 39 and 40 sites, respectively out of a total of 41 sites where the species was detected overall (Table 5). We identified many cases where *A. stuartii* was detected on a plot by a given method but not by an alternative one. This is demonstrated by the comparisons of trapping and hair funnels; there were 23 sites where *A. stuartii* was recorded by trapping only and a further 14 where it was detected by both techniques. There were no cases where the species was detected by the hair funnel but not trapping (Table 5).

Contrasts in the effectiveness of different detection methods for *R. fuscipes* are presented in Table 5. This species was recorded at a total of 31 sites. Analyses of these data indicated that the highest detection rates were returned by trapping (Tables 4 and 5); combinations of methods that included trapping gave the highest proportion of the total number of plots where the species was detected per se. The hair funnel performed poorly and there were few cases where it was the only one of a pair of methods to yield a positive record of *R. fuscipes*. Moreover, counts in the "other" category tended to be relatively high where it was one of pair of methods being examined (Table 5). The small, dimpled and large hairtubes were intermediate between trapping and the funnels in their rates of detectability. More detections of *W. bicolor* were recorded using large hairtubes than other methods (Tables 4 and 5) and there were fewer instances of failure to detect the species when it was one of a pair of techniques examined. The highest number of detections of *V. ursinus* were made with large hairtubes. Other methods performed relatively poorly (Table 5).

### *3.3. Landscape context and covariate effects – probability of occurrence as measured by hair funnels*

Logistic regression (McCullagh and Nelder, 1989) was used to assess the effects of covariates for the response variable presence/absence of a species at a site. Sites in remnant native forest were sub-divided in two shape classes; narrow linear strips and elliptical-shaped patches. Short transects with fewer plots were established on the small remnants $<3$ ha. To reduce the possibility for confounding between sampling intensity and area, remnants with four or fewer plots were excluded leaving a total of 157 sites in the analysis.

Multi-dimensional scaling procedures (Digby and Kempton, 1987) were employed to reduce (and orthogonalize) the number of potential covariates and help overcome problems associated with collinearity between variables, particularly the climate-derived parameters (see Nix et al., 1992).

There were few records of most species of mammals (Appendix A) and only four species were detected frequently enough to permit detailed modeling: *Trichosurus* spp., *W. bicolor*, *A. stuartii*, and *V. ursinus*. Results for each species are outlined below.

There was no significant ($P=0.19$) effect of landscape context on the probability of occurrence of *W. bicolor* (Fig. 3(A)). The mean probability of occurrence of the species was similar across sites dominated by *P. radiata*, sites in eucalypt remnants and sites in large areas of contiguous forest – on average 38% (the 95% confidence interval were 30–46% [hereafter shown in square brackets]). However, *W. bicolor* was significantly ($P<0.001$) less likely to be detected by hair funnels on sites with a high cover value for bracken and shrubs (Table 6, Fig. 4(A)).

A significant landscape context effect was identified for *A. stuartii* ($P=0.026$). When the contrast was restricted to differences between *P. radiata* sites and all eucalypt sites combined, *A. stuartii* was detected significantly ($P=0.006$) less often in *P. radiata* forest (8% [2–21%] than in eucalypt forest 27% [19–35%]) (Fig. 3(B)). In addition, *A. stuartii* was: more likely ($P=0.005$) to be detected in large remnants (Fig. 4(C)), less likely ($P<0.001$) to be detected in forest dominated by *P. radiata*, *E. dives*, *E. bridgesdiana* and *E. macrorhynca*, and had a higher probability ($P=0.03$) of occurrence in forests with a high stand basal area (Fig. 4(B) and Table 7).

There was no significance difference ($P=0.25$) in the probability of detecting *V. ursinus* between sites characterized by different landscape contexts (Fig. 3(C)) – the mean probability of detection was 7% and the associated values for the 95% confidence interval around this value were 4–13%. When landscape context effects were simplified to a contrast between *P. radiata* and eucalypt sites (i.e. remnants and large contiguous areas of native forest combined), there was a suggestion that *V. ursinus* was more likely to be detected in stands of *P. radiata* but this trend was not significant ($P=0.057$). No significant covariate effects were identified from analyses of hairtube data for *V. ursinus*.

There was a significant ($P=0.004$) landscape context effect for *Trichosurus* spp. The probability of occurrence was significantly lower in stands dominated by *P. radiata* (20% [10–35%]) than in eucalypt forest (i.e. remnants and large areas of contiguous eucalypt forest) (44% [36–54%]) (Fig. 3(D)). There was some evidence of a higher detection rate in the remnants than large areas of contiguous eucalypt forest, but this difference was not statistically significant.

### *3.4. Landscape context and covariate effects: presence and abundance at sites as measured by traps*

Traps were placed at a maximum of 13 plots at most of the 58 sites targeted for study. Twelve of the 41

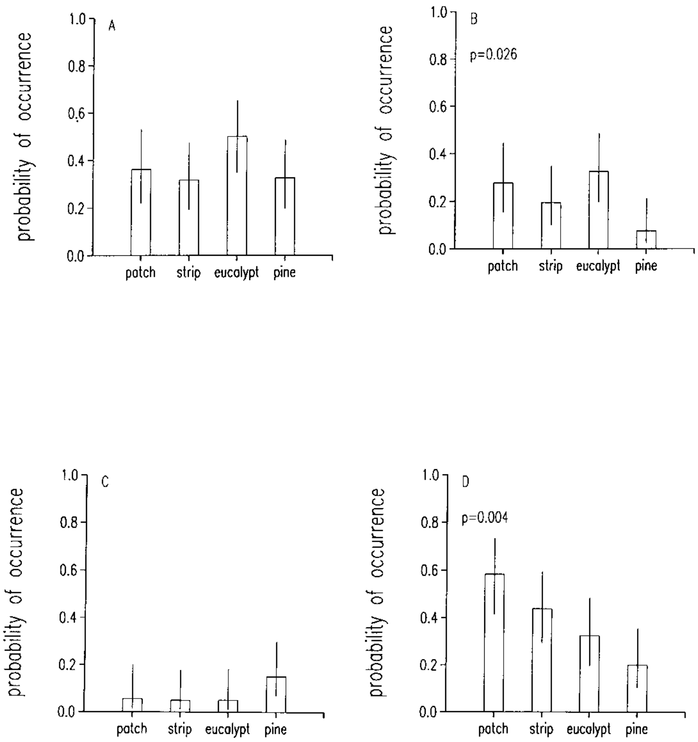



Fig. 3. Landscape context effects for four species of mammals for the probability of detection by hair funnels at 157 sites. The species are: (a) *W. bicolor*, (b) *A. stuartii*, (c) *V. ursinus*, and (d) *Trichousurus* spp. Probability values are given where landscape context effects are significant.

remnants surveyed had eight or fewer plots and they were excluded from the analysis to avoid confounding sampling intensity and remnant area. Only two species of mammals were captured frequently enough to allow detailed statistical analysis – *A. stuartii* and *R. fuscipes*. For the purposes of the analyses completed in this component of the work, occurrence was defined as at least one capture in any plot on the site. Abundance was defined as the total count of all animals caught on a given site. Occurrence data were modelled using logistic regression. Data on animal abundance were modelled negative binomial regression (rather than Poisson regression) as there was evidence that the location of animals was spatially dependent (that is, aggregations of animals were occurring).

There was evidence ($P = 0.04$) of a higher probability of occurrence of *A. stuartii* in eucalypt forest (i.e. remnants and large contiguous areas of eucalypt forest; 76% [60–87%]) than in *P. radiata* forest 37% [12–72%]. In addition, the probability of occurrence of *A. stuartii* was higher ($P = 0.001$) on steeper slopes.

Abundance data revealed significantly ($P = 0.007$) fewer *A. stuartii* captured on sites dominated by *P. radiata* than those in eucalypt remnants and large areas of contiguous eucalypt forest. No significant covariates were identified from analyses of abundance data for *A. stuartii*.

No landscape context effects were found for the presence/absence of *R. fuscipes* at a site ($P = 0.21$). However, as in the relationship for *A. stuartii*, the probability of occurrence of *R. fuscipes* was significantly higher ($P = 0.006$) on steeper slopes. Data were too scant for meaningful statistical modeling of the abundance of *R. fuscipes*.

### *3.5. Landscape context and covariate effects – probability of occurrence at a plot as measured by traps*

An alternative measure of prevalence of *A. stuartii* and *R. fuscipes* is the probability of their detection at plot; a measure initially estimated as the proportion of the total number of plots at a site where animals were captured. If the probability of detection is the same for all plots within a site, then the probability of detecting at least one animal at a site can be derived analytically by applying the Binomial theorem. Initial analyses

Table 6
Parameter estimates and associated standard errors for the relationship between the probability of occurrence of *W. bicolor* and statistically significant ($P < 0.05$) measured covariates. Analyses are based on data from 166 sites gathered using hair funnels

| Variable | Estimate | Standard error |
|---|---|---|
| Constant | −0.700 | 0.179 |
| Cover score [a] | −0.606 | 0.169 |

[a] Cover score corresponds to the density of vegetation in the ground and shrub layers.

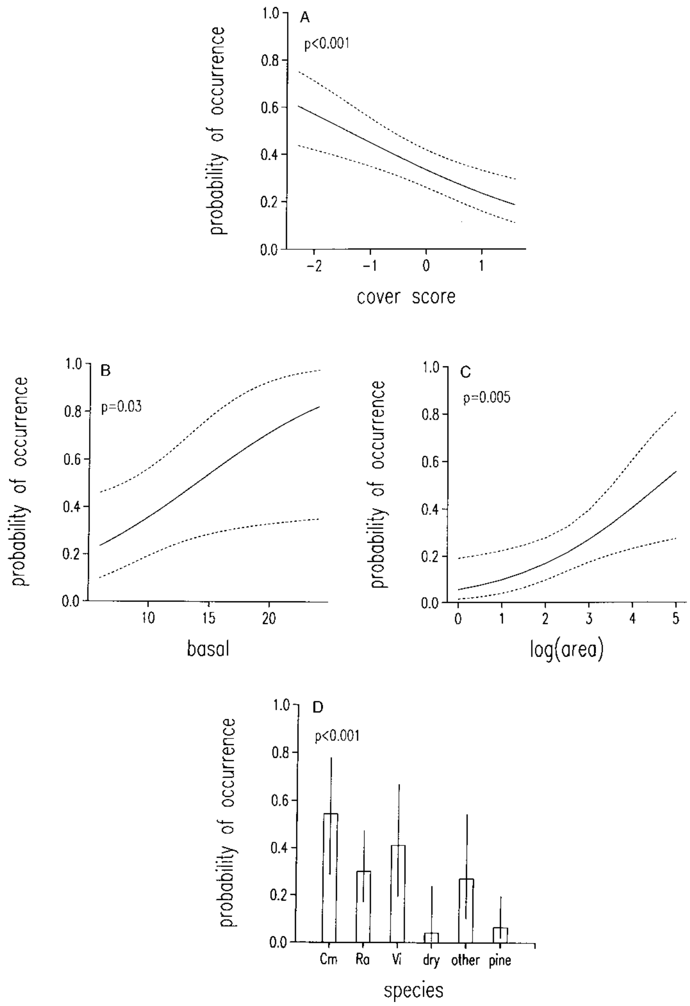



Fig. 4. Significant covariates for the probability of species occurrence at a site derived from hair funnel data for: (a) *W. bicolor*, (b) *A. stuartii* (all eucalypt sites, i.e. sites in remnants and large contiguous areas of eucalypt forest combined), and, (c) *A. stuartii* (remnants only). Note that in the case of predictions in C, values on the $x$-axis on the the $\log_e$ scale.

showed a discrepancy between actual estimates of site detection and the one based on plot data. This suggests possible aggregation of animals at particular plots. The appropriate statistical analysis was therefore logit regression modeling for grouped binomial data allowing for over-dispersion.

Plot detection rates for *A. stuartii* were significantly ($P=0.005$) lower in stands of *P. radiata* than in either the remnants or large areas of contiguous *Eucalyptus* forest (Fig. 5(A)). In addition, there was strong evidence ($P=0.003$) of a decrease in the probability of detection of *A. stuartii* at a plot in remnants with increasing distance from large areas (>1000 ha) of contiguous native *Eucalyptus* forest (Table 8). Predictions from the model for this relationship (Fig. 5(B)) showed that the mean probability declined from approximately 35% for remnants close to large blocks of native forest to about 10% for those 6000 m away.

*R. fuscipes* was trapped at significantly ($P=0.002$) fewer plots per site in stands of *P. radiata* than in either the remnants or large areas of contiguous *Eucalyptus* forest (Fig. 6(A)). Additionally, there was a significant ($P=0.05$) increase in the probability of detection with an increase in the area of the remnants (Table 8, Fig. 6(B)).

Table 7
Parameter estimates and associated standard errors for the relationship between the probability of occurrence of *A. stuartii* and statistically significant measured covariates

| Variable | Estimate | Standard error |
|---|---|---|
| Constant | −5.54 | 2.19 |
| Vegetation basal area | 0.235 | 0.128 |
| Log area × context (eucalypt) | 0 | 0 |
| Log area × context (patch) | 1.047 | 0.426 |
| Log area × context (strip) | 0.704 | 0.424 |
| Log area × context (pine) | 0 | 0 |
| Tree species (pine) | 0 | 0 |
| Tree species (dry)[a] | −2.61 | 1.38 |
| Tree species (other)[a] | −2.05 | 1.30 |
| Tree species (*E. radiata*) | −0.76 | 1.05 |
| Tree species (*E. viminalis*) | −0.56 | 1.02 |

[a] See Table 1 for taxa in these tree species categories.

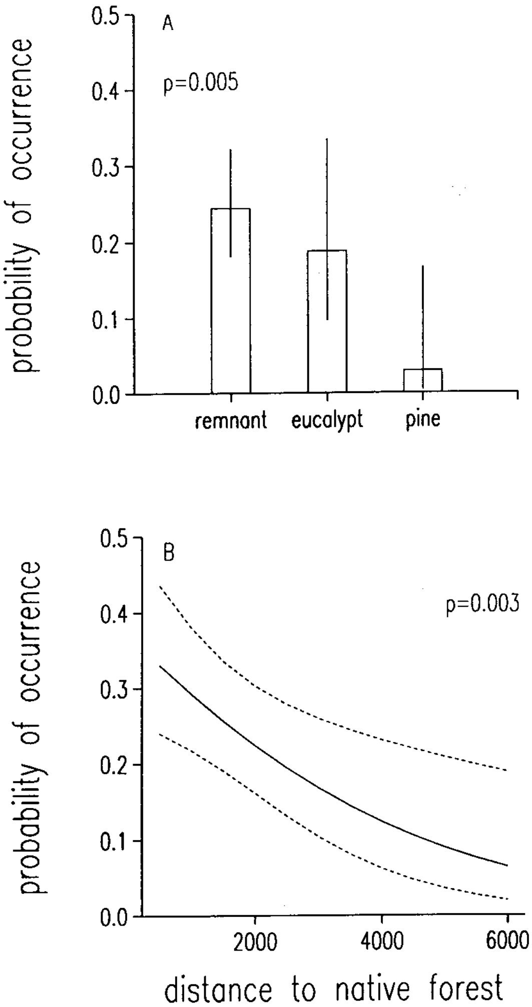



Fig. 5. Effects of context and distance to native forests on the probability of occurrence of trapping *A. stuartii*. Data are the probability of detection at the plot (see text).

Table 8
Parameter estimates and associated standard errors for the logit relationship between the proportion of plots at a site where *A. stuartii* and *R. fuscipes* were trapped and statistically significant measured covariates

| Variable | Estimate | Standard error |
|---|---|---|
| A. *Model for A. stuartii* | | |
| Constant | −0.526 | 0.262 |
| Distance to native forest (remnants) | −0.00036 | 0.00013 |
| B. *Model for R. fuscipes* | | |
| Constant | −3.731 | 0.924 |
| Log of area (remnants) | 0.815 | 0.351 |

## 4. Discussion

### 4.1. Method differences

Substantial differences occurred in the detection rates of different field techniques and this varied between species. Large hairtubes yielded the most detections for the larger species such as *Trichosurus* spp., *V. ursinus*, and *W. bicolor*, whereas other methods performed better for the two species of small mammals investigated (*R. fuscipes* and *A. stuartii*), especially trapping but also the small and dimpled hairtubes. The hair funnel was a tapered shape and designed specifically to combine the size characteristics of both large hairtubes (i.e. a wide aperture at the mouth of the device) and small ones (i.e. a constricted end near the bait chamber). However, the hair funnel typically produced inferior results for small mammals relative to other methods. The glue used as an adhesive surface in the hair funnel has an odour and it is possible this is a deterrent for some animals.

The general method differences between detections of large and small mammals were expected as they appear to correspond to the ability of animals to enter (and leave fur samples) in hairtubing devices with different dimensions. Indeed, in this study, as well as a previous one using different hair sampling techniques (Lindenmayer et al., 1996), we recorded many instances where scats of small mammals such as *R. fuscipes* and *A. stuartii* were deposited in large hairtubes and funnels but remained undetected by these same devices.

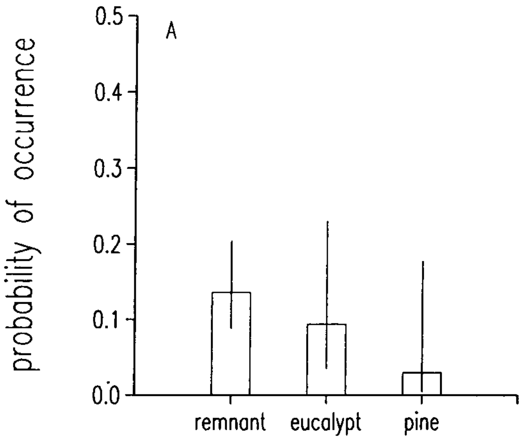
No one technique was superior for all taxa. Hence, for some species, lack of detection may not mean it is absent; rather that the taxon failed to be recorded by that technique (see also Sutherland, 1996; Catling et al., 1997). Thus, several field methods may be needed if a key objective of field survey is to detect a wide range of species (Lindenmayer et al., 1994; Wilson et al., 1996).

Studies of the effectiveness of field counting methods are important in conservation biology because interpretations of faunal response to factors like landscape context and habitat fragmentation are conditional on the data obtained. For example, in our study, conclusions relating to *R. fuscipes* based only on hairtubing suggested a paucity of animals *throughout* the Tumut region. However, trapping data showed otherwise. Knowledge of method effects is valuable because careful design to account for variations in counts can allow a reduction in counting error and hence increase the power of field studies.

### 4.2. Landscape context effects

Outcomes from surveys where traps and hairtubing methods were used provide the best indication of response for small mammals (*A. stuartii* and *R. fuscipes*) whereas the extensive hair funnel survey was most appropriate for *V. ursinus* and *W. bicolor*.

*W. bicolor* and *V. ursinis* exhibited no significant response to landscape context. These results were expected as both species are known to be common inhabitants of native forests (Lunney et al., 1988; Triggs,



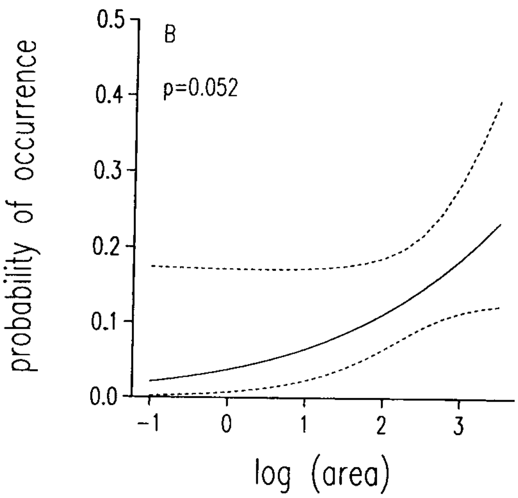




Fig. 6. Effects of context and remnant area on the probability of occurrence of trapping *R. fuscipes* (remnants only). Note that in the case of predictions in B, values on the *x*-axis on the $\log_e$ scale. Data are the probability of detection at the plot (see text).

1990) as well as stands of *P. radiata* (Friend, 1982; Rishworth et al., 1995).

Landscape context effects for *Trichosurus* spp., *A. stuartii* and *R. fuscipes* varied depending on the methods employed to count animals. Analyses of data from 157 sites surveyed with hair funnels revealed that *Trichosurus* spp. was recorded significantly less often in *P. radiata* sites than forest dominated by eucalypts (i.e. sites in remnants and sites in large contiguous areas of *Eucalyptus* forest). Notably, a significant context effect for *T. vulpecula* also was identified from analyses of spotlighting surveys for arboreal marsupials in all 57 sites in the Tumut study (Lindenmayer et al., 1997a).

Significant landscape context effects obtained in some analyses of *A. stuartii* and *R. fuscipes* were due to fewer animals being detected on sites dominated by *P. radiata* trees. The paucity of *Trichosurus* spp., *A. stuartii* and *R. fuscipes* in stands of *P. radiata* is likely to be associated with the absence of key habitat attributes such as nesting sites in large trees with hollows and foraging resources. *P. radiata* trees, like many species of conifers, are not prone to the development of cavities (McComb et al., 1986). This is important for hollow-dependent like *A. stuartii* and *Trichosurus* spp. (Cockburn and Lazenby-Cohen, 1992; Gibbons and Lindenmayer, 1997). Dietary items such as invertebrate prey consumed by *A. stuartii* and *R. fuscipes* and which are commonly associated with stands of *Eucalyptus* forest may be rare or absent in *P. radiata* plantations (Suckling et al., 1976).

The paucity of *A. stuartii* and *R. fuscipes* in stands of *P. radiata* in our investigation provide an interesting contrast with earlier studies of small mammals in softwood plantations. For example, Warneke (1971), Barnett et al. (1977), Suckling and Heislers (1978) and Smith (1982) found that species such as *R. fuscipes* were relatively common in *P. radiata* plantations. These differences could be result of a range of factors. Unlike, softwood forests examined in earlier studies, the plantation at Tumut has experienced prolonged use of heavy machinery to thin and harvest trees. It is possible that recurrent intensive and extensive disturbance has made conditions unsuitable for small mammals. Indeed, the rare detections of small mammals in older stands of *P. radiata* where typically where intact windrows of logs remain. These are legacies of the original eucalypt forest cleared to plant softwood. Animals appear to be virtually absent where heavy machinery has destroyed or badly damaged these structural legacies.

Trapping data revealed significant landscape context effects in the case of the proportion of plots where *A. stuartii* and *R. fuscipes* were trapped, but not for the presence or absence of one of these species (*R. fuscipes*) at the site level. The contrast in the outcomes between the final statistical models for the different response variables (i.e. plot or site level presence) even for the same species illustrate the importance of careful selection of the appropriate measures for analysis. For example, plot and site-level analyses are addressing quite different ecological questions. This issue is re-visited in following section on the implications for survey design and data analysis.

An important finding of our study was the *lack* of differences between the probability of occurrence of mammals within remnants versus those in sites in large contiguous areas of native *Eucalyptus* forest. This finding is interesting given the relative paucity of several species (*A. stuartii*, *R. fuscipes* and *Trichosurus* spp.) in the extensive *P. radiata* plantation which surrounds the remnants. Several (inter-related) explanations could account for the absence of landscape context effects between the remnants and sites in large contiguous areas of *Eucalyptus* forest for *A. stuartii*, *R. fuscipes* and *Trichosurus* spp:

- These species have well developed dispersal mechanisms and can reach areas of remnant vegetation, even when they are embedded within very large areas of *P. radiata* forest. Moreover, vegetation cover provided by *P. radiata* trees could facilitate the movement of animals between areas of suitable habitat.
- Populations residing within remnant areas are sufficiently large to make them relatively immune to localised extinction, thereby negating potential remnant isolation and thus landscape context effects.
- Small populations of *A. stuartii*, *R. fuscipes* and *Trichosurus* spp. may inhabit areas of *P. radiata* surrounding the remnants. Because the *P. radiata* plantation is extensive (so overall it could contain many animals), dispersalists from these areas may supplement populations in the remnants and rescue (sensu Brown and Kodric-Brown, 1977) or reinforce them.

It is presently not possible to determine the actual basis for the lack of landscape context effects between the remnants and areas of contiguous *Eucalyptus* forest. However, we are planning a number of patch removal and re-colonisation experiments in our study area in an attempt to address these important issues.

### *4.3. Combined context and covariate effects*

Trapping data from a subset of 58 sites showed significant relationships between the size of remnants and the probability of occurrence of *R. fuscipes*. The model for *A. stuartii* developed from surveys of 157 sites using hair funnels also contained a remnant size effect. Notably, another study of fragmentation effects on small mammals found a significant remnant area effect for *A. stuartii* (Dunstan and Fox, 1996). These remnant size responses could have been due to a number of interrelated factors:

- Larger remnants may have a greater chance of supporting suitable habitat (Simberloff, 1988).
- Larger remnants could support higher populations of a given species and these, in turn, may have a reduced chance of local (i.e. patch) extinction due to factors such as demographic, genetic and environmental stochasticity (Burgman et al., 1993).
- Larger remnants may have a greater chance of being contacted by animals during dispersal resulting in more animals successfully colonizing such areas (Forman, 1996).
- Larger remnants have a higher probability of supporting some suitable refuge habitat than smaller ones in the event of a catastrophic event such as a fire (McCarthy and Lindenmayer, 1998).

Some of our data on *A. stuartii* and *W. bicolor* showed vegetation cover effects. Other authors have identified correlations between attributes of vegetation structure and the occurrence of species such as *A. stuartii* (e.g. Barnett et al., 1978; Catling and Burt, 1995). Dense cover could provide protection from potential predators, both for *A. stuartii* (Predavec, 1990) and *W. bicolor* (Lunney and O'Connell, 1988). Vegetation cover also may reflect the suitability of foraging substrates for these species.

Our data for *A. stuartii* on the proportion of plots per site revealed a significant isolation effect in which animals were trapped at more plots within remnants close to large contiguous areas of *Eucalyptus* forest. This effect could be related to the ability of dispersing *A. stuartii* to move from potential source populations in large contiguous areas of *Eucalyptus* forest. Metapopulation theory suggests that habitat patches close to source areas should have a higher probability of being occupied and contain more animals than distant ones (Hanski, 1994; Hanski et al., 1995). However, our data on the abundance of animals at the site level did not identify significant landscape context differences between remnants and large contiguous areas of *Eucalyptus* forest as would be predicted given variations in the spatial isolation of the remnants we targeted for survey. This suggests that other (presently unknown) factors could be influencing the dynamics of *A. stuartii* populations in the fragmented forest landscape at Tumut.

### *4.4. Implications for survey design and analysis*

The results of this study have a number of important implications for the design of field surveys and the interpretation of data gathered from such efforts. First, the response of different species to landscape context and measured covariates varied depending on the dataset being examined and thus the methods employed to gather field data. Any conclusions from ecological studies are necessarily conditional on the quality of the data collected. However, while considerable emphasis has been given to field surveys and the analysis and interpretation of extensive resulting datasets, less effort has focussed on counting methods per se (Sutherland, 1996) and their validity and effectiveness is rarely questioned or assessed (but see for example Read et al., 1988 [for small mammals] and Recher, 1988 and Ralph et al., 1997 [in the case of birds]). It is clear that more critical appraisals of survey techniques and observation methods are required, particularly because of the expanding number of surveys being undertaken that underpin land management decisions (e.g. environmental impact statements) as well as the increasing number of scientific studies of human impacts such as habitat fragmentation (see reviews by Andren, 1994; Zuidema et al., 1996).

In our study, trapping and hairtubing was undertaken at plots placed at 50 and 100 m intervals. Hairtubing does not provide data on the identity of individuals and so the same animal could have been recorded in two or more plots. When multiple plots are used to sample a site, it is important to be careful in interpreting data on the probability of occurrence at a site. This is not the same as probability of occurrence at a sample plot. Given independence and equal capture probabilities, it is analytically equivalent to the probability of capturing at least one animal in at least one plot and so will depend on the number of sample plots. The probability of detection or capture at a site will therefore be much higher than the probability of capture at a single plot. If animals tend to aggregate in an area (and/or are double counted), the assumption of independence will be violated and so differences may not be as marked.

### 4.5. Implications for plantation design

The results of our study indicated that patches of remnant eucalypt forest support a range of species of mammals, even when they have been fragmented by extensive surrounding areas of exotic conifer plantations for prolonged periods. These findings have some important implications for the future design of plantations of *P. radiata* trees which are being expanded at a rapid rate in some parts of Australia such as south-eastern NSW (Resource Assessment Commission, 1992). For example, in south-eastern Australia, softwood holdings established by State Forests of NSW exceed 150 000 ha and are expanding at a rate of 2000 ha per year. Many of these new plantings are occurring on farmland that still contain areas of remnant native forest. Because many of these areas continue to support populations of both mammals (this study) and birds (Lindenmayer et al., 1997b), they may contribute to the conservation of wildlife at a regional scale. Indeed, although the removal of native vegetation in some Australian States has declined in more recent times, clearing is set to increase again (e.g., in Victoria) as a consequence of proposals to establish plantations, particularly exotic softwoods (The Commonwealth of Australia and Department of Natural Resources and Environment, 1997). Therefore, we strongly believe such areas of remnant vegetation should *not* be cleared as part of the plantation establishment process, thereby enabling some taxa to persist that could otherwise be eliminated from these landscapes. Moreover, larger remnant patches or fragments with particular habitat attributes such as extensive ground cover should have special priority for exemption from clearing since this study indicates they have a higher probability of supporting some species such as *A. stuartii* and *R. fuscipes*. Finally, protocols for plantation management limit the extent of softwood plantings in water courses. We recommend that gully areas where harvesting does not occur should be re-vegetated with native indigenous vegetation because, if restored, such areas have habitat value for taxa not able to live in adjacent stands of *P. radiata*.

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## Appendix A

Number of plots per site where different species of mammals were detected by hair funnels. A total of 166 sites was surveyed by this method.

| | Number of plots per site | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Species | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| *Trichosurus spp* | 104 | 33 | 20 | 7 | 1 | 0 | 1 | 0 |
| *W. bicolor* | 107 | 34 | 14 | 8 | 3 | 0 | 0 | 0 |
| *A. stuartii* | 132 | 13 | 9 | 6 | 5 | 0 | 1 | 0 |
| *R. fuscipes* | 159 | 5 | 2 | 0 | 0 | 0 | 0 | 0 |
| *F. cattus* | 157 | 9 | 0 | 0 | 0 | 0 | 0 | 0 |
| *C. familiaris* | 163 | 3 | 0 | 0 | 0 | 0 | 0 | 0 |
| *P. breviceps* | 165 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| *S. scrofa* | 165 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |

*(continued)*

| Species | Number of plots per site | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| *R. lutreolus* | 164 | 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| *T. aculeatus* | 166 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *O. cuniculus* | 164 | 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| *R. rattus* | 155 | 9 | 2 | 0 | 0 | 0 | 0 | 0 |
| *V. ursinus* | 154 | 11 | 1 | 0 | 0 | 0 | 0 | 0 |
| *V. vulpes* | 164 | 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| *M. musculus* | 164 | 0 | 1 | 0 | 1 | 0 | 0 | 0 |

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