Islands of bush in a sea of pines:

A summary of studies from the Tumut Fragmentation Experiment (August 2000)

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Foreword

The Tumut Fragmentation Experiment ranks highly among the most significant ecological research in Australia over recent years. World class science, applied in a meticulous manner at a landscape scale to a high priority conservation issue, has generated insights and lessons which should have a major on-ground impact. David Lindenmayer's summary of this work should be essential reading for environmental policy makers and conservation planners throughout Australia, as well as foresters, planners and managers of large scale plantations.

The loss, fragmentation and degradation of native vegetation is the single greatest driver of biodiversity loss in Australia, as well as being a primary cause of dryland salinity and a significant component of greenhouse gas emissions. The conservation of remnant native vegetation, and large scale revegetation (commercial and non-commercial), are accordingly high priority actions in a plethora of national, state, regional and catchment strategies. If these strategies are implemented, we will see hundreds of thousands, if not millions, of hectares of revegetation in southern Australia over the next decade (the State Salinity Strategy in Western Australia alone calls for three million hectares of strategic revegetation).

Yet it is far from axiomatic that large scale revegetation is compatible with conservation of remnant native vegetation, or that large scale revegetation is a 'good thing' for biodiversity. Pine plantations have generally displaced native forest, rather than being established on cleared agricultural lands, although these landscapes are now being targeted more frequently. Even in the late 1990s, the impact on remnant vegetation of large scale establishment of blue gum plantations in south-western Victoria has generally been detrimental, with routine destruction of habitat trees and negligible attention paid to either retention of remnants or complementary environmental plantings.

The Tumut Fragmentation Experiment, funded by LWRRDC and Environment Australia through the National R&D Program on Rehabilitation, Conservation and Management of Remnant Vegetation, has made some important findings for conservation of arboreal marsupials, small mammals, birds, reptiles, frogs and plants — especially where pine plantations dominate the landscape.

- As expected, larger patches of remnant vegetation support more native animals than smaller patches, but patches as small as half a hectare support much higher numbers of vertebrates than previously realised. Even isolated small patches can have significant conservation value.
- The intuitive priority accorded to riparian vegetation is confirmed by this research, which suggests that all remnant vegetation along streams and gully lines should be retained, and native vegetation should be restored in these areas as a priority.
- Large plantations, even of exotic vegetation like *Pinus radiata*, can retain some biodiversity value (much higher than previously realised) if they contain a mosaic of remnant patches of native vegetation, especially if these are linked by riparian native vegetation.
- Second and subsequent rotations of pines should be established using reproductively sterile families to prevent invasion of remnant patches of bush by pine wildlings.

The report concludes with a set of practical principles and guidelines for plantation establishment, and for retention of native vegetation. There is an urgent need for the lessons developed so rigorously through this research by Dr Lindenmayer and his large team of collaborators, and outlined so clearly in this report, to be widely promulgated and applied wherever large scale revegetation is contemplated. This work has already informed codes of practice for plantation establishment. Extension workers, local governments, non-government organisations and landholders interested in large scale revegetation should also all find space for this report in their information toolkit.

This report is a very powerful illustration of the value of landscape scale ecological research applied to contemporary land management issues. It deserves a wide audience.

Andrew Campbell
Executive Director
Land and Water Resources Research and Development Corporation

Executive summary

This report summarises some of the key findings of the Tumut Fragmentation Experiment, a major project in progress near Tumut in south-eastern New South Wales and funded by Environment Australia and the Land and Water Resources Research and Development Corporation (LWRRDC). The project focused on determining the biodiversity values of patches of remnant native eucalypt forest and woodland surrounded by extensive stands of exotic radiata pine (*Pinus radiata*). Patches of remnant vegetation have been isolated for between 15 and almost 70 years — a prolonged period during which the localised extinction of species could be expected to occur. Several biotic groups were targeted for detailed study: arboreal marsupials, small mammals, birds, reptiles, frogs and plants.

The main aims of the experiment at the time of its establishment in mid 1995 were to:

- provide new information on the contribution of vegetation remnants for biodiversity conservation by integrating techniques and information from landscape ecology, metapopulation dynamics, and conservation genetics;
- apply molecular genetic techniques to examine the role of animal dispersal and movement in contributing to the persistence and genetic status of subpopulations and metapopulations of wildlife in fragmented landscapes;
- examine the predictive ability of computer simulation packages, particularly those used for population viability analysis;
- provide an overarching synthesis of information to land managers and government/non-government organisations that would assist them to maintain and design networks of retained habitat which will be effective for the conservation of biodiversity in fragmented landscapes; and
- to widely disseminate the key findings of the project to ensure the adoption of important generic design principles for retained systems of vegetation in multi-use landscapes.

The following are some of the experiment's key findings to date:

- Larger patches (ie. > 3 ha) of remnant native vegetation support more native animals than smaller patches, but small to intermediate-sized patches (0.5–3 ha) nevertheless support considerably higher levels of vertebrate biodiversity than was expected. The results of the experiment highlight the importance for biodiversity of conserving native vegetation, even remnants as small as 0.5 ha. This is particularly relevant in parts of eastern Australia that are targeted for conversion from grazing to landscapes dominated by radiata pine plantations.
- Remnant patches close to (< 500 m) large continuous areas of native vegetation are more likely to be occupied by some vertebrate taxa (eg. small mammals and arboreal marsupials) than more isolated ones. However, even isolated patches can have significant conservation value for many species (eg. birds) and therefore should not be cleared simply because they are isolated.
- Intact areas of riparian vegetation appear to be important dispersal routes for small mammals such as the bush rat (*Rattus fuscipes*). Streamlines and gullies should be targeted for retention during softwood plantation development. In addition, restoration of native vegetation should occur along gully lines to link existing patches of remnant native vegetation that occur within the softwood plantation estate.
- A landscape comprised of a mosaic of remnant native vegetation and softwood stands will have significantly higher biodiversity value than a radiata pine monoculture, particularly for forest and woodland bird species.
- Remnant native vegetation surrounded by radiata pine is at high risk of invasion from exotic weed species such as radiata pine wildlings

and blackberry (*Rubus fructicosus*). Efforts should be made to develop and use sterile radiata pine trees for regenerating softwood plantations after the final clearfell harvest. This is because radiata pine wildlings threaten the integrity of patches of remnant native vegetation. Where possible, existing radiata pine wildlings should be removed from remnant vegetation patches.

- Testing of computer models for predicting population viability has shown that the simulation of populations within habitat patches must take account of the ability of organisms to use, and move across, the surrounding radiata pine matrix. Consideration of the temporal and spatial variation in conditions within the radiata pine matrix was also found to be a fundamentally important part of population modelling. The results also indicated it is critical to check model assumptions before models are applied to *real* landscapes and conservation problems.

An important outcome of the Tumut Fragmentation Experiment has been the development of a set of principles and guidelines for plantation establishment that would ensure that such areas also have some value for biodiversity conservation. A complementary set of principles for conserving areas of remnant native vegetation was also developed. These principles are important for large parts of south-eastern Australia, particularly in semi-cleared grazing lands that have been targeted for expansion of the softwood plantation estate.

The Tumut Fragmentation Experiment has focused on remnant vegetation located within an already well established softwood plantation estate. There are important issues that the Tumut Fragmentation Experiment did not address, such as the impacts on biodiversity when grazed landscapes are transformed to plantation-dominated landscapes. A new experiment — The Nanangroe Experiment — was therefore recently implemented. The new activity is examining the effects on vertebrate and plant populations of conversion of the landscape surrounding woodland patches from semi-cleared grazing land to extensive stands of radiata pine. The same groups of animals and plants targeted in the Tumut Fragmentation Experiment are also being examined in the Nanangroe Experiment and it will be possible to make useful comparisons between the results of the two studies in future years.

Some Tumut project activities, including those on the genetics of fragmented mammal populations, are still in progress and findings from them are expected to become available during late 2000–mid 2001.

1 Introduction

Habitat loss and habitat fragmentation are two of the key processes threatening the conservation of biodiversity worldwide (Saunders *et al.*, 1987; Groombridge, 1992; Burgman and Lindenmayer, 1998). These threatening processes can have multi-faceted impacts on biota (Zuidema *et al.*, 1996), including species loss and extinction (Andrén, 1994), reordered community composition (Davies *et al.*, 2000), altered patterns of species behaviour (Rolstad and Wegge, 1987), and loss of genetic variability (Sacchari *et al.*, 1998). These factors often interact (Gilpin and Soulé, 1986) leading to cumulative effects which can, in turn, make it extremely difficult to accurately predict the impacts of landscape change on biota (MacNally and Bennett, 1997). A classic example is the set of extinction 'vortices' described by Gilpin and Soulé (1986). These vortices are positive feedback loops in which there are interactions between biological and environmental factors that affect population dynamics and threaten species persistence (Gilpin and Soulé, 1986). For example, habitat loss and fragmentation may reduce population size and change the spatial distribution of remaining sub-populations by confining them to remnant patches.

Reduced population size and the isolation of sub-populations may, in turn, result in increased genetic drift and loss of heterozygosity and genetic variation. Interrelationships between inbreeding depression and demography (eg. juvenile fitness and mortality rates among offspring) (Ralls *et al.*, 1988; Lacy, 1993a) can reduce population growth rates and overall numbers of animals; problems further exposing populations to increased genetic drift. Interactions between threatening processes means that multi-faceted studies are needed to help determine, and thus better anticipate, the varied and often cumulative effects of landscape modification and fragmentation. Importantly, such information could assist with proactive approaches to landscape management and address biodiversity conservation problems before they become critical and require high risk strategies to resolve (eg. captive breeding and reintroduction) (Burgman and Lindenmayer, 1998).

The Tumut Fragmentation Experiment is a set of large-scale, multi-faceted studies that integrates demographic and genetic studies with computer simulation modelling to examine the influence of habitat fragmentation and landscape conditions on arboreal marsupials, terrestrial mammals, birds, and plants. The objectives of the original project brief for the Tumut Fragmentation Experiment were to:

1. provide valuable new information on the contribution of vegetation remnants for biodiversity conservation by integrating techniques and information from landscape ecology, metapopulation dynamics, and conservation genetics;
2. apply various molecular genetics techniques to examine the role of animal dispersal and movement in contributing to the persistence and genetic status of subpopulations and metapopulations of wildlife in fragmented landscapes;
3. examine the role of computer simulation packages in the estimation of extinction risks of biodiversity;
4. provide a formal test of the accuracy of predictions generated from the application of computer simulation approaches, by comparing the results of field surveys with those from computer models;
5. provide an overarching synthesis of information to land managers and government/non-government organisations that will assist them to maintain and design networks of retained habitat which will be effective for the conservation of biodiversity in fragmented landscapes; and
6. widely disseminate the key findings of the project and facilitate the adoption of important generic design principles for retained systems of vegetation in multi-use landscapes.

This report summarises some of the more substantive sub-projects that have been, or are currently being, undertaken as part of the Tumut Fragmentation Experiment and which address the six objectives set out above. Other work, which is outside the objectives of the original project brief, is also briefly summarised. More detailed information on the results of the various projects can be found in the published material from the Tumut Fragmentation Experiment (listed in Appendix 4). The results of the Tumut Fragmentation Experiment have particular relevance for large parts of south-eastern Australia where major expansions of the radiata pine plantation estate are occurring. These landscape changes are taking place on semi-cleared grazing lands that support patches of remnant native vegetation. The findings summarised in this report can be used in designing plantation landscapes so they retain some value for biodiversity conservation. Such design issues are discussed in Sections 11 and 12 of this report.

2 The study area and history of fragmentation

The Tumut Fragmentation Experiment (hereinafter called 'the Tumut experiment') is focused on the Buccleuch State Forest which lies 100 km west of Canberra in southern New South Wales (NSW), south-eastern Australia (Figure 1). The Buccleuch State Forest is a 50,000 ha plantation of radiata pine (*Pinus radiata*), an exotic softwood species, established on areas that formerly supported native eucalypt forest. Extensive clearing of native forest for radiata pine commenced in the mid-1930s and continued for 50 years, until new areas of softwood plantation were established on grazing land that had been cleared previously. The precise time of fragmentation of each eucalypt remnant is known, because accurate records of the clearance of native forest have been kept by State Forests of NSW when the stands of radiata pine were established.

Plate 1. Aerial view of eucalypt patches embedded within the radiata pine matrix at Tumut

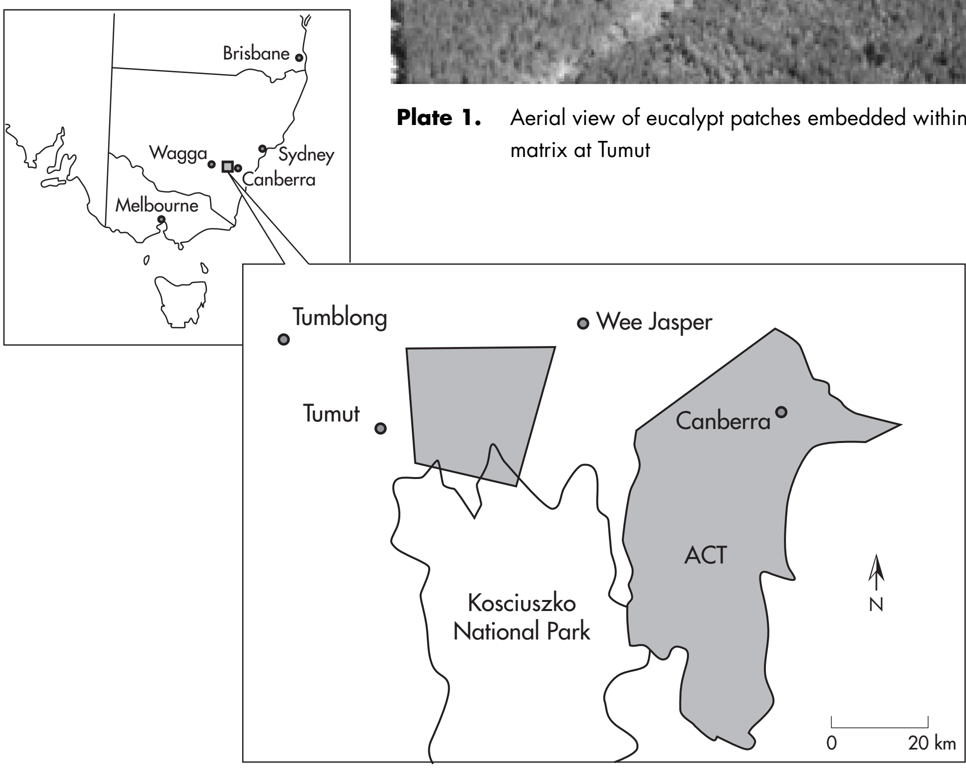

Figure 1. The location of the Tumut Fragmentation Experiment

3 Field-based studies of habitat fragmentation

Large-scale landscape change can result in major changes in the distribution and abundance of species (eg. Bennett, 1990; Estades and Temple, 1999). For example, in the Tumut region, widespread clearing of native forest to establish radiata pine plantations has the potential to isolate and fragment populations of plants and animals that remain in uncleared eucalypt patches. A major objective of the Tumut experiment was to determine the extent of such fragmentation effects on a range of animal groups. The Tumut region is characterised by three broad types of landscape components, which have been termed landscape context classes for the purposes of this project:

- **Landscape Context Class 1.** Remnant patches of native eucalypt forest (see Plate 1). These remnants vary in size (1–124 ha), shape (long and narrow versus elliptical or round), vegetation type, and other features.
- **Landscape Context Class 2.** Extensive areas of exotic radiata pine forest which surround the eucalypt remnants. This part of the landscape is often referred to as the landscape matrix in this report.
- **Landscape Context Class 3.** Large continuous areas of native eucalypt forest that occur beyond the boundaries of the plantation and which include the Kosciuszko and Brindabella national parks and the Bondo and Bungongo State forests.

A key part of the Tumut experiment has been to gather data on the presence and abundance of arboreal marsupials, small mammals, forest birds and plants on sites in these three landscape contexts.

3.1 Experimental design

There are 192 patches of remnant *Eucalyptus* spp. forest of varying size, shape and vegetation type that were not cleared during plantation establishment in the Buccleuch State Forest. Eighty-six of the 192 eucalypt remnants were selected for sampling using a randomised and replicated statistical procedure (Lindenmayer *et al.*, 1999a). The selection of the 86 eucalypt remnants was stratified across:

- four patch size classes (1–3 ha, 4–10 ha, 11–20 and > 20 ha);
- two isolation age classes (less than and greater than 20 years since fragmentation); and
- five dominant eucalypt forest type classes — (i) ribbon gum (*Eucalyptus viminalis*), (ii) narrow-leafed peppermint (*E. radiata*), (iii) mountain swamp gum (*Eucalyptus camphora*), (iv) 'dry forest' (red stringybark *Eucalyptus macrorhyncha*, and apple gum *Eucalyptus bridgesiana*), and (v) 'other forest' mountain gum (*Eucalyptus dalrympleana*), snow gum (*Eucalyptus pauciflora*) and black sallee (*Eucalyptus stellulata*).

A set of 40 sites dominated by radiata pine trees and which formed the landscape matrix in the study region was selected (= Landscape Context class 2). The environmental, climatic, and terrain conditions of the 40 radiata pine sites were matched to the environmental, climatic, and terrain conditions characteristic of the 86 eucalypt remnants.

Forty sites were also selected within large continuous areas of *Eucalyptus* forest (= Landscape Context Class 3). These 'control' sites were matched to the 86 eucalypt remnants on the basis of environmental and climatic conditions, terrain and vegetation cover in the Tumut region.

In summary, 166 sites were chosen for sampling of vertebrates and plants, 86 in eucalypt remnants surrounded by extensive stands of radiata pine (Landscape Context Class 1), 40 dominated by radiata pine trees which formed the landscape matrix in the study region (Landscape Context Class 2), and 40 in large continuous areas of native eucalypt forest (Landscape Context Class 3).

3.2 Design features of the Tumut experiment

Important design features of the Tumut experiment that provide a strong inferential basis for the interpretation of the results, are highlighted below.

- Sites in large areas of continuous eucalypt forest provide 'control' areas. These areas cover tens of thousands of hectares — large enough to support viable populations of the array of species which should occur in the study region. In an extensive review of fragmentation studies, Andrén (1994) noted that only 10% of investigations he assessed included habitat patches greater than 1000 ha. On this basis, the biggest patches in the vast majority of studies were not large enough to support viable populations of some taxa — this problem reduces the extent of inferences that can be made from such studies.
- The 40 sites in radiata pine stands are an additional key feature of the Tumut experiment. Many fragmentation studies focus solely on what are perceived to be habitat fragments and ignore the potential habitat value of the surrounding landscape matrix (Simberloff *et al.*, 1992; Beier and Noss, 1998). Overlooking the interrelationships between habitat fragments and the matrix can give an inaccurate view of true fragmentation effects (Wiens, 1994).
- The field survey protocols for various groups (eg. birds and arboreal marsupials) were established following a pilot study (Lindenmayer *et al.*, 1997a; Cunningham *et al.*, 1999 — see later section on field sampling protocols).
- Stratification for the selection of the eucalypt remnants ensured the full 'environmental space' (range of environments) of the study region was represented.

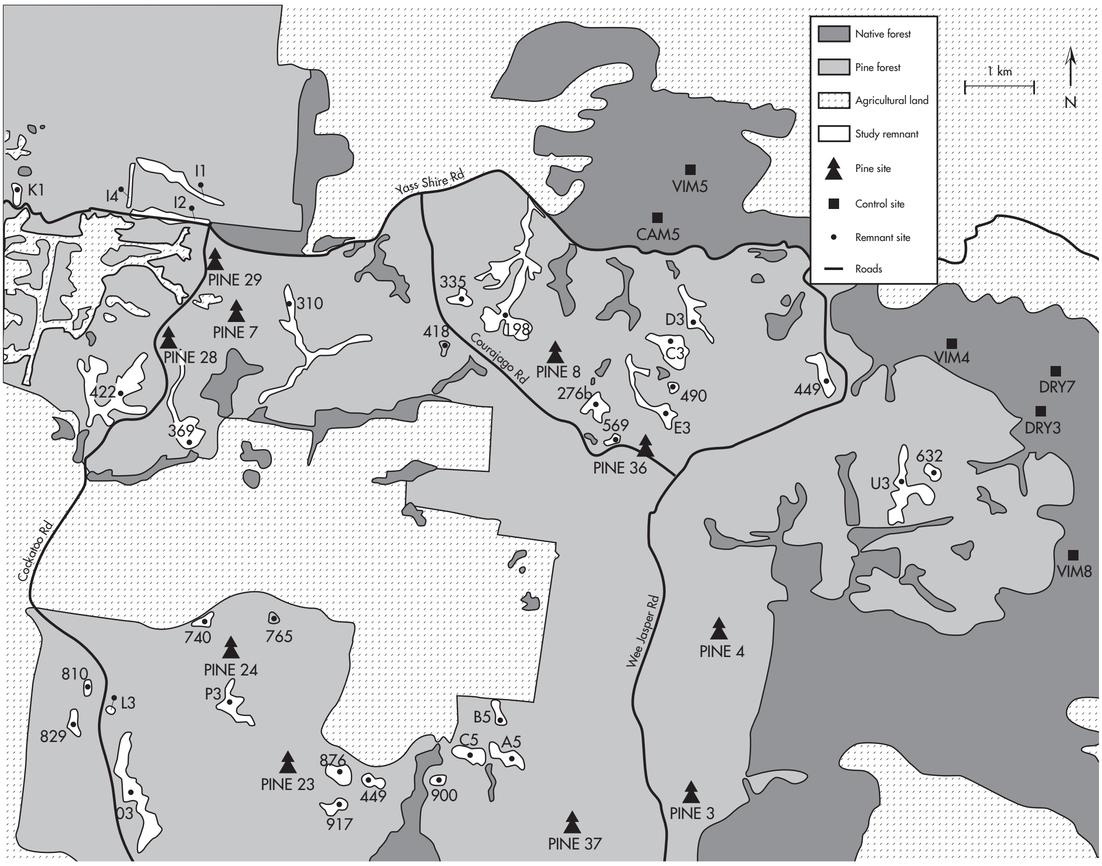

Figure 2. A subsection of the study region with sites in the three broad context classes

- Random selection within each strata for the selection of the 86 eucalypt remnants (see above) minimised the chance of bias and averaged the influence of random factors.
- Climate, forest type and geology data were used to crossmatch the 166 sites in the study, ensuring that the range of environmental and other conditions were matched across the three landscape context classes (Lindenmayer *et al.*, 1999a).
- Experimental units were of fixed size (a 600 m long transect).
- Sampling intensity was independent of remnant size, which was appropriate for our comparative investigation (ie. animal occurrence in patches was not confounded with sampling intensity).

In the case of the areas of remnant eucalypt forest in the Tumut experiment, the experimental unit was a remnant and not observations within a remnant. In comparative studies such as this experiment, there are compelling statistical arguments in favor of increasing the number of experimental units rather than increasing the number of observations per unit (Lindenmayer *et al.*, 1999a). Accordingly, 86 remnants were selected, rather than the alternative of choosing multiple sites in fewer remnants.

3.3 Results and discussion

3.3.1 Arboreal marsupials

Large landscape context effects were identified for arboreal marsupials. This finding was partly a consequence of the complete absence of most species from the radiata pine matrix. Also, remnant patches of eucalypt forest surrounded by radiata pine forest had a faunal assemblage that differed from that observed in a site embedded within extensive continuous eucalypt forest. Two species — the yellow-bellied glider (*Petaurus australis*) and the squirrel glider (*Petaurus norfolcensis*) — were lost from all the remnants — including the very large ones (> 120 ha). Possible reasons for the loss of these species are that the squirrel glider was rare at the time of fragmentation and the yellow-bellied glider has a very large home range — larger than the size of most patches (Lindenmayer *et al.*, 1999a).

Significant landscape context and habitat fragmentation effects were observed for the two species absent from the radiata pine matrix [the common brushtail possum, *Trichosurus vulpecula*; and the greater glider, *Petauroides volans* (Lindenmayer *et al.*, 1999a)]. Conversely, landscape context and habitat fragmentation effects were *not* found for the two species that persisted at small population sizes in the radiata pine matrix (the common ringtail possum, *Pseudocheirus peregrinus;* and the mountain brushtail possum, *Trichosurus caninus* (Lindenmayer *et al.*, 1999a). Indeed, the data suggested that both these species *increased* in abundance in the remnants relative to the controls (Lindenmayer *et al.*, 1999b), an effect that would not be forecast by widely cited paradigms such as island biogeography theory (Macarthur and Wilson, 1963, 1967) or metapopulation theory (Hanski, 1999).

Recent data analyses using computer-derived measures of landscape cover have shown that populations of arboreal marsupials in remnants were higher in isolated remnants than in remnants with other neighbouring eucalypt patches in the surrounding radiata pine matrix. This may have been because the radiata pine-dominated landscape matrix was hostile to dispersal, and induced animals to remain within the patch in which they were born. This, in turn, would increase population densities in isolated remnants above those in less isolated remnants where animals may have been more prone to disperse (Lindenmayer *et al.*, 2001a). This phenomenon is known as a 'fence effect' (Wolff *et al.*, 1997). Again, metapopulation theory and island biogeography theory would *not* forecast these effects (ie. lower animal density in more isolated patches). Whatever the cause of the effects observed, they clearly demonstrate strong interrelationships between matrix conditions and habitat fragments. Hence, information on both is needed to interpret population dynamics in complex landscape mosaics (Lindenmayer *et al.*, 2001a).

Statistical analysis of the patterns of occurrence of arboreal marsupials in the Tumut experiment has shown that the presence and abundance of animals is significantly influenced by patch attributes such as size, dominant forest type, vegetation structure and the steepness of the terrain. In general, animals were more likely to occupy larger patches dominated by ribbon gum and narrow-leafed peppermint stands and on flatter terrain (Lindenmayer *et al.*, 1999a). However, each taxon exhibited a different (species-specific) response to fragmentation and landscape context effects and for some (eg. the common ringtail possum and the mountain brushtail possum), factors such as remnant size were not important.

3.3.2. Terrestrial mammals

Two major surveys sampled terrestrial mammals in the Tumut experiment. Hairtubing (a technique for detecting animals from the analysis of fur collected in a small portable bait station) was used at all 166 sites selected in the study. Trapping and a combination of different types of hairtubing were then employed at a subset of 58 sites. Data from these surveys were 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 for counting mammals (see section 6 on sampling methods). 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 was the superior method for small mammals such as the agile antechinus (*Antechinus agilis*) and the bush rat (*Rattus fuscipes*) (see section 6).

In general, small mammals were recorded significantly less frequently at radiata pine sites than at sites in large continuous areas of eucalypt 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 radiata pine stands, there were no significant differences in mammal presence and abundance between sites located in large continuous areas of eucalypt forest and sites in fragments of remnant eucalypt forest surrounded by the softwood plantation (Lindenmayer *et al.*, 1999c). This finding suggests either that animals from potential population sources in continuous eucalypt forest can move through the softwood plantation and colonise the remnants, or that populations residing in the fragments of remnant eucalypt forest are large enough to resist local extinction. Strong positive relationships also were observed between the remnant area and the probability of patch occupancy by the agile antechinus and the bush rat; small patches were likely to be empty. In the case of the agile antechinus, isolated remnant patches also were less likely to be occupied (Lindenmayer *et al.*, 1999c).

Conditions in the matrix strongly influenced the ability of small mammals to persist there. For example, piles of windrowed eucalypt logs remaining after clearing of the original native forest provided critical habitat for small mammals in radiata pine stands. These were the only locations in the radiata pine matrix where these taxa were recorded. For example, small mammals were absent from elsewhere in the softwood plantation where windrows had been destroyed by heavy machinery as part of repeated pine thinning operations (Lindenmayer *et al.*, 1999c).

3.3.3 Birds

Strong interrelationships between the eucalypt remnants and the surrounding radiata pine matrix were recorded for birds. The forest mosaic at Tumut provided habitat for many birds (more than 90 species), and complex landscape context, habitat fragmentation and landscape matrix effects were identified. Some birds, such as the grey shrike thrush (*Colluricuncla harmonica*), were ubiquitous. Another group of taxa was recorded most often in the remnants (eg. the little raven, *Corvis mellori*; the superb fairy wren, *Malurus cyaneus*; and the shining bronze cuckoo, *Chyrysococcyx lucidis*). Of these, some were more likely to be recorded in small eucalypt remnants: the Australian magpie (*Gymnorhina tibicen*), the eastern yellow robin (*Eopsaltria australis*) and the superb lyrebird (*Menura superba*) in the intermediate-sized eucalypt remnants, and the red wattlebird (*Anthochaera carunculata*), the sacred kingfisher (*Todiramphus sanctus*), the leaden flycatcher (*Myiagra rubecula*), and the whitenaped honeyeater (*Melithreptus lunatus*) in larger remnants. Other birds which typically favoured large continuous areas of native forest were the cicada bird (*Coracina tenuirostris*), the gang-gang cockatoo (*Callocephalon fimbriatum*) and the olive-backed oriole (*Oriolus sagittatus*). Several native species were significantly more likely to occur in the radiata pine matrix (eg. the rufous whistler, *Pachycephala rufiventris*; and the brown thornbill, *Ancathiza pusilla*).

Analyses of the composition of the bird assemblage at each site were based on a combined measure of species presence and abundance (termed a 'bird frequency profile'). There was neither a fixed community of birds in the three broad landscape context classes nor a climax bird community, but rather a complex reassembling of the composition of the bird assemblages in relation to landscape context, remnant area, and conditions in the landscape surrounding a given site. There was strong empirical evidence for a gradient in the bird frequency profiles between radiata pine stands and large continuous areas of native eucalypt forest. Changes in the bird frequency profiles along this continuum encompassed changes both in the identity of the taxa in the assemblage and relative abundance of each species between the two broad radiata pine and continuous eucalypt landscape context classes. The remnants connected the bird frequency profiles of these two forest types, and the nature of the gradient depended strongly on remnant size. As remnant size increased, the bird assemblage was increasingly like that characteristic of large continuous areas of native eucalypt forest and less like the surrounding radiata pine matrix (Lindenmayer *et al.*, 2000a). However, the change in the bird frequency profile for the various types of sites was strongly influenced by the landscape conditions that surrounded the field sites. For example, the occurrence of many bird species in the radiata pine matrix was significantly related to the amount of eucalypt forest surrounding these pine sites (Lindenmayer *et al.*, 2000a). Pine sites where the surrounding landscape contained some eucalypt remnants had a bird frequency profile that differed from that for pine sites where the surrounding landscape was pure radiata pine. Radiata pine sites with adjacent eucalypt patches had a bird frequency similar to that of small and intermediate-size eucalypt remnants (Lindenmayer *et al.*, 2000a).

Many individual bird taxa at Tumut were distributed across the different landscape components at varying levels of abundance and these species were *not* confined to only one landscape context type. The red wattlebird provides a good example; the species was significantly more abundant in large continuous forest than in radiata pine stands and had intermediate levels of abundance in the remnants and the radiata pine matrix (Figure 3).

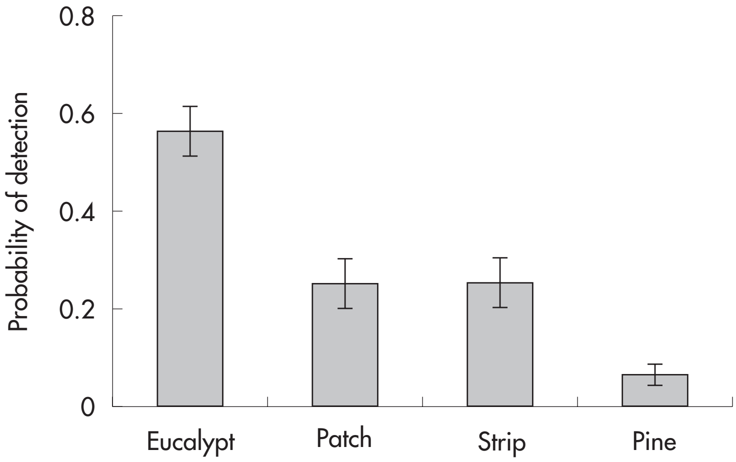

Figure 3. The probability of detection of the red wattlebird across different landscape contect classes: large, continuous areas of eucalypt forest (denoted 'eucalypts'), patch-shaped eucalypt remnants, strip-shaped eucalypt remnants, and the radiata pine matrix (denoted 'pines')

As in the case of arboreal marsupials, recent analyses using measures of landscape cover showed that some taxa responded positively to the total area of remnant vegetation when it was dispersed among many eucalypt patches (eg. the rufous whistler and the crimson rosella, *Platycercus elegans*). In contrast, other species were significantly more likely to occur if eucalypt patches were consolidated as a single (or small number) of large patches (eg. the red wattlebird and the golden whistler, *Pachycephala pectoralis*) (Lindenmayer *et al.*, 2001a).

Extensive analyses of patterns of spatial dependence in bird distribution (eg. Koenig, 1998) was completed. These analyses showed that the distribution of many species did not conform to that expected if classic metapopulation dynamics were occurring (*sensu* Hanski, 1999), with particular taxa restricted to only a 'mainland' (here the extensive native forest areas) or to certain patches or types of patches. Rather, the radiata pine matrix surrounding the remnants provided suitable or partially suitable habitat for many species.

Understorey conditions also were statistically significant predictors of the presence and abundance of many species of diurnal forest birds within radiata pine stands in the Tumut experiment (Lindenmayer *et al.*, 2000a). For example, occurrences of native understorey plants such as dogwood (*Cassinia aculeata*) and bracken fern (*Pterideum esculenteum*) were important for providing cover for taxa like the brown thornhill (*Ancathiza pusilla*) and the white-browed scrub-wren (*Sericornis frontalis*). The presence of these structural features often meant that overall differences in species richness were less than expected between radiata pine stands (mean = 16 species), remnants (mean = 20 species) and large continuous areas of native forest (mean = 23 species) (Lindenmayer *et al.*, 2000a).

In summary, studies of birds at Tumut produced a range of interesting new results. First, small and intermediate-sized eucalypt remnants (1–10 ha) supported a wide range of species — and clearly have considerable conservation value. Second, there were strong spatial interrelationships between the radiata pine matrix and remnant patches of eucalypt forest. Many taxa occurred in the radiata pine matrix because of its closeness to eucalypt forest. Third, some of the responses to landscape condition and habitat fragmentation observed in the study (eg. the preferential use of small and intermediate-sized patches by some native taxa) were quite different from those seen in other fragmentation investigations. Moreover, some of the novel results were not consistent with widely accepted paradigms such as nested subset theory in which new taxa would added to an original (minimal) assemblage of birds in an ordered and progressive fashion in response to increasing remnant size (Patterson, 1987). Rather, there were substitutions in the species represented in the different bird assemblages across the gradient from small to large remnants and the controls.

Most theories associated with fragmentation are derived from agricultural landscapes where habitat remnants are surrounded by a relatively hostile matrix. More complex responses, such as those derived from the Tumut experiment, may occur where the surrounding matrix is less inhospitable. This has implications for investigations of fragmentation, because important effects may be overlooked if: (1) the use of the landscape matrix is ignored (Beier and Noss, 1998); (2) only a limited suite of fragment sizes is studied (eg. Fisher and Goldney, 1998; Deacon and MacNally, 1998); or (3) 'control sites' (the large continuous areas of native forest at Tumut) are unavailable or are not examined (Margules, 1992).

The results of the Tumut experiment highlighted why it is important not to assume that what appear to be patchy landscapes from a human perspective automatically correspond to patchy wildlife populations with dynamics conforming to metapopulation processes. The results also highlighted that the concurrent consideration of the landscape mosaic at Tumut (ie. the interplay between eucalypt remnants *and* the surrounding landscape matrix) was critical for determining the response of birds.

4 Tests of the predictive accuracy of simulation models for population viability analysis

One of the aims of this project was to test the accuracy of predictions made using generic models for population viability analysis (PVA). These models have been used extensively throughout the world to make forecasts of the risks of species extinction, particularly of rare, declining and threatened taxa (Boyce, 1992). Indeed, there have been several hundred applications of PVA models in the past decade (reviewed by Lindenmayer and Possingham, 1994). Despite the widespread use of PVA models, predictions made using them have very rarely been tested — a major criticism of the approach (Caughley and Gunn, 1995). The Tumut experiment is one of the first studies where actual field data for patch occupancy by birds, small mammals, and arboreal marsupials have been compared with predictions of the same measures derived by spatially-explicit computer simulation models for metapopulation dynamics.

The simulation modelling component of the study has concentrated on a 5500 ha area in the north-eastern part of the study area which contained 39 patches of eucalypt forest ranging in size from 0.2 ha to 40.4 ha. Additional fieldwork, particularly repeated sampling efforts of the 39 patches, has taken place here to establish patch occupancy and animal abundance for small mammals, birds and arboreal marsupials.

4.1 Arboreal marsupials

Testing the application of PVA models to arboreal marsupials has involved assessing the accuracy of three computer programs — VORTEX (Lindenmayer *et al.*, 2000b), ALEX (Lindenmayer *et al.*, 2000c), and Hanski's (1994) incidence model (Lindenmayer *et al.*, 1999b). Results from these studies are briefly summarised below and publications are cited for those interested in further details.

Model testing using VORTEX involved making predictions using a suite of scenarios including those where: (1) the rate of exchange of animals between patches was varied; (2) different models for the migration of animals between habitat patches were invoked; (3) different levels of emigration (or dispersal) from a large neighbouring source area were simulated; (4) variations in habitat quality between remnant patches were incorporated in the model; and (5) the influence of the radiata pine landscape matrix surrounding the remnant patches was included in model specifications (Lindenmayer *et al.*, 2000b). Models where the carrying capacity of remnants was assumed to be a simple function of patch area and home range size substantially over-predicted the number of occupied patches and the total abundance of animals (summed across all patches). These results were observed irrespective of the dispersal model and rates of inter-patch movement incorporated in the model. Notably, even these simple models were substantially more complex than population models used in most other studies to forecast population dynamics in fragmented landscapes. Only when model complexity was increased was better congruence found between predictions from VORTEX and actual values for patch occupancy and overall animal abundance. This was assessed by incorporating the effects of within-patch habitat quality in the model based on dominant forest type, together with the negative effects of the surrounding matrix on dispersal mortality. Even in those cases where the most complex models were invoked, it was not possible to accurately forecast the number of animals in a given patch. The predicted number of animals was often either well above or well below the observed abundance, possibly a result of the stochastic nature of extinction and recolonisation events that characterise the dynamics of metapopulations (Figure 4). However, it is also possible that other (unknown) factors not included in the model (eg. the effects of predation) could have contributed to the limited predictive ability of the model on a patch-by-patch basis (Lindenmayer *et al.*, 2000b).

In the case of tests of the ALEX model, congruence was examined between field data for the greater glider and predictions from PVA under several metapopulation modelling scenarios. Logistic regression analysis showed highly significant positive relationships between predicted patch occupancy and actual patch occupancy for the greater glider. When the model-derived values for the probability of patch occupancy were high there was greater congruence between actual patch occupancy and the predicted probability of occupancy. For many patches, probability distribution functions indicated that model predictions for animal abundance in a given patch were not outside those expected by chance. However, for some patches, the model either substantially over- or under-predicted actual abundance. It is possible, therefore, that some important processes like inter-patch dispersal that influence the distribution and abundance of the greater glider may not have been adequately modelled (Lindenmayer *et al.*, 2000c).

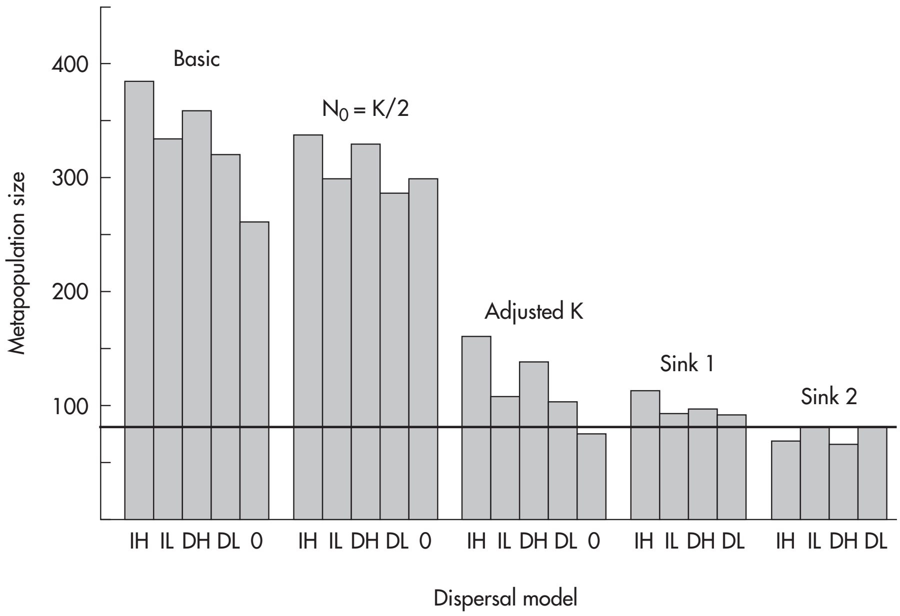

Figure 4. Predicted number of *Petauroides volans* in the study system for various modelling scenarios and rates of migration. IH = island model with a high migration rate IL = island model with a low migration rate. DH = size/distance^2 with a high migration rate. DL = size/distance^2 with a low migration rate. 0 = no migration. The horizontal line corresponds to the observed numbers from field surveys.
Basic: no variation in habitat quality between patches and all simulations commenced with patches at maximum carrying capacity.
N_0 = K/2 scenario: initialisation of simulations with population sizes in patches set to half carrying capacity.
Adjusted K scenario: Variation in habitat quality between remnant patches.
Sink scenarios: variation in the use of the pine matrix surrounding remnant patches. Animal survival during dispersal was set to 50% in the Sink 1 scenario and to 25% in a more severe Sink 2 scenario.

For tests of Hanski's (1994) incidence model, patch occupancy was predicted for the common brushtail possum, the mountain brushtail possum, the common ringtail possum and then greater glider, then compared with actual data on patch occupancy gathered from extensive field surveys. Data analyses revealed large differences in the results for different species. In the case of the common ringtail possum, there were several models for which it was not possible to derive the parameter estimates required by the model (ie. relationships for extinction and colonisation as a function of patch size and patch isolation). The ability of the species to persist at low density in the surrounding landscape matrix may have precluded the calculation of these estimates. There was reasonable congruence between predictions and actual field data for patch occupancy for the greater glider and for the common brushtail possum. Conversely, none of the sub-models for the mountain brushtail possum produced results consistent with the observed data on patch occupancy for this species.

4.2 Birds

All PVA model testing for birds has been conducted using ALEX. Two major studies have been completed, each involving pairs of relatively closely related species: (1) the sacred kingfisher and the laughing kookaburra (*Dacelo novaeguineae*) (Lindenmayer *et al.*, 2000e); and (2) the white throated treecreeper (*Cormobates leucophaea*) and the red-browed treecreeper (*Climacteris erythrops*) (McCarthy *et al.*, 2000). As in the case of work on arboreal marsupials, model testing involved comparing predicted patch occupancy and animal abundance with actual data for these same measures.

Modelling of the sacred kingfisher and the laughing kookaburra produced contrasting results for the two species. For the sacred kingfisher, logistic regression analysis showed that observed patch occupancy was not significantly different from that predicted using the ALEX model. Thus, patches with a high predicted probability of occupancy were often found to be occupied during field surveys. Conversely, for the laughing kookaburra, ALEX significantly over-predicted the number of occupied patches, particularly remnants dominated by certain forest types — ribbon gum and narrow-leafed peppermint. The predictions remained significantly different from observations, even when the habitat quality of these patches was reduced to zero in the model. Changing the rate of dispersal into the system was then changed in the model. This resulted in overall predicted patch occupancy being not significantly different from observations. Nevertheless, the predicted occupancy rates for the different forest types was significantly different from the field observations. The lack of congruence between field data and predictions from the computer models for the laughing kookaburra may have arisen because the species was modelled as a metapopulation. However, birds may change their home range movements in response to fragmentation, and use of an array of different patches by moving frequently between them to access spatially-separated food and nesting resources (Lindenmayer *et al.*, 2000e).

Modelling of the two species of treecreepers also produced interesting results. The first models used underestimated the occupancy of the patches. They were then modified using the results of the tests in conjunction with further information on the biology of the species. Several different modifications were made to the model to generate results that matched the observations. The best of these modifications made reasonable predictions, although this is not equivalent to a test with independent data because the data were known before the modifications. The best-fitting modified models were tested by comparing the observed number of extinction and colonisation events with the predicted number. The models underestimated the observed number of events, although imperfect field survey methods may have contributed to these differences. The tests of the stochastic models contributed to their development by highlighting the nature of the predictive error. The modified models predicted that the white-throated treecreeper would be likely to persist over the next

100 years in most of the 40 patches (McCarthy *et al.*, 2000). In contrast, the red-browed treecreeper was predicted to become extinct in most patches within approximately 50 years of fragmentation. Notably, in the case of the white-throated treecreeper, predictions were greatly improved if the model included the ability of the species to forage up to 500 m from the remnant eucalypt patches and into the surrounding radiata pine matrix (McCarthy *et al.*, 2000). Hence, adjustments to the models to account for matrix effects — increasing their complexity beyond the simple mainland-patch or inter-patch models typically employed in metapopulation modeling — significantly improved predictive ability.

4.3 Small mammals

Model testing for small mammals will use the ALEX and VORTEX packages. This work has recently commenced and preliminary results have been obtained for one of the models (VORTEX). These show that the extensive between-year population fluctuations in animal abundance which can occur as a result of factors like drought, can make it difficult to generate accurate predictions of patch occupancy and population size.

4.4 Modelling summary

All models invariably simplify the systems they attempt to portray (Burgman *et al.*, 1993). Metapopulation models are no different in this regard (Hanski, 1999) and models like Hanski's (1994) incidence function model consistently favour simplicity above model complexity. Nevertheless, a key conclusion from the Tumut experiment has been that it is essential to consider temporal and spatial variation in matrix conditions as part of metapopulation modeling of dynamic, managed landscapes. Therefore, it is critical to check model assumptions before models are applied to real landscapes and real conservation problems (Wiens, 1994). Examples of the white-throated treecreeper and the laughing kookaburra clearly demonstrate that metapopulation modelling and the simulation of populations within habitat patches must take account of the ability of organisms to use, and move across, the surrounding landscape matrix. Incorporating these types of processes into metapopulation modelling will allow this class of models to better account for the heterogeneity that characterises real landscapes. This will, in turn, increase the value of population models (including metapopulation models) for use in applied natural resource management and biodiversity conservation.

Much of the modelling work completed as part of the Tumut experiment has compared outcomes for closely related sets of species (eg. the two species of brushtail possums and the two species of treecreepers). In almost all cases, there were marked differences in findings between each species in a given pair. The reasons for the marked differences between species are not clear. However, they indicate that knowledge of the response of one species to disturbance (eg. habitat fragmentation) may not necessarily provide a useful guide to the possible response of other taxa, including those that are very closely related (Lindenmayer *et al.*, 1999b). This has major implications for the reliability of methods like indicator species approaches to the conservation of biodiversity (Lindenmayer *et al.*, 2000d).

5 Genetic analysis of habitat fragmentation effects

The potential impacts of habitat fragmentation on patterns of genetic variability have been widely discussed in the literature, but there are remarkably few empirical investigations which link genetic analysis with detailed field-based demographic studies (but see Sarre, 1995; Saccheri *et al.*, 1998). The patch structure and field sampling framework at Tumut have facilitated detailed genetic studies that have run concurrently with the demographic investigations. The results of genetic analysis and demographic studies will ultimately be integrated, as the combined information from both will be substantially greater than could be derived from the sum of either one conducted independently (Lindenmayer and Peakall, 2000).

Genetic analyses in the Tumut experiment have examined (or soon will examine) patterns of genetic variability among small mammal and arboreal marsupial populations in relation to eucalypt patch structures (Hewittson, 1997; Lindenmayer *et al.*, 1999d; Lindenmayer and Peakall, 2000). A summary of the preliminary findings from the work completed to date follows, although substantial additional work is continuing.

5.1 The bush rat

Demographic studies of the bush rat (*Rattus fuscipes*) at Tumut indicated that the species occupied remnants of eucalypt forest surrounded by extensive stands of radiata pine and that the probability of occurrence of the species was significantly higher in larger patches (Lindenmayer *et al.*, 1999c). Genetic analyses of patch populations, together with those in large continuous areas of native forest, revealed interesting patterns of genetic variability.

In the area targeted for detailed trapping of small mammals (a 10 km × 15 km area in the north-eastern part of the study area – see section 3.3.2), significant genetic differentiation has been detected among populations. Some neighbouring pairs of remnant populations (< 0.5 km apart) showed above-average genetic differentiation, relative to other more distant populations. Genetic variability was also detected amongst populations in continuous native forests. Thus, neither random mating nor isolation by distance can explain the genetic patterns, nor can habitat fragmentation alone account for the findings, suggesting that other processes have contributed to the patterns. There are early indications that heterogeneity between years within sites can be as great as that between sites. Hence, both spatial and temporal heterogeneity may confound attempts to understand the consequences of habitat fragmentation.

No correlation between genetic distance and geographic distance was found in the bush rat (Hewittson, 1997). Rather, populations of this species located a considerable distance apart were more closely related if they occurred in patches connected by a drainage line than were spatially adjacent populations not connected by a watercourse (Hewittson, 1997). The most straightforward explanation for this result is that animals use watercourses as dispersal routes, and there is limited movement among patches not linked via a streamline, even when they are close together (Lindenmayer and Peakall, 2000). This result confirms the importance of riparian vegetation as key habitat for small mammals such as the bush rat, and emphasises the value of its protection, particularly for the maintenance of connectivity between subpopulations. Hence, the maintenance of intact aquatic ecosystems (and associated riparian vegetation) may mean that modified landscapes may be less fragmented for some taxa than they otherwise would be.

5.2 The agile antechinus

Preliminary trapping data for the agile antechinus (*Antechinus agilis*) at Tumut (Lindenmayer *et al.*, 1999c) indicated that the species was almost never captured at sites dominated by stands of radiata pine. Based on this observation, additional trapping was completed to determine the degree to which pine plantations were a barrier to dispersal. To provide information on dispersal rates in native forests, four sites were placed in the continuous eucalypt forest. These sites were positioned along the edge of the pine plantation so that they provided reasonable coverage of the most likely source areas for immigrants into the remnant sites. Four of the remnant sites were 'peninsular' sites, being connected to continuous forest by long (1 to 1.5 km), narrow strips of eucalypt forest running along streamlines. The remaining four sites were 'insular sites', being completely surrounded by pine plantations. Movement from the continuous forest to these eucalypt islands via the path with the least amount of pine forest would require traversing from between 50 m and over 500 m of pine forest. The final genetic data analysis was carried out on 314 animals.

At the start of this project, there were no genetic markers available that would be appropriate for fine-scale population analysis. Therefore, a genomic library was constructed for the agile antechinus and developed using a suite of microsatellite markers. During this process, a new, highly efficient cloning technique (MOUSE) was developed. While primarily targeting longer microsatellites (because of their informativeness on a fine scale), a set of six short microsatellites was also developed for use in a project studying evolutionary relationships within the genus *Antechinus*. The suite of longer, highly variable microsatellites used for the population analysis consisted of 17 markers. Null (non-amplifying) alleles were a problem with many of the initial primers designed, so considerable effort was put into testing new primers such that there was no statistical evidence of null alleles in the final data set. There are very few publications in the area of molecular population ecology that have used more than 10 microsatellite markers. Thus, despite starting with no available markers in mid 1998, this data set is now among the most comprehensive of its type.

Initial analysis of the population-level data has commenced and it shows that the impact of radiata pine forest on dispersal in the agile antechinus is not as dramatic as expected. Most notably, heterozygosity is expected to decline sharply in isolated populations of small size. Trapping results suggest that some of the remnant patches had extremely small populations (fewer than 30 animals), which should translate into rapid declines in heterozygosity with isolation. Instead, what was observed was that average heterozygosity for continuous, peninsular and insular sites, respectively, were all in a similar range of variation. The only site showing a significantly lower level of variability was the most isolated insular site but, even there, levels of heterozygosity were inconsistent with isolation for even a few generations. These simple data indicate that, while pine plantations are not suitable habitat for the agile antechinus, they do not represent an insurmountable barrier to dispersal. These results are in contrast to results of previous studies of habitat peninsulas and islands where fragmentation has taken place over a similar length of time.

Analytical avenues that will be explored include a detailed analysis of population structure of the agile antechinus in relation to habitat type, an analysis of sex-bias in dispersal using genotype likelihoods, and a comparison of relatedness in remnant sites and continuous sites. In addition, data from field studies will be used in conjunction with simulation modelling to improve predictions of patch occupancy using VORTEX.

5.3 The greater glider

Comparative genetic and demographic studies of the greater glider are an exciting and unique component of the Tumut experiment. Numerous specimens of the greater glider were collected in the mid-1960s in the study area as large areas of native eucalypt forest were cleared to establish stands of radiata pine (Tyndale-Biscoe and Smith, 1969). The precise locations where the specimens were collected were mapped before they were subsequently lodged with the Australian Museum, the National Museum of Victoria, the South Australian Museum, and the National Wildlife Collection (CSIRO Sustainable Ecosystems). Samples of hair, skin and teeth have been taken from these specimens and DNA is currently being extracted from them.

Populations of greater glider persist in some of the remnant eucalypt patches at Tumut, including those close to where the original specimens were collected approximately 35 years ago. In addition, populations of the species occur throughout the extensive areas of continuous eucalypt forest that exist beyond the northern, eastern and southern boundaries of the radiata pine plantation. Blood samples have been collected from living animals that reside in the eucalypt remnants and in continuous forest (Viggers and Lindenmayer, 2000). This array of historical and current samples allows for a number of key questions to be addressed relating to the effects of habitat fragmentation on patterns of genetic diversity in the greater glider.

Before the onset of detailed genetic analyses, a number of hypotheses about the possible impacts of fragmentation on the greater glider were constructed. These hypotheses were based on general conservation biology and conservation genetics principles and were published before the start of work on the laboratory component of genetics studies of the species (Lindenmayer *et al.*, 1999d). The broad categories of questions posed were:

- do populations in continuous eucalypt forest show genetic differentiation related to geographic distance?
- are the populations in the eucalypt fragments in the radiata pine plantation isolated from each other and/or from continuous eucalypt forest?
- what are the genetic origins of animals in the patches?

Work on the greater glider is continuing and at present it is not possible to answer either these questions or those posed in Lindenmayer *et al.* (1999d). However, results to date make it clear there has been no loss of genetic diversity in the patch system relative to the continuous forest, suggesting that populations of gliders in remnant patches do not consist of highly inbred individuals descended from the animals originally confined to these patches following clearing. Rather, there appears to have been some degree of gene flow (exchange of breeding animals) between patches. This outcome is consistent with radio-tracking observations of between-patch movements by the greater glider (Pope *et al.*, unpublished data; see below). By integrating genetic and demographic studies, ultimately it should be possible to study dispersal patterns and, in turn, relate these to spatial patterns of remnant vegetation such as the existence of wildlife corridors.

6 The accuracy and effectiveness of field survey methods

All empirical studies of habitat fragmentation are underpinned by the quality of the field data gathered. The quality of these data are, in turn, influenced by the field methods employed. Failure to consider the efficacy of such methods may mean that fragmentation effects are artifacts of the field-sampling techniques rather than true fragmentation effects. On this basis, a sub-theme in the Tumut experiment has been to test the accuracy and effectiveness of methods for sampling the major groups of vertebrates — terrestrial mammals, birds and arboreal marsupials — targeted in the study. These data have been used to assist in the interpretation of field data or modify field counting protocols to ensure the best quality data are gathered.

6.1 Arboreal marsupials

Field data on arboreal marsupials were gathered by spotlighting. A field calibration study was completed to test the effectiveness of the method to detect the greater glider — the species of arboreal marsupial that is thought to be one of the most readily detected by spotlighting. The location of animals revealed by spotlighting was compared with the precise locations of a known population of radio-collared individuals (determined simultaneously by another observer using radio-telemetry equipment and working independently from the spotlight observer). The calibration study showed that spotlighting can seriously underestimate the abundance of the greater glider — sometimes by more than 50%. However, the extent of such bias may be similar in a given forest type and the spotlighting method is likely to be valid for comparisons between 'treatments' such as patches dominated by similar types of eucalypt forest (Lindenmayer *et al.*, 2001b).

6.2 Birds

Field surveys for birds entailed completing counts at more than 160 sites. Multiple volunteer observers were required to complete these surveys to ensure that sampling was confined to a short period when calling and other behavioural patterns (which influence bird detectability) were relatively uniform. Field trials were conducted to compare the ability of different observers to count birds in different forest types (eucalypts versus pine) using different counting protocols (point-intervals counts, zig-zag walks and straight transects) (Cunningham *et al.*, 1999).

The results showed there were significant differences between observers in their ability to detect particular groups of birds (eg. medium-sized birds that forage in the understorey and call frequently), even among highly experienced observers (Lindenmayer *et al.*, 1997b; Cunningham *et al.*, 1999). To account for this problem, we employed counting protocols that resulted in each site being sampled twice on a given day by two different experienced observers. In addition, the extent of observer differences was taken into account as part of detailed analyses of the response of birds to landscape context and habitat fragmentation effects at Tumut (Lindenmayer *et al.*, 2000a).

6.3 Terrestrial mammals

Two field sampling methods were employed in surveys of terrestrial mammals: aluminum 'Elliott' traps and hairtubing. These methods are used widely in field surveys throughout Australia. A detailed comparison of the two methods was completed as part of field surveys in the Tumut experiment. These comparisons were made by establishing many hundreds of field plots, each with several types of hairtubes (eg. devices varying in entrance diameter), as well as a single Elliott trap. Patterns of concurrent detection of a given species by trapping and different types of hairtubes were then examined.

The method which produced the highest number of detections varied between species. For small mammals such as the bush rat and *Antechinus* spp., trapping was significantly more effective than hairtubes at detecting animals. Indeed, there were many plots where these species were trapped but never recorded in any of the four types of hairtubes trialled. One of the most common species of small mammals at Tumut, the bush rat, was rarely recorded in a newly-developed type of hairtube called a 'hair funnel' deployed widely in the experiment. Yet, the species was often captured in Elliott traps at these same sites (Lindenmayer *et al.*, 1999e). Species of mammals too large to be captured in an Elliott trap were occasionally detected in hairtubes. However, the type of hairtube producing the most records varied between species and showed no clear pattern relating to the body size of animals or other obvious life history attributes. Notably, concurrent detection of a given species by more than one type of hairtube on a given survey plot was rare (Lindenmayer *et al.*, 1999e). The findings from work on terrestrial mammals have highlighted the importance of accounting for sampling methodology effects in interpreting the potential impacts of habitat fragmentation.

7 Other studies in the Tumut Fragmentation Experiment

Enormous effort was invested in finding a study area with the special attributes that made the Tumut region an excellent place to work. In addition, extensive effort was expended to establish the necessary infrastructure associated with the study (eg. site selection, site marking, and vegetation sampling). On this basis, there were other important research opportunities in the Tumut experiment. This section outlines some of the more substantial additional studies undertaken that complement the original objectives of the project.

7.1 Patch use by the greater glider

A radio-tracking study of patch use by the greater glider is being undertaken by Mr M. Pope as part of a MSc program at the Centre for Resource and Environmental Studies, The Australian National University. The work is investigating home range movements, den use, and feed tree use in an ensemble of remnant eucalypt patches of varying size and shape. The work was scheduled for completion in July 2000 and is showing some important effects of fragmentation on patterns of animal behaviour. Population densities are increased and there is greater overlap in peripheral (but not core) home ranges in smaller eucalypt remnants. Patterns of den tree use are also altered in small remnants, with males in particular occupying far more dens in larger remnants (where there are more suitable trees available to occupy). Finally, home range shape is altered in small eucalypt remnants and may conform to patch boundaries *per se* rather than territory boundaries of neighbouring animals (M. Pope *et al.*, unpublished data).

7.2 Weed invasions of remnant vegetation

Detailed information on vegetation structure and plant species composition has been gathered at all 166 sites targeted for study in the Tumut experiment (see section 3.1). Two key measurements from these extensive vegetation surveys were used to examine the problems of weed invasion. These measures were the presence/absence of radiata pine wildlings and the density of cover of blackberry (*Rubus fructicosus*). Extensive statistical analyses of the factors influencing the occurrence of both weed species have been completed (Lindenmayer and McCarthy, 2000). This work has shown that some types of eucalypt remnants are particularly susceptible to weed invasion. Remnants that have been surrounded by radiata pine stands for a prolonged period were more likely to contain pine wildlings. Also, pine wildlings were significantly more likely to occur in dry forest and woodland types such as those dominated by apple box and broad-leaved peppermint. In the case of blackberry, occurrence in remnants increased significantly with closeness to the surrounding radiata pine stands. It also was more prevalent in wetter forest types, particularly gully systems dominated by mountain swamp gum (Lindenmayer and McCarthy, 2000). The findings of the analysis of these two major weed problems indicate their prevalence may increase over time and existing weed control options are probably limited at present. However, the adoption of some protocols governing the movement of machinery between existing and new plantations (which presently do not have severe weed infestations) could limit, or at least slow, the spread of these weeds (Lindenmayer and McCarthy, 2000).

7.3 Factors influencing hollow development in forest and woodland landscapes at Tumut

Trees with hollows are a key habitat attribute for a wide range of vertebrates in Australian ecosystems (Gibbons and Lindenmayer, 1997). Radio-tracking studies of the greater glider at Tumut indicated that particular types of trees with hollows are favoured by the species (M. Pope *et al*., unpublished data). Given this, a study was completed of the factors influencing the abundance of cavities in the various species of eucalypts which were the predominant canopy trees at Tumut (Lindenmayer *et al*., 1999f).

Forty sites encompassing the major forest types in the region were selected for detailed sampling. That is, forests dominated by narrow-leafed peppermint (*Eucalyptus radiata*), mountain swamp gum (*Eucalyptus camphora*), mountain gum (*Eucalyptus dalrympleana*), red stringybark (*Eucalyptus macrorhynca*), ribbon gum (*Eucalyptus viminalis*) and broad-leaved peppermint (*Eucalyptus dives*). Each site consisted of a 400 m long transect with tree measurements gathered at 100 m intervals.

The study identified a simple, general rule that highlighted the relationships between cavities and readily measured tree attributes. In general, both the number of cavities and cavity size were directly proportional to tree diameter, but inversely proportional to the square root of tree height. This proportionality changed between different tree species. Ribbon gum and broad-leaved peppermint supported, on average, larger cavities than other species, whereas the cavities in red stringybark were smaller than the other taxa sampled. This simple general relationship may allow rapid estimates of cavity abundance across large areas of forest by measuring simple tree attributes such as tree diameter and tree height (Lindenmayer *et al*., 1999f).

7.4 Edge effects and artificial nest predation

One of the potential impacts of habitat loss and habitat fragmentation is that edge effects occur at the boundaries of remaining habitat fragments. Various types of edge effects include abiotic changes such as increased wind speeds and altered thermal regimes (Chen et al., 1992) and biotic changes such as increased nest predation and brood parasitism (Paton, 1994). There is considerable potential for edge effects to arise at Tumut given (1) the fragmented radiata pine/eucalypt forest mosaic, and (2) the extensive road network that is required to harvest timber (several researchers (eg. Burkey, 1993) have found edge effects associated with roading systems). On this basis, a study of predation rates of artificial nests containing quail eggs was completed at Tumut. The study examined levels of nest predation in different types of roadways (Lindenmayer *et al*., 1999g). Four broad categories of sites were established, each with eight replicates. These were: (1) gravel roads surrounded by extensive areas of radiata pine; (2) gravel roads located within large continuous areas of eucalypt forest; (3) gravel roads adjacent to extensive stands of radiata pine on one side and large contiguous areas of eucalypt forest on the other; and (4) gravel roads adjacent to extensive stands of radiata pine on one side and a remnant patch of eucalypt forest surrounded by extensive areas of radiata pine on the other. At each of the 32 sites, a 400 m long, unmarked transect was established. A gravel road bisected each site at the 200 m point along each transect. Nine artificial nests were set at 50 m intervals along each transect.

The study showed that the rate of egg predation from artificial nests did not vary with distance from roads into the forest or the types of forest that surrounded roadways. In addition, the species of plant in which a nest was positioned was not significant. The reasons for the lack of significant effects in the investigation are not clear. However, the work was confined to a completely forested setting; a factor which may have contributed to the absence of observed effects (Lindenmayer *et al*., 1999g). Many of the studies where significant nest predation effects have been identified in edge environments (like those associated with roads) are in northern hemisphere agricultural landscapes where there are large contrasts between vegetation remnants and the surrounding environment (eg. Andrén, 1992; Bayne and Hobson, 1997). Thus, the level of structural contrast between vegetation remnants and the surrounding matrix may significantly influence the magnitude of edge effects (Lindenmayer and Franklin, 2000).

7.5 Landscape indices and generic measures of forest fragmentation

Generic measures to describe patterns of landscape fragmentation have been sought as part of the development of sustainability criteria for forest management. As part of a study funded by the Forest and Wood Products Research and Development Corporation, the remnant patch system at Tumut was used to test the generic applicability of an array of landscape metrics for assessing habitat fragmentation and, in addition, the impacts of habitat fragmentation on biodiversity. Detailed analysis of data for birds and arboreal marsupials showed that each species responded differently to the set of metrics used to characterise the landscape mosaic of radiata pine and eucalypt remnants at Tumut. Even attributes like remnant size, which are considered key ones in paradigms like metapopulation dynamics and island biogeography theory, did not feature in landscape models developed for some species (Lindenmayer *et al.*, 2001a).

The inherently species-specific responses to landscape context and habitat fragmentation at Tumut mean that it is unlikely that robust and generically applicable metrics of landscape cover for assessing fragmentation effects for all taxa (or even a significant subset of them) can be identified. Rather, the principal objectives of employing a given set of landscape metrics, and the taxa for which they are targeted for use, need to be explicitly stated.

Although, the results of landscape analysis showed there was no single landscape metric or set of metrics for all biodiversity, the study of landscape metrics nevertheless yielded some important new findings about the response of individual taxa to the landscape mosaic. For example, species such as the rufous whistler and the common ringtail possum responded strongly to landscapes where the area of remnant eucalypt forest was dispersed across many patches, rather than being consolidated as a single remnant (Lindenmayer *et al.*, 2001a).

7.6 The role of the matrix in forest biodiversity conservation

A fundamentally important finding derived for the array of studies in the Tumut experiment has been the importance of the matrix, not only for supporting populations of species, but also its influence on population processes such as patch size effects, edge effects, dispersal biology, metapopulation dynamics and a range of other processes (eg. weed invasion). These findings have stimulated a major review of the importance of the matrix for biodiversity conservation (Lindenmayer and Franklin, 2000).

8 The Nanangroe 'natural' Experiment

Only scant information was available on animal abundance in the Tumut Fragmentation Experiment when landscape disturbance commenced. This ignorance of the status of species before fragmentation is a common feature of almost all fragmentation studies (Margules, 1992). Often interest is in the direct study of temporal changes and relationships that occur as a result of intervention. In these cases, long-term (longitudinal) studies are necessary, as they can distinguish changes over time from differences among sites in initial population levels (Davies *et al.*, 2000). That is, cohort effects can be separated from age effects, which were confounded in the Tumut experiment. Further, as each site becomes its own control, a longitudinal study may provide convincing evidence of relationships among key variables, which may not be discerned from data obtained in cross-sectional studies like that at Tumut.

A new study funded by RIRDC has recently commenced that addresses the limitations of the Tumut experiment and, at the same time, examines the impacts of plantation expansion on biota inhabiting woodland that will be surrounded by stands of radiata pine. The new study, called the Nanangroe Experiment, is a long-term (longitudinal) study with the defining feature that repeated observations have been (and will continue to be) taken on individual sites, enabling the direct study of change.

The Nanangroe Experiment focuses on a grazed woodland landscape near Jugiong in south-eastern New South Wales, southern Australia, approximately 15 km north-east of the boundary of the Tumut study area. It contrasts strongly with other fragmentation experiments where extensive clearing of trees occurred to isolate habitat fragments (eg. Margules, 1992; Bierregaard and Stouffer, 1997). Rather, it is examining a landscape that is already largely cleared of the original vegetation cover and which now supports only fragments of the native eucalypt woodland. The landscape matrix surrounding these woodland fragments is undergoing a major and rapid transition from one that is largely cleared and dedicated to grazing domestic livestock, to one dominated by extensive plantations of radiata pine trees. The Nanangroe Experiment will quantify the changes that occur in vertebrate fauna inhabiting woodland remnants when the surrounding landscape undergoes extensive change. The groups targeted for study are birds, terrestrial mammals, arboreal marsupials, reptiles and frogs.

A total of 126 sites was chosen for sampling in the Nanangroe Experiment and these encompass four site 'landscape contexts':

- woodland remnants where the surrounding grazing land has recently been converted to stands of radiata pine (50 sites). The age of cohorts of radiata pine varied for these 50 woodland remnants —pine established in 1998, pine established in 1999, and pine establishment set to be completed in mid-2000;
- newly planted stands of radiata pine trees that formed the landscape matrix surrounding the 50 woodland remnants (ten sites);
- woodland remnants located on semi-cleared private properties where the primary land use is grazing by sheep (*Ovis ovis*) and cattle (*Bos taurus*) (56 sites); and
- cleared paddocks that form the landscape matrix surrounding the 56 woodland remnants (10 sites).

Populations of birds, small mammals, arboreal marsupials, and birds have been sampled in the Nanangroe Experiment over the past two years. Baseline data from all groups except birds are presented in Lindenmayer *et al.* (2001c).

Statistical analyses of baseline data have been completed for several species. They show that structural and landscape attributes of woodland remnants influence their suitability as habitat for a number of taxa. For example, arboreal marsupials are more likely to be found in larger remnants that contain more trees with cavities. The four-fingered skink (*Carlia tetradactyla*) is more likely to be found either where there are more exposed rocks or more standing dead trees (Lindenmayer *et al.*, 2001c).

All sites in the Nanangroe Experiment will be sampled at regular intervals over the next 10 or more years to allow the direct study of change in species occurrence and community composition. It is likely that the statistical relationships obtained for many species will change as the surrounding landscape matrix is transformed, particularly for arboreal marsupials such as the common ringtail possum (*Pseudocheirus peregrinus*), a species for which stands of radiata pine will provide suitable, or partially suitable, habitat.

9 Future directions and further studies in the Tumut Fragmentation Experiment

The Tumut Fragmentation Experiment has provided many new insights into habitat fragmentation effects on biodiversity. A substantial body of information has resulted from the work undertaken in the past five years (see Appendix 4). Nevertheless, a considerable amount of work remains to be completed. Many of the results of genetic sampling and associated analyses have yet to be published, and a major effort will be directed at bringing these studies to completion in the next few years. Findings from these studies will have particular value when they are integrated with the demographic and simulation modelling components of the experiment. For example, plans are well advanced to forecast patterns of genetic variability among small mammal populations in the patch system at Tumut using the generic model VORTEX (Lacy, 1993b). Predictions will then be contrasted with actual values for various gene metrics presently being obtained from laboratory analysis of samples collected from small mammals in these same patches.

Other studies have recently commenced. For example, sampling of frog populations in the Tumut experimental area started in February 2000 and will be repeated in October 2000. Vegetation and patch attributes will be measured and used as covariates in statistical modelling efforts to identify factors influencing the distribution and abundance of species in this group. In addition, a study of the effects of landscape context and habitat fragmentation on plant species has been proposed and will commence in December 2000 if funding is successful (E. Pharo, personal communication). A major ARC-funded study of the dispersal and recolonisation biology of small mammals at Tumut began in March 2000 and will continue until 2002. This project is determining how rapidly animals recolonise empty eucalypt patches and if recolonisation dynamics are related to measures of patch size and patch isolation.

10 Summary of key findings from the Tumut Fragmentation Experiment (as at August 2000)

- The presence and abundance of some animal species in eucalypt remnants surrounded by intensively managed plantation forests were significantly different to values obtained for those species in equivalently sampled eucalypt forest sites surrounded by extensive areas of similar eucalypt forest. Thus, landscape context effects are important for many species.
- Landscape context differences between eucalypt remnants and large continuous areas of native eucalypt forest were *not* significant for those species of arboreal marsupials that occur in the matrix.
- Patches of remnant vegetation are very important as refugia for native vertebrates. Even though remnant eucalypt vegetation at Tumut is unlikely to ever be part of a reserve system, it will nevertheless make an important contribution to biodiversity conservation in the region.
- Small and intermediate-sized remnant eucalypt patches (0.5 to 3 ha) have considerable value for forest vertebrates and are used by many taxa for shelter and breeding. Larger remnants supported more species of arboreal marsupials, small mammals and birds, but small and intermediate-size contributed significantly to the maintenance of forest biodiversity. Therefore, patches larger than 0.5 ha should be exempt from clearing.
- Some species (eg. yellow-bellied glider and squirrel glider) may not be adequately conserved within patches of remnant eucalypt forest within the plantation estate, even if large remnant patches are set aside, and streamside reserves are established.
- The distance of remnants from large, continuous (potential source) areas appears to be very important for only a limited number of species (the agile antechinus for example). This implies that the pine matrix may provide important cover to assist the movement of animals even though the majority of native mammal species can not permanently inhabit these areas.
- Genetic data from the bush rat indicate no relationships between remnant proximity (geographic distance) and genetic distance. The most straightforward interpretation of these data is that dispersal is taking place along streamlines — connectedness along gullies (particularly through retaining intact riparian vegetation) seems to be a critical strategy for linking wildlife populations in remnant native patches. The value of corridors would appear (in the case of this species) to be enhanced by establishing or restoring links between remnants along streamlines. Remnant vegetation in gullies should have priority for retention and/or restoration.
- The structural condition of the vegetation within the radiata pine forest (eg. large logs on the forest floor and native understorey vegetation) strongly influenced the ability of some birds and small mammals to persist there.
- Edge effects resulting from increased nest predation do not appear to be an important process influencing nest success in birds within pine/remnant vegetation systems at Tumut.
- Some types of native eucalypt remnants surrounded by pine forest appear to be very susceptible to invasion by weeds, especially pine wildlings and blackberry.
- The dynamics of animal populations within habitat fragments can be strongly influenced by conditions in the surrounding matrix. Uncoupling interrelationships between these

two landscape components and focusing solely on habitat fragments and ignoring the matrix can lead to erroneous interpretations of fragmentation effects and will result in important phenomena being overlooked.

- The responses to patch use varies markedly between all species. However, an overarching and common theme relating to patch occupancy appears to be that persistence in the matrix substantially increases the chances of inhabiting remnants.
- Most theories associated with fragmentation are derived from agricultural landscapes where habitat remnants are surrounded by a relatively hostile matrix. More complex responses to landscape conditions, such as those derived for birds in the Tumut experiment, may occur where the surrounding matrix is less inhospitable.
- Plantation estates around the world are usually considered to have few conservation values. However, the implementation of some landscape design strategies such as the maintenance of protected areas within the matrix, and the retention of attributes of aquatic ecosystems (eg. riparian vegetation), can significantly enhance the value of plantations for biodiversity.

11 Protocols and guidelines for enhancing the conservation value of new and existing softwood (radiata pine) plantations[1]

11.1 Background

Landscapes dominated by softwood plantations have wood and paper production as their primary aim. However, some changes in land-use protocols will contribute significantly to the conservation value of these landscapes. The following protocols and guidelines are based on the findings the Tumut Fragmentation Experiment. Recommendations are made for both new and existing softwood plantings within an adaptive management framework and the recommendations below may change as new information becomes available. New findings will be relayed to softwood forest managers to better inform approaches for improved plantation design.

11.2 New softwood plantings

The expansion of softwood plantations is occurring on semi-cleared land that was formerly used for grazing and supports patches of remnant native vegetation. The following recommendations aim to promote the conservation value of landscapes where new plantings of softwoods are planned or underway.

1. Published in Lindenmayer (2000)

- Remnant patches of native woodland and forest provide important habitat for native mammals, birds, reptiles and plants.
- Larger patches of remnant native vegetation (eg. greater than 3 ha) support more native animals than smaller patches. However, remnant patches of native vegetation as small as 0.5 ha have considerable value for biodiversity.
- Remnant patches of native vegetation that are 0.5 ha or larger should not be cleared during softwood plantation establishment.
- Remnant patches close to (within 500 m) large continuous areas of native vegetation are more likely to be occupied by some vertebrate taxa (eg. small mammals, arboreal marsupials and birds) than more isolated ones. However, even isolated patches can have significant conservation value for many species (eg. birds) and they should not be cleared simply because they are isolated.
- A landscape comprised of a mosaic of remnant native vegetation and softwood stands will have significantly higher biodiversity value than a radiata pine monoculture.
- Restoration of native vegetation should occur along gully lines to link existing patches of remnant native vegetation that occur within the softwood plantation estate.
- Plantation establishment may require the clearing of isolated paddock trees. The trade-off for the removal of these stems should be concerted efforts to restore native vegetation elsewhere in the plantation estate, particularly along gully lines.
- Initial plantings of native forest and woodland will require large numbers of native trees and understorey plants. This is because of high natural rates of mortality among planted stems.
- Physical connectivity (eg. wildlife corridors) between native remnant vegetation and revegetated areas within and outside the plantation estate should be maintained, established or enhanced.
- Extensive developments of the softwood plantation estate (eg. greater than 1000 ha) should aim to contain at least 30% of remnant or reestablished native vegetation within the

boundaries of the plantation. Restoration efforts may be needed to reach such levels of native vegetation cover within the plantation estate.

- Firewood collection and culling of trees should be excluded from remnant patches of native woodland and forest that have been retained within the boundaries of newly established softwood plantations.
- Grazing by domestic stock should be excluded for at least five years from patches of remnant native vegetation or revegetated areas retained within newly established softwood plantations. This should facilitate the regeneration of some native plants in patches of formerly grazed remnant vegetation.
- Efforts should be made to further develop and use reproductively sterile radiata pine trees for softwood plantation establishment and any wildlings removed from remnant vegetation patches as they threaten the integrity of these areas.
- Hygiene protocols are needed for logging and other machinery to stop the spread of blackberry from the existing plantation estate (where it is already established) to other areas targeted for the development of new plantation forests.
- Management effort is required to control presently minor outbreaks of blackberry in recently established parts of the plantation estate (eg. those planted in the past five years).
- Robust ecological principles to promote biodiversity conservation in plantation landscapes include establishing, maintaining or enhancing landscape connectivity and landscape heterogeneity among areas of remnant native vegetation.
- Inappropriate application of concepts like indicator species will result in poor land-use planning, such as the clearing of small vegetation remnants.

11.3 Existing softwood plantings

- Extensive areas of native vegetation were cleared as part of softwood plantation establishment until a few decades ago. Native vegetation in gullies and along streamlines should be reestablished at the completion of the final clearfell operation as these are areas used as habitat and for dispersal by wildlife.
- Restoration activities should use native tree species endemic to the local area and link existing patches of remnant native vegetation that occur within the softwood plantation estate.
- Buffer strips of native vegetation reestablished along streams within the plantation estate should be a minimum of 40 m wide.
- Efforts should be made to further develop and use reproductively sterile radiata pine trees for regenerating softwood plantations after the final clearfell harvest. This is because radiata pine wildlings threaten the integrity of patches of remnant native vegetation. Where possible, existing radiata pine wildlings should be removed from remnant vegetation patches.
- Firewood collection and culling of trees should be excluded from remnant patches of native woodland and forest that have been retained within the boundaries of newly established softwood plantations.
- The decay of windrowed eucalypt logs should not be accelerated by damage from harvesting machinery during logging operations as they can be important habitat for wildlife.
- Where possible, the cutting schedule of clearfelled plantation stands adjacent to remnants should be staggered to ensure that, at any one time, eucalypt remnants are linked by some areas of advanced regrowth radiata pine in the landscape matrix. Maintaining such connectivity can be enhanced by staggering the softwood planting schedule (and thus the time of final harvest) around patches of remnant vegetation.

12 The conservation value of remnant vegetation

12.1 Background

The following protocols and guidelines on maintaining and enhancing the conservation value of remnant vegetation are based on the findings of the Tumut and Nanangroe experiments. Recommendations are made at the landscape and patch levels to enhance the conservation value of remnant vegetation. Work is continuing in both experiments and as new data becomes available they will be relayed to land managers to better inform approaches for the conservation and management of remnant native vegetation.

12.2 Landscape-level considerations

- Remnant patches of native woodland and forest provide important habitat for native mammals, birds, reptiles and plants.
- Larger patches of remnant native vegetation (eg. more than 3 ha) support more species of native animals than smaller patches. However, remnant patches of native vegetation as small as 0.5 ha can have considerable value for biodiversity.
- Patches of remnant native vegetation that are 0.5 ha or larger should not be cleared.
- Remnant patches close to (within 500 m) large continuous areas of native vegetation are more likely to be occupied by some vertebrate taxa (eg. small mammals, arboreal marsupials and birds) than more isolated ones. However, even isolated patches can have significant conservation value for many species (eg. birds) and they should not be cleared simply because they are isolated.
- The assemblages of native animals vary significantly between different types of forest and woodland dominated by different species of trees. Efforts to conserve and restore native vegetation should ensure that a range of forest and/or woodland types occur across a landscape.
- The condition of the landscape surrounding patches of native vegetation significantly influences the conservation value of these remnants. Consequently, foraging substrates, such as paddock trees in agricultural regions, should be maintained in the landscape surrounding remnant patches.
- Revegetation efforts in cleared landscapes should focus on the restoration of riparian and gully vegetation. These areas are particularly valuable for wildlife, and can create links between existing patches of remnant native vegetation.

12.3 Patch-level considerations

- Old, dead trees with hollows should not be felled (eg. for firewood collection) from patches of remnant native vegetation as they provide particularly valuable habitat for wildlife.
- Large logs should be left on the ground and understorey vegetation maintained (eg. by reducing grazing pressure) as they provide significant habitat for a wide range of vertebrate animals in forest and woodland remnants.
- Clearing an existing area of native vegetation and establishing new plantings elsewhere on a farm or in a given region will typically have negative findings for biodiversity conservation. This is because recently established tree plantings do not have the same value as existing patches of remnant native vegetation.

12.4 General factors

- Robust ecological principles to promote biodiversity conservation in plantation landscapes include establishing, maintaining or enhancing landscape connectivity, vegetation complexity (eg. large, old trees with hollows), plant species composition and landscape heterogeneity.
- Inappropriate application of concepts like indicator species will result in poor land-use planning such as the clearing of small vegetation remnants.

13 Dissemination of information

One of the major objectives of the original brief for the Tumut Fragmentation Experiment was to widely disseminate the key findings of the project to ensure the adoption of important landscape design principles for retained systems of vegetation in multi-use landscapes. Substantial effort has been dedicated to achieving this objective. A full-time research officer has been based at the Tumut Office of State Forests of NSW for the duration of the project. This person (see Appendix 1) and the Principal Investigator in the Tumut Fragmentation Experiment have interacted extensively with staff from a wide range of State government agencies (State Forests of NSW, NSW National Parks and Wildlife Service, NSW Department of Land and Water Conservation), Federal Government agencies (Environment Australia; Agriculture, Forestry & Fisheries – Australia), officials from timber companies (CSR, Fletcher Challenge), local councils, graziers, and local landholders. Numerous field days were held to discuss major issues in landscape conservation, landscape design, plantation establishment, conservation values of remnant vegetation, and community concerns about plantation expansion. Many public lectures, scientific seminars and media engagements also were undertaken to further disseminate the key findings of the Tumut experiment.

Importantly, much of the new information generated from the Tumut Fragmentation Experiment has been used to inform the 'Draft code of practice for plantation design in NSW'. In addition, seminars and workshops were given in Tasmania, Western Australia and Victoria where there are significant issues associated with the design of expanded plantation estates and nature vegetation conservation.

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16 Appendixes

Appendix 1. Contributors to the Tumut Fragmentation Experiment

Principal Investigators

- Dr David Lindenmayer (Centre for Resource and Environmental Studies and Department of Geography, The Australian National University, Canberra).
- Associate-Professor Ross Cunningham (Statistical Consulting Unit, The Australian National University).
- Ms Christine Donnelly (Data Analyst) (Statistical Consulting Unit, The Australian National University, Canberra).

Field Research Staff

- Mr Chris MacGregor (Field Research Officer; 1997-onward) (Centre for Resource and Environmental Studies, The Australian National University — but based at State Forests of NSW, Tumut Office).
- Mr Matthew Pope (Field Research Officer; 1995–1998) (Centre for Resource and Environmental Studies, The Australian National University [now a Master of Science student in the project]).
- Mr Ryan Incoll (Field Research Officer; 1996–2000) (Centre for Resource and Environmental Studies, The Australian National University).
- Mr Craig Tribolet (Field Research Officer; 1998–2000) (Centre for Resource and Environmental Studies, The Australian National University — but based at State Forests of NSW, Tumut Office).
- Mr David Rawlins (Field Research Officer; 2000-onward) (Centre for Resource and Environmental Studies, The Australian National University — but based at State Forests of NSW, Tumut Office).

Scientific investigators and collaborators (alphabetical order)

- Dr Andrew Claridge (Ecologist) (NSW National Parks and Wildlife Service, Queanbeyan, NSW).
- Mr J. Fischer, (Ecologist; Honours Student) (Department of Geography, The Australian National University, Canberra).
- Dr Robert Lacy, (Mathematical Modeller and Geneticist) (Center for Conservation Biology, Brookfield Zoo, Chicago, U.S.A).
- Dr Sarah Legge (Behavioural Ecologist) (Division of Botany and Zoology, The Australian National University, Canberra).
- Dr Rob Lesslie (Ecologist) (Department of Geography, The Australian National University, Canberra).
- Dr Michael McCarthy (Mathematical Modeller and Forest Ecologist) (Centre for Resource and Environmental Studies, The Australian National University, Canberra).
- Mr Ed Merrett (GIS Unit, State Forests of NSW, Albury, NSW).
- Professor Craig Moritz (Geneticist) (Centre for Conservation Biology, University of Queensland).
- Professor Henry Nix (Ecologist and Climate Analysis Expert) (Centre for Resource and Environmental Studies, The Australian National University, Canberra).
- Dr Rod Peakall (Geneticist) (Division of Botany and Zoology, The Australian National University, Canberra).
- Dr Kirsten Parris (Herpetologist and Ecologist) (Centre for Resource and Environmental Studies, The Australian National University, Canberra).
- Dr David Patkeau (Geneticist) (Centre for Conservation Biology, University of Queensland).
- Professor Hugh Possingham (Mathematical Modeller and Ecologist) (Department of Environmental Science, University of Adelaide).
- Ms Janette Stanley (Social Scientist; PhD candidate) (Centre for Resource and Environmental Studies, The Australian National University, Canberra).

- Dr Andrea Taylor (Geneticist) (Department of Environmental Science, Monash University, Clayton, Victoria).
- Professor Jim Trappe (Ecologist/Mycologist) (University of Oregon, Corvallis, Oregon, USA).
- Professor Hugh Tyndale-Biscoe (Ecologist) (Research School of Biological Sciences, The Australian National University, Canberra).
- Dr K. Viggers (Veterinary Scientist and Ecologist) (Research School of Biological Sciences, The Australian National University, Canberra).

Appendix 2. Organisations supporting the Tumut Fragmentation Experiment

- Land and Water Resources Research and Development Corporation
- NSW Department of Land and Water Conservation
- Rural Industries Research and Development Corporation
- RIRDC/LWRRDC/FWPRDC Joint Venture Agroforestry Program and the Natural Heritage Trust
- Environment Australia
- State Forests of NSW
- NSW National Parks and Wildlife Service
- Canberra Ornithologists Group
- Australian Research Council
- VISY Industries (Pratt Foundation)
- CSR Ltd
- Jim Atkinson and Di Stockbridge (private donation)

Appendix 3. Projects undertaken in the Tumut Fragmentation Experiment

Landscape context studies — Tumut main study

- The distribution of possums and gliders in the pine/eucalypt landscape
- The distribution of small mammals in the pine/eucalypt landscape
- The distribution of birds in the pine/eucalypt landscape
- The distribution of frogs in the pine/eucalypt landscape
- The robustness of landscape indices as predictors of, and surrogates for, landscape fragmentation
- Remnant condition and landscape context (blackberry, dieback and pine wildlings across sites in the system)

Testing computer simulation model predictions in the pine/patch system

- Field tests of the simulation model VORTEX for predicting patch occupancy by small mammals and arboreal marsupials
- Field tests of the simulation model ALEX for predicting patch occupancy by birds, small mammals and arboreal marsupials
- Field tests of Hanski's (1994) simple incidence model for predicting patch occupancy by arboreal marsupials

Testing field methods for assessing animal use of pine/patch landscapes

- Appraisal of methods for counting birds in different forest ecosystems
- Comparisons of small mammal survey techniques in different forest ecosystems
- Comparisons of spotlighting and radio-tracking methods for detecting the Greater Glider

Patch use by the greater glider (Master of Science study by Mr M. Pope)

- Radio-tracking studies of patch use and den use within remnants patches by the greater glider
- Inter-patch movement by the greater glider
- Life history attributes of populations in different sized habitat patches

Studies of genetic variability in the pine/patch system

- Genetic tests of predictions by the simulation model VORTEX of population variability among small mammals and arboreal marsupials in the pine/patch/control system
- The genetics of bush rat populations in a pine/patch/control ecosystem
- The genetics of brown antechinus populations in a pine/patch/control ecosystem
- Ancient DNA and current genetic diversity comparisons in remnant populations of the greater glider
- Contrasts in genetic variation between patch populations of the greater glider and populations in large contiguous areas of native forest

Other investigations

- Hollow development in different species of wet and dry eucalypt tree species and its relationships with tree and site-level factors.
- Habitat fragmentation and mycophagy in the bush rat
- Remnant patch use by sulphur-crested cockatoos
- Presence and prevalence analysis of blackberry and pine wildling invasion of remnant eucalypt patches
- Recolonisation dynamics of remnant patches by small mammals
- The use of the indicator species concept in forest biodiversity conservation
- Edge effects and nest predation in a pine/patch ecosystem
- The haematology and biochemistry of the greater glider

Landscape context studies — Nanangroe main study

- The distribution of possums and gliders in the remnant in pine versus remnants in agricultural landscapes

- The distribution of small mammals in the remnant in pine versus remnants in agricultural landscapes
- The distribution of birds in the remnant in pine versus remnants in agricultural landscapes
- The distribution of reptiles in the remnant in pine versus remnants in agricultural landscapes
- Remnant condition and landscape context (blackberry, dieback and pine wildlings across sites in the system)
- Frogs, farm dams and changes in the landscape matrix
- The use of remnant woodland patches by the brown treecreeper
- The role and importance of paddock trees and stepping stones effects
- Social impacts of large scale plantation establishment (vacation scholar study — M. V Mason/PhD program — Ms J. Stanley)

Appendix 4. Publications from the Tumut Fragmentation Experiment (August 2000)

In press

Lindenmayer, D.B., Cunningham, R.B., Donnelly, C.F. and Nix, H.A. The distribution of birds in a fragmented landscape. *(Ecological Monographs).*

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