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Plantation Design and Biodiversity Conservation

**A report for the RIRDC/ Land and Water Australia/ FWPRDC
Joint Venture Agroforestry Program
Supported by the Natural Heritage Trust**

by David B. Lindenmayer

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Foreword

Large areas of Australia are dedicated to plantation forestry – both non-native and native tree species. The size of the plantation forest estate is increasing under a range of State and Federal Government initiatives in this arena. Although the primary aim of plantation forests is to produce large quantities of wood for pulp and timber production, there are ways of designing and managing plantation forests to enhance their value for biodiversity conservation.

This study, funded under the Joint Venture Agroforestry Program (JVAP), aimed to identify ways to enhance the conservation value of exotic softwood Radiata Pine (*Pinus radiata*) plantations in south-eastern Australia. The work was focussed in the Tumut region of southern New South Wales (NSW).

This publication outlines the design of a study which has begun to address key issues of plantation design and management in the Tumut region. It also summarises some of the principles that can be embraced to increase the conservation value of both existing plantation landscapes and new areas targeted for future plantation expansion.

This project was funded by the Joint Venture Agroforestry Program (JVAP) and the Natural Heritage Trust. The JVAP is supported by three Research and Development Corporations — Rural Industries, Land & Water Australia and Forest and Wood Products. These Corporations are funded principally by the Federal Government..

This report, a new addition to RIRDC's diverse range of over 700 research publications, forms part of our Agroforestry and Farm Forestry Research and Development program, which aims to integrate sustainable and productive agroforestry within Australian farming systems.

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Peter Core

Managing Director

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Work on forest birds at Nanangroe and Tumut was possible only through the concerted efforts of many dedicated volunteers from the Canberra Ornithologists Group, particularly Bruce Lindenmayer, Henry Nix, Malcolm Fyfe, Mike Doyle, Jenny Bounds, Nicki Taws, Phillip Veerman, Anothys, Terry Munro, Malcolm Moffat, Mark Clayton. Much of the work on birds at Nanangroe and Tumut was co-ordinated by Bruce Lindenmayer.

Associate-Professor Ross Cunningham was responsible for the statistical design of the Nanangroe and Tumut Fragmentation Experiments; these projects were only possible because of his extraordinary insights and critical thinking.

We are most grateful to the private landholders in the Nanangroe area who most kindly allowed regular access to their properties - Mr. B. Luff, Mr N. and Mrs. S. Keatinge, Mr. K. Skinner, Mr. G. Greeney, Mr. A. Waugh, Mr. J. Waugh, and Mr. S. Tate. Ms. V. Mason conducted extensive interviews with the landholders in the study area.

The work at Nanangroe has succeeded only because of the efforts of several Research Officers – Chris MacGregor, Mason Crane, Craig Tribolet, and Dave Rawlins.

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Executive Summary

Plantations are making an increasing contribution to wood and pulp production in Australia and the plantation estate is set to expand rapidly in many parts of this country. The conservation of biodiversity is increasingly recognised as a key part of the management of existing plantations and the establishment of new ones. However, there are few studies either in Australia or overseas to guide how conservation values can be best integrated into plantation management.

In an effort to address the current knowledge gaps on integrating plantation management and biodiversity conservation, two large scale “natural experiments” have been established in the Tumut region of southern New South Wales, south-eastern Australia. They are the “Nanangroe Landscape Experiment” and the “Tumut Fragmentation Experiment” and they are located in exotic softwood (Radiata Pine) dominated landscapes. The two studies aim to help generate a better understanding of how to establish and manage plantations so they retain some values for biodiversity.

Chapter 2 of this report describes in detail the background to, and the design of, the Nanangroe Landscape Experiment that has been established between Gundagai and Tumut. That work, together with the results of its “sister” project – The Tumut Fragmentation Experiment” (see Lindenmayer, 2000a) highlights some of the key strategies which can be adopted to promote conservation in plantation landscapes. These are detailed in Chapter 2 and Appendix 1 of this report. Some of the more important ones include:-

1. Retain native eucalypt forest or woodland remnants within plantation landscapes. Even small remnants of 1-3 ha were found to have important value as habitat for a wide range of species such as birds, mammals, reptiles and other taxa. Moreover, a landscape mosaic comprised of stands of plantation trees and remnant patches of native vegetation will support significantly higher levels of native taxa than plantation landscapes that are monocultures.
2. Protect native vegetation along gully lines as these areas can be valuable dispersal routes for some species (e.g. small terrestrial native mammals). These areas are also often quarantined from plantation establishment for quality reasons and they might be useful places to target for native vegetation restoration efforts.
3. Take steps to control weed invasion problems (e.g. by pine “wildlings “ and blackberry) within remnants of native vegetation within the plantation estate. This is best achieved in new plantations before the level of weed invasion becomes significant and weed control is still feasible.

A range of other management strategies are outlined in this report, particularly in Appendix 1 which is based on a Short Report published by RIRDC in 2000 (Lindenmayer, 2000b).

1. Introduction

Plantation forests (defined here as planted forests of commercially important tree species) (Eldridge *et al.*, 1994) are assuming increasing importance in the supply of timber and pulpwood in many countries around the world. Indeed, the plantation estate is enormous and in 1996 the combined area of plantations worldwide was estimated to exceed 130 million ha (Cubbage *et al.*, 1996). There are almost 20 million ha of eucalypt plantations alone. Managing plantations to contribute to biodiversity is, therefore, important because of their extent. In places such as the United Kingdom and New Zealand, where much of the original forest cover has been removed, a large proportion of the existing forest estate is in the form of plantations (Spellerberg and Sawyer, 1997; Peterken, 1999). In Australia, plans are well advanced to triple the extent of plantations in the next two decades (Department of Primary Industries and Energy, 1997).

Planted forests may be composed of exotic species, such as the conifer plantations in the United Kingdom, South Africa, New Zealand and Australia or the extensive areas of eucalypts in Brazil, China, Spain and almost 100 other countries worldwide (Doughty, 2001). Alternatively, they can be planted to areas of trees that are native to a given continent such as Loblolly Pine (*Pinus taeda*) in south-eastern U.S.A. (Moore and Allen, 1999) and Blue Gum (*Eucalyptus globulus*) and Shining Gum (*Eucalyptus nitens*) in Australia (Eldridge *et al.*, 1994). Often the trees used in these plantations have been subject to programs of tree breeding and genetic modification. Intensive site preparation (e.g. ripping and mounding), thinning and the application of herbicides and pesticides (McLaren, 1996; Peterken, 1996) is often characteristic of plantation forestry, further modifying site conditions. Indeed, plantations often share many attributes with intensive agricultural systems, except that they are managed on longer rotations.

The primary goal of plantation forestry is the efficient production of large quantities of timber and pulp. However, there are also important opportunities for designing and managing plantations to enhance their value for biodiversity (Clout, 1984; Hanowski *et al.*, 1997; Spellerberg and Sawyer, 1999). Inferences from several studies are that changes in plantation management regimes can contribute to biodiversity conservation, sometimes significantly. In other cases, even the limited structural complexity of plantations provides suitable habitat for some forest species or enhances connectivity (*sensu* Forman, 1995) for others (Renjifo, 2001) or both.

A large scale Radiata Pine (*Pinus radiata*) plantation exists in the Tumut region, approximately 100 km to the west of Canberra in southern New South Wales. The Tumut region has been the focus of a major set of integrated studies since 1995 and a summary of some aspects of that work is given in Lindenmayer (2000a). Under the JVAP program, a large scale landscape “natural experiment” - the - Nanangroe Study, was instigated in 1998. The Nanangroe Experiment focuses on a grazed woodland

landscape near Jugiong in south-eastern New South Wales. It contrasts strongly with other fragmentation experiments where extensive clearing of trees occurred to isolate habitat fragments (e.g. 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. The background to, and preliminary results from, the Nanangroe Experiment are presented in Chapter 2 of this report. This chapter is based on a manuscript that was submitted to the journal “Biological Conservation” for publication (Lindenmayer *et al.*, 2001). The work at Nanangroe and Tumut (10 km to the south) has produced an array of important insights into how plantations might be established and managed to enhance their conservation value. Some of these insights are briefly outlined in Chapter 3 of this report. A set of guidelines for plantation establishment and management was published in the Short Report series (No. 77) by RIRDC in 2000 (Lindenmayer, 2000b) and the key principles from that work are reproduced in Appendix 1. Several other appendices have been included in this report to give readers further background to the ongoing work that is taking place at Nanangroe Tumut. These appendices include a list of other researchers working at Tumut (Appendix 2), a list of the projects taking place at Nanangroe and Tumut (Appendix 3), and a list of publications derived from the work at Nanangroe and Tumut (Appendix 4).

Finally, readers of this report are urged to recognize that the work at Nanangroe and Tumut is extensive and long-term and many projects are ongoing (see Appendix 3). New results from these projects may change the recommendations made for designing and managing plantations. In addition, while many of the outcomes and principles from the integrated set of studies at Nanangroe and Tumut are likely to be relevant to many other plantation landscapes, there will be no generic “recipes” for biodiversity conservation that can be applied uncritically to all plantations. Rather, the most appropriate strategies will vary for each landscape and each part of the plantation estate depending on management objectives, faunal assemblages and conservation values and a range of other considerations (Lindenmayer and Franklin, 2002). Nevertheless, it is clear that plantations can be better managed to improve their conservation values – an important consideration given the increasing area of the plantation estate.

2. The Nanangroe Natural Landscape Experiment

2.1. Summary:

The design of a longitudinal landscape-scale “natural experiment” of Australian woodland vertebrates is described. The experiment will allow the direct study of changes in fauna inhabiting woodland fragments as the surrounding grazed landscape is transformed into a Radiata Pine (*Pinus radiata*) plantation. It will also provide data to enable the study of relationships between fauna and habitat and landscape variables, both over time and among sites. Data for terrestrial mammals, arboreal marsupials, and reptiles occurring in woodland remnants surrounded by newly planted Radiata Pine seedlings and pasture are presented. These data provide a reference set against which future changes in vertebrate fauna can be assessed and hence will be baseline data for the longitudinal study.

Statistical analyses for several species showed that arboreal marsupials are more likely to be found in larger remnants that contain more trees with cavities and the Four-fingered Skink (*Carlia tetradactyla*) is more likely to be found either where there are more exposed rocks or more dead trees. We predict that these responses 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.

2.2. Background

In his seminal text on landscape ecology, Forman (1995) recognised three landscape components – patches, corridors and the matrix. Patches and corridors are typically either the remnants of the original vegetation cover in a landscape, or areas that have been restored to some state of “naturalness”. In landscapes extensively modified by humans, patches and corridors areas have often been termed “habitat fragments” (Schwartz, 1997). Forman (1995) defined the third landscape component, the matrix, as “the background ecosystem or land-use type in a [landscape] mosaic, characterized by..... a major control over dynamics”. The vast majority of fragmentation studies in the past three decades have focussed on the biota of habitat fragments and many have largely ignored the surrounding landscape matrix (reviewed by Crome, 1994, 1997). Yet, an increasing number of investigations are demonstrating that the dynamics of populations within habitat fragments is strongly influenced by conditions in the landscape matrix which surround them (e.g. Laurance, 1991; Estades and Temple, 1999). For example, the Biological Dynamics of Forest Fragments Project in Brazil has consistently highlighted the important role of the landscape matrix in fragmentation effects (Tocher *et al.*, 1997; Gascon *et al.*, 1999). Other studies have produced similar outcomes (e.g. Webb *et al.*, 1984;

Aberg *et al.*, 1995; Sisk *et al.*, 1997). For example, a number of investigations have demonstrated that many species which persist in habitat fragments are also those which occur in the surrounding landscape matrix (Blake, 1983; Diamond *et al.*, 1987; Ås, 1999).

Given the fundamental importance of the landscape matrix as a landscape component (Forman, 1995), we have commenced a large scale “natural experiment” designed specifically to quantify how wildlife use of habitat fragments changes as the surrounding landscape changes. This paper describes the design of this study which has the defining feature that repeated observations are taken on individual sites enabling the direct study of change. This natural experiment is called the Nanangroe Study and it focuses on a grazed woodland landscape near Jugiong in south-eastern New South Wales, southern Australia. Most fragmentation experiments have examined habitat fragments before and after clearing of the surrounding vegetation (e.g. Margules, 1992; Bierregaard and Stouffer, 1997). In contrast, in the Nanangroe Study, the landscape is already largely cleared of native vegetation and it now supports only fragments of the original cover of eucalypt woodland. The landscape surrounding the woodland fragments is undergoing a major and rapid transition from one that is largely cleared and dedicated to grazing domestic livestock, to one that will be dominated by extensive plantations of Radiata Pine (*Pinus radiata*) trees. We have taken advantage of these changes to design a large scale longitudinal study to track the changes that occur in vertebrate fauna inhabiting woodland remnants when the surrounding landscape undergoes extensive change from a grazing one with isolated paddock trees to a plantation-dominated system.

The use of natural experiments to address ecological questions is an attractive idea, but it is often argued that meeting fundamental statistical criteria of experimental design is prohibitive in resources and hence cost. It often follows that unreplicated experiments are promoted as a useful alternative (Dunning *et al.*, 1995). This is often done without a clear understanding of the implications of such “experiments” for inference; these are not experiments and should never be treated as such.

The inferential value of large-scale field experiments in ecological and environmental research is well accepted (Robinson *et al.*, 1992; Schmiegelow and Hannon, 1993; Margules *et al.*, 1994). For example, we recently reported the findings of a large-scale cross-sectional “natural” experiment in south-eastern Australia designed specifically to measure the effects of landscape context and habitat fragmentation on forest fauna (see Lindenmayer *et al.*, 1999a, 1999b, 2000). That study, called the Tumut Fragmentation Experiment, demonstrated that it is possible to meet replication and randomisation requirements for natural experiments in fragmentation studies. A summary of important design principles of the cross-sectional study at Tumut is given in Lindenmayer *et al.* (1999a, 1999b, 2000). Clearly, an essential ingredient of these natural experiments is careful planning and a willingness to commit substantial resources to successfully complete them.

In our earlier cross-sectional study at Tumut, only scant information was available on animal abundance when landscape disturbance commenced. Lack of knowledge of the status of species prior to fragmentation is a common feature of almost all fragmentation studies (see Margules, 1992). Often interest is in the direct study of temporal changes and relationships that occur as a result of intervention. In these cases, longitudinal studies are important as they can distinguish variation and co-variation in fauna over time from variation and co-variation in fauna among sites. Further, they provide data to enable the estimation of the change over time in fauna per unit change in habitat and/or landscape variables. In cross-sectional studies, temporal and between site effects cannot be separated. Effects and relationships in cross-sectional studies may be obscured due to considerable variation among sites but can be discerned from data obtained in longitudinal studies. This is because each site becomes its own control and hence such studies tend to be more powerful for studying change than cross-sectional studies.

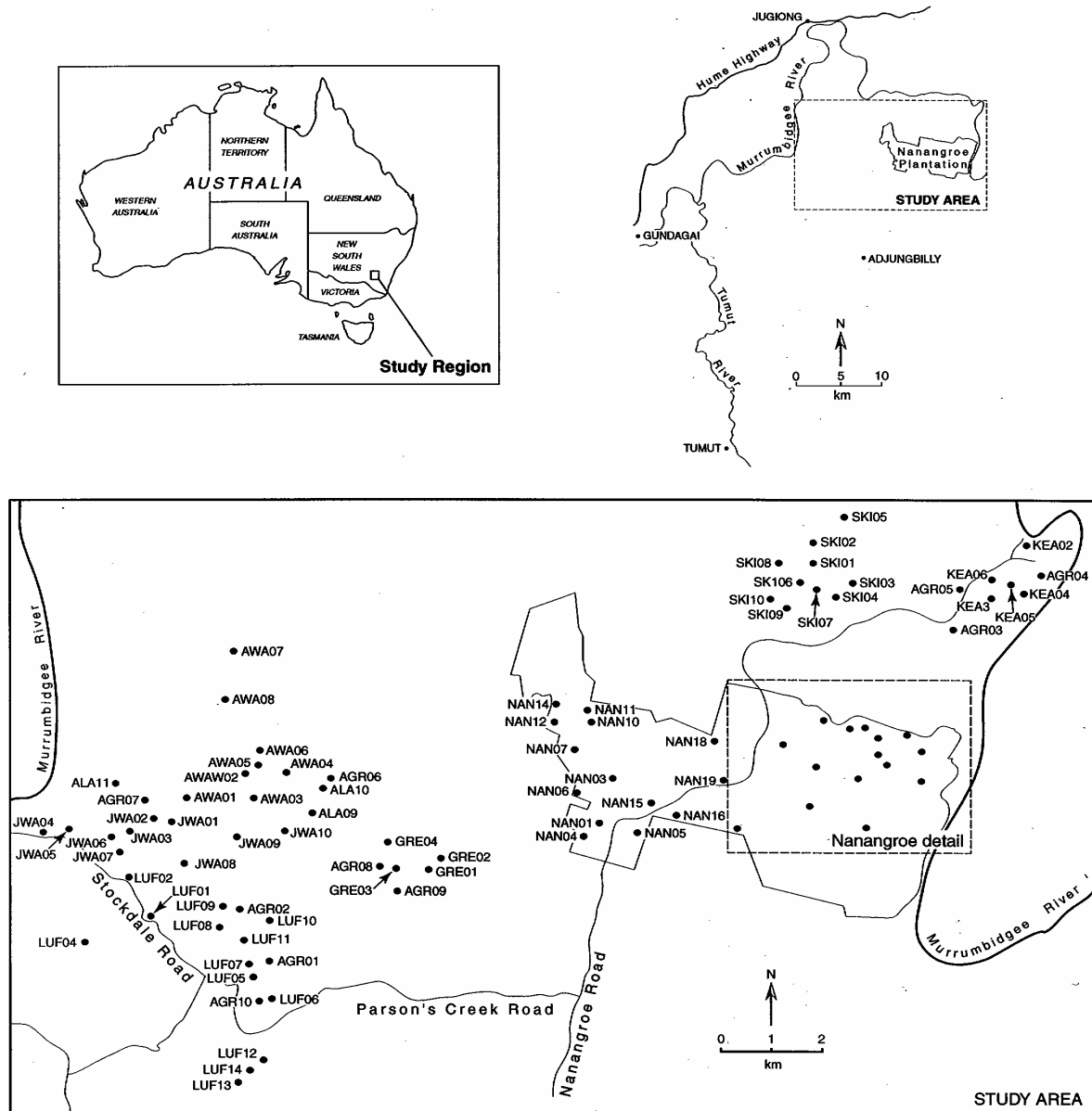
There are important reasons why we have chosen a woodland system for detailed study. Woodlands throughout Australia have been heavily modified since white settlement and between 70%-95% of them have been cleared in States like New South Wales (NSW) (Yates and Hobbs, 1997; Hobbs and Yates, 2000). In the case of particular vegetation types such as White Box (*Eucalyptus albens*), only a tiny fraction of the original levels of cover remain (Prober and Thiele, 1995). In addition, many woodlands are highly degraded as a result of human disturbance such as livestock grazing, tree removal (e.g. for firewood), and mining (Hobbs and Yates, 1997; Arnold and Weeldenburg, 1998). Clearing of woodlands and their ongoing degradation has had a negative impact on groups such as plants (Yates *et. al.*, 2000), invertebrates (Abensperg-Traun and Smith, 1999), reptiles (Hadden and Westbrooke, 1996), birds (Barrett *et. al.*, 1996; Read, 1999), and mammals (Deacon and Mac Nally, 1998). Major efforts to conserve and restore Australian woodland ecosystems have commenced, but such work depends in part, on understanding what features are critical for biota (Saunders *et al.*, 1993). There is limited information of this sort for the vast majority of Australian woodlands. Hence, in addition to outlining the design of the Nanangroe natural experiment, we also present data on terrestrial mammals, arboreal marsupials, and reptiles gathered from field surveys of remnant woodlands within a grazed woodland system. This information serves as baseline data for the longitudinal study. It also characterizes fauna occupying small woodland remnants at the time of establishing a Radiata Pine plantation in the surrounding landscape. Finally, we also report statistical models of the relationships between the occurrence of a selected set of animals and woodland habitat variables.

2.3. Study area

The study area is 10-20 km south-east of the town of Jugiong in southern NSW (Figure 1), and it is bounded by the Murrumbidgee River to the north and the Bungongo State Forest, 5-8 km to the south and east. Annual precipitation across the study area ranges from 775 to 900 mm and is uniformly distributed throughout the year. Summers are typically hot. The name of the field study is taken from the Nanangroe Station - a large property where a major new Radiata Pine plantation has recently been established. The study region was chosen because:-

- Recent large-scale changes in landscape cover have occurred due to the establishment of new Radiata Pine plantations at four former grazing properties newly acquired by State Forests of NSW.
- Long-term access to semi-cleared grazing properties which support numerous woodland remnants and which are located adjacent to the new Radiata Pine plantation has been obtained.
- The region contains a wide range of woodland vegetation types (see below). This will allow us to quantify the differences in fauna between different types of woodland. This makes our natural experiment different from many other studies that have focussed on one or only a few woodland types (e.g. Er, 1995; Prober and Thiele, 1995; Haddon and Westbrooke, 1996; Arnold and Weeldenberg, 1998).
- The woodland remnants in the study region vary in their physical condition, location (hilltops versus midslopes etc), and many other attributes (see Table 1) making it possible to sample a broad range of environmental conditions and, in turn, model the relationships between species occurrence and these covariates.

Figure 1. General Location of the Nanangroe Study Area



The original vegetation cover in the study area included a suite of woodland vegetation types, particularly those dominated by Yellow Box (*Eucalyptus melliodora*), Red Box (*Eucalyptus polyanthamos*), White Box (*Eucalyptus albens*), Red Stringybark (*Eucalyptus macrorhycha*), and Blakely's Red Gum (*Eucalyptus blakleyi*). Much of the original cover has been cleared over the past 150 years, primarily for domestic stock grazing (Bungongo Centenary Committee, 1986). Only fragmented patches now remain of what was formerly continuous woodland vegetation cover.

Clearing operations to plant Radiata Pine in the areas surrounding the woodland remnants involves the felling and burning of isolated paddock trees and other shrubby vegetation. The cleared land is then deep-ripped with a bulldozer to create mounds of earth in which Radiata Pine seedlings are planted. These are standard plantation establishment procedures employed widely throughout south-eastern Australia.

2.4. The design of the Nanangroe Study

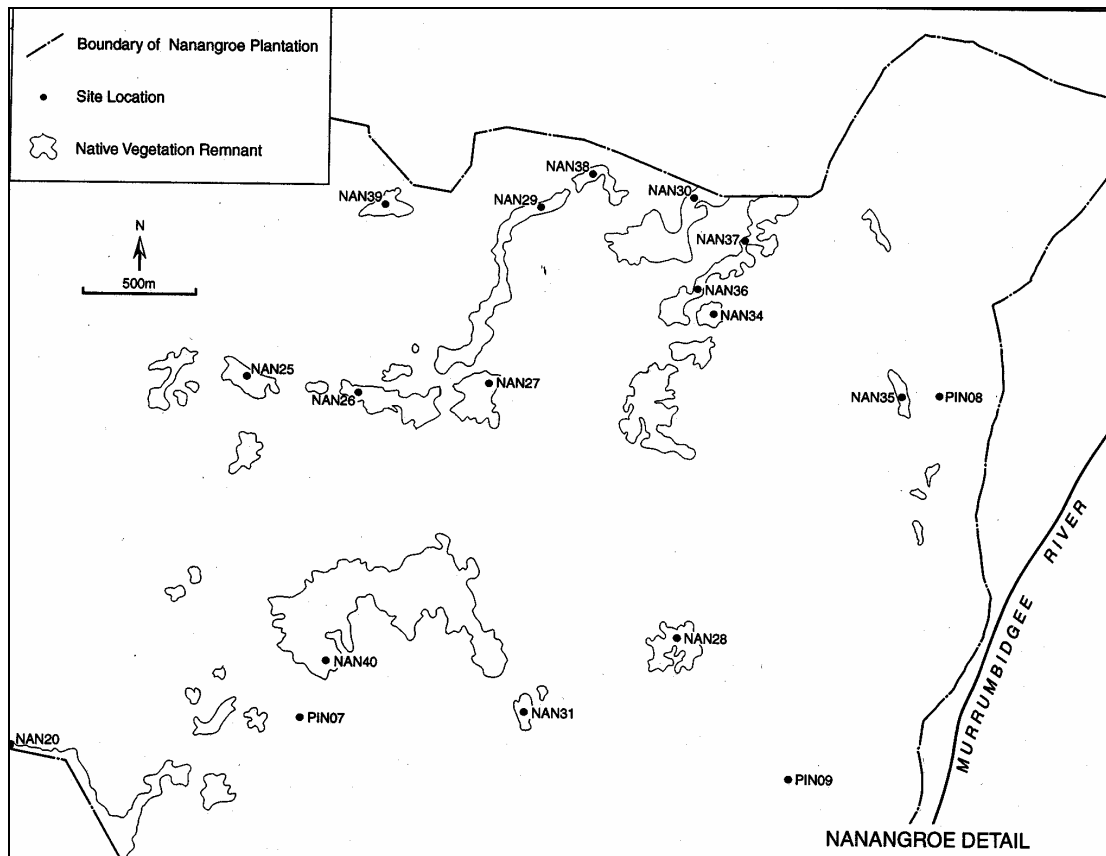
The principle objective of the Nanangroe study is to directly quantify changes in woodland vertebrate assemblages and their relationships with habitat variables when the surrounding landscape matrix is converted from a semi-cleared grazing landscape to a landscape dominated by an exotic softwood plantation. Thus, the initial phase of the experiment is the establishment of a set of foundation sites. This involved characterising all patches of remnant native vegetation on areas designated for pine plantation. Attributes of the 70 remnants included patch size (ha), dominant tree species, age and condition of overstorey trees, understorey condition, shape class, topographic position, and the density of trees within the patch. Patch sizes varied from 0.5 ha to 9.7 ha. Four broad vegetation classes were recognised as part of field surveys. The species in these groups were:-

- (1) Red Box and Red Stringybark (co-dominant), Apple Box (*Eucalyptus bridgesiana*), Long-leaf Box (*Eucalyptus goniocalyx*), and Broad-leaved Peppermint (*Eucalyptus dives*).
- (2) Swamp Gum (*Eucalyptus camphora*).
- (3) Yellow Box, White Box, Red Stringybark (co-dominant) and Blakely's Red Gum. And
- (4) River Oak (*Allocasuarina cunninghamiana*).

These groupings were based on forest league classifications developed by Forests Commission of New South Wales (1989).

Fifty of a possible 70 woodland remnants >0.5 ha were randomly selected, with stratification, for study. This gave 13 remnants in the 0.5-0.9 ha class, 20 remnants in the 1-2.4 ha size class, 15 remnants in the 2.5-4.9 ha class, and two remnants in the 5-10 ha class. The extent of previous clearing to promote livestock grazing meant few large remnants were available for subsequent selection and sampling. The number of remnants in the broad tree species groupings were:- 19 sites in Vegetation Group 1, 8 in Group 2, 19 in Group 3, and 4 sites in Group 4. A subsection of the study area is shown in Figure 2.

Figure 2. Subset of woodland remnant sites in the Nanangroe Study



Three age cohorts of recently planted stands of Radiata Pine presently occur in the study area; trees established in 1998 (cohort 1), trees established in 1999 (cohort 2), and a final round of plantation establishment completed in mid-2000, giving a third age cohort (cohort 3). Pine age cohort 1 surrounds 21 woodland remnants, cohort 2 surrounds 15 remnants, and there are 14 remnants in cohort 3. Having three Radiata Pine age cohorts in our study will allow the estimation of effects due to cohort and year.

For comparison with the 50 woodland remnants surrounded by Radiata Pine, an additional 56 woodland remnants on semi-cleared, private grazing properties adjacent to the new plantation estate were randomly chosen for study. The 56 remnants were matched to the 50 remnants in the plantation estate on the basis of patch size and dominant vegetation type to ensure that the two groups of remnants were as similar as possible.

Finally, ten permanent sites in cleared paddocks around the woodland remnants on the grazing properties and ten sites in areas dominated by newly planted Radiata Pine trees were established as “landscape matrix” sites’.

In summary, 126 sites were chosen for study within the four different “landscape context classes”. These were:

- Woodland remnants where the surrounding grazing land has been converted to stands of Radiata Pine (50 sites) in the three years 1998-2000, inclusive.
- Newly planted stands of Radiata Pine trees that surround the 50 woodland remnants (ten sites).
- Woodland remnants located on semi-cleared areas within the variegated landscape matrix where the primary land use is grazing by domestic livestock (Sheep [*Ovis ovis*] and Cattle [*Bos taurus*]) (56 sites).
- Cleared paddocks that surround the 56 woodland remnants (ten sites).

Each of the 126 sites was marked with coloured flagging tape and plastic cattle tags. Star pickets were then used to highlight the 0m, 50m, 100m, 150m, and 200m points along each marked transect.

Data from all 126 sites will be collected at regular intervals over at least the next 10+ years.

2.5. Data and field sampling protocols

The foundation year for collecting data was 1998 when surveys were undertaken for diurnal birds (results to be reported elsewhere), arboreal marsupials, small mammals, and reptiles (see below).

Spotlighting surveys were undertaken at each of the 126 sites for arboreal marsupials. Data recorded were the number of each species of arboreal marsupial seen.

Two methods were employed to sample terrestrial mammals; hairtubing (*sensu* Scotts and Craig, 1988) and Elliott trapping. One Elliott trap and the three types of hairtubes were set out at nine points, 25 m apart, along the transect established at each site. Traps were cleared each day for five successive days. Animals captured were marked, sexed and weighed.

Two sample points for reptiles were established at the 0m and 100m mark at the 126 survey sites. These sample points were constructed from three distinct types of artificial habitats placed on the ground for use by reptiles:- three overlaid sheets of corrugated iron measuring 1m x 2m, four 1m long Mountain Gum (*Eucalyptus dalrympleana*) fence posts joined with chicken wire, and four standard roof tiles. The number and identity of each species of reptile sheltering under these artificial habitats at each survey site was recorded.

Vegetation plots measuring 10m x 10m in size were established at the 0m, 50m, 100m, 150m, and 200m points along the marked transect at each site. The measures recorded at each plot are summarised in Table 1. In addition, permanent photographic points were established at the 0m and 100m points along each transect, providing an extensive library of images of vegetation cover and structure for each field site.

Table 1. Measures of the vegetation structure and plant species composition recorded in the study.

Variable	Description
Dominant tree	The dominant species of trees in a remnant (identified from buds and fruits - see Costermans, 1994).
Stand basal area	Measured in m ² per ha using a basal area wedge.
Topography	The topographic position of a site, in one of six categories:- flat, gully, north-facing slope, east-facing slope, south-facing slope, and west-facing slope.
Disturbance	Evidence of disturbance was recorded and classified as mining, grazing, fire, logging, other and none.
Dieback index	Evidence of dieback among dominant trees was recorded (e.g. crown and/or lateral branch death).
Number of dead trees	The number of dead trees per vegetation plot was recorded.
Mistletoe index	The number of clumps of mistletoe in each vegetation plot was recorded.
Hollow trees	The abundance of trees with bayonet and branch hollows (<i>sensu</i> Jacobs, 1955) was recorded.
Slope angle	The inclination of a plot measured using a clinometer.
Rock Index	A rock cover index (= the quantity of exposed rock) was recorded for each plot as one of six classes:- none, 1-5%, 5-15%, 15-30%, 30-60%, and >60%.
Ground Cover	The % cover of the ground layer was assigned to one of six classes:- none, 1-5%, 5-15%, 15-30%, 30-60%, and >60%.
Number logs	The number of logs in each diameter classes was recorded (10-20 cm, 20-30 cm, 30-40 cm, 40-50 cm and >50 cm).
Dominant cover	The % cover of dominant trees was recorded as one of six classes:- none, 1-5%, 5-15%, 15-30%, 30-60%, and >60%.
Sub-dom. cover	The % cover of sub-dominant plants was recorded as one of six classes:- none, 1-5%, 5-15%, 15-30%, 30-60%, and >60%.
Shrub cover	The % cover of shrubs was recorded as one of six classes:- none, 1-5%, 5-15%, 15-30%, 30-60%, and >60%.
Grass Index	The % cover of grass was recorded as one of six classes:- none, 1-5%, 5-15%, 15-30%, 30-60%, and >60%.
Grass Height	The height of the grass (m) was measured.

Blackberry index	An index describing the prevalence of introduced <i>Rubus fruticosus</i> scored from none to 100% in six categories each of 20% intervals.
Regrowth index	An index describing the extent of young regrowth vegetation in each plot (from a score of 1 to 4).
Plant Matrix	A two-way height and diameter matrix was completed for each plot. Each stem in the plot was assigned by one of five height and seven diameter classes. The height categories were 1-2 m, 2-4 m, 4-8m, 8-16 m, 16-30 m, and > 30 m. The diameter classes were:- 1-5 cm, 5-10 cm, 10-20 cm, 20-30 cm, 30-40 cm, 40-50 cm, and > 50 cm.
Stream index	A measure of the "moistness" of a site calculated from information on the distance to a watercourse and stream order (<i>sensu</i> Strahler 1957).

2.6. Statistical analysis

For spotlighting data (arboreal marsupials), trapping data (small mammals), hairtubing data (terrestrial mammals and arboreal marsupials), and reptile counts, summary tables provide numbers of woodland remnants where particular species were recorded. Logit regression modelling (Collett, 1991) was used to assess differences in fauna among the sites in the four different landscape context classes and to explore relationships between the occurrence of selected arboreal marsupial and reptile species and woodland attributes.

2.7. Results

2.7.1. Small mammals, terrestrial mammals and arboreal marsupials –detection by hairtubes and Elliott traps

As virtually no animals had been detected or captured in the initial 81 sites surveyed by hairtubing and Elliott trapping, counts of small mammals and terrestrial mammals were terminated before all sites were surveyed. All 50 woodland remnants in the Radiata Pine landscape were surveyed, but only 20 of the 56 woodland sites on private grazing lands were sampled. No animals were detected in the six Radiata Pine sites and five pasture sites surveyed. Table 2 gives the total number of detections for each species, together with the number in remnant woodland sites where at least one detection was made. As it is not possible to distinguish between individuals in hairtubing data, total detections should not be interpreted as abundance. The species most commonly detected by hairtubing was the Common Brushtail Possum (*Trichosurus vulpecula*). This result was consistent with spotlighting data (see below). The species was recorded by hairtubing on 16 of 70 remnants (=22% approx.) compared to 23 of 106 sites surveyed by spotlighting (=22% approx.).

Table 2. Records of small mammals and terrestrial mammals detected by hairtubing for 70 woodland remnants.

Common name	Species name	Total no. sites recorded	Total no. of detections
Domestic Cattle	<i>Bos taurus</i>	9	17
Swamp Wallaby	<i>W. bicolor</i>	8	11
Rat species	<i>Rattus</i> spp.	3	3 ⁺
Antechinus species	<i>Antechinus</i> spp.	3	3 [*]
Common Wombat	<i>V. ursinus</i>	1	1
Echidna	<i>T. aculeatus</i>	1	1
Feral Cat	<i>F. catus</i>	2	2
Red Fox	<i>V. vulpes</i>	1	1
Common Brushtail Possum	<i>T. vulpecula</i>	16	24

⁺Most probably the introduced Black Rat (*Rattus rattus*).

^{*}Most probably Agile Antechinus (*Antechinus agilis*).

Despite extensive effort, only one native species - Agile Antechinus (*Antechinus agilis*) (four animals on three sites) (Table 3) was captured by trapping. The most commonly trapped small mammal was the exotic House Mouse (*Mus musculus*); a species which was not detected by hairtubing. The exotic Black Rat (*Rattus rattus*) was captured during field surveys, but records were uncommon (Table 3). The trapping results for small mammals were broadly consistent with hairtubing data.

Table 3. Records of small mammals by trapping for 70 woodland remnants. Incidental trap records of the skink (*Egernia* spp.) and Red-bellied Black Snake (*Pseudechis porphyriacus*) have been included.

Common Name	Species Name	No. sites recorded	Animals captured
House Mouse	<i>M. musculus</i>	7	10
Agile Antechinus	<i>A. agilis</i>	3	4
Black Rat	<i>R. rattus</i>	3	3
Egernia (skink species)	<i>Egernia</i> spp.	4	6
Red-bellied Black Snake	<i>P. porphyriacus</i>	1	1

2.7.2. Arboreal marsupials – detection by spotlighting

Three species of arboreal marsupials were detected by spotlighting of all 126 sites - Common Brushtail Possum, Sugar Glider (*Petaurus breviceps*), and Common Ringtail Possum (*Pseudocheirus peregrinus*). Table 4 gives the total number of detections for each species, together with the number of remnant woodland sites where at least one detection was made. The Common Brushtail Possum and Common Ringtail Possum were relatively frequently recorded, whereas the Sugar Glider was uncommon.

There was no evidence from our baseline data of a difference in the probability of occurrence or the abundance of arboreal marsupials between the four different landscape context classes (as defined above). Thus, we have simply shown aggregate data for the abundance of animals recorded during field surveys (see Table 4).

Table 4. Arboreal marsupials recorded in 106 woodland remnants.

Common Name	Species Name	Sites recorded	Animals observed
Common Brushtail Possum	<i>T. vulpecula</i>	23	35
Sugar Glider	<i>P. breviceps</i>	6	7
Common Ringtail Possum	<i>P. peregrinus</i>	23	44

2.7.3. Reptile data

Eight species of reptiles were recorded - Eastern Three-lined Skink (*Bassiana duperreyi*), Marbled Gecko (*Christinus marmoratus*), Four-fingered Skink (*Carlia tetradactyla*), Olive Legless Lizard (*Delma inornata*), Three-toed Skink (*Hemiergis decresiensis*), Delicate Skink (*Lampropholis delicata*), Garden Skink (*Lampropholis guitcheenoti*), and Boulenger's Skink (*Morethia boulengeri*) (Table 5). Most species were infrequently recorded (< ten sites), except for the Four-fingered Skink (25 sites), and the Three-toed Skink (12 sites). There also were a small number of incidental captures of *Egernia* spp. and Red-bellied Black Snake (*Pseudechis porphyriacus*) in Elliott traps deployed to sample small terrestrial mammals (Table 3).

There was no evidence from our baseline data of a difference in the probability of occurrence or the abundance of reptiles between the four different landscape context classes. Thus, we have simply shown aggregate data for the abundance of animals recorded during field surveys (see Table 5).

Table 5. Reptiles recorded at all 126 sites in the Nanangroe Study. Incidental records of reptiles captured in Elliott traps are shown in Table 3.

Common name	Species Name	No. sites recorded		No. animals observed	
		All sites	Woodland sites only	All sites	Woodland sites only
Eastern Three-lined Skink	<i>B. duperreyi</i>	3	0	5	0
Marbled Gecko	<i>C. marmoratus</i>	1	1	2	2
Four-fingered Skink	<i>C. tetradactyla</i>	25	16	37	26
Olive Legless Lizard	<i>D. inornata</i>	2	1	3	1
Three-toed Skink	<i>H. decresiensis</i>	12	2	14	2
Delicate Skink	<i>L. delicata</i>	7	0	17	0
Garden Skink	<i>L. guitcheenoti</i>	6	0	8	0
Boulenger's Skink	<i>M. boulengeri</i>	1	0	1	0

2.7.4. Relationships between the presence of arboreal marsupials, the presence of the Four-fingered Skink, and remnant woodland characteristics

A summary of statistical relationships between the expected probability of an arboreal marsupial *per se*, the Common Ringtail Possum and the Four-fingered Skink and site attributes is given in Table 6a-c. All effects are shown graphically in Figure 3. Arboreal marsupials were more likely to occur in larger remnants ($p=0.005$) and in remnants having more trees with cavities ($p=0.01$). In particular, larger woodland remnants ($p=0.02$), especially those with a high mean density of living trees per plot ($p=0.002$), and supporting numerous hollow-bearing trees ($p<0.001$) were significantly more likely to support the Common Ringtail Possum. Two alternative predictors of the presence of the Four-fingered Skink were found: the species was more likely to occur on sites with more exposed rocks ($p=0.007$), or on sites supporting more dead trees ($p=0.003$).

Table 6a. *Parameter estimates and associated standard errors for the relationship between the probability of occurrence of an arboreal marsupial per se and measured site attributes. Effects are shown graphically in Figure 3a. Note that the parameterisation of the cavity effect – an effect due to the presence of cavities; and a linear effect associated with the log of the number of cavities (see Figure 3a, Part 1).*

Variable	Estimate	Standard Error
Constant	-1.36	0.421
Log of remnant area	0.913	0.341
Presence of cavities	0.448	0.453
Linear effect of log (#cavities) given presence	0.75	0.312

Table 6b. Parameter estimates and associated standard errors for the relationship between the probability of occurrence of the Common Ringtail Possum and measured site attributes. Effects are shown graphically in Figure 3b. Note that the parameterisation of the cavity effect – an effect due to the presence of cavities and a linear effect associated with the log of the number of cavities (see Figure 3b, Part 1).

Variable	Estimate	Standard Error
Constant	-5.05	1.12
Log of remnant area	1.05	0.473
Log of number of living trees	1.31	0.473
Presence of cavities	1.44	0.724
Linear effect of log (#cavities) given presence	1.46	0.435

Table 6c. Parameter estimates and associated standard errors for two alternative models of the relationship between the probability of occurrence of the Four-fingered Skink and measured site attributes. Effects are shown graphically in Figure 3c.

Variable	Estimate	Standard Error
Constant	-1.623	0.302
Number of exposed rocks	0.042	0.016

OR

Constant	-1.72	0.321
Number of dead trees	0.511	0.194

Figure 3a. Predicted values and the associated 95% confidence intervals for the relationship between the probability of occurrence of any arboreal marsupial (i.e. The Common Ringtail Possum [PPE], Sugar Glider [PBR] and Common Brushtail Possum [TV]), and, **(left diagram)** the number of hollow-bearing trees, and, **(right diagram)** remnant area (ha) (see Table 6a).

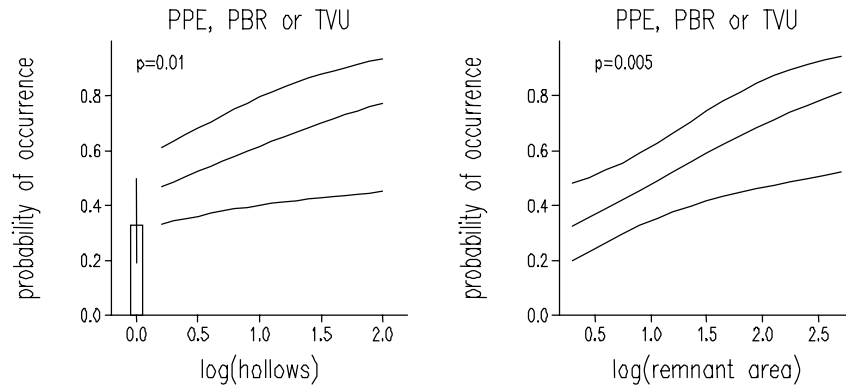


Figure 3b. Predicted values and the associated 95% confidence intervals for the relationship between the probability of occurrence of the Common Ringtail Possum (denoted ringtail), and, **(top left)** the number of hollow-bearing trees, **(top right)** the mean number of living trees per plot, and, **(bottom left)** remnant area (ha) (see Table 6b).

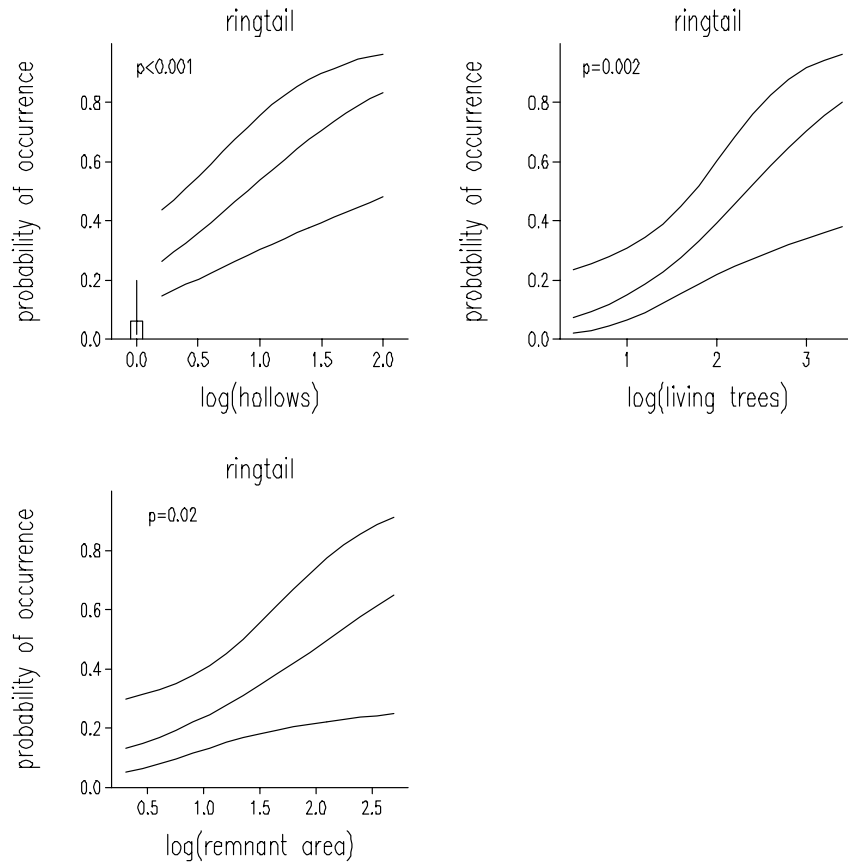
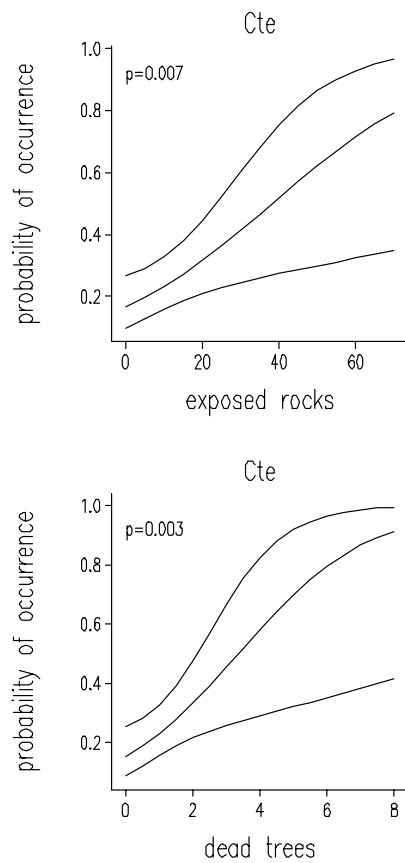


Figure 3c. Predicted values and the associated 95% confidence intervals for two alternative models for the relationship between the probability of occurrence of the Four-fingered Skink (denoted C_{te}) and (A) exposed rocks or (B), and, **(top)** exposed rocks, or, **(bottom)** the number of dead trees (see Table 6c).



2.8. Discussion

2.8.1. Species occurrence and woodland attributes

Remnant area effects were found for various species of arboreal marsupials in the Nanangroe Study (Table 6, Figure 3). Remnant area effects on biota in fragmented landscapes have been observed in numerous studies (reviewed by Hanski, 1994). In general, larger areas may contain more suitable habitat and larger, less extinction-prone populations. They also might have a higher probability of containing a “sample” population of a species at the time fragmentation occurs (Andrén, 1994). Notably, remnant area effects were not found for Common Ringtail Possum in the Tumut Fragmentation Study (Lindenmayer *et al.*, 1999a). A plausible explanation for this is that mature stands of Radiata Pine surrounding the remnants provide partially suitable habitat for the Common Ringtail Possum. This is not the case at Nanangroe where the landscape surrounding the eucalypt woodlands is largely cleared and unsuitable for arboreal marsupials.

Studies in forest ecosystems have highlighted the critical importance of trees with hollows for many vertebrate taxa (Gibbons and Lindenmayer, 1997; Soderquist *et al.*, 1998), and our study has confirmed the value of such trees for arboreal marsupials. In the case of the Common Ringtail Possum, the results at Nanangroe support the observation that the species is a facultative user of hollows. That is, the species appears to be dependent upon hollows in cold environments (such as Snow Gum woodlands [Green and Osborne, 1994] and relatively warm environments like Nanangroe and other woodland habitats (Soderquist *et al.*, 1998), but constructs dreys in temperate climates (How *et al.*, 1984). Indeed, in the Tumut Fragmentation Experiment where climatic conditions are wetter and more mesic than in the Nanangroe Study, habitat relationships for the Common Ringtail Possum did not include the number of tree hollows (Lindenmayer *et al.*, 1999a).

The Four-fingered Skink is terrestrial and is known to forage around rock outcrops (Cogger, 1998). Fallen timber also is an important foraging substrate (Jenkins and Bartell, 1980) and branch shedding from dead trees may create suitable habitat for the species. It is therefore not surprising that these factors were found to be statistically significant predictors of the probability of occurrence of the Four-fingered Skink.

An unexpected result of this study was the almost complete absence of small native mammals in woodlands. The entire study area has been subject to prolonged intensive grazing for more than a century and understorey vegetation is limited in many remnants. Vegetation cover is important for small mammals (Lindenmayer *et al.*, 1994; Catling and Burt, 1995) and grazing may have major indirect effects on these animals through its impacts on vegetation structure (see Yates *et al.*, 2000).

Activities like clearing, grazing-related degradation and firewood collection can reduce the size of remnant woodlands and remove trees with hollows and dead stems and so reduce the woodland fauna. In woodlands large dead trees including many which contain hollows, are often those selected for

firewood collection (Wall, 2000). The emerging pine plantation should limit human access and so help restore some of the key, conservation related features of woodlands. Moreover, as trees with hollows take a prolonged period to develop (typically many hundreds of years; Gibbons and Lindenmayer, 1997) woodland restoration efforts will need to be very long-term to replace key habitat attributes that have been lost as a result of clearing, firewood harvesting, and other activities.

2.8.2. Large-scale natural experiments in wildlife conservation and forecasts of the response of selected species to landscape change

Large-scale field experiments are very important in ecology (Lovejoy *et al.*, 1984; Margules, 1992; Schiemegelow *et al.*, 1997) and they can reveal unexpected outcomes with important implications for biodiversity conservation (Margules *et al.*, 1994; Dooley and Bowers, 1998; Gascon *et al.*, 1999; Lindenmayer *et al.*, 1999a). The need for large-scale experiments has particular relevance in parts of southern Australia because extensive areas will enter another major period of landscape modification over the next 20-30 years. Large sections of south-eastern Australia have undergone extensive clearing in the past 150 years (Walker *et al.*, 1993) to facilitate the development of grazing industries. Only a small proportion of the original vegetation cover remains in some areas (Benson, 1999). A large number of domestic livestock and grazing enterprises are now only marginally profitable, often due to poor management. Therefore, many areas of semi-cleared grazing lands are being increasingly targeted for the establishment of exotic softwood plantations - the plantation estate is set to treble in the next two decades (Department of Primary Industries and Energy, 1997). While many fragmented plant and animal communities are still responding to widespread clearing instigated many decades ago, a second phase of landscape change is now occurring. Many taxa in these areas will be subject to two major landscape changes in less than 200 years. Such large-scale changes in such a short period make it important to track their effects on biodiversity. For example, if many species have adapted to woodland fragments surrounded by a predominantly grazed landscape, some may be maladapted to a subsequent landscape transformation to a predominantly Radiata Pine landscape. If this is the case and species become isolated within woodland remnants surrounded by “hostile” exotic Radiata Pine forest, then theoretical extinction models predict that species loss from fragments would be very rapid at the onset of isolation and the decline gradually over time (Macarthur and Wilson, 1967; Wilcox, 1978). However, we did not find isolation time effects on species loss in the Tumut Fragmentation Experiment and this raises questions about the validity about such theoretical predictions. Thus, in the Nanangroe Study we will be in a position to more closely observe transitions. As a prelude to this, forecasts of possible future changes in species occurrence are outlined below. These predictions are based on the outcomes of the cross-sectional study in the Tumut Fragmentation Experiment 10-30 km to the south of the Nanangroe Study. For example, it will be interesting to determine if the effect of the number of live trees in a eucalypt remnant on Common Ringtail Possum differs as the Radiata Pine trees develop in the surrounding landscape (see Figure 3). It is plausible that the woodland remnant

size and hollow tree effects will disappear as the surrounding landscape eventually provides suitable or partially suitable habitat for the Common Ringtail Possum. This predicted change could occur because of the ability of the species to eat Radiata Pine needles and make nests or dreys from such foliage. Hence, animals will no longer be totally reliant on resources within woodland remnants for persistence, but rather may also use resources available in the surrounding landscape as it transforms from a grazed one to one supporting a softwood forest. Notably, in an earlier forest fragmentation and landscape context study, Lindenmayer *et al.* (1999a) found the Common Ringtail Possum was significantly more likely to be detected in remnant vegetation patches surrounded by Radiata Pine stands than in similar vegetation types located within large continuous areas of native eucalypt forest. In this case, extra resources created at the boundaries of eucalypt remnants and Radiata Pine stands may have elevated population densities above that observed in continuous eucalypt forest. Hence, it is possible that sizes of populations of the Common Ringtail Possum may increase as our natural experiment at Nanangroe progresses.

The Common Brushtail Possum was absent from Radiata Pine stands in our earlier study at Tumut (Lindenmayer *et al.*, 1999a), and on the basis of those results, the species may not be advantaged by the landscape change taking place at Nanangroe. In the case of the Sugar Glider, which does not inhabit Radiata Pine forest, future changes in habitat relationships and population sizes are also not easy to predict. For example, it is possible that the advent of landscape cover dominated by trees could facilitate the movement of the species and assist it to reach suitable areas of remnant woodland. Conversely, if the species is unable to move through stands of Radiata Pine, then woodland remnants may become (or remain) isolated for the Sugar Glider. The uncertainty in species' responses makes it important to gather good data to quantify the changes that do take place.

Recent work in the Tumut region to the south of the Nanangroe study area has highlighted the conservation value of remnant native vegetation embedded within extensive areas of Radiata Pine (Lindenmayer *et al.*, 1999a). The results of that work have stimulated NSW State Government agencies to better protect native vegetation as part of plantation establishment. Such efforts are important because some of the vegetation types within areas targeted for plantation expansion have already undergone extensive clearing (e.g. White Box woodlands). While existing information suggests that patches of remnant native vegetation are valuable for wildlife, the impacts on biodiversity of changing the landscape surrounding such remnants from a grazing-dominated one to a softwood-dominated one are unknown. Indeed, a number of studies suggest there may be problems in using species responses from fragmented systems characterised by a cleared agricultural lands to forecast the effects of fragmentation in forest ecosystems (e.g. Estades and Temple, 1999; Monkkonen and Reunanen, 1999). Given this, it is important to determine which species, if any, from a range of vertebrate groups, are directly affected by surrounding native woodland remnants with Radiata Pine plantations.

2.8.3. Longitudinal Studies

As described in previous sections, the Nanangroe Study is a longitudinal experiment designed specifically to directly measure changes in woodland taxa, as well as to quantify relationships between taxa and associated changes in landscape context (i.e. the transformation in the landscape surrounding woodland fragments) and habitat attributes. The major advantage of such a study over a cross-sectional study is that it will enable relationships between the response and explanatory variables arising from co-variation among sites to be distinguished from those arising from co-variation within sites. In longitudinal studies, repeated observations on the same site tend to be more alike compared to those on different sites. It is important when making inferences about effects that this correlation be accounted for in the statistical analysis. Recent advances in statistical modelling provide a powerful framework for the study relationships between the response and explanatory variables where correlation patterns between observations may be complicated, as is likely in this study. Details of appropriate statistical models will be given in a subsequent publication following analysis of data to be collected over the next few years.

3. The design of exotic softwood plantations to enhance biodiversity conservation: Lessons from studies at Nanangroe and Tumut in south-eastern Australia

3.1. Summary

Extensive areas of land have been planted with exotic softwood (*Radiata Pine*) plantations in south-eastern Australia over the past 50 years. In the past, large areas of native *Eucalyptus* forest were cleared to establish Pine forests. Present expansions of plantations in states like New South Wales (N.S.W.) are continuing primarily on grazing lands that support remnant forest and woodland. Preliminary results from a large-scale fragmentation experiment taking place within a softwood plantation near Tumut, southern N.S.W., indicate that although softwood establishment is high wood-fibre-yielding enterprise, new plantations can be planned to increase their value for wildlife conservation. Design strategies include the retention of existing native vegetation remnants within the boundaries of softwood plantations (particularly larger patches), restoration of native vegetation along gully-lines, and targeting strategic areas for re-planting with indigenous species to link retained patches of native vegetation within and across catchments. Harvesting practices within long-established softwood plantations also could be modified to help conserve biodiversity such as staggering clearfall schedules in stands of Pine trees that surround large patches of native forest and ensuring that thickets of important indigenous understorey vegetation are not extensively damaged during cutting operations.

3.2. Introduction

Extensive areas of exotic softwood plantations have been established in Australia over the past few decades and they are expanding at a rate of more than 30 000 ha per year (Resource Assessment Commission, 1992; State of the Environment Australia, 1996). Much of the softwood plantation estate in south-eastern Australia is dominated by stands of Radiata or Monterrey Pine (*Pinus radiata*). Timber extracted from exotic softwood plantations now constitutes an increasing proportion of the total sawn timber consumed in the various Australian States (Clark, 1992). Thus, the plantation industry makes an important contribution to the Australian economy. However, a number of authors have suggested that there may be negative effects of plantation establishment on biodiversity (e.g., Pawsey, 1966; Disney and Stokes, 1975; Suckling *et al.*, 1976; Suckling and Heislars, 1978; Smith, 1982; see review by Ray *et al.*, 1983). This is because:- **(1)** in the past, large areas of native *Eucalyptus* forest were cleared to establish softwood plantations (Tyndale-Biscoe and Smith, 1969; Routley and Routley, 1975), and, **(2)** stands of Pine forest often lack key habitat attributes and food sources such as tree hollows, flowers, seeds and fruit that are needed by Australian forest-dependent animals (Smith, 1982).

In states like New South Wales (N.S.W.), much of the present expansion of the softwood plantation estate is occurring on predominantly cleared agricultural and grazing lands that often support remnant patches of the original woodland and forest cover. Although the primary goal of plantation forestry is clearly the efficient production of large quantities of timber and pulp, important opportunities exist to design new softwood plantations to enhance their value for the wildlife. Similar opportunities occur as part of harvesting existing softwood plantations, particularly when the next rotation is being established. These initiatives are important as the softwood plantation estate is presently large; more than one million hectares (Resource Assessment Commission, 1992; State of the Environment, 1996) and is set to increase substantially in the coming years. Indeed, although the removal of native vegetation in some Australian States has declined in more recent times, clearing is set to increase again (e.g., in Victoria) as a consequence of proposals to establish plantations, particularly exotic softwoods (Commonwealth of Australia and Department of Natural Resources and Environment, 1997).

In this chapter, some of the possible approaches to the design and management of exotic softwood plantations to promote their value for wildlife conservation are briefly outlined. The strategies discussed are preliminary ones based on the outcomes of the large-scale landscape quasi-experiments (*sensu* Dunning *et al.* 1995) at Tumut and Nanangroe in southern N.S.W. (Lindenmayer *et al.* 1996; 1997a, 1997b, 1998, 1999a, 1999b, 2001, 2002) together with the findings of a radio-tracking investigation of patch use by one species; the Greater Glider (*Petauroides volans*) (Pope and Lindenmayer, 1997).

3.3. The Tumut Fragmentation Experiment

The large-scale fragmentation experiment at Tumut has focussed on 192 patches of remnant eucalypt forest embedded within a 45 000 ha softwood (Radiata Pine) plantation in the Buccleuch State Forest. These patches vary in size (0.2-124 ha), shape, dominant tree species, time since isolation (5-65 years) and a host of other variables (see Lindenmayer *et al.* 1996, 1997a, 1999a, 1999b, 2002). Extensive areas of native forest abut the plantation, including those located in Kosciuszko National Park, Bondo State Forest, and Bungongo State Forest. The main objective of the experiment is to compare the presence and abundance of vertebrates (small mammals, arboreal marsupials and birds) in three broad groups of sites:- **(1)** sites in large contiguous areas of native eucalypt forest adjacent to the softwood plantation (40 sites), **(2)** sites within remnant patches of native eucalypt forest surrounded by stands of Radiata Pine (86 remnants), and, **(3)** sites dominated by Radiata Pine trees that comprise the softwood plantation in the study area (40 sites) (Lindenmayer *et al.*, 1997a, 1999a, 2002). A rigorous approach to experimental design has underpinned the study and this has involved:- **(i)** A stratified, randomised and replicated patch selection procedure to guide the selection of remnants in four different size classes, two different shape classes, five different forest types, and two different isolation time categories. **(ii)** Cross matching between groups of remnants and sites in large contiguous native forest on the basis of climate, geology and vegetation types. And, **(iii)** The measurement of a suite of covariates at each site such as stand structure and plant species composition as well as isolation distance and other landscape indices (for the 86 remnants only) (see Lindenmayer *et al.*, 1997a, 1999a, 2002).

The landscape experiment at Tumut has been underway since mid-1995 and preliminary results are available for arboreal marsupials (Lindenmayer *et al.*, 1997a, 1998; 1999a, Pope and Lindenmayer 1997) and small mammals (Lindenmayer *et al.* 1999b). Some analyses have been completed for birds (Lindenmayer *et al.* 1996, 1997b; 2002). The following discussion of principles for plantation design is based predominately on findings for arboreal marsupials and small mammals. These design principles will be expanded on the basis of new information, particularly for birds. This is because birds are by far the most species-rich group of vertebrates at Tumut and they exhibit a very wide of responses to landscape context and fragmentation effects (Lindenmayer *et al.*, 2002).

3.4. New Softwood plantings

The value of existing remnant native vegetation

As outlined above, the current expansion of the softwood plantation estate in N.S.W. is occurring in areas that have a history of agriculture and/or grazing. The native vegetation in these areas has been largely cleared and only remnants of the original forest or woodland remain. The results of the Nanangroe and Tumut Fragmentation Experiments clearly indicate that remnant patches of eucalypt forest surrounded by softwood plantations have value as habitat for native mammals and that they should not be cleared as part of plantation establishment. Studies of arboreal marsupials and small mammals have indicated that remnant patches, including those that have been isolated for prolonged periods (up to 65 years), are occupied by a wide range of taxa including the Greater Glider (*Petauroides volans*), Common Ringtail Possum (*Pseudocheirus peregrinus*), Sugar Glider (*Petaurus breviceps*), Feathertail Glider (*Acrobates pygmaeus*), Common Brushtail Possum (*Trichosurus vulpecula*), Mountain Brushtail Possum (*Trichosurus caninus*), Agile Antechinus (*Antechinus agilis*), Dusky Antechinus (*Antechinus swainsonii*), Bush Rat (*Rattus fuscipes*), Echidna (*Tachyglossus aculeatus*), Common Wombat (*Vombatus ursinus*), Eastern Grey Kangaroo (*Macropus giganteus*), Red-necked Wallaby (*Macropus rufogriseus*) and Black Wallaby (*Wallabia bicolor*). Thus, while some species do not appear to be able to persist in vegetation remnants (the Yellow-bellied Glider [*Petaurus australis*] and Squirrel Glider [*Petaurus norfolcensis*] were absent from these areas), the patches did provide suitable habitat for many taxa.

The importance of large patches

Larger patches of native vegetation on semi-cleared grazing lands should have priority for exemption from clearing plantation establishment. Analyses of data gathered at Tumut have revealed positive statistical relationships between patch size and the presence and abundance of several species of mammals (Lindenmayer *et al.*, 1997a, 1999). The probability of occurrence of an arboreal marsupial was > 50% in remnants 3 ha or larger and > 80% in those exceeding 20 ha, with the lower bound of the 95% confidence interval exceeding 50% in remnants measuring about 8 ha). Small mammals such as the Brown Antechinus and the Bush Rat show similar responses to patch size (Lindenmayer *et al.*, 1999b). On the basis of these results, we recommend that remnants 3 ha or larger be exempt from clearing.

3.5. Existing softwood-dominated landscapes

Softwood plantations have existed in the Tumut region for many decades and the first plantings were established in the early 1930's. The results of our studies at Tumut have indicated some modifications to current practices within existing softwood plantations could enhance their conservation value.

Restoration of riparian and gully areas

A proportion of the remnants in the patch system targeted for study at Tumut are located within gullies. These areas, like the other remnants surveyed, support a wide range of mammals (see above) as well as many species of birds (Lindenmayer *et al.*, 2002). Indeed, riparian areas in many forest ecosystems have been found to be species-rich (e.g. Recher *et al.*, 1980; Loyn *et al.*, 1980; Naiman *et al.*, 1993), although these areas do not provide suitable habitat for all forest-dependent taxa (Claridge and Lindenmayer, 1994). Notably, in more recent decades, riparian native vegetation at Tumut has been exempt from clearing to establish Radiata Pine. Timber harvesting in areas established prior to this time is subject to special prescriptions in and near gully and riparian zones due to water quality and aquatic habitat considerations. Given these considerations, together with the potential importance of riparian areas for fauna, we recommend that native vegetation be restored in gully areas following the final clearfelling operation that completes a given logging rotation. Restoration of gully or riparian vegetation provides an opportunity to link retained areas within and across catchments. This may aid the dispersal of some species, particularly aquatic taxa (Wardell-Johnson and Roberts, 1993) as well as those in which movement and/or dispersal is guided by particular topographic features such as streamlines (see Taylor *et al.*, 1985; Rosenberg *et al.*, 1997). Notably, other authors working in softwood production landscapes characterised by patches of remnant eucalypt forest have recommended that the original gully vegetation be restored to enhance the value of plantations for biodiversity (Recher *et al.*, 1987).

Staggering the spatial configuration of clearfall harvesting

Although existing patches of remnant eucalypts within the boundaries of the softwood plantation at Tumut are exempt from cutting, the surrounding Radiata Pine is clearcut prior to the commencement of a new rotation. Radio-tracking of the Greater Glider at Tumut has indicated that animals use the Pine forest to move between eucalypt habitat patches (Pope and Lindenmayer, 1997; Pope *et al.*, unpublished data). Therefore, the clearfelling of stands of softwood trees surrounding eucalypt remnants may temporarily limit the movements of animals like the Greater Glider and isolate sub-populations in patches from those residing within other remnants in the patch system. One way to enhance functional connectivity (*sensu* Bennett, 1998) between sub-populations that reside within spatially separated eucalypt patches would be to stagger the spatial configuration of clearfelled Radiata Pine stands adjacent to remnants. Thus, at any one time, some areas of advanced regrowth Radiata Pine in the matrix would link eucalypt remnants. Harris (1984) has made similar suggestions for

guiding cutting regimes to buffer, and maintain connectivity between, areas of old growth Douglas Fir forest in the Pacific Northwest of the U.S.A.

Conservation of components of understorey vegetation and ground cover

Careful treatment of understorey vegetation within stands of Radiata Pine could make an important contribution to the conservation of some species, including those that are considered to be at risk. For example, surveys of birds in our experiment have indicated that the Olive Whistler (*Pachycephala olivacea*) often occurs within stands of Radiata Pine where there are intact thickets of understorey *Leptospermum* spp. (Lindenmayer *et al.*, 2002). Approaches that either minimise the disturbance of understorey vegetation or promote its regeneration following harvesting could help species like the Oliver Whistler to persist in softwood plantations. Notably, such understorey vegetation often occurs in gullies or the wet seepage areas associated with the margins of swamps; places that could be readily captured within riparian zones.

Field observations completed at Tumut to date have indicated that a range of species of birds are closely associated with windrows of eucalypt logs that are the remains of the original stands cleared to plant softwoods. Several other studies have highlighted the importance for native fauna of windrows of cleared eucalypts within softwood plantations (e.g. Friend, 1982; Curry, 1991). Given their value, it is important that the decay of these windrows is not accelerated by damage from machinery during harvesting operations in stands of Radiata Pine.

3.6. Caveats

The plantation estate is presently being expanded at a rate of approximately 1000-2000 ha per year (D. Hobson personal communication). This process will not be halted while new information is being generated. Moreover, the data gathered and analyzed thus far indicate that the adoption of some of the design principles outlined in this paper could substantially improve the value of softwood plantation for wildlife conservation. Thus, it is important to document some principles now although considerable further work needs to be completed. This is necessary to ensure that valuable existing conservation opportunities associated with the current establishment of new plantations are not foregone. However, there are few studies worldwide that have explored issues associated with plantation design to enhance the value of such areas for wildlife (Hanowski *et al.*, 1997; Lindenmayer and Franklin, 2002). On this basis, there is a clear need for more studies to study and monitor plantation forests (and the remnants of native vegetation they may contain) to help develop approaches that ensure they retain some nature conservation values. Indeed, baseline studies are required that examine the changes in species assemblages that occur when agricultural landscapes with areas of remnant native vegetation are transformed to landscapes dominated by softwoods encompassing fragments of the original native forest and woodland cover – this was the motivation for the Nanangroe study described in Chapter 2 of this report. These studies should be set within an adaptive management framework (Walters and Holling, 1990; see Lindenmayer and Franklin, 2002) so that new data can be forwarded to softwood forest managers to better inform approaches for improved plantation design.

The Nanangroe and Tumut Fragmentation Experiments have focussed on native forest and woodland and their value for wildlife within softwood plantations. Remnant grassland habitats on grazed lands have not been considered, but some areas targeted for planting may support these types of vegetation communities that have experienced substantial reduction and degradation since white settlement. Grassland communities warrant careful attention and the potential effects of plantation establishment on them as well as approaches for their conservation in such intensive production environments, should be a topic for further investigation.

4. References

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APPENDIX 1. Guidelines for Plantation Management and Biodiversity Conservation

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. This appendix reproduces some of the key principles and guidelines for better integrating biodiversity conservation and plantation management that were initially published as a RIRDC Short Report (No. 77) in 2000 (Lindenmayer, 2000b).

1. 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.

- Remnant patches of native woodland and forest provides important habitat for native mammals, birds, reptiles and plants.
- Larger patches of remnant native vegetation (e.g. > 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 as part of softwood plantation establishment.
- Remnant patches close (< 500m) to large continuous areas of native vegetation are more likely to be occupied by some vertebrate taxa (e.g. small mammals, arboreal marsupials and birds) than more isolated ones. However, even isolated patches can have significant conservation value for many species (e.g. birds) and they should not be cleared simply because they are isolated.
- A landscape mosaic comprised of both 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 native vegetation restoration efforts 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 (e.g. wildlife corridors) between native remnant vegetation or revegetated areas within and outside the plantation estate should be maintained, established or enhanced.
- Extensive developments of the softwood plantation estate (e.g. > 1000 ha) should aim to contain at least 30% of remnant or re-established 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 (e.g. 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.

2. 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 re-established at the completion of the final clearfell operation as they are used as habitat and for dispersal by wildlife.
- Restoration activities should utilise 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 re-established along streams within the plantation estate should be a minimum of 40 metres 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.

APPENDIX 2. Contributors to Key Studies in the Nanangroe and Tumut Regions

Principal Investigators

- Dr. David Lindenmayer (Centre for Resource and Environmental Studies, The Australian National University, Canberra).
- Associate-Professor Ross Cunningham (Centre for Resource and Environmental Studies, 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. Mason Crane (Field Research Officer 2000- onward) (Centre for Resource and Environmental Studies, The Australian National University)
- Mr. Matthew Pope (Field Research Officer; 1995-1998) (Centre for Resource and Environmental Studies, The Australian National University [now a Masters 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).
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Scientific Investigators and collaborators (alphabetical order)

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- Dr. Robert Lacy, (Mathematical Modeller and Geneticist) (Center for Conservation Biology, Brookfield Zoo, Chicago, U.S.A).
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- Dr. Rob Lesslie (Ecologist) (Department of Geography, The Australian National University, Canberra).
- Mr. Bruce Lindenmayer (Ornithologist) (17 Monkman St., Chapman, ACT).
- Dr. Michael McCarthy (Mathematical Modeller and Forest ecologist) (Centre for Resource and Environmental Studies, The Australian National University and School of Botany, University of Melbourne).
- Mr. Ed Merrett, GIS Unit, State Forests of NSW, Albury, NSW.
- Professor Henry Nix (Ecologist and climate analysis expert) (Centre for Resource and Environmental Studies, The Australian National University).
- Dr. Rod Peakall (Geneticist) (Division of Botany and Zoology, The Australian National University).
- Dr. Kirsten Parris (Herpetologist and ecologist) (Centre for Resource and Environmental Studies, The Australian National University and School of Botany, University of Melbourne).
- Dr. Emma Pharo (Botanist/Bryophyte specialist) (University of Tasmania, Hobart).
- Professor Hugh Possingham (Mathematical Modeller and Ecologist) (The Ecology Centre, University of Queensland).
- Ms. Monica Ruibal (Geneticist, Honours Student) (Division of Botany and Zoology, The Australian National University, Canberra).
- Mr. Peter Smith (Botanist and Ecologist) (NSW Department of Land and Water Conservation and Macquarie University, Sydney).

- Ms Janette Stanley (Social Scientist; PhD student) (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).
- Mr. Darius Tubelis (Ecologist, PhD student) (Centre for Resource and Environmental Studies, The Australian National University, Canberra).
- 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).
- Mr. Sam Woods (Geneticist, PhD student) (Department of Environmental Science, Monash University, Clayton, Victoria).

APPENDIX 3. Projects being undertaken in the Nanangroe and Tumut Regions

Landscape context studies - Nannangroe main study

- The distribution of possums and gliders in the remnant in pine vs remnants in agricultural landscapes
- The distribution of small mammals in the remnant in pine vs remnants in agricultural landscapes
- The distribution of birds in the remnant in pine vs remnants in agricultural landscapes
- The distribution of reptiles in the remnant in pine vs 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 - Ms. V Mason/Phd program - Ms. J. Stanley)

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

APPENDIX 4. Publications from research in the Nanangroe and Tumut Regions

(as at September 2001)

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*). (in press).

Lindenmayer, D.B., Cunningham, R.B., Lesslie, R., and Donnelly, C.F. Landscape indices and vertebrate species response in two Australian forest landscapes. (*Forest Ecology and Management*). (in press).

Lindenmayer, D.B., and Lacy, R.C. Small mammals, patches and PVA models: a field test of model predictive ability. (*Biological Conservation*). (in press).

Lindenmayer, D.B., Manning, A., Smith, P.L, McCarthy, M., Possingham, H.P., Fischer, J., and Oliver, I. The focal species approach and landscape restoration: A critique. (*Conservation Biology*) (in press).

Lindenmayer, D.B. The Greater Glider as a model to examine key issues in Australian forest ecology and management. Invited Chapter in Book on 50 Year Centenary of CSIRO Wildlife and Ecology. D.A. Saunders, editor. Surrey Beatty and Sons, Chipping Norton, Sydney, Australia. (in press).

Fischer, J., Lindenmayer, D.B. The conservation value of paddock trees for birds in a variegated landscape in southern New South Wales. I. Species composition and site occupancy patterns. (*Biodiversity and Conservation*) (in press).

Fischer, J., Lindenmayer, D.B. The conservation value of paddock trees for birds in a variegated landscape in southern New South Wales. II. Paddock trees as stepping stones. (*Biodiversity and Conservation*) (in press).

Fischer, J. and Lindenmayer, D.B. The conservation value of small habitat patches: two case studies on birds from southeastern Australia. (*Biological Conservation*). (in press).

Possingham, H.P. Lindenmayer, D.B., and Tuck, G.N. Decision theory for Population Viability Analysis. In: D. McCulloch, editor. Metapopulation dynamics and Population Viability Analysis. Island Press. (in press).

Taylor, A.C. and Lindenmayer, D.B. Microsatellites for the Greater Glider, *Petauroides volans*. *Molecular Ecology* (in press).

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- Lindenmayer, D.B., Cunningham, R.B., Tribolet, C.R., Incoll, R.D., Welsh, A.W., Pope, M.L., Viggers, K.L. and Donnelly, C.F. The detectability of the Greater Glider. *Wildlife Research*, **28**, 105-109.
- Lindenmayer, D.B. and Munks, S. 2001. Part 2. Principles and recommendations. Fauna Issues and Plantation Design Workshop. June 2000. *Tasforests*, **12**, 173-180.
- Lindenmayer, D.B. 2001. Plantation design and fauna conservation in Tasmania. Part 1. Workshop Abstracts. Fauna Issues and Plantation Design Workshop. June 2000. *Tasforests*, **12**, 162-164.
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