



An Australian Government Initiative



Fauna conservation in Australian plantation forests

– *a review*

**A report for the
RIRDC/L&WA/FWPRDC
Joint Venture Agroforestry Program**

by D.B. Lindenmayer and R.J. Hobbs

May 2007

RIRDC Publication No 05/128
RIRDC Project No UMU-31A

© 2007 Rural Industries Research and Development Corporation.
All rights reserved.

ISBN 1 74151 191 7
ISSN 1440-6845

Fauna conservation in Australian plantation forests – a review

Publication No. 05/128

Project No. UMU-31A

The information contained in this publication is intended for general use to assist public knowledge and discussion and to help improve the development of sustainable regions. You must not rely on any information contained in this publication without taking specialist advice relevant to your particular circumstances.

While reasonable care has been taken in preparing this publication to ensure that information is true and correct, the Commonwealth of Australia gives no assurance as to the accuracy of any information in this publication.

The Commonwealth of Australia, the Rural Industries Research and Development Corporation (RIRDC), the authors or contributors expressly disclaim, to the maximum extent permitted by law, all responsibility and liability to any person, arising directly or indirectly from any act or omission, or for any consequences of any such act or omission, made in reliance on the contents of this publication, whether or not caused by any negligence on the part of the Commonwealth of Australia, RIRDC, the authors or contributors..

The Commonwealth of Australia does not necessarily endorse the views in this publication.

This publication is copyright. Apart from any use as permitted under the *Copyright Act 1968*, all other rights are reserved. However, wide dissemination is encouraged. Requests and inquiries concerning reproduction and rights should be addressed to the RIRDC Publications Manager on phone 02 6272 3186.

Researcher Contact Details

David Lindenmayer
CRES
Building 43
Australian National University ACT 0200

Phone: 02 6125 0654
Fax: 02 6125 0757
Email: davidl@cres.anu.edu.au

Richard Hobbs
School of Environmental Studies
Murdoch University
Murdoch WA 6150

Phone: 08 9360 2191
Fax: 08 9360 7412
Email: rhobbs@essun1.murdoch.edu.au

In submitting this report, the researcher has agreed to RIRDC publishing this material in its edited form.

RIRDC Contact Details

Rural Industries Research and Development Corporation
Level 2, 15 National Circuit
BARTON ACT 2600
PO Box 4776
KINGSTON ACT 2604

Phone: 02 6272 4819
Fax: 02 6272 5877
Email: rirdc@rirdc.gov.au
Website: <http://www.rirdc.gov.au>

Published in May 2007
Printed on environmentally friendly paper by Canprint

Foreword

The Joint Venture Agroforestry Program has commissioned a number of projects to develop guidelines on different aspects of agroforestry design and practice for farm advisers, catchment managers and landholders. The literature review that comprises this publication informed the third guideline in this series, *Trees and Biodiversity: a guide for Australian farm forestry*. The other guidelines published so far are *Design Principles for Farm Forestry*; *Trees Water and Salt: an Australian guide to using trees for healthy catchments and productive farms*; and *Trees for Shelter: a guide to using windbreaks on Australian farms*.

This report is a review of the value for fauna (wildlife) of conifer and eucalypt plantations in Australia. It reviews and discusses available information on faunal use of plantations at the landscape and stand scales, as well as other issues for plantation management, including trade-offs between intensifying production and increased reservation, and the management of pest animals in plantations. The review showed that almost all research undertaken in Australian plantations, both in conifers and eucalypts, has highlighted the importance of landscape heterogeneity and stand structural complexity for fauna conservation. The review presents principles for maintaining wildlife in plantations that are applicable in Australia and elsewhere in the world.

This review will be of interest and use to landholders, farm forestry advisers, and a wide Natural Resource Management (NRM) audience, including biologists, ecologists, catchment and plantation managers, policy makers and planners.

This project was funded by the Joint Venture Agroforestry Program (JVAP), which is supported by three R&D Corporations – Rural Industries Research and Development Corporation (RIRDC), Land & Water Australia, and Forest and Wood Products Research and Development Corporation (FWPRDC), together with the Murray-Darling Basin Commission (MDBC). The R&D Corporations are funded principally by the Australian Government. State and Australian Governments contribute funds to the MDBC.

This report is a new addition to RIRDC's diverse range of over 1600 research publications. It forms part of our Agroforestry and Farm Forestry R&D program, which aims to integrate sustainable and productive agroforestry within Australian farming systems. The JVAP, under this program, is managed by RIRDC.

Most of our publications are available for viewing, downloading or purchasing online through our website:

- downloads at www.rirdc.gov.au/fullreports/index.htm
- purchases at www.rirdc.gov.au/eshop

Peter O'Brien

Managing Director

Rural Industries Research and Development Corporation

Acknowledgments

The authors would like to thank the Joint Venture Agroforestry Program (and particularly Roslyn Prinsley) for funding our work on plantations and wildlife conservation. David Lindenmayer would also like to thank Land & Water Australia and the Winnifred Violet Scott Trust for funding major projects in the Tumut region of southern New South Wales from where many insights into plantation management have arisen. He also would like to thank R.B. Cunningham, A. Manning, D. Tubelius, C. MacGregor, M. Crane, M. Pope and D. Michael for detailed discussions on plantation management and aspects of fauna conservation. A wide range of colleagues kindly provided information on plantations research projects that are currently underway in Australia. Monica Ruibal kindly assisted in the collection of the extensive (and rapidly growing) literature that now exists on wildlife conservation in Australian plantations. Comments by Rod Keenan greatly improved an earlier version of this paper.

Contents

Foreword	iii
Acknowledgments.....	iv
Executive Summary	vi
Introduction	1
Definition	1
Chapter 1 - Motivations for fauna conservation in Australian plantations.....	2
Chapter 2 - Background	3
The biota of conifer plantations.....	3
The biota of eucalypt and other types of plantations.....	5
Plantations versus cleared (agricultural) land.....	5
Chapter 3 - Conserving wildlife in plantation forests – landscape-level issues.....	7
Where plantations are located and the land cover they replace.....	7
Landscape mosaics within plantations – juxtapositions of different patch types, sizes and shapes....	7
Adjacency effects	9
Adjacency and browsing by “pest” animals	10
The scheduling of harvesting	10
Chapter 4 - Conserving fauna in plantation forests – stand-level issues.....	12
Species composition and mixtures	12
Stand age	12
Biological legacies at the stand level.....	13
Tree spacing and thinning	14
Chapter 5 - Other issues for plantation management.....	15
Trade-offs between intensifying production and increased reservation.....	15
Landscape restoration.....	15
“Pest” animals in plantations.....	15
Chapter 6 - Tensions between wildlife conservation and typical plantation management objectives and practices	17
Chapter 7 - Principles for enhancing wildlife conservation in plantations	19
General principles.....	19
Landscape level principles	19
Stand level principles	19
Chapter 8 - Data limitations.....	20
Chapter 9 - Concluding remarks	21
References	23

Executive Summary

What the report is about

This report is a review of the value for fauna (wildlife) of conifer and eucalypt plantations in Australia. The report identifies the motivations for wildlife conservation in plantations and summarises published information up to 2003, on the biota of pine and eucalypt plantations. It reviews and discusses available information on faunal use of plantations at the landscape and stand scales as well as other issues and tensions for plantation management, including trade-offs between intensifying production and increased reservation, and the management of pest animals in plantations.

Who is the report targeted at?

This review will be of interest and use to a wide Natural Resource Management (NRM) audience. The comprehensive review of use of plantations by wildlife will prove valuable for biologists and ecologists. Catchment and plantation managers will benefit from the discussion of wildlife conservation issues at the landscape and stand scales. Policy makers and planners will find useful application for the planning and management principles.

Although the review focuses on medium to large scale plantations (given the paucity of information available at the patch or farm scale), the key findings and general principles will also be useful for landholders and farm forestry advisors.

Background

Plantations of trees cover extensive parts of the earth's surface. In almost all places where they have been established, production of large quantities of wood and fibre is the primary purpose (e.g. for timber and paper production). Indeed there is a global trend toward greater reliance on wood sourced from plantations, and an increasing emphasis on "industrialized" plantation forestry in the Southern Hemisphere. However, there can be important fauna conservation opportunities within plantations.

We believe this review is important for several reasons. First, although a compendium of literature was assembled more than two decades ago, there has been no previous review of fauna conservation in Australian plantations. The use of plantations by wildlife is a question frequently asked by catchment managers, foresters and conservationists in Australia. Second, some of the general fauna conservation principles (rather than the specific details) identified in this review may be useful in the management of plantations elsewhere around the world. This is an important consideration given the substantial and rapidly increasing area of plantations worldwide. Moreover, species in the genera *Pinus* and *Eucalyptus* that are the focus of this review, comprise 20% and 10% of the world's plantations respectively, with more than 20 million ha of plantation eucalypts occurring in almost 100 countries.

There are five key reasons why wildlife conservation should be considered as part of plantation management:

- (1) The plantation estate in Australia is set to triple in the coming decades, and where new plantations are located and how they are managed will impact on the biota that currently exist in such landscapes. This is particularly critical in many semi-cleared former grazing landscapes where the establishment of new plantations is being focused.
- (2) The maintenance of some elements of the biota within plantations could have benefits for key ecosystem processes like pest control.
- (3) Although some species cannot be conserved in plantation-dominated landscapes, many species can be through the adoption of (sometimes minor) modifications to forest management.
- (4) The maintenance (or loss) of biota in plantations is relevant for moves toward ecological standards and the certification of plantations in many parts of the world.
- (5) Simple plantation forestry (*sensu* Kanowski, 1997) which has a narrow and intensive management focus on producing a forest crop for a limited array of purposes, may not meet societal demands for a range of outputs from plantations in addition to wood and pulp. It also may not be congruent with the principles of ecological sustainability.

Aims/Objectives

The aim of this report is to review the published literature on fauna conservation in medium to large scale Australian pine and eucalypt plantations and present key findings and principles to inform better management of wildlife in plantations. This information has only been assembled once in Australia and not for over 20 years. As such, the review aims to address a significant knowledge gap by synthesising available data into a series of key findings and guiding principles for management.

Methods used

Over 140 papers on faunal use of Australian plantations were assembled and reviewed. The available information was assessed to:

- (1) identify motivations for wildlife conservation in plantations
- (2) describe the biota of pine and eucalypt plantations
- (3) summarise key issues at the landscape and stand scales
- (4) synthesise into principles for incorporating fauna conservation into plantation management.

Results/Key findings

Many studies of the biota of Australian conifer (*Pinus*) plantations have been completed in the past 30 years. In comparison there have been far fewer investigations of eucalypt plantations. However the work completed to date has demonstrated that:

- (1) Although some species are rare or absent from plantations, these areas are not biological deserts.
- (2) The assemblage of native species that inhabit plantation landscapes will be different to that which occurs in landscapes dominated by large areas of grazing land.
- (3) Remnant native vegetation within the boundaries of plantations is valuable for many species of native animals ranging from invertebrates to mammals.
- (4) More species occur in parts of plantation landscapes that contain remnant vegetation than in plantation monocultures.
- (5) The size and shape of patches of remnant vegetation within plantations can have an important influence on which species can persist in such landscapes. However, even relatively small patches (including individual paddock trees) can be useful for some species of native fauna.
- (6) Stands of plantation trees adjacent to patches of remnant native vegetation support more species than more isolated stands of plantation trees.
- (7) Riparian areas can be particularly valuable for wildlife and may act as dispersal routes for some taxa.

Our review showed that almost all research undertaken in Australian plantations, both in conifers and eucalypts, highlighted the importance of landscape heterogeneity and stand structural complexity for fauna conservation. At the landscape level, patches of retained native vegetation, strips of riparian vegetation, dams, open and clearing areas can significantly increase the number of native species that occur within plantations. Some species that occur in these areas can also use adjacent planted areas, a result common to conifer and eucalypt plantations. The spatial juxtaposition of stands of varying ages throughout plantation landscapes also can contribute to the maintenance of some populations of native taxa. At the stand level, structural complexity is also important for fauna with many species responding positively to the presence of native understorey plants, the presence of windrowed logs, and logging slash left on the forest floor.

Implications for relevant stakeholders

The management of plantations to promote landscape heterogeneity, stand structural complexity and enhance the conservation of fauna will, in many cases, involve trade-offs that will impact upon wood and pulp production. The extent to which this occurs depend on the objectives of plantation management and how far they extend toward the complex plantation forestry model of Kanowski (1997) to incorporate social and environmental values in addition to wood and pulp production. It will also be linked with other initiatives linked to ecological sustainable uses of natural resources, such as certification.

Recommendations

We recommend that the principles for enhancing wildlife conservation in plantations, as outlined in this report, are considered in making management decisions. General, landscape and stand level principles are provided. In considering trade-offs between production and conservation, critical considerations are: where plantations are located, and the land cover they replace. Also, the pre-existing conservation values of areas where new plantations might be established, warrant careful consideration.

Plantations should not replace vegetation communities that have experienced substantial reduction and degradation since white settlement, such as native grasslands. In other cases, we believe that clearing native vegetation to establish plantations (e.g. as is presently occurring in Tasmania) is an inappropriate land use practice, given the known and well-documented negative ecological impacts of land clearing. Of particular concern are the highly productive parts of the north-west and north-east of Tasmania – areas that are important for some elements of the biota but which are already heavily fragmented by agriculture and existing plantations.

We also recommend that researchers implement new studies to rigorously assess the effectiveness of codes of practice and highlight where they can be improved to better meet plantation estate objectives.

Introduction

Plantations of trees cover extensive parts of the earth's surface. The primary aim of plantations in almost all places where they have been established is the production of large quantities of wood and fibre (e.g. for timber and paper production) (Doughty, 2001; Wood *et al.*, 2001); indeed there is a global trend toward a greater reliance on wood sourced from plantations (Food and Agriculture Organisation of the United Nations, 2001), with an increasing emphasis on "industrialized" plantation forestry in the Southern Hemisphere (Franklin, 2003). However, there can be important fauna conservation opportunities within plantations (Peterken and Ratcliffe, 1995; Moore and Allen, 1999; Hartley, 2002), and in this paper, we explore issues associated with fauna conservation in Australian plantations.

Our review focuses largely on two broad sorts of Australian plantation forests – those dominated by stands of exotic pines (*Pinus* spp) and those dominated by eucalypts such as blue gum (*Eucalyptus globulus*) and shining gum (*E. nitens*). This is because they are by far the most common types of plantings in Australia (Eldridge *et al.*, 1994; Wood *et al.*, 2001). We first outline five reasons why wildlife conservation is important in the plantation estate. We then explore fauna conservation issues at the landscape and stand levels. Other issues which do not fit easily within either of these two scales are then addressed in the third major section of the paper. Finally, some tensions between fauna conservation and plantation management objectives and practices are discussed.

We have not examined issues associated with plant conservation in plantations because the bulk of research and survey has focused on animals – especially birds. Our focus is primarily on medium to large-size plantations (over several hundreds to several thousand and tens of thousands of hectares) and we also have not examined smaller plantings, such as those typically undertaken in agricultural areas by farmers in rural Australia (widely termed "farm forestry; *sensu* Race *et al.*, 1998). This is because a careful examination of the literature indicated that very limited research work has been undertaken to date on plantings at such small scales.

We believe this review is important for several reasons. First, although a compendium of literature was assembled more than two decades ago (Ray *et al.*, 1983), there has been no previous review of fauna conservation in Australian plantations. Second, some of the general fauna conservation principles (rather than the specific details) identified in this review may be useful in the management of plantations elsewhere around the world. This is an important consideration given the substantial and rapidly increasing area of plantations worldwide. For example, in 1996, the combined area of plantations worldwide was estimated to exceed 130 million ha (Cubbage *et al.*, 1996) and in 2001 it was 187 million ha (Food and Agriculture Organisation of the United Nations, 2001). Moreover, species in the genera *Pinus* and *Eucalyptus* that are the focus of this review, comprise 20% and 10% of the world's plantations respectively (Food and Agriculture Organisation of the United Nations, 2001) - with more than 20 million ha of plantation eucalypts occurring in almost 100 countries (Doughty, 2001).

This review encompasses literature up to 2003.

Definition

For the purposes of this paper we use the definition of a plantation in the Australian Forestry Standard (2003, p. 16) which is: '*Stands of trees of native or exotic species, created by the regular placement of cuttings, seedlings or seed selected for their wood-producing properties and managed intensively for the purposes of future timber harvesting*'.

Chapter 1 - Motivations for fauna conservation in Australian plantations

There are five key reasons why the conservation of wildlife in Australian plantations is an important issue.

(1) The plantation estate in Australia increased from more than one million ha in the mid 1990s (Resource Assessment Commission 1992; State of the Environment 1996) to almost 1.5 million ha in 2000 (Wood *et al.*, 2001). The plantation estate is set to triple in the size by the year 2020 to three million hectares (Department of Primary Industries and Energy, 1997). Where new plantations are located and how they are managed will impact on the biota that currently exist in such landscapes (Lindenmayer *et al.*, 2001). New plantations are being established in semi-cleared grazing lands (Price *et al.*, 2000) where the original native woodland and grassland cover has been extensively cleared (Wood *et al.*, 2001). These heavily modified native vegetation types are poorly represented in reserve systems (Hobbs and Yates, 2000) and the remaining areas, although limited (Gibbons and Boak, 2002) have considerable conservation value (Fischer and Lindenmayer, 2002). Hence, designing emerging plantations to incorporate remnant native vegetation and maintain (and even enhance) some conservation values is important (Lindenmayer *et al.*, 2001; Hobbs *et al.*, 2002a).

(2) The maintenance of some elements of the biota within plantations could have benefits for the maintenance of key ecosystem processes like pest control. There are a number of invertebrate taxa that exhibit pest outbreak behaviour in eucalypt plantations, but not in native forests, possibly because of the absence of natural predators (Steinbauer *et al.*, 2001). The presence of animals such as native insectivorous birds might reduce the risk of pest problems in plantations.

(3) Although it is clear that some species cannot be conserved in plantation-dominated landscapes, many species can be through the adoption of (sometimes minor) modifications to forest management (Lindenmayer, 2000).

(4) The maintenance (or loss) of biota in plantations is relevant for moves toward ecological standards and the certification of plantations in many parts of the world (Spellerberg and Sawyer, 1996). Notably, plantations are increasingly being considered under certification agreements (Food and Agriculture Organisation of the United Nations, 2001) such as those developed under the Forest Stewardship Council guidelines (Cauley *et al.*, 2001). For example, biodiversity provisions were included as the document “Principles for commercial plantation forest management in New Zealand” that was signed by many stakeholder groups in that country in 1995. Given the globalisation of markets for forest products it seems likely that steps toward the certification of plantations in some countries will increase pressure on other nations to do likewise.

(5) Plantation forestry can be thought of a continuum from what Kanowski (1997) has termed “simple plantation forestry to complex plantation forestry”. He considered simple plantation forestry to be a narrow and intensive management focus on producing a forest crop for a limited array of purposes. Kanowski (1997) argued that complex plantation forestry, whilst still being a relatively intensive management regime, attempted to include other land uses and values within plantation boundaries and aims to produce goods and services in addition to wood products. Kanowski (1997) further believed that complex plantation forestry was an important way forward in many situations because: **(a)** society will demand outputs in addition to wood and pulp from plantations, and, **(b)** simple plantation forestry is not congruent with the principles of ecological sustainability.

Chapter 2 - Background

The biota of conifer plantations

The history of analysis of fauna conservation in Australian plantations goes back several decades. From the late 1960's onward, considerable concerns were raised about the impacts of clearing native forests to establish extensive stands of radiata pine (e.g. Routley and Routley, 1975; Recher, 1982; reviewed by Ray *et al.*, 1983) and early research showed that resident adults of some species were virtually eliminated from cleared areas by such practices. For example, populations of arboreal marsupials such as the greater glider (*Petauroides volans*), the mahogany glider (*Petaurus gracilis*) and the mountain brushtail possum (*Trichosurus caninus*) maintained strong home affinity during clearing for plantation establishment and most animals tended to die *in-situ* (Tyndale-Biscoe and Smith, 1969; How, 1972; Van Dyck, 1993). In the case of the greater glider and the mountain brushtail possum, animals which survived were the ones with part of their home range intact. Friend (1979) found that although adult populations of small mammals were eliminated as a result of forest clearing, young dispersing individuals assisted populations to re-establish.

A large number of studies have contrasted the differences in the faunal assemblages of radiata pine plantations and stands of native forest (e.g. Pawsey, 1966; Davidson, 1976; Disney and Stokes, 1976; Gepp, 1976, 1979; Suckling *et al.*, 1976; Friend, 1978; 1980, 1982a; 1982b; Neumann, 1978, 1979a; Smith, 1982, 1987). The majority of studies have found that animal assemblages in plantations are less diverse than those of native forests (e.g. McIlroy, 1978, see Figure 1). For example, Lindenmayer *et al.* (2002a) found that the average bird species richness of radiata pine stands was 17 species in comparison with 23 in stands of unfragmented native eucalypt forest.

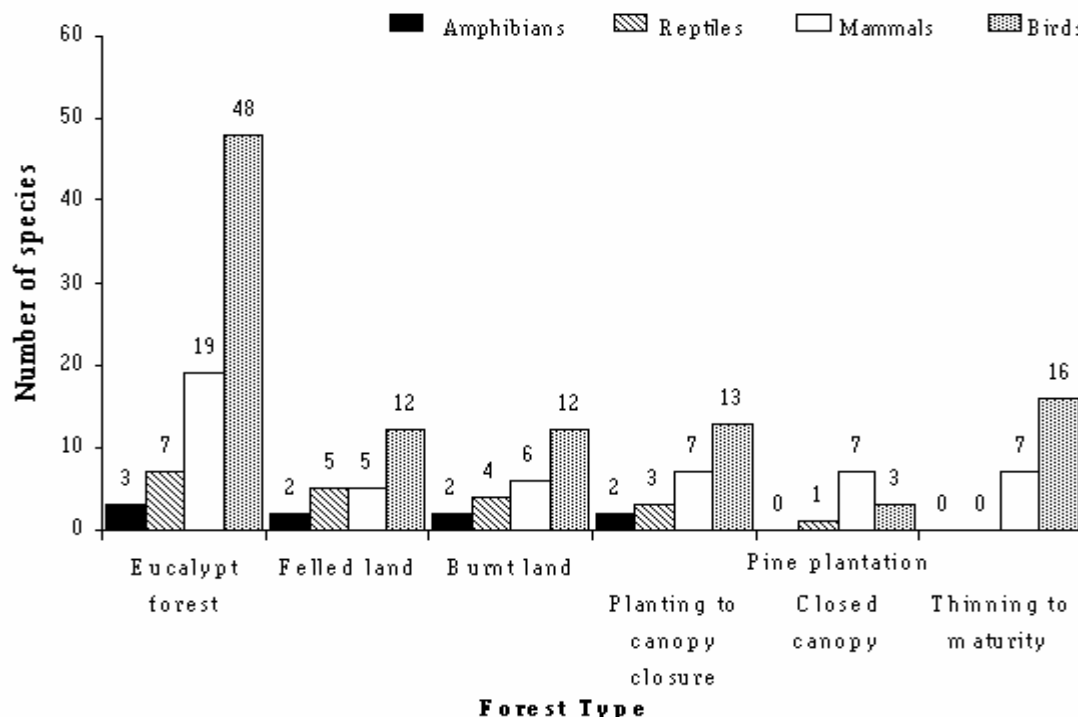


Figure 1. Vegetation type and conditions relationships with vertebrate species diversity Buccleuch State Forest at Tumut in southern New South Wales (based on data in McIlroy, 1978).

There have also been comparisons between the faunal assemblages of the native species hoop pine (*Araucaria cunninghamii*) and adjacent rainforest, with the results for birds showing (like many other studies of plantations) that diversity was higher within areas of indigenous vegetation (Fischer, 1974). Particular sorts of vertebrates such as hollow-using birds and arboreal marsupials as well as nectivorous, frugivorous, foliage-gleaning and canopy-feeding birds were found to be absent or greatly reduced in abundance from radiata pine plantations (e.g. Kikkawa, 1968; Cowley, 1971; Gepp, 1976; Driscoll, 1977; Friend, 1982a, 1982b; Smith 1982). This is most probably because these exotic conifer-dominated stands lacked these key nesting and foraging resources. Although many native species of birds do not occur in conifer plantations, a range of taxa can be relatively common there. For example, Lindenmayer *et al.* (2002a) recorded relatively high detection frequencies for species in radiata pine stands such as the golden whistler (*Pachycephala pectoralis*), rufous whistler (*Pachycephala rufiventris*), eastern whipbird (*Psophodes olivaceus*), yellow-faced honeyeater (*Lichenostomus chrysops*), grey fantail (*Rhipidura fuliginosa*) and scarlet robin (*Petroica multicolor*). The work by Lindenmayer *et al.* (2002a) showed that species with particular types of life history attributes were likely to be those found in stands of radiata pine. These included species belonging to sweeper and ground carnivore foraging guilds (*sensu* Mac Nally, 1994) and those which did not construct their nests high above the ground.

There have been large differences in the results of studies comparing small mammals of radiata pine stands and eucalypt forests. Warneke (1971) and Heislars (1974) and Suckling *et al.* (1976) found that the bush rat (*Rattus fuscipes*) and other native species such as the agile antechinus (*Antechinus agilis*) may survive in radiata pine stands. However, Lindenmayer *et al.* (1999b) found that populations of small mammals were absent from radiata pine stands except where extensive areas of windrowed eucalypt logs occurred. Notably, many of the areas examined by Lindenmayer *et al.* (1999b) differed from those of earlier workers in that they were second rotation stands where intensive mechanised harvesting and subsequent slash burning or slash dispersion practices had removed residual eucalypt logs. Friend (1982a) also noted that native species of small mammals were absent from second rotation radiata pine stands where windrows were absent.

In the case of invertebrates in radiata pine stands, Ahern and Yen (1977) found significant differences in invertebrate assemblages between radiata pine plantations and eucalypt forests. More species and more individuals of a range of groups were found in foliage, bark, soil and understorey habitats within eucalypt forests, although more mites occurred in litter habitats within stands of radiata pine. Neumann (1979) found greater beetle species diversity in native eucalypt forests than radiata pine plantations, although overall more taxa occurred in pines than eucalypts. Bonham *et al.* (2002) examined components of the invertebrate fauna of conifer plantations in Tasmania and compared it with that found in eucalypt plantations and native forest. They found that native land snails and millipedes were less diverse and less abundant in plantations than native forests. However, they nevertheless found a substantial native fauna in both conifer and eucalypt plantations including some rare species such as the velvet worm *Ooperipatellus cryptus*. Interestingly, Bonham *et al.* (2002) found that conifer plantations were more favourable habitats for invertebrates than eucalypt plantations. To the best of our knowledge, this is the only study in Australia that has compared the fauna of conifer and eucalypt plantations.

In summary, key outcomes of the work undertaken on the biota of conifer plantations is that some sorts of species are uncommon or absent from these areas (e.g. the majority of species of arboreal marsupials). Nevertheless, while the biota of conifer plantations is depauperate, these areas are not “biological deserts” because they provide foraging habitat, nesting habitat or both for a range of birds (Friend, 1982b; Smith, 1982; Lindenmayer *et al.*, 2002a), small mammals (Suckling and Heislars, 1978) and invertebrates (Neumann, 1978). It is notable that much of the focus on the species which do and don’t occur in conifer plantations has been on birds and mammals with some additional work done on invertebrates – in part because of potential pest problems (see below). In contrast there has been a dearth of detailed research on groups such as reptiles and frogs (but see McIlroy, 1978; Klomp *et al.*, 2001) as well as fish (Friend, 1980). The occurrence of much of the fauna in plantations is strongly related to the mosaic of types of patches of native forest and the treatment

history of planted areas (e.g. thinning regimes and stand ages). These key topics are explored in greater detail in subsequent sections of this paper.

The biota of eucalypt and other types of plantations

The history of work on fauna within eucalypt and other types of plantations has a shorter history and is much less extensive than the research in radiata pine plantations. The bias in studies toward radiata pine is not surprising given that it is the dominant tree species in the Australian plantation estate (Wood *et al.*, 2001). However, the size of the area established under eucalypt plantations in Australia has been steadily increasing in the past decade. For example, it increased from 19 000 in 1995 to 84 000 in 2000 (Wood and Allison, 2000). Indeed, in the period 1995-2000, the average annual increase in the area established under eucalypt plantations was 60 000 ha or more than twice that for softwoods (~ 26 000 ha) (Wood *et al.*, 2001). Given such rapid changes, much of the limited work on fauna conservation in eucalypt plantations has been recent (e.g. Abbott *et al.*, 1998; Klomp and Grabham, 2002; Borsboom *et al.*, 2002; Hobbs *et al.*, 2002a, 2002b; Klomp and Grabham, 2002). For example, a recent set of studies has examined young blue gum plantations established on grazing properties in north-eastern Victoria – in particular the value of large retained eucalypt trees for bird fauna was examined (Grabham *et al.*, 2002). Studies of the wildlife values of blue gum plantations in Western Australia provide results similar to those discussed for conifer plantations – i.e., vertebrate and invertebrate assemblages are less diverse than those of native vegetation, in large part due to the relative structural simplicity of the plantations (Hobbs *et al.*, 2002a, 2002b). Nevertheless, as for pine plantations, blue gum plantations are not “biological deserts”, but provide habitat or resources for a range of species, including a selection of bird species considered to be at conservation risk. For this group of species, together with bats, species abundances were greater in plantations adjoining extensive areas of remnant vegetation than in isolated plantations.

Work on eucalypt plantations to date (2003) has shown that, like conifer plantations, some elements of the biota are largely missing from these areas. For example, hollow-using arboreal marsupials are virtually absent from all type of plantations. This is not surprising given that hollows in eucalypts that are suitable for use by arboreal marsupials take can take several hundred years to develop (Gibbons and Lindenmayer, 2002) – far longer than the rotation times of plantations. Birds that use tree hollows are sometimes found in plantations, but they are not nesting there. It is notable that when artificial hollows are added to plantations, they are used by some cavity-dependent fauna including arboreal marsupials and bats (Smith and Agnew, 2002).

Plantations versus cleared (agricultural) land

Work by Klomp and Grabham (2002) showed that the diversity of birds was higher in planted eucalypt forests than in the areas of exotic pastures where stands of trees had been established, although species assemblages were still depauperate in comparison with native woodlands. Kavanagh *et al.* (2001) and Borsboom *et al.* (2002) also found that eucalypt plantations supported more species of birds, mammals, amphibians and reptiles than existed on grazing lands. Bonham *et al.* (2002) suggested that plantations established on previously cleared agricultural land may promote the conservation of a range of forest-dependent invertebrates in Tasmania, although data were lacking to support this conclusion.

Higher species diversity is not always the best outcome for wildlife conservation as a better measure will often be the composition of particular faunal assemblages (Burgman and Lindenmayer, 1998). Notably, extensive large-scale experimental work in newly established radiata pine plantations on former grazing lands (see Lindenmayer *et al.*, 2001) has indicated that the bird and mammal fauna is different but not necessarily “better” than what previously occurred. The results to date have indicated there have been replacements of open-country bird species by taxa more typical of forest landscapes (Lindenmayer *et al.*, unpublished data). Notably, some of the species which have colonised the radiata pine plantings are the rufous whistler (*Pachycephala rufiventris*) and the eastern

yellow robin (*Eopsaltria australis*) which have been thought to be declining in native eucalypt woodland environments. It is possible that radiata pine stands act as suitable structural mimics of native eucalypt habitats for these species, although this hypothesis requires further testing. Similarly, Hobbs *et al.* (2002a, 2000b) found that bird species considered to be “at risk” such as the western yellow robin (*Eopsaltria griseogularis*), inland thornbill (*Acanthiza apicalis*) and western gerygone (*Gerygone fusca*) occurred in blue gum plantations in southwestern Australia.

While plantations may not provide suitable habitat for particular species, they may alter landscape permeability and connectivity (Taylor *et al.* 1993; Wiens 1997) and allow species to move across the landscape more readily. The importance of understanding how the nature of the landscape matrix (*sensu* Forman, 1995) in determining species movement and persistence has been highlighted recently by Davies *et al.* (2001). Finally, plantations established on cleared pastures (such as those in tropical areas) may be useful intermediary restoration vehicles that assist the regeneration of native plant taxa (and associated fauna) that cannot become established in other ways (e.g. through competition with grasses) (Keenan *et al.*, 1999).

Chapter 3 - Conserving wildlife in plantation forests – landscape-level issues

The conservation of forest fauna – both within plantations and in native forests – is a multi-scaled problem (Lindenmayer and Franklin, 2002). This section focuses on landscape-scale issues and the one that follows it examines approaches at the stand level.

Where plantations are located and the land cover they replace

In most parts of Australia, extensive areas of plantation forest were formerly established by clearing native forest. This has major immediate and long-term negative impacts on the biota that formerly occurred in an area (e.g. Tyndale-Biscoe and Smith, 1969; Van Dyck, 1993). In many areas, the rate of native vegetation clearing has declined, although it may increase again (e.g., in Victoria and Western Australia) as a consequence of proposals to establish plantations, not only exotic softwoods (Commonwealth of Australia and Department of Natural Resources and Environment 1997), but also eucalypt plantations (Hobbs *et al.*, 2002a, 2002b). In Tasmania, the Regional Forest Agreement for the state allowed for up to 85 000 ha of native eucalypt forest (and 20% of a given biogeographic province) to be cleared for exotic plantations of radiata pine and fast-growing eucalypts from mainland Australia. These will be managed on a 15–30 year rotation (Forestry Tasmania, 1999). In the case of parts of southern New South Wales and Victoria, plantation expansion will take place on semi-cleared grazing lands which support patches of remnant native forest and woodland. Careful consideration of native vegetation clearing for plantation establishment is important in these locations because even though many remnant patches are small (often less than 3 ha; see Gibbons and Boak, 2002), they are often representatives of vegetation communities that have experienced extensive past clearing such as white box (*Eucalyptus albens*) (Prober and Thiele, 1995) and yellow box (*E. melliodora*) (Er and Tidemann, 1996).

Landscape mosaics within plantations – juxtapositions of different patch types, sizes and shapes

A range of studies have highlighted the value for conservation of maintaining patches of remnant native forest or woodland within the boundaries of plantation forest (Fisher, 1974; Friend, 1980; Suckling, 1982; Recher *et al.*, 1987a; Lindenmayer *et al.*, 1999a, 1999b, 2002a, 2002b). Such patches have been shown to provide valuable habitat for many species of vertebrates (Kavanagh and Goldingay, 1991; Fisher and Goldney, 1998, Carthew *et al.*, 1999; Lindenmayer, 2000). Other studies within radiata pine plantations have shown the value of remnant eucalypt patches for invertebrates (Margules *et al.*, 1994; Davies *et al.*, 2000, 2001).

In general, larger patches of retained native vegetation within plantations support more species of vertebrates. For example, larger patches of native eucalypt forest and woodland within radiata pine forest at Tumut in south-eastern Australia supported more birds (Lindenmayer *et al.*, 2002a), arboreal marsupials (Lindenmayer *et al.*, 1999a) and small mammals (Lindenmayer *et al.*, 1999b). There can be complex inter-relationships between the attributes of patches (e.g. patch size) and both their use by biota and their use of surrounding plantation. Tubelius *et al.* (in review) have shown that several species of native birds move further into surrounding radiata pine stands from smaller patches than larger ones. Lindenmayer *et al.* (2002a) showed that the bird fauna of small (> 1-5 ha) eucalypt patches was similar to that of the neighbouring radiata pine stands. Larger patches (e.g. those 10-20 ha and larger) supported bird assemblages not unlike continuous areas of eucalypt forest. They found that the bird community re-assembled in response to the gradient of increasing patch size (Lindenmayer *et al.*, 2002a). In the case of arboreal marsupials and terrestrial mammals in the same system, remnant patch attributes in addition to size such as tree species composition and the steepness of the terrain significantly influenced species occurrence (Lindenmayer *et al.*, 1999a,

1999b). Other workers (e.g. Recher *et al.*, 1987a) have observed similar effects on the presence and abundance of native mammals and birds in retained habitats within radiata pine plantations.

Although some studies have shown that larger patches of remnant forest and woodland support more species of vertebrates, retained patches do not always have to be large to be useful. Work in radiata pine plantations at Tumut indicated that remnant patches of eucalypt forest as small as 1 ha had value as habitat for forest birds, reptiles, frogs, and mammals. High levels of invertebrate biodiversity were recorded in retained patches as small as 0.5 ha in the Wog Wog Experiment within radiata pine plantations established in south-eastern N.S.W. (Davies and Margules, 1998; Davies *et al.*, 2000). Work in north-eastern Victoria has shown that even single isolated former paddock trees retained within young eucalypt plantations can have significant value for native birds (Grabham *et al.*, 2002).

The spatial pattern of remnant vegetation has been shown to influence wildlife distribution patterns within plantations. Lindenmayer *et al.* (2002b) found that several species of birds and mammals responded not only to the total area of eucalypt cover, but also to how that cover is spatially arranged. Some taxa were more likely to be recorded where eucalypt cover was consolidated (e.g. red wattlebird [*Anthochaera carunculata*]), whereas the opposite effect was identified for other species (i.e. eucalypt cover was dispersed - e.g. crimson rosella [*Playtcerus elegans*]). Similarly, the common ringtail possum was more likely to occur in a patchy (rather than consolidated) distribution of eucalypt remnants. This effect may be due to positive responses to edge conditions. The eucalypt-pine boundary may provide additional resources for some species. For example, the common ringtail possum can use eucalypt forests and neighbouring stands for both food and shelter (Friend, 1980).

In addition to remnant size and the spatial pattern of remnant cover, another key attribute for wildlife with plantations is patch shape. A study of eucalypt remnants within radiata pine plantations in south-eastern Australia by Recher *et al.* (1987a) showed that some species of birds were unable to persist in linear-shaped eucalypt remnants. This was because the long and narrow shape of some remnants made it difficult to gather food resources or maintain key social interactions in an energetically-efficient way; as forecast by Central Foraging Place Theory (see Recher *et al.*, 1987a). Animals that required widely dispersed food and/or which had complex social systems were disadvantaged in linear-shaped eucalypt remnants (Recher *et al.*, 1987a) and some taxa only occurred in the widest strips (e.g. yellow-bellied glider [*Petaurus australis*] and several species of large-bodied birds). Lindenmayer *et al.* (2002a) also found significant differences in the bird assemblages of narrow eucalypt remnants and more elliptical-shaped eucalypt remnants embedded within the radiata pine plantation at Tumut. However, they attributed such differences to covarying factors such as the presence of riparian areas and access to water rather than remnant shape *per se*.

The location of remnant patches within plantations can have a significant impact on their value for wildlife conservation. For example, native riparian vegetation can provide habitat for many species within plantation landscapes (Suckling *et al.*, 1976; Suckling and Heislars, 1978; Recher *et al.*, 1987a; Lindenmayer *et al.*, 2002a). Riparian areas are often species-rich environments (e.g. Recher *et al.* 1980; Loyn *et al.* 1980; Naiman *et al.* 1993), and some taxa are more fecund in such places (Soderquist and Mac Nally, 2000). Riparian vegetation also can act as dispersal corridors for terrestrial fauna within plantations, thereby contributing significantly to connectivity (Lindenmayer and Peakall, 2000). The retention of areas of riparian vegetation can be valuable, in part, because timber and pulpwood harvesting may be restricted there because of water quality considerations (see section below on landscape restoration). Other aquatic features within plantations such as dams also can have positive impacts on wildlife (Kloeden, 1973).

The total area of remnant native vegetation within a plantation is an attribute likely to have a significant influence on the occurrence of many elements of the biota in plantation landscapes. Such relationships have been documented in studies of plantations in North America and Europe (Staines, 1983; Parker *et al.*, 1994). In Australia equivalent work on relationships between the total area of native vegetation cover and bird species richness has been examined in semi-cleared grazing systems (Bennett and Ford, 1997) but not in plantations. Such types of relationships have some resonance

with work on threshold theory whereby species loss from landscapes is correlated with habitat loss until native cover drops below a given threshold value and factors in addition to habitat loss (like negative edge effects and metapopulation extinction) accelerate levels of species loss (Rolstad and Wegge, 1987; Andren, 1994). Studies of native vegetation cover and threshold effects on species assemblages pose enormous challenges for researchers because rigorous experimental testing requires access to many plantation landscapes that encompass different amounts of native vegetation ranging from almost none to virtually complete. Replication would be impossible even if these types of areas existed – which they currently do not. Despite the problems in the empirical testing of native vegetation cover levels, it does seem as though this attribute of landscape cover is an important one for consideration for wildlife conservation in plantations (Hartley, 2002).

In summary, conserving patches of native forest and woodland within the boundaries of plantations will produce a landscape mosaic rather than a plantation monoculture. Such landscape heterogeneity can promote wildlife conservation within plantations. Other features in addition to remnant vegetation can add to landscape heterogeneity and enhance wildlife conservation including dams, and open areas such as clearings and firebreaks (Bevege, 1974; Fisher, 1974; Davidson, 1976; Friend, 1980; Curry, 1991). The retention of patches of remnant native vegetation, including riparian areas as well as other types of features, is fundamental to plantation design criteria in the semi-cleared grazing lands of south-eastern Australia that are increasingly targeted for conversion to widespread radiata pine plantations (Lindenmayer *et al.*, 2001). They are similarly important in the rapidly expanding blue gum plantation estate such in south-western Australia (Hobbs *et al.*, 2002a, 2002b). While the woodland remnants in these areas are often small they are the remains of heavily cleared vegetation types and detailed studies have shown that many species of vertebrates will often occur in them (Fischer and Lindenmayer, 2002). An important caveat with the retention of native vegetation within plantations is that in many cases they will not represent the full range of environments that naturally occurred in a landscape. For example, they might be confined the steep terrain or gully areas and some elements of the biota may be absent as a result. As outlined above, retained areas also may be too small or an inappropriate shape to support some species (see Recher *et al.*, 1987a).

Adjacency effects

A number of studies have shown that the highest diversity and abundance of native animals in plantations occur in stands adjacent to native vegetation. This has been observed for small mammals and birds in radiata pine plantations (Fielding, 1976; Barnett *et al.*, 1977a; Friend, 1982a, 1982b; Lindenmayer *et al.*, 2002a) and birds in hoop pine plantations (Fisher, 1974). How (1972) showed that the common and mountain brushtail possums used the margins of radiata pine stands but were absent from plantations remote from native forest. Small native mammals such as the brown antechinus (*Antechinus stuartii*) and the bush rat (*Rattus fuscipes*) were largely absent from areas deep within radiata pine plantations in northern New South Wales where they were replaced by exotic species such as the black rat (*Rattus rattus*) and the house mouse (*Mus musculus*) (Barnett *et al.*, 1976). Gepp (1976) identified complex adjacency effects for birds in South Australian radiata pine forests. More species of birds occurred at the edges of unthinned pine stands than in the interior. However, such a response did not occur in either young or old plantations (Gepp, 1976). Lindenmayer *et al.* (2002a) found that bird assemblages in radiata pine stands distant from native vegetation were markedly different from stands adjacent to patches of remnant eucalypt forest. Similarly, Smith (1982) and Curry (1991) reported that bird species diversity and abundance declined significantly with increasing distance from the plantation boundary with native forests. In the later study, a sharp decline was observed within the first 200 metres of the plantation edge. Friend (1982b) showed that the edges of plantations were more diverse habitats than interior areas and hypothesized that this was the reason why more species of birds occurred there.

The adjacency effects recorded in radiata pine plantations have also been observed in eucalypt plantations. Grabham *et al.* (2002) found that bird species richness in eucalypt plantations declined from an average of 26 species in areas in the immediate area around large old retained trees to only

11 species in plantations 60-90 m away from such trees. Hobbs *et al.* (2002a, 2002b) found that bird species considered “at risk” were most abundant in native vegetation but that within plantations, abundances were highest at the plantation edge adjacent to remnant vegetation. They also found that bats were most frequently recorded in native vegetation but were also more abundant in plantations adjacent to remnant vegetation than in isolated plantations.

The adjacency of native forest also may assist in the biocontrol of pest invertebrate populations in eucalypt plantations (Strauss, 2001). Hobbs *et al.* (2002a) found little evidence of a consistent effect of adjacency to native vegetation on the invertebrate fauna of plantations, and little data to support the idea of an increase in natural enemies in the plantations. However, work in blue gum plantations in Brazil demonstrated strong relationships between the distance of plantation forest from native forest, the reduced abundance of lepidopteran pests and the increased abundance of natural predators (Zanuncio *et al.*, 1995; Bragança *et al.*, 1998). In addition to the potential pest control role of animals moving into plantations from adjacent areas, such types of animal movements also may promote plant biodiversity values within plantations. For example, Keenan *et al.* (1997) examined a range of types of plantations in North Queensland and found high levels of native plant regeneration underneath stands of planted overstorey trees. Many of these plants were bird-dispersed highlighting the importance of bird movements into plantations from elsewhere in the landscape.

In summary, many studies have shown that the adjacency of native vegetation has a significant effect on the biota which occur in neighbouring plantations. This has implications not only for the conservation of biodiversity (including the occurrence of native understorey plants), but also for the occurrence of pests and their control, and the extent of browsing damage. The extent of adjacency effects is closely allied with plantation geometry as the size and shape of planted areas and how they juxtapose native vegetation will influence the length of boundaries and the size of interior parts of plantations distant from such boundaries.

Adjacency and browsing by “pest” animals

There can be some negative impacts of the adjacency of conifer plantations to native forests. Barnett *et al.* (1977b) showed that the extent of browsing damage by possums was greatest between 25 and 250 metres from boundary with native forest, particularly wetter forest types where the mountain brushtail possum was abundant. The adjacency effects relating to increased browsing in conifer plantations (Barnett *et al.*, 1977b) are also seen in eucalypt plantations, such as those in Tasmania (MacArthur, 2000) where a range of native herbivores such as the common brushtail possum and the pademelon (*Thylogale billardierii*) cause considerable damage. Issues relating to pest animals in plantations are explored further in a subsequent section of this paper.

The scheduling of harvesting

There can be positive benefits for fauna conservation arising from changes in the spatial and temporal pattern of harvesting in plantation forests. Given that a number of authors have observed differences in the biotas of plantations of different ages (see below), maintaining landscapes with a mosaic of stand age classes may increase the wildlife conservation value of plantations (Gepp, 1976). In south-eastern Australia, in the pine-eucalypt remnant system at Tumut in southern New South Wales, Lindenmayer and Pope (2000) believed that functional connectivity (*sensu* Bennett, 2000) between populations of the greater glider residing in eucalypt patches could be maintained by staggering the spatial configuration of clearcut radiata pine stands adjacent to remnants. Radio-tracking of the animals revealed they use the radiata pine forest to move between eucalypt habitat patches (2003). Therefore, at any one time, some areas of advanced regrowth radiata pine in the matrix should link eucalypt remnants to maintain connectivity. Smith (2000) predicted that the rare Tasmanian carnivorous snail *Tasmaphena lamproides* would be sensitive to aggregated patterns of harvesting. The implication of this work is that forest managers should avoid creating large continuous areas of cutover forest. Rather, they should schedule the spatial location of compartments

to create a scattered pattern of smaller coupes interspersed among stands of older forest from where snails can disperse.

Another aspect of harvest scheduling is the rotation time. Longer rotation times can allow stands to better develop particular structural attributes that can be useful for some species. This issue is addressed in further detail in the section below on stand age.

Chapter 4 - Conserving fauna in plantation forests – stand-level issues

Stand level practices can contribute, sometimes significantly, to fauna conservation in plantations. These are the primary topics of the following section.

Species composition and mixtures

The diversity of animal species can be positively related to the diversity and abundance of plant taxa. Recher *et al.* (1987b) found that some native species of birds persisted within stands of radiata pine because the presence of scattered regrowth eucalypts created a mixed tree species composition. Understorey vegetation within stands of radiata pine also can make an important contribution to the conservation of some species of vertebrates (e.g. birds; Davidson, 1976; Gepp, 1976), including some that are considered to be at risk. For example, surveys of birds in stands of radiata pine at Tumut in southern N.S.W. 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.* unpublished data). Curry (1991) found that the presence of understorey plants enabled birds to penetrate further into plantations than where such vegetation was absent. Hobbs *et al.* (2002a, 2002b) found that blue gum plantations in southwestern Australia had a homogenous closed tree cover and an almost complete absence of shrub and ground layers, which resulted in a low habitat suitability for most ground-dwelling of -feeding vertebrate taxa.

Stand age

The age of plantations can have a significant impact on many elements of biodiversity. Borsboom *et al.* (2002) recorded increasing vertebrate species richness with increased stand age in eucalypt (*Eucalyptus cloeziana*) plantations in south-eastern Queensland. Investigations of birds have found that species diversity increases with stand age within radiata pine plantations (e.g. Gepp, 1976; Friend, 1982b; Smith, 1982; Figure 2) and hoop pine plantations (Fisher, 1974). These results have been attributed to older stands developing more structurally diverse conditions which, in turn, promote species richness. Gepp (1979) found that as stands of radiata pine aged, birds that forage on tree trunks and on open ground became more common. Pawsey (1966) also observed increasing bird species richness with radiata pine stand age and concluded that this may be associated with greater insect species diversity in structurally more complex older plantation forests.

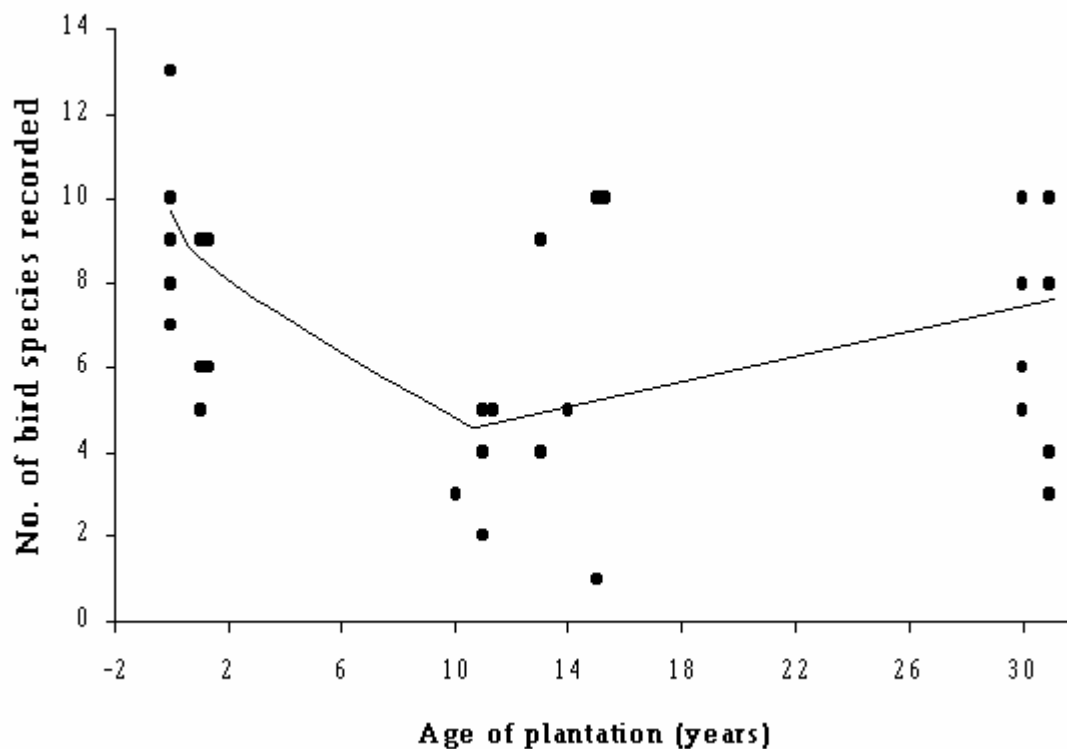


Figure 2. Age class and birds species diversity in plantation pine stands at Clouds Creek in northern New South Wales (redrawn from Smith, 1982).

Populations of some species within plantations can vary with stand age in complex ways. For example, bird species richness may increase soon after the establishment of stands (within an influx of open-country taxa), then decline with canopy closure of trees but then increase again with stand maturation and when grass cover has developed as a consequence of thinning operations (Smith, 1982; 1987). In the case of the common wombat (*Vombatus ursinus*) in radiata pine forests, the numbers of animals are low when plantations are first established, probably because practices like deep-ripping for site preparation eliminate burrows (Rishworth *et al.*, 1995). Populations then increase for 5-6 years until tree canopy closure reduces grass cover – a key food resource for the common wombat. The species remains scarce until stands are thinned at about 12-15 years and grass cover can re-establish on the forest floor (Rishworth *et al.*, 1995). Neumann (1978, 1979a) found that populations of most groups of invertebrates in north-east Victorian radiata pine plantations varied in response to stand age in a similar way to that described above for birds. For example, species diversity in beetles was greatest in young and old stands and lowest in stands of intermediate age (Neumann, 1979a).

Biological legacies at the stand level

Biodiversity conservation in plantation forests can be promoted through the retention of elements of the original stand (termed “biological legacies” – *sensu* Franklin *et al.*, 2000) at the time of harvesting. For example, trees retained at the time of regeneration harvesting have been found to be used by many species of birds (Kavanagh and Turner, 1994). Grabham *et al.* (2002) highlighted the value for birds of retaining large trees within young eucalypt plantations in north-eastern Victoria. Bird species richness was markedly higher in plantations near large retained trees than in planted areas more distant from they key structures. Tree stumps with bark and deep furrows in the ground next to ploughed mounds produced moist microhabitats favourable for a range of invertebrate taxa in

Tasmanian conifer and eucalypt plantations (Bonham *et al.*, 2002). Bonham *et al.* (2002) also emphasized the importance of leaving logging slash after thinning and/or pruning to rot on the forest floor to provide habitat for invertebrates in Tasmanian plantation forests, including several species that would otherwise be sensitive to timber harvesting operations. Fallen debris left after thinning and pruning was believed to underlie an increase in bird species diversity in eucalypt plantations in north-eastern Victoria (Klomp and Grabham, 2002). Similarly, the retention of slash on the floor of radiata pine plantations has been recommended to improve habitats for invertebrates, and in turn, for native birds (Davidson, 1974).

Several studies have highlighted the importance for native fauna of windrows of cleared eucalypts left within softwood plantations (e.g., Friend 1982a). For example, they have been found to assist the movement of birds through loblolly pine (*Pinus taeda*) plantations in northern New South Wales (Curry 1991). Lindenmayer *et al.* (1999b) found that areas of radiata pine forest with windrows were the only places that supported populations of native small mammals at Tumut in southern New South Wales. Smith (1982) noted that areas immediately adjacent to windrows within conifer plantations were important for native plants and speculated that this because birds used the log piles for perching and deposited many seeds there. Additional nutrients in these areas released from burned logs was also thought to have influenced plant growth in these areas (Smith, 1982). Bonham *et al.* (2002) considered that the presence of windrows was one of the factors contributing to the diversity of native invertebrates recorded in Tasmanian conifer and eucalypt plantations. Friend (1982a) found the burrows of the common wombat in radiata pine plantations were closely associated with windrows. Given the importance of windrows, it is important that their loss is not accelerated by damage from machinery during harvesting operations (Lindenmayer and Pope, 1999). Conversely, le Mar (2000) recommended that windrows be destroyed because they provide shelter for populations of the pademelon in Tasmanian eucalypt plantations which then cause significant damage to planted trees.

Tree spacing and thinning

Several studies of vertebrate fauna in radiata pine plantations have indicated that the stage of development in the silvicultural cycle (e.g. unthinned vs first and second thinning) may affect the density of animals (Suckling and Heislars 1978, Friend 1980). Rishworth *et al.* (1995) highlighted the importance of thinning and canopy opening for grass growth and hence in providing a food resource for the common wombat in radiata pine plantations. They suggested that thinning plantations early in the growth cycle may not only create additional habitat for the species but also enhance tree growth. Gepp (1976) found more species of birds in older thinned stands than younger unthinned ones. However, there is some confounding between age and thinning making it difficult to determine whether the response of birds is due to more structural complexity associated with older trees or altered light, foraging and other conditions linked with thinning. Residues left after thinning can provide habitat for some taxa and their potential value was discussed in a previous section.

Chapter 5 - Other issues for plantation management

Trade-offs between intensifying production and increased reservation

In some cases, the best outcome for fauna conservation may be intensive (simple) plantation forestry in some areas traded off against enhanced forest management or the establishment of reserves in other areas. There are no examples of this in an Australian context. However, Hunter (1994) and Seymour and Hunter (1999) use forests in the state of Maine (north-eastern USA) to discuss this issue. Timber yields from plantations in Maine are three times greater than from multiple-use forests, and therefore wood production can be maintained while setting aside three hectares in dedicated reserves for each hectare allocated to intensive plantation forestry (Seymour and Hunter, 1999). In Maine, 2% of the forest is currently in dedicated reserves, 90% in multiple-use forest management, and 6% in intensively managed plantations. A 2.5% increase in plantations could theoretically allow a 10% increase in dedicated reserves with no loss in wood production (Hunter, 1994). While this approach might be appropriate for Maine, it cannot be applied uncritically in all forest landscapes. For example areas committed to plantations should be carefully selected to avoid foreclosing future options for conservation management and impacting key elements of the biota. The flat and highly productive areas most suitable for plantations are also often richest in biodiversity and sites of key ecological processes (e.g. Braithwaite, 1984; Spellerberg and Sawyer, 1997).

Landscape restoration

There is scope within some plantation estates to promote fauna conservation through the restoration of targeted areas. Riparian zones, in particular, may be valuable places for such work. Harvesting is often restricted in riparian areas because of water quality and aquatic habitat considerations. Therefore, they are useful places to exempt from tree planting in new plantations and allow the regeneration of native vegetation or to actively restore native vegetation cover following the final clearfelling operation that completes a given logging rotation within an already established plantation. 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 animal movement and/or dispersal is thought to be guided by particular topographic features such as streamlines (see Taylor *et al.*, 1985). 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 wildlife (Recher *et al.* 1987a).

“Pest” animals in plantations

Some elements of the biota in plantations may have undesirable effects. For example, both Australian conifer and eucalypt plantations are vulnerable to damage caused by native and introduced animals and there is an extensive literature on this topic (e.g. Loch and Floyd, 2001; Strauss, 2001). Radiata pine plantations in Australia support more than 40 species of pest invertebrates and most of these are introduced (Neumann, 1979b). Strauss (2001) noted that more than 85 species of invertebrates are pests of eucalypt plantations in Australia and the majority of them are native and have been found on the same tree species or closely-related tree species within stands of native vegetation. She argued that the extent of the pest invertebrate problem in eucalypt plantations was likely to increase in the future as the size of the plantation estate increases and exchanges of animals between regions takes place – highlighting a need for strict quarantine protocols within Australia. Moreover, as it appears to take some time for pest invertebrates to switch hosts, the potential problems in the eucalypt plantation estate further increase in the future. Loch and Floyd (2001) have documented such trends

in the rapidly expanding blue gum plantations of south-western Western Australia. Strauss (2001) also recognised the potential for increased numbers of some invertebrates within plantations to move into adjacent native eucalypt forests and compromise the integrity of such areas. Indeed, Loch and Floyd (2001) and Hobbs *et al.* (2002) found significant numbers of newly introduced pest invertebrates not only in blue gum plantations in Western Australia, but also in adjacent remnant native vegetation.

Large numbers of introduced animals can occur in plantations, including rodents such as the house mouse, black rat and rabbit (Barnett *et al.*, 1976; Borsboom *et al.*, 2002; Hobbs *et al.* 2002). The red fox (*Vulpes vulpes*) and feral cat (*Felis catus*) have also been recorded, sometimes in relatively large numbers, in plantations (Friend, 1982a; Lindenmayer *et al.*, 1999b; Hobbs *et al.* 2002). These animals can be significant predators of native animals. In the case of birds, introduced species such as the goldfinch (*Carduelis carduelis*) and European blackbird (*Turdus merula*) can be common in radiata pine plantations (Friend, 1982b; Lindenmayer *et al.*, 2002a), although the impacts of these species on native animals does not appear to be pronounced. In contrast, Bonham *et al.* (2002) noted that the substantial populations of introduced land snails that inhabit conifer and eucalypt plantations in Tasmania may compete with native taxa.

Some species of introduced and native animals can become pests in plantations and cause significant browsing damage to trees (Bulinski, 1999; Bulinski and MacArthur, 1999). The pale field rat (*Rattus tunneyi*) can cause significant damage in young hoop pine plantations in Queensland (Kehl, 1980) and the bush rat is known to damage radiata pine plantations in Victoria (Warneke, 1964; 1971). The mountain brushtail possum is known to cause considerable browsing damage in some radiata pine plantations in New South Wales (Barnett *et al.*, 1977b; Winter and Dickman, 2001) and Victoria (MacNally, 1955). Barnett *et al.* (1977b) found that almost 15% of the loblolly pine plantation they studied in northern N.S.W. had suffered browsing damage by the mountain brushtail possum. They also noted that the common ringtail possum (*Pseudocheirus peregrinus*) was responsible for damaging conifer plantations in northern New South Wales. The species is not only eats pine needles but also uses them to make their nests (termed dreys) (Friend 1980). Saunders (1974) noted that large populations of the white-tailed black cockatoo (*Calyptorhynchus baudinii*) exceeding 5000 birds can occur in Western Australian maritime pine (*Pinus pinaster*) plantations and consume large quantities of seeds from pine cones. However, he concluded that the birds inflicted little structural damage to trees. Montague (1996) reported relatively significant browsing damage in radiata pine and eucalypt plantations in southern Victoria, even when extensive poisoning baiting programs were undertaken. Most of the damage was attributed to the swamp wallaby (*Wallabia bicolor*), although damage from other animals such as the introduced goat (*Capra hircus*) and European rabbit (*Oryctolagus cuniculus*) was believed to have occurred (Montague, 1996). Trees in eucalypt plantations were almost twice as likely to suffer browsing than those in radiata pine stands. Montague (1996) estimated that the costs of browsing could exceed \$A650 per ha (in 1996 dollar values) and he recommended that control measures should be focussed in areas where damage is likely to be greatest.

Some of the most extensive studies of browsing damage to plantations have taken place in Tasmania where considerable problems are created by native herbivores, particularly in eucalypt plantations. For example, the common brushtail possum (*Trichosurus vulpecula*) is known to create significant browsing damage to plantations in that State, including specially developed frost tolerant hybrid eucalypts (Scott *et al.*, 2002). As in the case of conifer plantations, the most significant browsing damage occurs at the periphery of plantations from animals inhabiting neighbouring native forest (Bulinski, 1999; McArthur, 2000). Some of the recommendation for mitigating such impacts are to reduce the amount of native vegetation (which provides habitat for native herbivores) both within and adjacent to plantations (McArthur, 2000). Notably, this is the opposite of any of the recommendations to promote wildlife within plantations that have been made in this paper and by other authors (e.g. Friend, 1980).

Chapter 6 - Tensions between wildlife conservation and typical plantation management objectives and practices

The document “Plantations 2020 Plantations for Australia, the 2020 Vision” states that the plantation sector will: “*be internationally competitive; and.... commercially orientated, market driven and market focused in all their operations*” (Department of Primary Industries and Energy, 1997, p. 2). Notably, wildlife conservation is not mentioned as one of the non-market benefits of plantations to the Australian economy. However, in contrast to that view, a key point of this paper is that while some species cannot be readily conserved within plantations, many species can be – sometimes with relatively minor modifications to forestry practices and management regimes (but see below). Therefore, tensions exist between management practices to maintain or increase wood and pulp production in plantations and practices to promote wildlife conservation in these areas (Keenan *et al.*, 1997; 1999). Some of these tensions are outlined below.

(1) It is generally recognised that more elements of the biota will occur where there are more plant taxa and this is supported by evidence gathered in Australian studies of plantations. However, the emphasis of the majority of commercial plantations has been to focus on the growth of a single tree species – including ones that have been subject to considerable genetic modification. There is often a substantial reduction in native understorey and ground cover elements in plantations. This may explain the use by wildlife of understorey-forming weeds like blackberry (*Rubus fruticosus*) and lantana (*Lantana camara*) that have replaced native understorey plants in many plantations (Suckling and Heislers, 1978; Lindenmayer and Viggers, 1994; Lindenmayer and McCarthy, 2001).

(2) It is well established that there are strong relationships between the structural complexity of forests and species diversity (reviewed by Lindenmayer and Franklin, 2002). However, the majority of silvicultural practices in plantations result in stand simplification. For example, structural complexity (and its associated biodiversity) can be reduced through the removal of windrows to control pest herbivores (le Mar, 2000), the application of weedicides and herbicides to eliminate unwanted or competing plants, and even the application of fertilizer to promote tree growth (with negative impacts on ectomycorrhizal fungi [Pampolina *et al.*, 2002]).

(3) Virtually all studies to date have highlighted the conservation value of remnant native vegetation within plantations, even patches that are relatively small (including single large old trees). In addition, many species can use plantations if native vegetation is nearby. However, retaining native vegetation means that some land is forgone on which to establish plantations – although sometimes these areas are unsuitable for planting (e.g. steep and rocky terrain). In addition, retained vegetation can retard the growth of neighbouring plantation trees. As an example, Bi *et al.* (2002) estimated that the retention of paddock trees within plantations could result in reductions in stand volume growth of as much as 27% per ha. They suggested an offset solution to this problem whereby paddock trees would be removed and new trees would be planted in non-productive parts of plantations such as gullies. However, the considerable ecological values of paddock trees (see Anon., 2001) are not immediately interchangeable with newly planted stems – a seedling may take 150 years to develop the hollows and flowering intensity or prevalence of mistletoe clumps that make paddock trees such valuable wildlife habitat.

(4) Retained areas of native vegetation can create problems for plantation managers through harbouring browsing vertebrates which can inflict serious damage on plantations, particularly at their periphery. Plantations can be a major source of weeds that can erode the habitat quality of neighbouring areas of native vegetation. In the case of eucalypt plantations, planted trees also can be a source of pollen to create new hybrids within adjacent vegetation and, in turn, alter patterns of genetic variability (Potts *et al.*, 2001).

These types of tensions can make it difficult to reconcile many aspects of plantation management and wildlife conservation. The extent to which forestry practices can be modified to accommodate fauna conservation will depend on the amount of flexibility in the objectives of plantation management, the implementation of codes of practice for plantation establishment and management (e.g. Plantations and Reafforestation (Code) Regulation 2001¹), and the degree to which agreements like the certification of sustainable practices are seriously embraced by state government agencies and private plantation owners. Perhaps the greatest opportunities lie in the establishment of new plantations on semi-cleared grazing lands. In these cases, there will be advantages in articulating plans and visions of what future plantation landscapes might look like so that values other than wood and pulp production can be embraced. As outlined above, existing remnant vegetation in these areas is extremely important. In addition, there will be a significant conservation role of existing (and restored) riparian native vegetation in these landscapes – a role that need not necessarily have a major negative impact on wood and pulp production given water quality considerations.

¹Readers are encouraged to check for the most recent Forestry Codes of Practice in each State.

Chapter 7 - Principles for enhancing wildlife conservation in plantations

Based on the results of the array of studies of wildlife use of plantations discussed above, we have derived a set of principles that may enhance fauna conservation in plantations. We are aware that not all principles will apply in all circumstances – there are no generic approaches that can be applied uncritically in all types of plantations. The extent to which these principles are embraced will be influenced by several factors, particularly the mix of objectives of a given plantation or the primacy of one objective (e.g. commodity production) over other possible objectives (such as wildlife conservation) (Keenan *et al.*, 1997). Finally, we are also aware that the short list set out below is not exhaustive - with additional research other factors that enhance fauna conservation may be identified.

General principles

- *Habitat suitability.* This is fundamental for fauna conservation not only in plantations but in all ecosystems. This is because each organism requires access to suitable habitat to survive.
- *Non-replaceability.* Some fauna may not persist in plantations and hence the replacement of native vegetation by plantations is a negative outcome for nature conservation.

Landscape level principles

- *Landscape heterogeneity.* Landscape diversity within a plantation can promote conservation values through variation in the range of age classes of stands and the spatial juxtaposition of stands of different types and ages. This principle is based on different elements of the biota having requirements for resources found in different age classes of forest.
- *Remnant native vegetation patch size within plantations.* Larger remnants of native vegetation within planted areas may be more likely to contain more resources for the species of interest. Larger populations in such larger areas may be more likely to be viable and persist for longer.
- *Remnant native vegetation patch shape within plantations.* The shape of native vegetation remnants within plantations can influence the magnitude of some types of edge effects (both positive and negative) for animals. Remnant shape also can influence foraging efficiency for some species of animals (birds and arboreal marsupials are good examples).
- *Riparian areas.* Riparian areas have considerable value for supporting biodiversity - values that are typically disproportionate to the relatively small part of landscapes they occupy. They also may function as dispersal routes for animals.
- *Connectivity.* Physical links between patches (remnant vegetation and/or planted areas) may assist the dispersal/movement of some elements of the biota.
- *Adjacency and landscape context.* The conservation value of plantations is likely to be greater if they are near native vegetation. In addition, the nature of the landscape surrounding a plantation estate may matter for some elements of biodiversity.

Stand level principles

- *Tree species diversity.* Greater plant diversity provides a range of different resources needed by fauna and typically leads to more species occurring in a given area.
- *Stand structure.* Many species need particular elements of stand structure to survive – logs, large trees, hollows etc. For example, the more layers of vegetation in a stand, the more foraging niches for animals and establishment niches for plants such as mosses and lichens.
- *Stand age.* Older trees are more likely to develop the sorts of structural features such as hollows, large branches or accumulations of bark that are needed by some types of animals.

Chapter 8 - Data limitations

Most investigations we examined for this review have documented the occurrence of particular species and assemblages in plantations, but very few have determined whether these taxa are actually breeding there (but see Disney and Stokes, 1976). This is a particular problem for mobile taxa such as birds where it has been shown that their presence in plantation forests is often strongly related to the occurrence of neighbouring areas of native vegetation. There has been a distinct bias in the groups targeted for study (particularly birds and mammals) and other groups such as frogs, reptiles and fish have received limited attention. This is a key issue because their responses to plantation conditions may be somewhat different to those other groups. Another problem is that many of the studies completed to date suffer from limited replication of sites and are more descriptive than experimental – more rigorous studies using more powerful experimental designs are needed to overcome such deficiencies. There have been virtually no studies comparing the biota of conifer and eucalypt plantations and the relative conservation merits of both (but see Hammond, 1999). Finally, we were unable to find quantitative studies of the responses of fauna to small-scale or farm forestry plantings in agricultural Australia. This must be a major area of future research given that the potential biodiversity benefits of farm forestry have been promoted in many government and policy documents (e.g. Department of Primary Industries, 1997) but they have yet to be adequately quantified.

Chapter 9 - Concluding remarks

Many studies of the biota of Australian conifer plantations have been completed in the past 30 years. In comparison there have been far fewer investigations of eucalypt plantations. However, the work completed to date has demonstrated that:

- (1) Although some species are rare or absent from plantations, these areas are not biological deserts.
- (2) The assemblage of native species that inhabit plantation landscapes will be different to that which occurs in landscapes dominated by large areas of grazing land.
- (3) Remnant native vegetation within the boundaries of plantations is valuable for many species of native animals ranging from invertebrates to mammals.
- (4) More species occur in parts of plantation landscapes that contain remnant vegetation than in plantation monocultures.
- (5) The size and shape of patches of remnant vegetation within plantations can have an important influence on which species can persist in such landscapes. However, even relatively small patches (including individual paddock trees) can be useful for some species of native fauna.
- (6) Stands of plantation trees adjacent to patches of remnant native vegetation support more species than more isolated stands of plantation trees.
- (7) Riparian areas can be particularly valuable for wildlife and may act as dispersal routes for some taxa.

A recurring theme in almost all work on plantations – both on conifers and eucalypts – is the importance of landscape heterogeneity and stand structural complexity for wildlife conservation. At the landscape level, patches of retained native vegetation, strips of riparian vegetation, dams, open and clearing areas can significantly increase the number of native species that occur within plantations. Some species that occur in these areas can also use adjacent planted areas – a result common to conifer and eucalypt plantations. The spatial juxtaposition of stand ages of varying ages throughout plantation landscapes also can contribute to the maintenance of some populations of native taxa. At the stand level, structural complexity is also important for fauna with many species responding positively to the presence of native understorey plants, exotic understorey plants (like blackberry and lantana), the presence of windrowed logs and logging slash left on the forest floor.

Where plantations are located and the land cover they replace is a critical issue for fauna conservation. The pre-existing conservation values of areas where new plantations might be established warrant careful consideration. Plantations should not replace vegetation communities that have experienced substantial reduction and degradation since white settlement such as native grasslands (Kirkpatrick, 1994). In other cases, we believe that clearing native vegetation to establish plantations (e.g. as is presently occurring in Tasmania²) is an inappropriate land use practice, given the known and well documented negative ecological impacts of land clearing. The situation in Tasmania is of particular concern because the areas targeted for plantation establishment are the highly productive parts of the north-west and north-east of Tasmania – areas that are important for some elements of the biota but which are already heavily fragmented by agriculture and existing plantations (M. Brown, personal communication).

Managing plantations to promote landscape heterogeneity, stand structural complexity and enhance the conservation of fauna will, in many cases, involve trade-offs that can impact upon wood and pulp production. The extent to which this occurs will be dependent on the objectives of plantation

² In Tasmania, the Regional Forest Agreement (1997) allows clearing of native vegetation where it complies with specified conditions. Additional controls were set out in a variation to the Tasmanian RFA, which was signed on 23 February 2007 by the Commonwealth and Tasmanian Governments. See <http://www.daffa.gov.au/rfa/regions/tasmania/rfa>

management and how far they extend toward the complex plantation forestry model of Kanowski (1997) to incorporate social and environmental values in addition to wood and pulp production. It will also be influenced by other initiatives linked with the ecologically sustainable use of natural resources such as certification. We believe that the types of considerations associated with the complex plantation model, including the conservation of wildlife, are a critical component of future visions for plantation landscapes. Notably, such considerations are now part of codes of practice for plantation establishment and management in several Australian states including New South Wales (State Forests of NSW, 1997; Plantations and Reafforestation (Code) Regulation 2001). On this basis, a key future direction will be for researchers to implement new studies that rigorously assess the effectiveness of codes of practice and highlight where they can be modified or improved to better meet objectives specified for particular parts of the plantation estate.

References

- Ahern, L.D. and Yen, A.L. (1977). A comparison of the invertebrate fauna under *Eucalyptus* and *Pinus* forests in the Otway Ranges. *Proceedings of the Royal Society of Victoria*, **89**, 127-136.
- Andrén, H. (1994). Effects of habitat fragmentation on birds and mammals in landscapes with different proportions of suitable habitat: a review. *Oikos* **71**: 355-366.
- Anonymous. (2001). Paddock trees. Who'll miss them when they are gone? Pamphlet produced by NSW National Parks and Wildlife Service, NSW Department of Land and Water Conservation, and Greening Australia.
- The Australian Forestry Standard. (2003). The Australian Forestry Standard. The Australian Forestry Standard Project Office, Canberra, Australia.
- Barnett, J.L., How, R.A., and Humpreys, W.F. (1976). Mammals of Clouds Creek, north-eastern New South Wales and their distribution in pine and native forests. *Australian Zoologist*, **19**, 23-34.
- Barnett, J.L., How, R.A., and Humpreys, W.F. (1977a). Small mammal populations in pine and native forests in north-eastern New South Wales. *Australian Wildlife Research*, **4**, 233-240.
- Barnett, J.L., How, R.A., and Humpreys, W.F. (1977b). Possum damage to pine plantations in north-eastern New South Wales. *Australian Forest Research*, **7**, 185-196.
- Bennett, A.F. (1998). Linkages in the landscape. The role of corridors and connectivity in wildlife conservation. IUCN, Gland, Switzerland.
- Bennett, A.F., and Ford, L.A. (1997). Land use, habitat change and the conservation of birds in fragmented rural environments: a landscape perspective from the Northern Plains, Victoria, Australia. *Pacific Conservation Biology* **3**, 244-261.
- Bevege, D.I. (1974). Pine plantations: farm or forest? *Proceedings of the 7th Triennial Conference of the Institute of Foresters of Australia*, **1**, 435-443. Caloundra, Queensland.
- Bi, H., Bruskin, S., and Smith, R.G. (2002). The zone of influence of paddock trees and the consequent loss in volume growth in young *Eucalyptus dunnii* plantations. *Forest Ecology and Management*, **165**, 305-315.
- Bonham, K. J., Mesibov, R. and Bashford, R., 2002. Diversity and abundance of some ground-dwelling invertebrates in plantation vs. native forests in Tasmania, Australia. *Forest Ecology and Management* **158**: 237-247.
- Borsboom, A.C., Wang, J., Lees, N., Mathieson, M., and Hogan, L. (2002). Measurement and integration of fauna biodiversity values in Queensland agroforestry systems. A report for the RIRDC/Land and Water Australia/Forest and Wood Products Research and Development Corporation Joint Venture Agroforestry Program. RIRDC Publication 02/44. Canberra.
- Bragança, M.A., Zanuncio, J.C., Picanco, M. and Laranjeiro, A.J. (1998). Effects of environmental heterogeneity on Lepidoptera and Hymenoptera populations in *Eucalyptus* plantations in Brazil. *Forest Ecology and Management*, **103**, 287-292.
- Braithwaite, L.W. 1984. The identification of conservation areas for possums and gliders in the Eden woodpulp concession district. In 'Possums and Gliders'. A. P. Smith and I. D. Hume (editors). Surrey Beatty and Sons, Sydney, Australia. pp. 501-508.
- Bulinski, J. (1999). A survey of mammalian browsing damage in Tasmanian eucalypt plantations. *Australian Forestry*, **62**, 59-65.
- Bulinski, J. and MacArthur, C. (1999). An experimental field study of the effects of mammalian herbivore damage on *Eucalyptus nitens* seedlings. *Forest Ecology and Management*, **113**, 241-249.
- Burgman, M.A., and Lindenmayer, D.B. (1998). Conservation biology for the Australian environment. Surrey Beatty and Sons, Chipping Norton, Sydney.
- Carthew, S.M., Goldingay, R.L and Funnell, D.L. (1999) Feeding behaviour of the Yellow-bellied Glider (*Petaurus australis*) at the western edge of its range. *Wildlife Research*, **26**, 199-208.
- Cauley, H.A., C.M. Peters, R.Z. Donovan, and J.M. O'Connor. (2001). Forest Stewardship Council Forest Certification. *Conservation Biology*, **15**, 311-312.

- Clark, J. (1992). The future for native forest logging in Australia. Centre for Resources and Environmental Studies Working Paper 1996/9. Centre for Resources and Environmental Studies, The Australian National University, Canberra.
- Clark, J. (1996). Forest plantations of Australia by James *et al.* Department of Forestry, Australian National University. A critique by Judy Clark. Centre for Resources and Environmental Studies Working Paper 1996/9. Centre for Resources and Environmental Studies, The Australian National University, Canberra.
- The Commonwealth of Australia and Department of Natural Resources and Environment. 1997. Comprehensive Regional Assessment - Biodiversity. Central Highlands of Victoria. The Commonwealth of Australia and Department of Natural Resources and Environment, Canberra.
- Cowley, R.D. (1971). Birds and forest management. *Australian Forestry*, **35**, 234-250.
- Cubbage, F.W., W.S. Dvorak, R.C. Abt, and G. Pacheco. (1996). World timber supply and prospects: Models, projections, plantations and implications. Central America and Mexico Coniferous (CAMCORE) Annual Meeting, Bali, Indonesia.
- Curry, G.N. (1991). The influence of proximity to plantation of diversity and abundance of bird species in an exotic pine plantation in north-eastern New South Wales. *Wildlife Research* **18**, 299-314.
- Davidson, P.M. (1976). Birds in pine forests. Department of the Capital Territory in Forest Environment No. 1. Australian Government Publishing Service, Canberra.
- Davies, K. F., Gascon, C. and Margules, C. R. (2001) Habitat fragmentation: consequences, management and future research priorities. In 'Conservation biology: research priorities for the next decade' (Ed. M. E. Soulé and G. H. Orians) pp. 81-97. (Island Press, Washington, D.C.)
- Davies, K.F., and C.R. Margules. (1998). Effects of habitat fragmentation on carabid beetles: experimental evidence. *Journal of Animal Ecology*, **67**, 460-471.
- Davies, K.F., C.R. Margules, and J.F. Lawrence. (2000). Which traits of species predict population declines in experimental forest fragments? *Ecology*, **81**, 1450-1461.
- Department of Primary Industries and Energy. (1997). *Plantations for Australia: The 2020 Vision*. Joint Report from Ministerial Council on Forestry, Fisheries and Aquaculture, Standing Committee on Forestry, Plantations Australia, Australian Forest Growers, National Association of Forest Industries. Department of Primary Industries and Energy, Canberra.
- Disney, H.J., and Stokes, A. 1975. Birds in Pine and native forests. *Emu* **76**, 133-138.
- Driscoll, P.V. (1977). Comparison of bird counts from pine forests and indigenous vegetation. *Australian Wildlife Research*, **4**, 281-288.
- Doughty, R.W. (2001). The Eucalyptus. John Hopkins University Press, Baltimore.
- Eldridge, K., J. Davidson, C. Harwood, and G. van Wyk. (1994). Eucalypt domestication and breeding. Clarendon Press, Oxford.
- Er, K. and Tidemann, C.R. (1996). Importance of Yellow Box-Blakely's Red Gum woodland remnants in maintaining bird species diversity: inferences from seasonal data. *Corella*, **20**, 117-125.
- Fielding, P. (1977). Birds in pine plantations in Tasmania. *Tasmanian Naturalist*, **45**, 5-8.
- Fischer, J. and Lindenmayer, D.B. (2002). The conservation value of small habitat patches: two case studies on birds from southeastern Australia. *Biological Conservation*, **106**, 129-136.
- Fisher, A.M. and D.C. Goldney. (1998). Native forest fragments as critical bird habitat in a softwood landscape. *Australian Forestry* **61**: 287-295.
- Fisher, W.J. (1974). Conifer plantations - biological deserts? Pp. 512-521. Proceedings of the 7th Triennial Conference of the Institute of Foresters of Australia. Caloundra, Queensland.
- Food and Agriculture Organisation of the United Nations (2001). State of the World's forests. 2001. Food and Agriculture Organisation of the United Nations, Rome.
- Forman, R.T. (1995). Land mosaics. The ecology of landscapes and regions. Cambridge University Press, New York.
- Franklin, J.F. (2003). Challenges to temperate forest stewardship – focusing on the future. In 'Towards forest sustainability'. D.B. Lindenmayer and J.F. Franklin, editors. CSIRO Publishing, Melbourne. pp. 1-13.

- Franklin, J. F., Lindenmayer, D. B., MacMahon, J. A., McKee, A., Magnusson, J., Perry, D. A., Waide, R., and Foster, D. R. (2000). Threads of continuity: ecosystem disturbances, biological legacies and ecosystem recovery. *Conservation Biology in Practice* **1**: 8-16.
- Friend, G.R. (1978). A comparison of predator scat analysis with conventional techniques in mammal survey of contrasting habitats in Gippsland, Victoria. *Australian Wildlife Research*, **5**, 75-83.
- Friend, G.R. (1979). The response of small mammals to clearing and burning of eucalypt forest in south-eastern Australia. *Australian Wildlife Research*, **6**, 151-163.
- Friend, G.R. (1982a). Mammal populations in exotic pine plantations and indigenous eucalypt forests in Gippsland, Victoria. *Australian Forestry* **45**: 3-18.
- Friend, G.R. (1982b). Bird populations in exotic pine plantations and indigenous eucalypt forests in Gippsland, Victoria. *Emu*, **45**, 80-91.
- Gepp, B.C. (1976). Bird species distribution and habitat diversity in an exotic forest in South Australia. *Australian Forestry*, **39**, 269-287.
- Gepp, B.C. (1979). The factors influencing bird species diversity in exotic forests (*Pinus radiata* D. Don) in the Mt. Lofty Ranges of South Australia. MSc thesis, Flinders University, Adelaide, South Australia.
- Gibbons, P., and Boak, M. (2002). The value of paddock trees for regional conservation in an agricultural landscape. *Ecological Management and Restoration* (in press).
- Gibbons, P. and Lindenmayer, D.B. (2002). Tree hollows and wildlife conservation in Australia. CSIRO Publishing, Melbourne. 211 pp.
- Gill, A.M. and Williams, J.E. (1996). Fire regimes and biodiversity: the effects of fragmentation of southeastern Australian eucalypt forests by urbanisation, agriculture and pine plantations. *For. Ecol. Manage.*, **85**, 261-278.
- Goldingay, RL and Kavanagh, RP. (1991). The Yellow-bellied Glider: a review of its ecology, and management considerations. In 'Conservation of Australia's Forest Fauna' Lunney (ed.), Royal Zoological Society of NSW, Sydney, pp 365-79.
- Grabham, C., Klomp, N. and Robinson, W. (2002). The influence of remnant trees retained within native hardwood plantations on the diversity and abundance of birds. Department of Natural Resources and Environment, Wangaratta, Victoria.
- Hammond, G. (1999). Ants (Formicidae), spiders (Araneae), farmed-based *Pinus radiata* plantations and biodiversity: a case study in the Albury region of southern NSW. Honours thesis, Charles Sturt University, Wagga.
- Hanowski, J.M., Niemi, G.J. and Christian, D.C. (1997). Influence of within-plantation heterogeneity and surrounding landscape composition on avian communities in hybrid popular plantations. *Conservation Biology* **11**: 936-944.
- Harris, L.D. (1984). *The Fragmented Forest*. University of Chicago Press, Chicago, Illinois.
- Hartley, M.J. (2002). Rationale and methods for conserving biodiversity in plantation forests. *Forest Ecology and Management*, **155**, 81-95.
- Heislors, A. (1974). Mammals and timber production – compatibility or conflict? *Proceedings of the 7th Triennial Conference of the Institute of Foresters of Australia*, **1**, 242-258.
- Hobbs, R. J. and Humphries, S. E. (1995). An integrated approach to the ecology and management of plant invasions. *Conservation Biology* **9**, 761-770.
- Hobbs, R.J. and Yates, S. (2000). Temperate eucalypt woodlands in Australia. Surrey Beatty and Sons, Chipping Norton, Sydney.
- Hobbs, R.J., Floyd, R., Cunningham, S., Catling, P. and Ive, J. (2002a). Hardwood plantations: quantifying conservation and environmental service benefits. Report to the Joint Agroforestry Program. Rural Industries Research and Development Corporation, Canberra., Publication No. R02/083.
- Hobbs, R.J., Catling, P., Wombey, J.C., Clayton, M., Atkins, L., and Reid, A. (2002b). Faunal use of Bluegum (*Eucalyptus globulus*) plantations in southwestern Australia. *Agroforestry Systems* (in review).
- How, R. A. (1972). The ecology and management of *Trichosurus* species (Marsupialia) in NSW. PhD Thesis. University of New England, Armidale.

- Hunter, M.L. (1994). Fundamentals of conservation biology. Blackwell, Cambridge, Melbourne.
- Kanowski, P. (1997). Plantation forestry in the 21st century. Special paper: afforestation and plantation forestry. XI World Forestry Congress, 13-22 October 1997.
- Kavanagh, R.P., and R.J. Turner. (1994). Birds in eucalypt plantations: the likely role of retained habitat trees. *Australian Birds* **28**: 32-41.
- Kavanagh, R.P., Law, B., Lemckert, F., Stanton, M., Chidel, M., and Towerton, A. (2001). Birds, mammals, reptiles and amphibians in eucalypt plantations near Albury-Woodonga: A pilot study of variables influencing biodiversity. State Forests of New South Wales. Pennant Hills, Sydney.
- Keenan, R., Lamb, D., Woldring, O., Irvine, T., and Jensen, R. (1997). Restoration of plant biodiversity beneath tropical tree plantations in Northern Australia. *Forest Ecology and Management*, **99**, 117-131.
- Keenan, R.J., Lamb, D., Parrotta, J. and Kikkawa, J. (1999). Ecosystem management in tropical timber plantations: Satisfying economic, conservation and social objectives. *Journal of Sustainable Forestry*, **9**, 117-134.
- Kehl, J.C. (1980). The biology and population biology of *Rattus tunneyi culmorum* in Hoop Pine plantations in south-east Queensland. MSc thesis, University of Queensland, Brisbane.
- Kikkawa, J. (1968). Ecological association of bird species and habitats in eastern Australia. *Journal of Animal Ecology*, **37**, 143-165.
- Kirkpatrick, J. (1994). *A continent transformed. Human impact on the natural vegetation of Australia*. Oxford University Press, Melbourne.
- Kloeden, J.L. (1973). Pine plantations. *Wildlife in Australia*, **10**, 130-133.
- Klomp, N., Grabham, C., and Herring, M. (2001). Fauna study of Ettamogah Forest 1994-2000. Johnstone Centre Report No. 154. Charles Sturt University, Albury. August 2001.
- Klomp, N. and Grabham, C. (2002). A comparison of the avifaunal diversity on native hardwood plantations and pastureland in north-east Victoria. Report No. 164 Johnstone Centre, Charles Sturt University, Albury.
- le Mar, K. (2000). Use of the forestry environment by herbivores. *Tasforests*, **12**, 169-170.
- Lindenmayer, D.B. (2000). Islands of Bush in a sea of pines. The Tumut Fragmentation Experiment. A summary of studies. Land and Water Resources Research and Development Corporation Research Report 6/00. Land and Water Resources Research and Development Corporation, Canberra. 48 pp.
- Lindenmayer, D.B., and Viggers, K.L. (1994). An extension of the range limits of the Long-nosed Potoroo (*Potorous tridactylus*). *Memoirs of the Queensland Museum*, **335**, 180.
- Lindenmayer, D.B., Pope, M., Cunningham, R. B., Donnelly, C.F., and Nix, H.A. (1996). Roosting in the Sulphur-Crested Cockatoo (*Cacatua galerita*). *Emu*, **96**, 209-212.
- Lindenmayer, D.B., Cunningham, R.B., Pope, M., and Donnelly, C.F. (1999a). The response of arboreal marsupials to landscape context: A large-scale fragmentation study. *Ecological Applications*, **9**, 594-611.
- Lindenmayer, D.B., Cunningham, R.B., Pope, M.L., Donnelly, C.F. (1999b). A large-scale "experiment" to examine the effects of landscape context and habitat fragmentation on mammals. *Biological Conservation*, **88**, 387-403.
- Lindenmayer, D.B., and Pope, M.L. (1999). The design of exotic softwood plantations to enhance wildlife conservation: preliminary lessons from the Tumut fragmentation experiment. In 'Nature Conservation in Production Environments: Managing the Matrix'. J. Craig, N. Mitchell, and D. A. Saunders, editors. Surrey Beatty and Sons, Sydney. pp. 44-49.
- Lindenmayer, D.B., and McCarthy, M.A. (2001). The spatial distribution of non-native plant invaders in a pine-eucalypt mosaic in south-eastern Australia. *Biological Conservation*, **102**, 77-87.
- Lindenmayer, D.B., Cunningham, R.B., Tribolet, C.R., Donnelly, C.F., and MacGregor, C. (2001). The Nanangroe Landscape Experiment - baseline data for mammals, reptiles and nocturnal birds. *Biological Conservation*, **101**, 157-169.
- Lindenmayer, D.B., and Franklin, J.F. (2002). Conserving forest biodiversity: A comprehensive multiscaled approach. Island Press, Washington 351 pp.

- Lindenmayer, D.B., Cunningham, R.B., Donnelly, C.F., Nix, H.A. and Lindenmayer, B.D (2002a). The distribution of birds in a novel landscape context. *Ecological Monographs*, **72**, 1-18.
- Lindenmayer, D.B., Cunningham, R.B., Donnelly, C.F., and Lesslie, R. (2002b). On the use of landscape indices as ecological indicators in fragmented forests. *Forest Ecology and Management*, **159**, 203-216.
- Loyn, R.H., E.A. Chestefield, and M.A. Macfarlane. (1980). Forest utilization and the flora and fauna in Boola Boola State Forest in south-eastern Victoria. Forest Commission of Victoria Bulletin **28**.
- MacNally, J. (1955). Damage to Victorian exotic pine plantations by native animals. *Australian Forestry*, **19**, 87-99.
- Mac Nally, R. (1994). Habitat-specific guild structure of forest birds in south-eastern Australia: a regional scale perspective. *Journal of Animal Ecology*, **63**, 988-1001.
- Margules, C.R., G.A. Milkovits, and G.T. Smith. (1994). Contrasting effects of habitat fragmentation on the scorpion *Cercophonius squama* and an amphipod. *Ecology*, **75**, 2033-2042.
- McArthur, C. (2000). Balancing browsing damage management and fauna conservation in plantation forestry. *Tasforests*, **12**, 167-169.
- McIlroy, J.C. (1978). The effects of forestry practices on wildlife in Australia: a review. *Australian Forestry*, **41**, 78-94.
- Montague, T. (1996). The extent, timing and economics of browsing damage in eucalypt and pine plantations of Gippsland, Victoria. *Australian Forestry*, **59**, 120-129.
- Moore, S.E. and H.L. Allen. (1999). Plantation forestry. In 'Managing biodiversity in forest ecosystems'. M.L. Hunter (editor). Cambridge University Press, Cambridge. pp. 400-433.
- Neumann, F.G. (1978). Insect populations in eucalypt and pine forests in north-eastern Victoria. *Australian Forest Research*, **8**, 13-24.
- Neumann, F.G. (1979a). Beetle communities in eucalypt and pine forests in north-eastern Victoria. *Australian Forest Research*, **9**, 277-293.
- Neumann, F.G. (1979b). Insect pest management in Australian Radiata Pine plantations. *Australian Forestry*, **42**, 30-38.
- Pampolina, N.M., Dell, B., and Malajczuk. (2002). Dynamics of ectomycorrhizal fungi in an *Eucalyptus globulus* plantation: effect of phosphorus fertilization. *Forest Ecology and Management*, **158**, 291-304.
- Parker, G.R., Kimball, D.G., and Dalzell, B. (1994). Bird communities breeding in selected spruce and pine plantations in New Brunswick. *Canadian Field Naturalist*, **108**, 1-9.
- Pawsey, C.K. (1966). Birds in relation to the pine forests of the south east of South Australia. *South Australian Ornithologist* **24**, 93-95.
- Plantations and Reafforestation (Code) Regulation (2001). New South Wales Department of Land and Water Conservation, Sydney, Australia.
- Pope, M. (2003). The patch and den use of habitat fragments by the Greater Glider (*Petauroides volans*). MSc thesis, Centre for Resource and Environmental Studies, The Australian National University, Canberra.
- Potts, B.M., Barbour, R.C., Hingston, A.B. (2001). The risk of genetic pollution from farm forestry using eucalypt species and hybrids. A report for RIRDC/Land and Water Australia/FWPRDC Joint Venture Agroforestry Program. February 2001.
- Price, L., McDonald, G., Robinson, W., and Sheahan, M. (2000). Bushlands, pines and pasture: The changing matrix of rural land use in the South West Slopes Region of New South Wales. Johnstone Centre Research in natural Resources and Society. Report No. 137. Charles Sturt University, Albury.
- Prober, S. and Thiele, J. (1995). Conservation of the Grassy White Box woodlands: relative contributions of size and disturbance to floristic composition and diversity of remnants. *Aust. J. Bot.*, **43**, 349-366.
- Race, D., Guijt, I., and Kanowski, P. (1998). Australian experiences in farm forestry. *Environmental Conservation*, **25**, 234-243.
- Ray, S., Robinson, D. and Werren, G. (1983). Pines versus native forests: an annotated bibliography. Native Forests Action Council, Melbourne.
- Peterken, G.F and Ratcliffe, P.R.(1995). The potential of biodiversity in British upland spruce forests. *Forest Ecology and Management*, **79**, 153-160.

- Recher, H.F. (1982). *Pinus radiata* – a million hectare miscalculation. *Australian Natural History*, **20**, 319-325.
- Recher, H.F., Rohan-Jones, W., and Smith, P. (1980). Effects of the Eden woodchip industry on terrestrial vertebrates with recommendations for management. *Forest Commission of New South Wales Research Note* **42**, 1-85
- Recher, H.F., J. Shields, R. Kavanagh and G. Webb. (1987a). Retaining remnant mature forest for nature conservation at New South Wales. In D.A. Saunders *et al.* (editors). 'Nature Conservation: The Role of Remnants of Native Vegetation'. Surrey Beatty and Sons, Chipping Norton. pp. 177-194.
- Recher, H.F., W.E. Davis, and R.T. Holmes. (1987b). Ecology of brown and striated thornbills in forests of south-eastern New South Wales, with comments on forest management. *Emu* **87**: 1-13.
- Resource Assessment Commission. (1992). Forest and Timber Inquiry. Final Report. Volume 1. Australian Government Printing Service, Canberra, Australia.
- Rishworth, C., McIlroy, J., and Tanton, M.T. (1995). Factors affecting population densities of the Common Wombat (*Vombatus ursinus*) in plantations of *Pinus radiata*. *Forest Ecology and Management*, **76**, 11-19.
- Rolstad, J., and Wegge, P. (1987). Distribution and size of capercaillie leks in relation to old forest fragmentation. *Oecologia* **72**, 389-394.
- Routley, R. and Routley, V. (1975). The fight for the forests: the takeover of Australian forests for pines, woodchips and intensive forestry. Research School of Social Sciences, The Australian National University, Canberra.
- Saunders, D.A. (1974). The occurrence of the White-tailed Black-cockatoo *Calyptorhynchus baudinii* in Western Australia. *Australian Wildlife Research*, **1**, 45-54.
- Scott, S.L., McArthur, C., Potts, B., and Joyce, K. (2002). Possum browsing – the downside to a eucalypt hybrid developed for frost tolerance in plantation forestry. *Forest Ecology and Management*, **157**, 231-245.
- Seymour, R.S., and M.L. Hunter. (1999). Principles of ecological forestry. In 'Maintaining biodiversity in forest ecosystems'. M.L. Hunter (editor). Cambridge University Press, Cambridge. pp. 22-61.
- Smith, G.C., and Agnew, G. (2002). The value of "bat boxes" for attracting hollow-dependent fauna to farm forestry plantations in southeast Queensland. *Ecological Management and Restoration*, **3**, 37-46.
- Smith, J.M. (1982). Ecological comparisons between pine plantations and native forests, Clouds Creek, New South Wales. Research Series in Applied Geography, University of New England, Armidale, Australia.
- Smith, J.M. (1987). Further ecological comparisons between pine plantations and native forests, Clouds Creek, New South Wales. Department of Geography and Planning, University of New England, Armidale, Australia.
- Smith, R.J. (2000). An investigation into the relationships between anthropogenic forest disturbance patterns, population viability and landscape indices. MSc thesis. Institute of Land and Food Resources, The University of Melbourne, Australia.
- Soderquist, T.R., and Mac Nally, R. (2000). The conservation value of mesic gullies in dry forest landscapes: mammal populations in the box-ironbark ecosystem of southern Australia. *Biological Conservation*, **93**, 281-291.
- Spellerberg, I.F., and J. Sawyer. (1996). Standards for biodiversity: a proposal based on biodiversity standards for forest plantations. *Biodiversity and Conservation* **5**: 447-459.
- Spellerberg, I.F., and J. Sawyer. (1997). Biological diversity in plantation forests. In 'Conservation outside nature reserves'. P. Hale, and D. Lamb (Editors). Centre for Conservation Biology, The University of Queensland, Brisbane. pp. 517-522.
- Staines, B.W. (1983). The conservation and management of mammals in commercial plantations with special reference to the uplands. In 'Forestry and Conservation'. E.H. Harris (editor). Royal Forestry Society. pp. 38-51.
- State Forests of New South Wales. (1997). Forest Practices Code. Plantation establishment and maintenance. State Forests of New South Wales, Pennant Hills, Sydney, Australia.
- State of the Environment Australia. (1996). State of the Environment Advisory Council. CSIRO, Melbourne, Australia.

- Strauss, S.Y. (2001). Benefits and risks of biotic exchange between *Eucalyptus* plantations and native Australian forests. *Austral Ecology*, **26**, 447-457.
- Steinbauer, M.J., McQuillan, P.B., and Young, C. (2001). Life history and behavioural traits of *Mnesamplea privata* that exacerbate population responses to eucalypt plantations: Comparisons with Australian and outbreak species of forest geometrid from the Northern Hemisphere. *Austral Ecology*, **26**, 525-534.
- Suckling, G.C. (1982). Value of reserved habitat for mammal conservation in plantations. *Australian Forestry*, **45**, 19-27.
- Suckling, G.C. and Heislars, A. (1978). Populations of four small mammals in Radiata Pine plantations and eucalypt forests in north-eastern Victoria. *Australian Wildlife Research* **5**: 305-315.
- Suckling, G.C., E. Backen, A. Heislars, and F.G. Neumann. (1976). The flora and fauna of Radiata Pine plantations in north-eastern Victoria. Forest Commission of Victoria Bulletin No. **24**. Forest Commission of Victoria, Melbourne, Australia.
- Taylor, R.J., Bryant, S.L., Pemberton, D. and Norton, T.W. (1985). Mammals of the Upper Henty River region, Western Tasmania. *Papers and Proceedings of the Royal Society of Tasmania* **119**, 7-15.
- Taylor, P. D., L. Fahrig, K. Henein and G. Merriam. (1993). Connectivity as a vital element of landscape structure. *Oikos*, **68**, 571-573.
- Tyndale-Biscoe, C.H. and Smith, R.F. (1969). Studies of the marsupial glider, *Schoinobates volans* (Kerr). III. Response to habitat destruction. *Journal of Animal Ecology* **38**, 651-659.
- Van Dyck, S. (1993). The taxonomy and distribution of *Petaurus gracilis* (Marsupialia: Petauridae), with notes on its ecology and conservation status, *Memoirs of the Queensland Museum*, **33**: 77-122.
- Wardell-Johnson, G., and Roberts, J.D. (1993). Biogeographic barriers in a subdued landscape: the distribution of the *Geocrinia rosea* (Anura: Myobatrachidae) complex in south-western Australia. *Journal of Biogeography* **20**: 95-108.
- Warneke, R.M. (1964). The life history and ecology of the Australian Bush Rat *Rattus assimilis* Gould in exotic pine plantations. MSc thesis, University of Melbourne, Melbourne.
- Warneke, R.M. (1971). Field study of the Bush Rat (*Rattus fuscipes*). Victorian Fisheries and Wildlife Division. Contribution No. 14.
- Wiens, J. A. (1997). Metapopulation dynamics and landscape ecology. In 'Metapopulation Biology: Ecology, Genetics, and Evolution. I. A. Hanski and M. E. Gilpin (eds). Academic Press, New York. pp. 43-62.
- Winter, J.W., and Dickman, C.R. (2001). Cuscuses and Brushtail Possums. In 'The new encyclopedia of mammals'. D. MacDonald (editor). Oxford University Press, Oxford. pp. 828-833.
- Wood, M., and Allison, B. (2000). National Forest Inventory (2000). National Plantation Inventory Tabular Report. Bureau of Rural Sciences, Canberra.
- Wood, M.S., Stephens, N.C., Allison, B.K., and Howell, C.I. (2001). Plantations of Australia – A report from the National Plantation Inventory and the National Farm Forest Inventory. National Forest Inventory, Bureau of Rural Sciences, Canberra.
- Zanuncio, J.C., Mezzomo, J.A., Guedes, R.N., and Oliveria, A.C. (1997). Influence of strips of native vegetation on Lepidoptera associated with *Eucalyptus cloeziana* in Brazil. *Forest Ecology and Management*, **108**, 85-90.
- Zavaleta, E. S., Hobbs, R.J. and Mooney, H.A. (2001). Maximizing the benefits of eradication: Why invasive species removal should be viewed in a whole-ecosystem context. *Trends in Ecology and Evolution* **16**, 454-459.