The Conservation Value of Regrowth Native Plant Communities:

A Review

FINAL REPORT

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New South Wales Scientific Committee

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EXECUTIVE SUMMARY

A literature review was undertaken on the conservation value of regrowth native vegetation, focussing on New South Wales but also reviewing relevant literature from other regions of Australia and overseas. Specific attention was paid to those papers dealing with regrowth arising on land subsequently abandoned after agricultural and pastoral clearing and thinning activities. However, due to the nature of the topic, regrowth was interpreted in a broad sense and consideration was also given to those papers dealing with other forms of regrowth arising from fire, logging, cessation of grazing and mining.

Excluding review papers and background articles, one hundred and forty one papers were reviewed in detail, although very few were found that specifically addressed the topic and a degree of interpretation and flexibility was needed to cover those papers which were less directly relevant. Due to the heterogeneous nature of regrowth native vegetation in space, time and history and the lack of detailed studies, it is difficult to make generalisations about conservation value. However, the key points that emerge from the literature are:

- very few studies attempt to measure the conservation value of regrowth *per se* and there is a very large knowledge gap because of this;
- key disturbances resulting in regrowth are clearing and thinning, fire, grazing, logging and mining;
- fragmentation will further modify the effects of these key disturbances;
- regrowth vegetation is a complex manifestation of a disturbance and successional interaction which may or may not produce a form of vegetation similar to the pre disturbance community;
- exposed mineral soil, propagule availability and cessation of a major disturbance are critical requirements to achieve any form of regrowth;
- short term clearing impacts will not affect the regrowth process to the same degree as severe soil modification will (ploughing, fertilising, pasture improvement);
- in order of major disturbances taken as single factors and their effects on the conservation value of subsequent regrowth, the sequence from most to least impact can be represented as:

  cultivation > clearing > grazing > mining > burning > logging > ‘unaltered’

- synergistic effects between the major disturbances and their history will further complicate this pattern as, for example, an area that has been cultivated for a considerable period and subsequently mined will suffer such fundamental change that regrowth of native vegetation *per se* will be impossible;
- regrowth may be primary, secondary or even tertiary in origin;
- areas ‘representative’ of a vegetation type / community will be difficult to define due to the difficulty of defining a ‘natural’ analog;

- while exotic weed species may be present in regrowth areas, this will only be critical where they are forming a significant part of the biomass and hindering the regeneration of native species;
- regrowth can be the habitat of common species or rare and threatened species but no adequate predictor of the probability of the relative proportions of rare to common species exists due to the historical uniqueness of most areas of regrowth;
- there is some evidence that certain threatened species are favoured by frequent disturbance, but this is not universally true;
- the effects of disturbance will have differential effects on plant and animal species in general, notwithstanding individual differences among species. Many plants have a greater number of traits that will allow them to persist under disturbance – foremost among these is their modular nature which allows resprouting. Animals generally rely on recolonisation after disturbance, which relies on source and sink populations. Fragmentation will greatly affect the recolonisation process.

With the exception of one study of clearing of Brigalow in Queensland, there are no before and after / control and impact manipulative studies addressing the topic. Many papers are inferential in their nature and attempt to reconstruct the nature of vegetation prior to clearing. Literature dealing with the effects of fragmentation does not appear to consider the disturbance history that may have occurred within fragments. This disturbance history may confound studies that attempt to assess differences between fragments and between fragments and the agricultural/pastoral landscape.

The degree of soil disturbance and time between disturbance and regrowth are fundamental factors in determining the type of regrowth that will eventuate and what type of successional pathway it will take. Propagule availability at the time of disturbance will determine the composition of the regrowth.

The conservation value of regrowth vegetation may be interpreted at a functional, structural or compositional level and the status of each level will have different implications for different taxa. Hence, while a functioning system will have a high conservation value overall, it will be especially important for native soil biota. By way of contrast, a structurally complex site may lack a fully functioning native soil system and be composed of a mixture of native and exotic species yet still provide important habitat for fauna, even threatened fauna. In relation to flora, an area may not be structurally complex enough to support an array of native fauna but may still reflect a compositional complexity of plant species or even simply conserve one threatened plant species, despite or in some cases because of, past disturbance.

Unfortunately, there is no simple generalisation that can be made from the literature in relation to the interaction between species richness, the occurrence of threatened species, structural complexity and successional stage as this interaction depends on the autecology of the species involved but also, more fundamentally, on the individual history of the area of regrowth under consideration. In terms of relative recoverability of overstorey versus understorey components, this will be particularly dependent on individual stand history.

However, seed bank status and re-sprouting abilities will be a prime driver in recoverability. As time from disturbance to an opportunity to regrow lengthens, only those species with a high site 'tenacity' via some form of propagule retention will be able to recover.

It can therefore be strongly argued that any patch of regrowth vegetation will have *some* conservation value, as even agricultural and urban landscapes provide habitat for some native species. It is a matter of whether the value is of local, regional or national significance. The conservation value of regrowth vegetation can be assessed on at least three major levels:

- **compositional importance** e.g. as individual species within a vegetation type including threatened species; as a vegetation type;
- **structural importance** e.g. as fauna habitat
- **functional importance** e.g. as a functioning native ecosystem;

and either one or more of these levels may be important with any given patch of regrowth. Depending on the status of these three levels, regrowth may be more or less 'natural' or to some degree 'synthetic' (Bridgewater 1990) and can probably only be regarded as having little or no conservation value if it is totally dominated by exotic species and bears no similarity at all to 'natural' vegetation.

Conservation value exists as a continuum from areas totally cleared, ploughed and devoid of native vegetation in a human dominated landscape to those areas comprised of vegetation essentially in a natural landscape. There can be no absolute measure of conservation value and it must be seen that conservation value will always be a relative term, depending on the context of any given area of regrowth - its disturbance history, the amount of the vegetation type left etc. All values may not be contained within one area of regrowth and values may be spread across a number of sites with varying levels of disturbance. Values may also change in time - there is a spatial and temporal context to the conservation value of a given area of regrowth vegetation. Unfortunately for the Scientific Committee, the literature covering the field is not large and those studies that are most relevant to the scope of the review reinforce the view that individual site history is the major determinant in the conservation value of regrowth vegetation and detailed site information is required for evaluation.

The evaluation process needs to consider:

Current State (Compositional Value):

- determine whether any flora or fauna of significance occurs on the site and if so determine its conservation status;
- determine native plant species richness and cover / biomass;
- determine exotic plant species richness and cover / biomass;
- determine native animal species richness and abundance;
- determine exotic animal species richness and abundance;

History and Habitat (Structural Value):

- determine the degree of previous major disturbance – how many years of control burning, how many times cleared, how many times cultivated and for how long;
- determine time since last major disturbance;
- determine if overstorey and understorey components are present;
- assess habitat complexity at the site;

Viability (Functional Value):

- determine the functionality of the soil-litter interface to gauge the viability of long term ecosystem processes. Measures such as litter quality and depth, soil organic matter and soil seed bank composition may be important;
- determine existing land use and surrounding land use and current and potential impacts and influences;

Context:

- place the vegetation into an available classification. Vegetation maps may or may not be available for areas under assessment, even if classifications are available;
- place the vegetation in a regional context. This will involve assessing which areas are environmentally similar to the area in question based on at least rainfall, climate, lithology, aspect and soil if known, as well as any vegetation maps;
- calculate the areal extent of the vegetation type or environmental unit;
- determine the reservation status of the vegetation type or environmental unit;

While this information should result in a stand alone assessment of an individual area, some analog site may still need to be chosen for comparative purposes.

In the absence of comprehensive data, an adaptive but conservative approach is warranted and it will probably be necessary to treat each case on its own merits in the absence of general principles. Unfortunately, the composition of a patch regrowth native vegetation will be as heterogeneous as its land use history has made it and it is therefore difficult to be predictive about trends in composition, structure or function of such stands.

1.0 INTRODUCTION

1.1 Project Brief

CSIRO Division of Wildlife and Ecology, Canberra, was contracted by the Scientific Committee (formed under the NSW Threatened Species Conservation Act, 1995) to undertake a review on the conservation value of regrowth native plant communities, with particular reference to NSW communities. For the purposes of the consultancy, regrowth refers to the recovery of flora and fauna after a particular human caused clearing or thinning event. The review was commissioned in order to provide the NSW Scientific Committee with information to assist it in its deliberations on matters relating to the conservation value of areas which have been previously disturbed by anthropogenic activity, but which may contain some natural heritage values for native flora and/or fauna.

1.2 Terms of Reference

The Scientific Committee required that the consultancy should undertake to:

> *1. Prepare a review of the conservation value of regrowth of native plant communities.*
>
> *2. Review the relevant literature and highlight case studies which may be used to assess the value of regrowth to conservation.*
>
> *3. Assess the likely contribution to the maintenance of ecological communities and biological diversity, in terms of species composition and the interactions between species, of regrowth areas. This should be done with the recognition that recovery after disturbance may take different trajectories as a result of environmental conditions, chance, the impact of other disturbances, etc.*
>
> *4. Consider:*
>
> > *a) that all plant communities, and the animals associated with them, occur under a regime of disturbance, e.g. fire, flood, tree fall etc, with the frequency and intensity of such disturbances varying both spatially and temporally. Such disturbance regimes have been, and are, influenced by human activity.*
> >
> > *b) both plants and animals have evolved mechanisms that allow them to persist in disturbance prone environments.*
> >
> > *c) in certain instances, components of, or all of, the above-ground flora have been removed at one point in time, e.g. tree clearing, tree thinning, chaining, grazing, use of bulldozers. After such disturbance, the flora and*

fauna may begin to recover, or given enough time fully recover, at the site via regrowth.

d) that other disturbance events will also affect flora and fauna.

5. The time scale of the process of restoration of communities via regrowth should be addressed using examples from different plant communities.

6. Particular attention should be paid to the role of the following as recovery mechanisms in regrowth:

Flora:
a) the soil seed bank;
b) vegetative regrowth from below ground lignotubers, rootstocks, bulbs, apical meristems;
c) dispersal of propagules into the disturbed area.

Fauna:
a) survival in situ;
b) dispersal and recolonisation.

7. Identify critical gaps in knowledge that need to be addressed, particularly in a NSW context.

The terms of reference were addressed in turn during the consultancy and used as a basis to structure the report. The specific requirements of the terms of reference are addressed in the Methods and Results sections of this report.

1.3 Scope

Regrowth vegetation and its associated complement of animal species will, by definition, be undergoing a process of secondary succession after a disturbance. For the purposes of this review, the focus was on anthropogenic secondary succession, rather than non-anthropogenic primary and secondary succession. The review was restricted to terrestrial native plant communities and did not attempt to assess information on freshwater (lakes; running waters) or marine (intertidal and sub-tidal algal; seagrass) communities. The plants which constitute these communities, while subject to a variety of disturbance regimes and a variety of human impacts, are not directly cleared, thinned or commercially harvested, at least in Australia. However, mangrove and saltmarsh communities were included in the review, as they are subject to direct impacts from clearing and reclamation and hence were regarded as terrestrial for the purposes of the consultancy.

This restricted scope was necessary given the large volume of literature on disturbance dynamics in relation to factors such as drought, flood, fire and wind. Although these types of studies involve disturbance and regrowth, it is assumed that naturally occurring disturbances *per se* will not affect the conservation value of an area, although it is certainly the case that some forms of natural disturbance will facilitate the access and egress of exotic species. It was simply not possible to fully canvass and interpret all the potential interactions between 'natural' and 'anthropogenic' disturbances in relation to conservation value of regrowth within the time and monetary constraints of the consultancy.

1.4 Conceptual Framework - Succession, Disturbance and 'Natural' Vegetation

There is a large volume of international literature on both plant and animal succession dating back to the late 19th and early 20th centuries. Included in this literature are debates, critiques and reviews on the nature of successional processes, the concept of the 'climax' and the nature of plant communities. There is also a large amount of literature from the 1960's, 1970;s and 1980's dealing with the topics of disturbance, 'diversity' and 'stability'.

Key concepts debated include relay floristics (Clements 1916, 1936); initial floristic composition (Egler 1954); holistic (Cowles 1911; Clements 1916, 1936; Cooper 1926; Phillips 1931) versus individualistic (Gleason 1939; Watt 1947) concepts of the plant community; the definition of ecosystems (Tansley 1935); the mediating role of disturbance (see Mooney and Gordon 1983); directed succession (Luken 1990) and climax communities versus multiple successional pathways or trajectories (see Glenn-Lewin, Peet and Veblen 1992). Many of these issues and the large body of literature associated with them were very thoroughly addressed by Whittaker (1953) who provided a detailed historical account and critique of plant succession and 'climax' theory and attempted to merge the views of Gleason and Tansley. Whittaker also contrasted the American and European approaches to these issues up until the early 1950's. He suggested that:

> '*There is no absolute climax for any area, and climax composition has meaning only relative to position along environmental gradients and to other factors*'.

Whittaker's review laid the groundwork for a more realistic assessment of succession based on individual species responses to their environment and Glenn-Lewin, Peet and Veblen (1992) note that Whittaker's main insight was to describe climax vegetation as '*.....varying continuously across a continuously varying landscape*.' This then led to further formulations of the continuum concept as originally proposed by Gleason (McIntosh 1967). Glenn-Lewin, Peet and Veblen give an excellent historical context to succession theory past and present and McIntosh (1985) gives a broader historical perspective.

However, it is not the purpose of this review to fully trace the history and development of the concept of succession nor to debate the nature of plant communities. Nonetheless, this debate is pertinent to the assessment of the conservation value of stands of native vegetation, particularly regrowth. It is therefore necessary that the underlying conceptual framework influencing the approach taken in this review is explicitly stated. Much ecological and almost all successional theory has traditionally been framed in the form of developmental laws (*sensu* Drury and Nisbet 1973) which are now generally thought to have low predictive value. The early ideas of Clements and their subsequent interpretation are good examples of this type of thinking and Peters (1991) states (p. 153):

> ‘*The presumed existence of an orderly sequence of stages enhances a tendency to typological thinking, thereby encouraging analysis of continuous processes as a succession of discrete types. The models which emerge from such analyses are frequently highly qualitative, infinitely detailed, typologically specific, and weakly extensible. They narrow the vision of researchers and therefore hinder the development of alternative theories. The potential for study of individual components of the types becomes irrelevant and the study of seemingly anomalous sites is discouraged.*’

Hence a more open-ended view of the models, mechanisms and pathways of succession is required. The attitude taken in approaching this present review is best summarised by quoting Glenn-Lewin, Peet and Veblen (1992) in the Prologue to *Plant Succession. Theory and Prediction* (p. 6):

> ‘*The contemporary view of vegetation dynamics may be termed a “dynamic” or “kinetic” view in which there is no assumption of either long-term site stability or of the existence of an endpoint to succession (Drury and Nisbet, 1971). The modern view of vegetation change emphasises the importance of repeated, relatively frequent disturbance and accepts continuous change in vegetation as the norm (Pickett and White 1985).*’

The premise underlying this review is that there is not necessarily a final endpoint or stable state during either a primary or secondary succession and any disturbance, whether ‘natural’ or anthropogenic, could lead to the creation of a new mix of species which is neither better nor worse than the pre disturbance mix of species, only different. Factors which will determine this outcome will be the disturbance regime and the ability of species to persist and recover on site or to recolonise from adjacent areas.

However, the critical issue still remains: how to assess the conservation value of regrowth areas in an objective and meaningful way. If for assessment purposes *biodiversity* is used in place of *conservation value*, then some measurement of ecosystem and/or species and/or genetic diversity may be required before an evaluation is possible and the conservation value of any given area of regrowth may fall into one or more of these components of biodiversity. It could also be argued that any measure of conservation value is essentially a measure of ‘naturalness’. That is, the less ‘natural’ the patch of vegetation, the less conservation value it has. This assumes that some benchmark or analog area exists with which to compare the regrowth patch. The regional context within which the area being assessed is situated may also be critical in the assessment process. These themes are further discussed in relation to the reviewed literature in Chapters 4 and 5.

2.0 Methods

2.1 Literature Search

A four part search for relevant titles for the review was undertaken using a) existing databases held at CSIRO Wildlife and Ecology b) INTERNET searches of library online public access catalogues (OPAC's) c) INTERNET searches of online abstracting services and d) manual searches through selected journals. A number of existing databases are held at CSIRO Wildlife and Ecology which have been developed over a number of consultancies and include:

- the Ecological Impacts of Forest Use database (RAC 1993);
- a Minesite Rehabilitation database and
- a Forest Biota Responses to Disturbance database.

These databases have an Australian focus, but also contain some international literature and are held in Excel and PROCITE format. All databases were searched for titles dealing with *conservation value* and/or *regrowth* and/or *vegetation* and/or *regeneration* and/or *disturbance*. A search using these key words was then undertaken of holdings of the CSIRO Library Network and the National Library of Australia using Voyager OPAC software and these same key words were used to search CAB Abstracts (CABI), Current Contents (CC), Publications by CSIRO Authors (CSIX) and CSIRO Publications List (CSPUBLIST) using SIM-PCI software. The additional key words *old field* and *soil seed bank* were also used to search these databases. The final level of search was a manual examination of the Indices of all volumes of: *Australian Journal of Ecology, Proceedings of the Ecological Society of Australia, Australian Journal of Botany, Cunninghamia, Wildlife Research* and *Australian Wildlife Research.*

2.2 Literature Assessment Criteria

Searching using the four part approach retrieved a large amount of literature which was potentially relevant. This literature was then evaluated in greater detail to decide if it was of actual value to the review. Assessment criteria were developed in order to cull out those publications which were of marginal or no relevance to the Terms of Reference.

Literature was included in the full assessment if it:

a) focussed on native plant communities *and*
b) studied flora and/or fauna *and*
c) studied regeneration or regrowth *and*
d) focussed on human induced impacts

The review initially attempted to focus primarily on the literature pertaining to New South Wales, but it was soon apparent once the review was undertaken that literature specific to New South Wales would narrow the focus of the review and literature from further afield was therefore included where appropriate. In decreasing order of relevance, other literature reviewed came from eastern Australia, Western Australia, Australia generally and overseas.

As the literature obtained was dealing in one way or another with disturbance, the assessment criteria were developed based on the categorisation of papers by the type of disturbance that was being addressed. Disturbances resulting in regrowth of native plant communities were categorised as being either essentially non-anthropogenic or essentially anthropogenic, recognising that many of these effects can be synergistic and a given area of regrowth may have been cleared, regrown, logged, and burnt by both hazard reduction burns and wildfire at various stages in its history. The effects of fire are particularly difficult to partition into one category or the other, but given the vast literature in this field, it was essential to try and review only the most relevant papers. It is recognised that the two categories have a somewhat arbitrary cut off point, but a cut point was required to cull out those papers dealing with essentially natural disturbance regimes. Non-anthropogenic disturbances that result in regrowth included wildfire, drought, flood, wind, grazing, disease and senescence while anthropogenic disturbances essentially were sorted into papers dealing with regrowth resulting from clearing, fire, grazing, logging, mining and in some cases fragmentation. Those papers dealing exclusively with non-anthropogenic disturbances were excluded, as there is a large volume of literature both locally and internationally on this topic. Much of the literature dealing with wildfire and ‘natural’ vegetation disturbance dynamics falls into this category and was therefore excluded. Additionally, those papers dealing with the more interventionist fields of forestry management, minesite rehabilitation and restoration ecology (see Jordan et al. 1988 for an introduction into this field) were also excluded, unless there was some component of ‘unassisted’ regeneration in the study. That is, those papers dealing with sites where rehabilitation or restoration approached a labour intensive plantation or ‘garden’ were excluded, whereas those papers dealing with vegetation establishment from soil seed stores in topsoil were included.

Chapter 3 presents the results of the review and in order to provide a logical framework is structured by these six types of anthropogenic disturbances and within these, by broad vegetation structural classes or geographic area, depending on the scope of the papers considered in each section. Thus for example, papers dealing with closed forest regrowth resulting from clearing will be together but separately reviewed from those papers dealing with closed forest regrowth resulting from fire. Key review papers for each topic are also cited under each heading where appropriate.

3.0 RESULTS

3.1 Overall Review

Excluding review papers and background articles, one hundred and forty one papers were reviewed in detail, although very few were found that specifically addressed the topic and. These papers are summarised in Appendix 1. A further 62 additional papers from the local and overseas literature which may be of some contextual relevance but which have not been reviewed were also obtained via abstract searches. These papers are summarised in Appendix 2 and comprise 37 papers on old-field succession, 4 papers on regeneration / regrowth / remnants and 21 papers on soil seed banks.

Due to the relatively broad search criteria used, many papers were obtained which dealt with a variety of disturbances, both anthropogenic and non-anthropogenic and their impact on biological values. Of these, the particular subject areas of clearing, fire, grazing, logging, mining and to a lesser extent fragmentation can be identified as major themes. All of these subject areas contain a large amount of literature, both local and international. As the focus of the present review is the conservation value of those areas of regrowth native plant communities recovering from clearing and thinning events in particular, papers dealing with regrowth from fire, logging and fragmentation were more sparingly reviewed due to the broader range of issues covered, with a focus in these instances on review papers. The papers were grouped into broad subject areas by the type of disturbance which led to regrowth and are discussed below.

Literature dealing with the impacts of anthropogenic activity across a broader range of potential impacts and values, but focussed solely on forest systems, is summarised in RAC (1993) which summarises 225 papers and reports. Most of these papers deal with measurement of an impact rather than measurement of conservation value *per se*. Additionally, the human impact on Australian soils in particular is addressed in Russell and Isbell (1986). However, the demarcation between those papers dealing with an impact and those papers dealing with the assessment of conservation value was not always easy to define during the course of the present review.

3.2 Regrowth after Clearing and Thinning

3.2.1 Agriculture and Pastoralism

Introduction

While the impact of clearing on native biota has been much studied in the literature, the value of subsequent regrowth after clearing is a topic that has largely been ignored. Indeed, in the semi-arid woodlands of Australia and particularly in New South Wales and Queensland, regrowth native vegetation is generally seen in terms of its economic impact (as ‘woody weeds’) and the habitat value of patches to native flora and fauna has only very recently begun to be studied. The approach that emerges from the literature is that areas are regarded as being either native vegetation and hence implicitly ‘natural’ or else cleared and regrown and therefore implicitly ‘unnatural’. Much of the Australian literature has therefore dealt primarily with assessing the impact of human use in terms of species loss from an area or in terms of threatening processes to individual species or the general value of remnants. Few authors consider the possible chequered history of the remnants they are studying in terms of anthropogenic and non-anthropogenic disturbance of the vegetation and how this relates to the current floristic or faunal composition. Many authors view any stand of vegetation composed of native species as a remnant, which is true in the broad sense, but if applied strictly, the most extreme ‘natural’ end of the remnant spectrum should be an area that can be used as a bench mark against which human impact on other areas can be measured and which has no known or measurable history of human impact (although this may be defined as post European impact). Most vegetation in the agricultural and pastoral landscape will not fall into this ‘natural’ category. Obviously, this type of benchmark will be difficult if not impossible to find in anything other than a relative sense, although pollen analysis, tree ring techniques and the newer discipline of forest history may be able to assist in this process. What is important is that disturbance history be considered in the assessment of current patterns of species’ distribution and abundance.

Historical Background

Dixon (1892) gives one of the earliest insights into the effects of settlement and pastoralism on native vegetation in Australia from a perspective gained over 30 years as a grazier. Although observational, he cites examples from south eastern Australia of the types of regrowth or lack thereof from different forms of land use. Examples discussed include:

- *Eucalyptus camaldulensis*, *Acacia decurrens* and *A. pycnantha* regenerating after the exhaustion of soil by cultivation followed by cattle grazing, with species of *Stipa*, *Danthonia* and *Panicum* appearing underneath;
- abundant regeneration of Cypress Pine (*Callitris verrucosa* – presumably *C. glaucophylla*) in the Cobar district attributed to over grazing and hence a lack of bushfires;
- lack of any regeneration in the mallee lands (*Eucalyptus oleosa* and *E. gracilis*) of north west Victoria and South Australia after clearing and cropping;
- lack of regeneration of edible saltbushes on the Riverina.

He discusses the potential for regeneration from soil seed stores if grazing is removed but points to rabbit browsing as still being a major obstacle to regeneration in the absence of livestock. Interestingly, it is his opinion that fires under Aboriginal burning regimes were much less frequent in the coastal forests and arid interior but much more widespread on the semi-arid plains. He perceptively predicted that while there has been a massive impact on the Australian flora, those species growing on soils of a ‘*siliceous nature*’ for example sandstone, are most likely to remain comparatively unaffected due to the lack of suitability of these soils for cultivation or for carrying stock – the Sydney Basin National Parks certainly attest to this prediction, as does the inadequate area protected in areas of more fertile soils such as on the Western Slopes (see Hall 1988 for an elaboration on this theme in relation to reserved lands - the ‘worthless lands hypothesis’).

Reed (1990) provides a more recent historical perspective on the degree to which natural vegetation has been modified by European settlement and land use practices. By 1890, 98.5% of the land area of NSW had been leased or alienated and by 1921 it is estimated that half of the state had been ring-barked and partially cleared. Much clearing has also taken place post 1921. However, this impact was not uniform and was concentrated on gentler and more productive terrain to such an extent that it is estimated 95% of vegetation of the NSW sheep/wheat belt (Central Division of NSW) has been cleared. What is not readily discernible is to what degree certain areas have been cleared and regrown cyclically or which may have been cleared at least once in the past.

The evidence for tree decline in western New South Wales was reviewed by Allen (1983) and he discussed its extent and the substantial areas that have been cleared, while noting that certain specific areas such as around Cobar - Byrock have ‘problems’ of ‘excessive’ regrowth of inedible shrubs and eucalypt saplings. Duyker (1983) provides some further detail on the impact of land use on areas further west between the Lachlan and Darling Rivers (Western Division of NSW) and also discusses the apparent ‘scrubbing up’ of this area from open grassy woodlands to degraded areas with little grass and dominance by ‘woody weeds’, due to overstocking, the advent of the rabbit and a supposed change in fire regime (a more recent perspective on the amount of land still being cleared in the Western Division can be obtained from Turner, Ruffio and Roberts 1996). However, it is interesting to note that the regrowth in this context is seen as being a problem in itself, rather than being an indicator of overall condition of the land or a response to a severe form of disturbance. Mitchell (1991) and Noble (1997) discuss and summarise the historical and research perspectives on this particular issue dating back to the mid 1800’s. A similar effect is also described for the lower Snowy River area (Eastern Division of NSW) by Pulsford et al. (1992 and 1993). This study combined historical accounts and dendrochronology to determine past forest structure of white cypress pine forests and compared this to present day structure. The study concluded that prior to the early 19th century , the trees were large and well spaced. However, after a history of logging, grazing, burning and feral animal activity, the present regrowth stands are effectively ‘locked’, given the longevity of the species. Given the drastic changes to the soils in these areas, the future direction of succession in these regrowth stands is unclear in the short term.

Other historical studies relating to clearing, logging and fire have been undertaken by Lunney and Leary (1988) for the Bega district, Lunney and Moon (1988) for Mumbulla State Forest, Fensham (1989) for the midlands of Tasmania, Norris, Mitchell and Hart (1991) for the Pilliga forests, Lunt (1997a, 1997b) for the lowland Gippsland Plain in Victoria, Fensham (1997) for Queensland, Fensham and Fairfax (1997) for the Darling

Downs in Queensland, Croft et al. (1997) for the Central West of New South Wales and Morcom and Westbrooke (1998) for the western and central Wimmera Plains in Victoria.

Sivertsen (1993) provides a less historical but similar perspective for the box and ironbark forest and woodlands of New South Wales and Benson (1991) provides a broader but informative perspective on the overall impact of 200 years of European settlement on the vegetation and flora of New South Wales.

A recent paper by Benson and Redpath (1998) seeks to evaluate the nature of pre-European vegetation in south-eastern Australia in response to claims in popular and un-refereed literature over recent years that the present vegetation of south eastern Australia is essentially all ‘regrowth’ initiated after the cessation of frequent Aboriginal burning and that there are now more trees in Australia than prior to European settlement. The implication is that clearing of this ‘regrowth’ and frequent burning return the vegetation to its pre-European state. The thesis is popular with various rural lobby groups but is convincingly discredited by Benson and Redpath, who combine historical and plant ecological information to refute the various points raised by those supporting the thesis. While certain areas, particularly in the semi-arid woodlands of eastern Australia, have undoubtedly become denser through shrub encroachment and sapling regeneration as a response to overgrazing and clearing (see Noble 1997), far more areas have been permanently transformed by clearing than are currently affected by regrowth. The fact that vegetation is in any case dynamic seems lost in the argument. Similarly, some areas may have been more frequently burnt historically to encourage new green growth to attract game, but frequent burning cannot be shown to have been widespread across all vegetation types. The irony is that while supporters of the thesis argue that the ‘whole country’ was open woodland or grassland, it is precisely these types of vegetation on the tablelands and western slopes that have been most impacted upon by grazing and agriculture and which are very poorly conserved. Prober (1993) for example estimates that less than 0.01% of the grassy White Box (*Eucalyptus albens*) woodlands of New South Wales remain in a relatively unmodified condition.

Closed Forest (Rainforest and Mangrove)

In one of the earliest experimental Australian studies, Webb et al. (1972) studied the dynamics of canopy species in an experimentally cleared (bulldozed) gap in subtropical rainforest in Queensland. While there was much regeneration from seed, suckers from stumps and roots had largely, but not completely, overtopped seedlings after 12 years. A patchy structure had developed which differed quantitatively rather than qualitatively in composition and they concluded that succession under these circumstances is not unidirectional and while pattern is determinate in its response to environmental discontinuities it is probabilistic on a finer scale, producing patchiness. While the objective of the experiment was to study regeneration processes generally, the fact that the area was cleared with a bulldozer gives some insight into regeneration processes after clearing and soil disturbance.

In relation to cool temperate rainforest, Read and Hill (1983) studied the invasion of rainforest species onto a cleared field in Tasmania, in one of the few Australian studies looking at old-field succession. The area had been cleared for rough grazing 60 years previously by knocking the vegetation over, only leaving a few of the larger trees standing. Fallen timber was left on the site and the area was sown with pasture species. The area was subsequently abandoned and stocked at low levels with cattle for 30 years. Despite 60 years elapsing, the rainforest old-field had only reached the stage of a shrub dominated grassland with few ‘climax’ trees present. The main species invading the site was the bird dispersed *Drimys lanceolata* (syn. *Tasmannia lanceolata*) although the ‘climax’ species *Nothofagus cunninghamii* and *Atherosperma moschatum* were slowly invading from the edges. The logs left after clearing became foci for the regeneration of woody species. The very slow invasion of ‘climax’ species onto the site was attributed to the lack of bare mineral soil for germination and the poor dispersal ability of the species involved.

A number of studies have investigated aspects of seed banks and seed dispersal in relation to secondary succession. Hopkins and Graham (1984) assessed the viable soil seed banks in disturbed lowland tropical rainforest sites in north Queensland in relation to primary forest. The viable soil seed banks of those sites composed of regrowth from one cycle of clearing and abandonment were composed of mainly secondary species, as was the primary forest. However, regularly burnt and unburnt *Imperata cylindrica* grasslands had mainly agricultural weed seeds in the viable soil seed bank without any secondary species, with the greatest number of species occurring in areas that had not been burnt for five years or more. They concluded that soil seed composition is the important determinant in the initial floristic composition of a site following disturbance. Abdulhadi and Lamb (1988) studied soil seed stores in secondary subtropical rainforest in Queensland in regrowth stands aged 2 (storm), 20 (cleared and burnt farmland), 50 (cleared and burnt farmland) and 59 (cleared and burnt pasture) years and compared these to two undisturbed stands. They concluded that short term effects were a sharp decline in species richness and in seed density. A large increase in herbs follows, which they infer to have arisen from soil stored seed which in this instance they estimate may last for up to 50 years. Vine and shrub species temporarily increased after disturbance but declined after about 20 years. Seed populations of secondary tree species steadily increased over time being a maximum at the oldest regrowth site. Many of these species may live for 50 to 100 years. They also found a high proportion of exotic species in the soil seed pool. Their final conclusion was that a simple disturbance in these forests can have consequences for soil seed populations lasting up to 60 years. Unfortunately, this chronosequence suffers from the problem that the sites have different types of disturbance histories and in fact the storm damaged site came out more similar to the adjacent undisturbed forest than it did to the other disturbed sites, but this may not be surprising given the gross soil disturbance and habitat modification at the other sites. Willson and Crome (1989) studied seed rain between a tropical rainforest and an old-field near Atherton in Queensland. They found that there was a considerable exchange of seeds between the two areas but that both vertebrate and wind dispersed seeds moved further from forest to field than vice versa. They also found that vertebrate dispersed seed moved further into the field from the forest than wind dispersed seed. Habitat structure in terms of shrub cover affected seed deposition in the field such that foci were created around bushes where vertebrate dispersers perched or sheltered.

Kooyman (1996) discusses the replanting of rainforest rather than regrowth *per se*. However, he stresses an initial floristic composition model and multiple potential pathways for secondary succession. Soil seed reserves are predominantly made up of early successional species with mostly short viability, mature phase seeds, having to be brought in by birds, bats (or other mammals) wind and water. He cites the ability of some weeds such as lantana to block or deflect rainforest regeneration and succession by forming a cover that restricts or delays the regeneration of mature phase or secondary species. For example, the persistence of a lantana (*Lantana camara*) thicket in an experimental clearing in rainforest in south-east Queensland after 35 years, in a small gap. Additionally, some native secondary species such as *Acacia melanoxylon* and *Acacia aulacocarpa* can have a similar effect.

More generally, Hopkins (1981, see also a later review, Hopkins 1990) discusses disturbance and change in Australian rainforest. Secondary succession after a disturbance, for example clearing, can take a pathway that leads either to the floristic and structural characteristics of primary rainforest in which case it is described as being ‘reconstructive’ (‘progressive’) or else to a situation where the regrowth stand is completely different from the original in which case it may be described as being ‘arrested’, ‘deflected’ or ‘regressive’. The pathway taken will depend on the degree of physical and biological change that the site has undergone. Soil loss may or may not cause the regrowth to be different from the original forest, depending on the specific soil type found on the site and its nutrient characteristics. In the absence of gross physical modification, regrowth may still differ due to a lack of propagules for species re-establishment and due to the presence of aggressive weeds such as *Lantana camara*. The final composition of regrowth stands of rainforest will ultimately be a reflection of the degree of gross physical disturbance and the local availability of propagules, either in the soil or in the local area. Additionally, Summerbell (1991) provides a review of regeneration processes in humid subtropical rainforest in eastern Australia and Adam (1992) provides a more comprehensive review of rainforest regeneration and responses to both anthropogenic and non-anthropogenic disturbance.

The international literature dealing with secondary rainforest regeneration is large, but two papers were sufficiently relevant to be included in the present review. Blankespoor (1991) studied vegetation structure and bird communities in three early secondary habitats in Liberia and compared them to primary forest. Despite increasing bird community complexity over time, most species found were generalists and the proportion of secondary forest specialists increased with increased time of regrowth. Few primary forest specialists occurred in the early regrowth habitat. Turner et al. (1997) compared tree species richness in primary and 100 year old secondary tropical forest in Singapore. Analysis of 59 plots produced three floristic communities - one primary forest unit and two secondary forest units. They found that even after 100 years of succession and being adjacent to contiguous primary forest the secondary forest was still significantly less diverse than primary forest in terms of tree species. 16 plots in primary forest contained a total of 340 species whereas 43 plots in secondary forest contained a total of 281 species. They concluded that:

> *'.....secondary forest cannot be assumed to accrete biodiversity rapidly in the tropics, and may not be of direct value in conservation. However, other indirect roles, such as providing resources for native animals, and buffering and protecting primary forest fragments may make the protection of secondary forest worthwhile.'*

Mangrove communities are generally regarded as closed forest and two papers of relevance were evaluated dealing with estuarine areas. Bird (1978) details the extent of exploitation of mangroves and associated ecosystems for the soap industry in the mid 19th century and suggests that a significant yet unrecognised impact may have occurred in these systems. Implicit is that given the extent of the industry at the time, many stands of mangrove vegetation, particularly around the Sydney region are regrowth from this period. Similarly, Clarke and Benson (1988) state regarding the mangrove communities (*Avicennia marina* and *Aegiceras corniculatum*) at Homebush Bay in Sydney that: '*Many of these patches are of recent origin. For example those in Powells Creek are no more than 40 years old*'. The largest stand of swamp Oak (*Casuarina glauca*) found in the same area at Silverwater is also apparently regrowth and is no more than 55 years old. Nonetheless, an array of native plant species are present in these communities, many of which are now uncommon and of regional significance.

Open Forest (Wet Sclerophyll Forest, Dry Sclerophyll Forest)

Calaby (1966) reported the results of a survey of the mammals of the upper Richmond and Clarence Rivers in north eastern New South Wales. Despite a long history of agricultural, pastoral and silvicultural disturbance, the area supported a rich mammalian fauna spread across a diversity of habitat. Of particular interest is the fact that of only two small populations of Potoroo (*Potorous tridactylus*) found during the survey, one (on the Acacia Plateau) was in an area of regrowth eucalypt woodland with a dense understorey of *Poa* tussocks, adjoining cleared paddocks. Calaby also states that another population was found '*recently*' at Dignam's Creek in the Moruya area on the NSW south coast in: *'…..an area of dense Poa tussocks under Acacia regrowth on the edge of Eucalyptus-dominated wet sclerophyll forest along a creek'*. Whether the species was utilising marginal habitat in these instances or whether the regrowth areas provided a similar habitat to a now missing but previously more widespread habitat element in the new agricultural / pastoral matrix is not clear and was not commented upon by Calaby. However, he did note that; *'Fodder crops such as lucerne and oats are inhabited by the short-nosed bandicoot and are grazed by the red-necked wallaby, scrub wallaby, rufous rat-kangaroo, and perhaps other macropodids, if their natural shelter habitat is not far away'* which emphasises the potential complex interactions between populations of native fauna remaining in remnant vegetation, whether regrowth or not and the availability and utilisation of new food resources. Fox (1990) discusses these interactions between native and introduced species in new habitats that have been created via the establishment of urban, industrial and agricultural landscapes in Australia.

Tyndale-Biscoe and Calaby (1975) reviewed the impacts of forestry and agricultural practices on mammals of open and tall open forest ecosystems. As would be expected, the impacts varied between species, with the most catastrophic impact of clearing shown by populations of the greater glider (Tyndale-Biscoe and Smith 1969). The mountain possum also falls into this category and these two species may be regarded as being forest dependent. By way of contrast, those species which are not strictly forest dependent such as the ringtail and brushtail possums manage to establish readily in regrowth vegetation within the cleared or plantation mosaic. The eastern grey kangaroo also falls into this category, as does the common wombat which have both adapted to the cleared and plantation mosaic (see Calaby 1966 for information on the eastern grey kangaroo and McIlroy 1973 for the common wombat) and are exploiting new suitable habitat. Thus in the long term, it would be predicted that the array of fauna in a ‘disturbed’ area will change in species richness and abundance as the nature of the vegetation changes via the process of regrowth, if and when it is able to be initiated, and those species not favoured by the subsequent density of the vegetation will become scarcer. Catling (1991) supports this prediction for the understorey, with a different array of species following ‘disturbance’ by frequent fires.

The past and present vegetation on the Mornington Peninsula, near Melbourne is described by Calder (1986). This area underwent extensive modification from timber extraction, lime gathering and clearing for agriculture. There is no discussion of conservation value of regrowth *per se*., but the study provides by implication some information on the conservation value of regrowth. Calder states that:

> ‘*Very few people realise that there is no original “bush” on the peninsula, but that all the surviving forests, woodlands, scrubs and heaths are secondary or tertiary regrowth communities.*’
>
> and
>
> ‘*It is estimated that few of the existing eucalypt trees are more than eighty years old, and some are much younger. A few widely scattered individuals remain, giving some indication of the size of fully mature trees.*’

This seems to be one of the few tacit acknowledgements that even in areas regarded as ‘remnants’ of native vegetation, there is likely to have been some modification from clearing or grazing or logging in the past.

A number of papers have examined post clearing and grazing successional processes in Tidbinbilla Nature Reserve in the ACT. Neave and Tanton (1989) used exclosures in this area to assess the impact of grey kangaroos and rabbits on vegetation and fauna habitat. They found a change in height and structure in the vegetation (grassland) from grazing but less impact in terms of floristics. Kirschbaum and Williams (1991) studied the colonisation by pasture of the native shrub *Kunzea ericoides* (Burgan). This species spreads from existing isolated individuals or clumps to form essentially monospecific stands. Once established, the species can resprout after fire and can also recruit within closed stands. Initially regarded as a ‘pioneer’ species, evidence in the short term indicates that the stands formed by this species are quite stable and may stay in that state for at least 70 years and any replacement by other forest species may take some centuries (Allen et al. 1992) thus forming stable vegetation. If disturbance recurs again before the stands senesce, the process may start over again. Unfortunately, the interaction between grazing and the establishment and success of this species has not been studied.

Liangzhong and Whelan (1993) provide the only study located which focuses on regrowth on abandoned farmland on the east coast mainland. The study site in the Cordeax catchment consists of small areas which were resumed in the 1930's for catchment protection. Previous land uses were cropping, fruit and cattle grazing. After 50 years, these holdings still consist of large areas of Blady Grass (*Imperata cylindrica*) and Bracken Fern (*Pteridium esculentum*) on the more fertile soils, with some patches of *Acacia* regeneration on the less fertile soils. The study was able to find no differences in soil properties between the abandoned farmland and surrounding uncleared vegetation and hence the reason for the lack of regeneration remained unclear. This may provide another case of an area ‘locked’ into a stable (at least in the short term) post disturbance vegetation pattern, the potential tree canopy regrowth being effectively ‘stalled’ by grass and fern regrowth. Whether competition from the existing layer is a factor, or whether due to cultivation there are no potential canopy species in the soil seed store would require further research and the lack of even gradual encroachment from surrounding forest edges into the previously cleared area is puzzling.

Lunney et al. (1995) cite an example from Gunnedah where Koalas were reported to be increasing in numbers after recolonising regrowth vegetation that had been previously cleared in the 1920’s. It was thought that the Koalas had survived in the interim in refugial areas on steep slopes, State Forests and in Travelling Stock Reserves. However, this evidence is at best anecdotal as the information was gained via a State wide postal survey and no one has as yet investigated the area on the ground. There are other reports of Koalas utilising regrowth vegetation and while it is clear that much prime Koala habitat has been permanently destroyed, there is still debate as to whether or not Koalas are favoured by the regrowth created by logging operations in more marginal habitat.

There is a reasonably large body of literature from England and the United States of America investigating the history and composition of regrowth forests and woodlands on abandoned farmland. Peterken and Game (1984) assessed vascular plant species in ancient and recent woods in Central Lincolnshire in the U.K. and found that ancient woods had a greater species richness than recent woods and that those recent woods which were isolated had an even more impoverished flora due to their effects of isolation on propagule availability. Whitney and Foster (1988) found similar effects for woods in central New England, U.S.A.

Loeb (1989) documents changes in forest composition in an urban park in New York from 1660-1981 and gives an interesting insight into the waves of clearing and regrowth that can occur in an area over a relatively short time. Smith et al. (1993) provide a similar perspective for another area in New York from 1790-1993 and state that over half of the forest stands within the area under study are post agricultural regrowth. Interestingly, they state that this post agricultural forest has coalesced over the years so that the degree of fragmentation and isolation of forest stands is less now than compared to 1900. However, they note they there are many differences in plant species composition between these secondary and the original primary forests. Additionally, Matlack (1994) found significant differences in understorey species composition of successional forest in Delaware/Pennsylvania compared to old regrowth stands. Older stands had greater understorey richness than younger stands, but younger stands closer to old regrowth stands had greater understorey richness than those younger stands that were disjunct. Accessibility to sources of propagules appears to be a critical factor in determining the understorey richness of these regrowth stands and hence seed dispersal can be identified as an important factor in determining the composition of regrowth, particularly after long periods where the soil seed bank has been run down or exhausted.

Matlack (1997a and 1997b) further traces the effects of four centuries of forest clearance and regeneration in the same region. He argues that the secondary forest in the region is little like the original, although composed of native species. Importantly, he suggests that cultivation of the soil has created the most persistent environmental changes especially for example in eliminating the original pit and mound microtopography that provides habitat for many understorey species. The secondary forest are therefore less diverse when compared to the few remaining old regrowth stands.

Temperate Woodland, Heathland, Shrubland and Grassland

Although vegetation communities where trees are dominant may show obvious signs of regrowth, such as small stem diameters and dense stocking rates, the age or history of communities such as grassland are much more difficult to determine. Particularly in agricultural regions, exotic species will form a major component of the grassland and grassy woodland flora, if not in absolute biomass terms then at least in terms of numbers of individuals. Morgan (1998) maintains that even in relatively disturbance free and species rich patches of native grassland, generalist non-native species are numerous and must be considered to be a permanent part of the flora of remnant native grasslands. While a high biomass of exotic species may indicate a highly disturbed patch, the presence of exotic species *per se* is not necessarily indicative of low conservation value.

Williams and Kukolic (1991) discuss the results of fauna surveys in woodland and grassland patches in the northern part of the Australian Capital Territory. These woodland and grassland areas have a chequered history of human impact involving clearing, thinning, grazing and altered fire regimes. However, despite being semi degraded and generally regrowth, significant numbers of native species were discovered via pitfall trapping, consisting of 4 species of reptile, 8 species of frog and two species of mammal. Of particular significance was the trapping of the Striped Legless Lizard (*Delma impar*), a threatened species. The species is found in areas of dense *Stipa bigeniculata* or *Themeda* *australis* grassland and is absent from pasture improved areas. Significantly, the authors note:

> '*While information on the biology of* Delma impar *is lacking, it does appear that the species may be capable of recolonising areas that have been previously disturbed, if the native grass cover returns. For example, at two sites where a number of* D. impar *were captured (sites 1 and 5) the paddock had been ploughed and cultivated for a couple of years approximately 20 years ago, but had then been left to return to its "natural" state. It is obvious that the presence of a breeding population somewhere nearby was essential for the re-establishment of the species at these sites.*'

The importance of source populations for fauna recolonisation is important where areas are left to regenerate to a floristic and/or structural form similar to that before disturbance. The soil seed bank or at least the availability of a local seed source is also crucial to start the rehabilitation process.

McIntyre and Barrett (1992) stress that although in some instances, there are abrupt boundaries between vegetation remnants and intensively cleared areas, many landscapes are composed of a matrix of vegetation in various states of modification. This habitat variegation will affect different species in different ways, depending on their ability to utilise the modified landscape. They cite as an example the grassy woodland mosaic of the Northern Tablelands where some plant species are confined to the more intact remnants whereas other more generalist species can exist across the landscape mosaic. In this sense, regrowth components of the mosaic can be placed in a regional context as habitat for plants and animals and it seems implicit that such areas cannot be assessed in isolation from the surrounding habitat mosaic.

Lunt (1997c) compared the germinable soil seed banks of anthropogenic native grasslands and grassy forest remnants on the Gippsland Plain in Victoria, to test the hypothesis that both vegetation types are derived from a previous (pre-European) more general distribution of the component species in the area but that many years under two differing management regimes had led to a divergence into separate distinct grassland and grassy forest types. If this proved true, there may be significant soil seed reserves of many species in common between the two types. The study found more species and individuals in forest seed banks than in grassland seed banks and only 7% of the total flora (standing vegetation plus seed bank) were recorded solely from the soil seed bank. Major patterns of standing vegetation were reflected in the soil seed bank. There was essentially little overlap between the grassland and grassy forest seedbanks and the study did not support the hypothesis proposed. The results imply that management of these regrowth areas must be kept separate and that grassland species cannot be promoted in grassy forest patches and vice versa. It is implicit in the study that once an area has been managed under a certain disturbance regime for a significant period, it will not be able to revert to some previous floristic state due to the absence of soil stored seed and the likely absence of local propagules. This may mean managing areas that were once originally grassland as grassy forest and managing areas that were once originally grassy forest as grassland, because the species composition has been 'forced' in a particular compositional direction for a sufficiently long period of time.

The Cumberland Plain west of Sydney provides an example of an area where the remaining vegetation consists almost entirely of regrowth from 200 years of intensive settlement. Despite this fact, it is rarely tacitly acknowledged that any given ‘remnant’ on the Cumberland Plain is likely to have been cleared at some stage in the past, if not grazed and burnt as well. This is unfortunate because there has been much flora and fauna survey work undertaken in the area, particularly recently. Benson (1992) provides a vegetation map with descriptions of the units for the Penrith 1:100,000 topographic map sheet. Benson notes for the Grey Box Woodland type (*Eucalyptus moluccana – E. tereticornis*) that the present mean tree density in many areas is higher than reported from the early days of settlement due to the denser regrowth occurring following clearing or disturbance. The shrub Blackthorn (*Bursaria spinosa*) may also have increased after clearing and disturbance and is quite prolific, but the evidence for an increase in its abundance is equivocal. Benson (1992) states:

> ‘*Though much of the vegetation that now remains has been heavily disturbed, some remnants still carry quite a large number of native species.*’

A pertinent example of the high conservation value of the regrowth vegetation in this area is given by the fact that out of a list of 84 species of conservation significance in western Sydney, 44% were recorded in Cumberland Plain Woodland vegetation. A recent detailed flora survey of Western Sydney (James 1997) described 46 plant communities for the area of which 70% are endemic and limited to only a small number of sites. Also, 1300 species of plant were recorded in total of which 54 were threatened at a national or state level and 950 of which were regarded as regionally vulnerable. A fauna survey for the same area (Jones et al. 1997) found a far greater impact in terms of species extinctions and reduced species richness and abundance of the vertebrate fauna. Five threatened bird species, 5 threatened frog species and 2 threatened reptile species were none the less recorded for the area, although many more had been previously recorded indicating high levels of extinctions. Thus while regrowth vegetation in this instance has high conservation value both for representative and threatened plant species, the suite of fauna remaining appears to be more significantly depleted and less ‘representative’ than the flora and has fewer uncommon species – only habitat generalists and opportunistic species remaining due to a lack of suitable habitat and predation from introduced species such as cats and foxes. However, the degree to which fauna is responding to the suitability of regrowth habitat *per se* as opposed to the effects of fragmentation (patch size, connectivity) is unclear. Both would appear to be important factors.

Yates and Hobbs (1997a) provide a review of the status, processes threatening persistence and techniques for restoration of temperate eucalypt woodlands in both eastern and western Australia.

Semi Arid Woodland, Shrubland and Grassland (including Mallee)

Onans and Parsons (1980) studied regeneration of native plants on abandoned mallee farmland in north western Victoria on sites undisturbed for periods ranging between 1 and

39 years and compared these to virgin stands. While there was an initial early change after abandonment from exotic and native annuals to native shrubs, there was no subsequent regeneration of mallee eucalypts and the areas remained dominated by native shrubs, with a maximum of 52% species overlap with the virgin stands after 33 years. The one exception to this was areas cleared early in the century where the mallee tops were left in situ after clearing and not burnt, allowing seed to fall onto the site and the eucalypts to germinate and establish. Many of the hard seeded native legumes are likely to have persisted on the sites as soil stored seed and subsequently regenerated after abandonment, whereas the mallee eucalypts require an on site seed source. The regrowth, while composed of native species, was nonetheless apparently floristically different to its inferred pre-clearing state, which was not directly measured. Whether this effect is short or long term is unknown.

Conversely, Barron, Bishop and Dalton (1996) studied the use of direct seeding to regenerate degraded mallee vegetation in South Australia. Although the paper deals with assisted rehabilitation, one important finding of their work was that ripping surrounding mallee roots had a significant positive impact on survival rates of seedlings by reducing moisture competition. In the absence of ripping, seedling recruitment was hampered. In this way, small gaps once created in semi arid and arid areas may differ significantly in their composition due to the inability of mature vegetation to establish, particularly in the absence of fire in the case of mallee vegetation.

Dick (1993) and Dick and Andrew (1993) studied the vegetation and vertebrate fauna respectively for the Wombeira Land System on the floodplains of the Culgoa, Birrie and Narran Rivers in Western New South Wales. The area consists of extensive Coolibah (*Eucalyptus microtheca*) Forest and Woodlands. Some of the area has already been cleared and much of the remaining area is subject to applications to clear ('thin') 'regrowth' to improve pasture productivity. In this instance, the regrowth vegetation is from natural flooding events and will in the fullness of time self thin, but is none the less seen as a pasture management 'problem'. It was found that the area provided habitats for 9 mammal, 8 bird and 4 reptile species which are of conservation significance at a national, state or regional level. However, the area at present is best regarded as an example of non anthropogenic regrowth, despite landholder perceptions that the country is denser with saplings than before European settlement. What would be interesting to monitor is the resultant regrowth from clearing operations that have been undertaken so far and the species found therein. It is unfortunate that no one has yet undertaken studies in areas that are regarded as 'infested' with 'woody weeds' to ascertain which species of flora and fauna utilise them and what value they have. The economic and environmental issues surrounding this 'problem' are discussed in detail by Maher (1995), who also discusses similar issues with proposed clearing ('thinning') of Black Box (*E. largiflorens*) regrowth.

In one of the few experimental approaches identified, Johnson (1997) summarises the results of a long term study begun in 1964 (Johnson 1981) in which an area of brigalow regrowth has been monitored for 30 years after pulling and burning. The resultant sucker regrowth of 28000 brigalow stems per hectare 9 months after burning has now halved, with a significant loss of stems at 27 to 32 years post clearing (4000-6000 stems per hectare was noted pre-clearing). Most of the pre-existing understorey and canopy species are present in the regrowth but at lower densities and all ground species recorded in untouched surrounding areas have been recorded at some stage in the regrowth. He states:

> '*I have little doubt that given time mature communities that arise from remnant suckers will be indistinguishable from uncleared communities.*'

He advocates that large areas of brigalow sucker regrowth be conserved as the existing reserves have concentrated on small, virgin remnants and these alone will be inadequate for long term conservation. However, he stresses that brigalow is among the most resilient communities and that what applies for plant species conservation may not apply for animal species conservation. This is the only Australian paper found that specifically assesses the conservation value of regrowth native vegetation and finds a high value in regrowth stands. In this instance, the regrowth has high value not only because 95% of the brigalow belt has been cleared but because the regrowth retains a high floristic similarity to virgin brigalow, notwithstanding short term structural differences.

3.2.2 Exotic Softwood and Native Hardwood Plantations

Introduction

The large expansion of the area cleared and planted for softwood plantations in the 1970's (particularly Monterey Pine, *P. radiata,* in New South Wales) resulted in a surge of papers on this topic. These papers deal with the effects of the clearing of native vegetation for plantations as well as studies on the subsequent utilisation of the plantations by native species, particularly fauna. In many ways, the secondary debate as to the utilisation of the forest was a non-issue; one camp claiming that the plantations had no value for native species and that they were effectively 'biological deserts' and the other reacting to this when some native species were found to utilise the forest by asserting their importance. The truth was not really 'somewhere in the middle' of these two points of view but depended on the resources that the new habitat provided based on the ecology of the potential local biota that could utilise it. Hence, there were some species favoured by the plantations but overall, clearing essentially reduced suitable habitat for many species.

Fewer papers dealt with clearing for hardwood plantations (commonly Shining Gum, *Eucalyptus nitens*, in southern New South Wales and Flooded Gum, *E. grandis,* and Blackbutt, *E. pilularis,* in northern New South Wales).

Clearing for Softwood Plantations

One of the earliest studies dealing with the effect of clearing on native fauna (with implications for the conservation value of regrowth) was that of Tyndale-Biscoe and Smith (1969). They studied the effects of clearfelling for *Pinus radiata* plantations on the greater glider in Buccleuch State Forest and found that rather than moving to suitable habitat elsewhere, 90% of individuals died within one week of clearing of the habitat. Only a proportion of those individuals whose home range was partially affected by the clearing managed to survive. Thus, for this arboreal species, re-colonisation of any regrowth that occurred would need to come from surrounding populations.

Barnett, How and Humphreys (1977) studied small mammals in pine and native forest at Clouds Creek. They found that the exotic black rat and house mouse were restricted to pine plantations and that the native brown antechinus and mosaic tailed rat were restricted to native vegetation. One species, the bush rat, had viable populations in both pine and native forest. They contrast these results with earlier work from Victoria which found more native species had viable populations within the pine forest. Provided that these studies are not confounded by the presence of pockets of suitable native vegetation within the pine forest, it seems that some small mammals will respond in different ways at different localities to the same alteration of habitat. A further study (Barnett, How and Humphreys 1978) looked at the use of habitat components by these species within the pine and native forests which showed that all species were associated with separate habitat components. Curry (1991) also worked in this area and demonstrated the importance of windrows as a habitat type for bird species within the pine forest. Wind rows were of greater significance than distance from edge for some species and it was postulated that they acted as corridors allowing greater utilisation of the interior of the plantations. It was suggested that a range of successional stages throughout a plantation combined with windrows and retention of native vegetation within and near plantations would increase their structural and floristic diversity, and hence their suitability as habitat, for a wider range of potential biota.

Gepp (1976) discusses the utilisation of pine forest by birds in the Mt. Lofty Ranges near Adelaide. Essentially, an edge effect was detected with minimal utilisation at the centre of the plantation. The plantation was in a cleared and forested mosaic and hence utilisation of the forest occurred by those species whose primary habitat was adjacent. Suckling and Heislers (1978) studied populations of four small mammals near Myrtleford in Victoria in pine and eucalypt forests and found, as did the NSW studies, that maintenance of native small mammal species within pine habitat was dependent on the retention or regeneration of suitable patches of native vegetation within the plantation. A similar phenomenon is noted by Neumann (1978, 1979) for insect and beetle communities in the same area.

Friend (1979) studied the response of small mammals to clearing and burning of eucalypt forest for pine plantations in Gippsland Victoria. Small mammals were trapped before, during and after a clearing operation for pine establishment on ridges and in adjacent gullies. There was little survival or movement from the ridge areas, but *Rattus fuscipes* and *Antechinus stuartii* began recolonising the cleared areas (windrows) from retained gully habitat. A further study in the same area (Friend 1982) studied mammal populations in pine plantations and eucalypt forests. Not surprisingly, it was found that species richness was lower and the proportion of exotic species was higher in plantations and that most arboreal marsupials, insectivores, nectivores and tree hollow users were uncommon in plantations and were restricted to retained native forest. Mammal species richness was greatest adjacent to native forest and near edges. There was some persistence of some small mammals provided that some native vegetation was retained or allowed to regenerate. However, this example is less likely to be indicative of the effects of clearing habitat which is isolated and not in a matrix of native vegetation. This theme is taken up by Suckling (1982) who studied mammal conservation in the matrix of cleared, forested and plantation land around Traralgon in Victoria and advocated the linkage of these areas with preserved habitat to ensure the retention of fauna regionally. His disturbance variables were fire, grazing and logging but the role of regrowth in agricultural areas was not discussed.

Saunders (1974) provides an example of an exotic species (*Pinus* spp.) providing a major source of food for a native species - the white-tailed black cockatoo. Although the areas utilised are exotic monocultures and the birds do not breed within them , they are in a human modified mosaic within which occur areas of natural vegetation which will be suitable for breeding habitat for the species. What becomes clear is that the resources required for certain species will be spread across a landscape and hence the evaluation of an areas conservation value, particularly regrowth, may have to be ascertained at a larger landscape level taking into account the ecology of the species of interest and whether its habitat is localised or dispersed.

McIlroy (1978) provides an Australia wide review up to that time, most of the literature dealing with this issue coming from eastern Australia where the amount of area under *Pinus* spp. plantations is the largest. Due to public outcry at the amount of native forest being cleared for plantations (see Routley and Routley 1975), public policy gradually shifted to utilising previously cleared areas for plantations and the drop in publications on this issue through the 1980's reflects this change.

Clearing for Hardwood Plantations

Little information was found on the effects clearing for hardwood plantations or the subsequent use of them by fauna. Woinarski (1979) studied the bird fauna of a eucalypt plantation and adjacent native forest. In contrast to pine plantations he found no edge effect and that there were species that could utilise the interior of the plantation. Otherwise, there was the typical differentiation in species based on habitat usage between the plantation and the natural habitat, as has been found with pine plantations.

Floyd (1980) studied the density of Swamp Wallabies (*Wallabia bicolor*) in *Eucalyptus grandis* plantations on the north coast of New South Wales. He compared numbers in the plantation with numbers from adjacent wet sclerophyll forest and found low numbers in 1 year old plantation growth but high numbers in two year old plantation growth. In both the native forest and 10 year old plantation, numbers were low to moderate in the middle but high where the 1 year old plantation adjoined.

3.3 Regrowth after Fire

While there is a large volume of literature on fire ecology, particularly the responses of individual species, the present review focussed particularly on the effects of so called ‘hazard reduction’ burns and the effects of changes in fire regime – frequency (return time), intensity (low, moderate, intense, severe) and seasonality (summer, autumn, winter, spring) on the conservation value of the resultant vegetation.

New South Wales

Fox and McKay (1981) studied small mammal succession following fire in eucalypt forest with two types of understorey in Myall Lakes National Park. The forest with the heath elements contained a significantly more diverse small mammal community. They suggest that for some small mammals, understorey vegetation may be a better predictor of distribution than canopy vegetation. A replacement sequence in time was observed for species reaching their maximum abundance post fire which ranged from 1 year for *Pseudomys novaehollandiae* to 8 years for *Rattus fuscipes*. Maintenance of suitable habitat to preserve the range of species in the landscape would therefore require a mosaic of adequately sized patches at different seral stages to be maintained. Fox and Fox (1986) studied the effect of fire frequency on the structure and floristic composition of a woodland understorey at Myall Lakes National Park in New South Wales. They had one study site, part of which was burnt once in 12 years (at year 6), and the other part twice in 12 years, but in the same season and with the same intensity. 12 transects were used. Two years after the second fire, they found that that part of the site burnt twice in 12 years had significantly more plant species, higher shrub density and greater cover than that part of the site burnt once. However, this larger number consisted mainly of vegetative regenerators and those species found only on the part of the site burnt once were all obligate seedling regenerators. They suggest that the implications are that too frequent burning (less than 6 years) may lead to loss of obligate seedling regenerators while areas not burnt often enough (greater than 12 years) may lose some vegetatively regenerating species and short lived obligate seedling regenerators. Fox (1988) investigated understorey changes in terms of structure and composition following fire at Myall Lakes National Park using data from 60 plots in stands ranging from 1 month to 16 years post fire. While plant species richness was greatest at 16 years, plant species diversity peaked at 10 years and dropped significantly by 16 years.

Other work has been undertaken in the Sydney area and Nieuwenhuis (1987) describes the effect of fire frequency on vegetation of West Head in Kuringai Chase National Park. He found that obligate seeder species were most adversely affected while vegetative regenerators were favoured under frequent fires (2-5 years). Clark (1988) carried out simulated control burns to examine the effect on populations of understorey plant species on Hawkesbury sandstone on the Woronora Plateau near Sydney. 37 plant species on 12 plots were assigned to spring burn and autumn burn treatments and a control and were monitored for 6 years until a second fire treatment, after which they were followed for one year. Most pre-fire species returned by 12 months after fire. However, 8 species had numbers consistently below pre-fire levels regardless of treatment, 7 showed better recovery on the autumn burn plots and 8 showed better recovery on the spring burn plots. The overall pattern was that recovery was better in autumn after the first burn but it was better in spring after the second burn, in terms of both species richness and abundance. Post fire rainfall appears to be of considerable importance in this process and species recovering better after the spring fire had higher rates of survival and recruitment while those recovering better after the autumn fire had better recruitment only. He speculates that summer conditions after the spring burn favour survival from rootstocks while winter conditions favour recruitment from seed.

Morrison et al. (1995a) and Cary and Morrison (1995) suggest that there is a complex interaction between inter-fire intervals and time-since-fire that maintains a wide variety of plant species in any particular Sydney sandstone community. Variability of the length of the inter-fire interval increases richness of both fire-sensitive and fire-tolerant species. In further work investigations on fire frequency, Bradstock, Tozer and Keith (1997) found that high frequency fires did not affect species richness but can deplete populations of some heathland species and that in their study, the dominant species *Banksia ericifolia* was most affected as it is an obligate seeder. The results indicate that high frequency fire will simplify community composition and structure and that vegetation may shift from heath-shrubland to herb-sedgeland under such a regime.

Although little studied, invertebrates are becoming an increasingly important focus for research on the impacts of altered fire regimes, particularly due to their importance in decomposition and nutrient cycling. York (1996) investigated the impact of fuel reduction burning on invertebrates on the north coast of New South Wales and his conclusion was that:

> '*Frequent low intensity fire resulted in a change in ant community composition and structure. There was a loss of habitat and dietary specialists, an increase in the number of generalist species, and a dramatic increase in the abundance of a disturbance indicator species. This suggested that, although species richness may be maintained at a local scale, the widespread use of this management practice will result in the loss of invertebrate biodiversity on a regional basis*'.

More broadly, Catling (1991) reviewed the ecological effects of prescribed burning on the mammals of south-eastern Australia using 97 sites from four case studies (Nadgee Nature Reserve, Kosciusko National Park, Jervis Bay and Chaelundi State Forest), with particular reference to the long term relationships between two extreme fire regimes and forest structure - a long term regime (fire regime 1) of autumn burns at low intensity (<500 kW m`$^{1}$) and high frequency (<8 years) and a long term regime (fire regime 2) of spring burns at high intensity (>3500 kW m`^{1}) and low frequency (>20 years). He concluded that fire regime 2 would enhance the complexity of forest structure and that fire regime 1 would reduce it. This has implications for the habitat suitability of the forests for mammal species because as habitat complexity is lost, species richness and abundance decrease for many species, while abundance of those species favoured by open environments, particularly many exotic species, increases.

Eastern Australia

Ellis and Graley (1987) studied soil chemical properties in areas undergoing secondary succession from former eucalypt forest and grassland to temperate rainforest in Tasmania. The successional process started in areas after a decrease in fire frequency after about 1830. The only identifiable gradients detected in soil properties were an increase in total and mineralisable N and a decrease in pH with progression toward ‘climax’ vegetation. Nitrification was most rapid mid way in the process between grassland and rainforest. However, the overall conclusion was that the soil chemical composition was a reflection of the vegetation types they carried and not vice versa, as all sites were on the same parent material, granite.

The impact of fire regimes on native forests in eastern New South Wales has been recently and comprehensively reviewed by Williams and Gill (1995). However, while many studies have investigated the effects of one or two fires, longer term monitoring is required across a large number of stratified and representative sites to enable long term monitoring to be undertaken.

Western Australia

Christensen and Kimber (1975) reviewed the short term effects of prescribed burning on vegetation, some small mammals, macropods and birds in wet and dry sclerophyll forests in south-west Western Australia. They concluded that to maximise biodiversity and reduce the risk of species loss, prescribed burning should result in a mosaic effect. Factors unlikely to favour this mosaic are high intensity fires and very frequent fires. The small amount of data on mammals suggested that no one fire regime will encourage maximum population levels of all mammal species. However, birds appear to be far less sensitive to the changes brought about by fire. A further and later evaluation is provided by Christensen and Abbott (1989) who reviewed literature on the effects of fire on soils, nutrient cycling, micro-organisms, vascular flora, soil and litter and other invertebrates, reptiles, amphibians, birds, mammals and exotic plants in the wet and dry forests of Western Australia. The review looked at the effects of fire at varying levels of detail, from studies of the effects of a the intensity of a single fire through to fire regimes and noted that there have been few studies on burning regimes, as opposed to single fire events. They found no evidence for dramatic or permanent change in soil properties and nutrient cycles following low intensity fire. However, their summary of the effects of fire on biota is more equivocal and deals primarily with the response to a single fire event which they regard as only producing transient effects. They propose some principles as a guide to devising fire regimes which maintain conservation values and are compatible with fire protection objectives:

1) institute a high diversity fire regime including unburnt controls, minimising fires at the intense end of the spectrum;
2) monitor - a) special indicator species and b) core (keystone) species;
3) monitor direction of change in the community;

4) find out the nature of past fire regimes;
5) use relevant information from other places.

Essentially the same information base is used in Abbott and Christensen (1994) to derive principles of forest management (see also a response by Calver et al. 1996 and a counter-response by Abbott and Christensen 1996).

Australian Reviews

Gill (1975) provides one of the early reviews on this topic which provides a synthesis on fire as an environmental variable; adaptive traits and fire; species adaptations; ‘natural’ fire regimes and the role of fire regimes in management. Gill, Groves and Noble (1983) provide further detail on many aspects of fire as a disturbance factor and cover the areas of fire history, the physical phenomenon of fire, responses of the Australian biota, responses of selected ecosystems and the role of fire in ecosystem management. Given the large volume of fire literature produced since the early 1980’s, the Bibliography of fire Ecology in Australia (Gill et al. 1994) a valuable source of most of the literature on fire up to that time. Gill et al. (1994) has been used as a basis for a number of recent reviews including:

- fire and environmental heterogeneity (Williams et al. 1994);
- fire, biodiversity and fragmentation (Gill and Williams 1996).

Keith (1996) reviews evidence and synthesises theory relating to the fire-driven extinction of plant populations, for Australian vegetation. Primary drivers of plant extinction included high frequency fires, low frequency fires and fires with little vertical penetration of heat and smoke as these regimes were associated with multiple mechanisms of plant population decline. In relation to vertebrate fauna, Wilson (1996) provides a review of fire effects and implications for fire management and conservation.

3.4 Regrowth after Cessation of Grazing

While grazing by exotic herbivores is widespread on both improved and native pastures and the resultant general literature base is large, the review focussed only on examples of the response of native vegetation to the removal of long term grazing, as has occurred in the contrasting areas of the Australian Alps and in areas such as the semi arid Western Division of New South Wales.

Temperate Woodland, Heathland, Shrubland and Grassland

Wimbush and Costin (1979a) undertook grazing trials on two pairs of plots in sub-alpine grassland from 1957 to 1971, in Kosciusko National Park, after the general removal of grazing and burning from the Park. They found that nature conservation values were very sensitive to livestock grazing in both relatively natural and previously disturbed herbaceous subalpine vegetation due to selective grazing. Soil conservation and catchment values were not permanently impaired by several years of grazing in the absence of fire in natural vegetation but were sensitive to grazing in areas of previous disturbance. Monitoring of subalpine (Wimbush and Costin 1979b) and alpine (Wimbush and Costin 1979c) range transects between 1959 and 1978 after the cessation of grazing and burning indicated that trends were favourable for nature conservation and water catchment values. Snow Gum (*Eucalyptus niphophila*) regenerated where semi-bare ground existed under existing trees. Areas that had more shrub cover effectively prevented regeneration. In severely degraded areas, where there were no trees to act as a seed source, no regeneration occurred. Herbs re-appeared where there was good grass cover and shrubs did not. Other areas consisted of a grass shrub mosaic where disturbance had been more severe. In some areas, the shrub component was seen to be greater than before disturbance, but shrub senescence was predicted to occur over a number of decades. They estimated that some of the successional processes started would continue for at least another 30 years for subalpine vegetation and 50 years for alpine vegetation until mature communities were reached. However, some severely disturbed sites may never achieve their pre-disturbance state and lack of Snow Gum regeneration was a problem in some areas. They undertook additional work on the effects of subalpine vegetation regrowth on drainage characteristics (Wimbush and Costin 1983) and found that despite the absence of burning and grazing, channel widening was still active in those valley streams where the peaty floor had eroded and incision had begun. Vegetation was only slowly beginning to stabilise these channel edges and was estimated to take another 20 to 30 years before species such as Sphagnum would successfully re-establish and form low velocity bogs.

Similar research has also been undertaken in the Victorian Alps and Wahren et al. (1994) summarised long-term research into vegetation change in relation to cattle grazing in subalpine grassland and heathland in the Bogong High Plains in Victoria from 1945-1994. Grazing created more bare areas and prevented the regeneration of palatable forbs and herbs, which increased in the absence of grazing. Grassland was interpreted to be in a degraded state, but stable. In heathland, short lived shrubs are senescing but non-palatable shrub cover is increasing under grazing. In the absence of grazing, the grass shrub mosaic will depend upon which species germinate in bare areas and whether these species are seeders or sprouters.

Gibson and Kirkpatrick (1989) studied the effect of cessation of grazing on temperate grassland and grassy woodland at four sites on the Central Plateau, Tasmania. They found that vegetation response to cessation of grazing is strongly correlated with site productivity with the greatest changes in structure and composition occurring at the most productive sites. The higher altitude less productive sites take longer to recover from grazing and are impacted more in terms of bare ground and dominance of shrubs over grass than the lower more productive sites where grazing reduces competition from grasses and shrubs and increases herb species richness.

At lower altitudes, Lunt (1990) studied the soil seed bank of a *Themeda triandra* (syn. *Themeda australis*) grassland in Victoria which had been grazed for 70 years before becoming a Nature reserve in 1985. The seed bank was dominated by exotic species and contained few native species which were not present in the standing vegetation. He suggested that in these long disturbed patches, activities such as ‘ecological’ burning are likely promote exotic weed species as much as native species, even though the dominant species in terms of biomass is native. The native soil seed bank had been depleted for too long to be able to provide increased diversity of native species under a new disturbance regime.

Semi-arid Woodland, Heathland, Shrubland and Grassland (including Mallee)

Pidgeon and Ashby (1940) studied regeneration after protection from grazing near Broken Hill 2 years after fencing. They found that in fenced off areas, individuals present before fencing underwent marked growth; the density of perennial individuals increased in those areas that were previously heavily grazed; the mean density of annuals decreased and the overall variety of perennial and annual species increased.

The results of a major long term monitoring exercise are summarised by Hall, Specht and Eardley (1964) focussing on regeneration in the Koonamore Vegetation Reserve in South Australia, from 1926 to 1962. The Reserve, on degraded grazing land, was originally fenced to exclude sheep and rabbits, but the fence failed to exclude rabbits and native mammal species also grazed in the area. Where the perennial species have been overgrazed and the soil surface eroded, regeneration is poor even after the exclusion and control of sheep and rabbits. One interesting point noted was that certain denuded areas in the Reserve have been successfully recolonised from adjacent stands of *Atriplex* spp. which acted as a seed source. They cite the preferred conditions for regeneration as being the availability of source plants in the area that:

- flower and fruit readily;
- have seeds which remain viable till a favourable season for germination;
- have a high germination rate;
- obtain a suitable seedbed for establishment and
- have relatively unpalatable seedlings

Ironically, these sorts of species are otherwise known to graziers as ‘woody weeds’ and are certainly the species most able to colonise areas that have been significantly degraded by grazing activities.

3.5 Regrowth after Logging

Of importance in this topic area, as with fire, was the impact upon and hence conservation value of areas subject to a logging regime – frequency (rotation length), intensity (clearfelling or selective) and to a much lesser extent seasonality. Included here are the implications for conservation value of the impacts of forestry operations in general. The literature base here is large but many studies have been short term and speculative in nature and the long term effects over a number of rotations have yet to be studied. A number of reviews have been undertaken on various aspects of the effects of logging and these will be relied upon in this section where appropriate.

New South Wales

Due to controversy related to the woodchip industry on the south coast of New South Wales, a number of papers have discussed the results of studies in the Eden area. Braithwaite, Dudzinski and Turner (1983) studied the relationship between forest habitat and densities, species richness and diversity of eight species of arboreal marsupials at Eden. New South Wales. They found that high densities and diversity of arboreal marsupials were correlated with forests with foliage containing high nutrient concentration, large basal area of gums and peppermints, a longer time since fire and higher floristic diversity. This was not the case with forests composed of low foliage nutrient species such as *Angophora floribunda*, *Eucalyptus bosistoana* and *E. sideroxylon*. The response of arboreal marsupials to low foliage nutrient species may also be complicated by the presence of secondary (perhaps toxic) compounds and tougher waxier foliage which may be related to nutrient levels. They cautioned that no measure was made of the understorey flora, such as species of *Acacia*, which are known to be important for the sugar glider. For example, the sugar glider and to some extent the feathertail glider, seem to be favoured by post fire successional regeneration of *Acacia* species and reach peak densities up to 30 years post fire. Other arboreal species are still increasing in abundance post 30 years. Braithwaite, Turner and Kelly (1984) further studied this relationship in relation to soil parent materials and demonstrated that the vegetation communities with high concentrations of nutrients in the foliage occur on soils of high fertility, thus providing a predictor of the suitability of an area for arboreal marsupials based on geology.

Additionally, Braithwaite et al. (1989) surveyed bird species at 39 sites within 500000 ha. of eucalypt forest on the south coast of New South Wales. The area was divided into 31 eucalypt communities and altitude, temperature, rainfall, landform profile, basal area of dead trees, basal area of all trees, basal area of acacias and indices of foliage nutrient concentrations of nitrogen, phosphorous, potassium and magnesium were used as predictors. Bird species richness over all surveys and in summer was shown not to be correlated with the same environmental variables as the arboreal marsupial fauna in the Eden Region and was correlated with foliar magnesium and tree basal area. Bird species richness in winter was negatively correlated with altitude and temperature but was positively correlated with tree basal area.

Further research was undertaken by Kavanagh et al. (1995a) who studied the distribution of seven species of nocturnal forest birds and eight species of mammals as well as bats in two groups (microchiropterans and megachiropterans) in relation to the logged-unlogged mosaic in south-eastern New South Wales. They stratified the survey area by geology and logging history and sampled 200 sites. They found that at the compartment scale, geology, or its analog, was a more important factor affecting the abundance of most species of nocturnal forest birds and arboreal mammals than logging. At a broader scale, geology became less important than elevation and predominant vegetation community and some confounding effects between geology, elevation and vegetation community were evident. Little evidence was found to suggest that the present stage of logging has caused any major changes to the distribution of nocturnal forest birds and arboreal mammals. However, little insight is given by the data as to the effects of several cutting cycles on this fauna. Kavanagh et al. (1995b) duplicated their study from south eastern New South Wales in north eastern New South Wales and looked at eight species of nocturnal forest birds and nine species of arboreal marsupials from 291 sites. They used a larger number of environmental variables to determine patterns of species distributions. They found that the dominant gradient contrasted higher-elevation forests with lower elevation forests. A second major gradient contrasted wet forest types with a dense mesic understorey with dry forest types having an open or sparse understorey. A third major gradient represented logging intensity. The most species rich environments were the disturbed coastal environments while greatest numbers of animals were recorded in the higher altitude forests. Most species occurred with similar frequency in logged and unlogged forests. The interaction between disturbance and other environmental variables complicates the general patterns found, as the study reflects broader land-use patterns only.

In relation to reptiles and amphibians, Webb (1995) found differential effects on lizard species from woodchip operations in the Eden area, four years after harvesting. Overall, 5 species occurred in common between logged and unlogged area, 2 species occurred in unlogged coupes only and one species was found only in one logged coupe. To the north of the Eden area, Goldingay et al. (1996) assessed the impacts of logging on reptiles and frogs in forests near Queanbeyan. Their survey among coupes of different ages since logging indicated that previous logging had not adversely affected the commonly occurring lizards. However, information on the impact of logging on snakes and amphibians did not provide any clear answers.

Eastern Australia

Loyn et al. (1983) studied the effects of harvesting on the composition of understorey vegetation in dry sclerophyll forest in East Gippsland, Victoria. It was found that the understorey regenerated with essentially the same species that were present before harvesting. However, Kellas, Jarrett and Morgan (1988) found a change in potential overstorey species composition after the adoption of shelterwood cutting in Wombat State Forest, Victoria. Effectively a form of thinning, the operation was designed to assist regeneration of Messmate (*Eucalyptus obliqua*) but instead allowed suppressed lignotuberous growth of Peppermints (*E. dives* and *E. radiata*) to be released and grow. Thus a simple change in harvesting technique resulted in a change in dominance in this forest.

Effects may differ between forest types though and Hickey (1994) compared the floristics of 20-30 year old silvicultural and wildfire regrowth to oldgrowth in wet mixed eucalypt forest in Tasmania. Most species common in oldgrowth mixed forest were represented in a similar fashion in silvicultural and wildfire regeneration. Epiphytic fern species were less frequent in the disturbed forest than in the oldgrowth forest. It is estimated that at rotation length of 80-100 years sufficient rainforest element should be retained to return to mixed forest. Similarly in Victoria, Ough and Murphy (1996) assessed the impact of logging activities in Wet Forest in Toolangi State Forest. Two and a half years after logging and slash burning only 14% of the tree ferns were alive and only 6% remained upright. The health and vigour of the remaining tree ferns also declined after logging. Epiphytic species reliant on tree fern trunks as a substrate are also disadvantaged. Murphy and Ough (1997) found that the majority of regeneration in one year old clearfelled and regenerated Wet Forest near Mt. Baw Baw was from seed. Very few resprouting species were recorded, despite their commonness in adjacent unlogged plots. It was proposed that unlike fire, where resprouters predominate after disturbance, soil disturbance from logging may expose resprouting species and destroy storage organs. Slash burns afterward may enforce this effect and also stimulate germination of soil stored seed. Wang (1997) also found a considerable seed bank of understorey species in regeneration of Mountain Ash (*Eucalyptus regnans*) up to 54 years of age, but most of these were herbs, forbs and graminoids and woody species were not well represented.

Barry (1984) studied small mammals in subtropical rainforest in south east Queensland in relation to soil fertility and past logging disturbance. It was proposed that the interaction between these two variables reduced the abundance and diversity of small mammals.

In Tasmania, Duncan (1995) studied the use of silvicultural regrowth by fauna in dry sclerophyll forest in the east and wet sclerophyll forest in the south. Partial logging proved to be preferable to clearfelling from a fauna perspective as greater habitat diversity is maintained via the retention of unlogged patches in the coupe. Bat activity was greater in mature dry forest compared to young regrowth forest. Where the retention of stand structure after partial logging was similar to mature forest, bat activity differed less. There was no difference in bat activity between mature and regrowth for wet forest. Pygmy Possum captures indicated lower densities in logged forest than mature forest and lower in 17 year old regeneration than in partially logged forest. No difference was found between mature and regrowth for wet forest. For herpetofauna, species preferring open environments were favoured by clearfelling, although one species was disadvantaged by both partial logging and clearfelling. While species diversity in partially logged forest was the same as or slightly higher than mature forest, the abundance of species was lower. Bettongs proved more problematic and had not colonised 9 year regrowth but had colonised one of two 18 year old regrowth patches.

Information on wildlife corridors in relation to the mitigation of logging impacts on fauna in wood production forests in south eastern Australia has been reviewed by Lindenmayer (1994). He found that it is currently not possible to assess the adequacy of prescriptions for wildlife corridors and that in fact very little is known about which species benefit from their provision. Different species will have different requirements so it is difficult to formulate generic prescriptions for fauna. In terms of habitat suitability, Gibbons and Lindenmayer (1997) provide a comprehensive review of the conservation of hollow dependent fauna in timber production forests in south eastern Australia. This suite of species is considered most vulnerable to logging activities due to the decrease in hollows after logging. However, they found that few studies have addressed the problem in sufficient detail to be able to establish adequate guidelines for the retention of hollow bearing trees. Critical considerations are tree species; whether living or dead trees are required; tree form; branching habit; tree size

More broadly, Brown (1996) discusses management of Tasmania’s forests at the landscape level.

Although not regarded as logging, Mallee Broombush harvesting is similar in nature to logging as a natural product is harvested and then left to regenerate. Woinarski (1989) studied the effect of Broombush (*Melaleuca uncinata*) harvesting on vertebrate fauna in north western Victoria. A minor effect was noted overall as no vertebrate species are restricted to Broombush and most species recorded in the survey were found in harvested areas. A possible impact that may need monitoring is the decrease in habitat of a suitable age for certain species over the long term, but no short term impacts were able to be detected.

Australian Reviews

McIlroy (1978) provides one of the earliest reviews on the effects of forestry practices on fauna and Attiwill (1994a, 1994b) discusses more broadly the role of disturbance in forest ecosystems and the implications for forest management (see also comment by Lindenmayer 1995 and further reply by Attiwill 1995).

3.6 Regrowth after Mining

The literature base on minesite rehabilitation in general is large, but the present review concentrated on examples where the objective of rehabilitation was to establish self maintaining vegetation from retained soil seed stores or volunteer species. Although many areas of Australia were explored and mined for minerals last century, particularly during the gold era of the middle to late 1800’s, of particular importance in recent times is literature from silica sand, mineral sand and bauxite rehabilitation operations. Examples from the first two mines types come primarily from the east coast particularly north of Newcastle, whereas the bauxite examples are primarily from Western Australia.

New South Wales

Cambage (1923) made some initial botanical observations on an area that was denuded for fill for railway construction at Bargo near Sydney in 1918. The area has subsequently been resampled in 1962 (Hannon and Evans 1963) and 1989 (Morrison et al. 1995). After 71 years, and in the absence of any further disturbance, the area does not yet appear to be becoming floristically similar to the adjacent undisturbed vegetation and many bare areas still remain. However, as this area was stripped back to bedrock, the processes involved may be more akin to primary rather than secondary succession. The differentiation between these two types of succession will be less clear in cases where an unknown degree of soil or nutrient loss has occurred and in these circumstances it will be difficult to compare the similarity of current regrowth to that of pre-disturbance vegetation.

The extensive sand dune areas north of Newcastle have been the subject of much investigation over the past 15 to 20 years. Fox and Fox (1984) studied small mammal recolonisation (two rodents - the introduced house mouse and the native New Holland mouse) during the first ten years following mineral sand mining at Myall Lakes National Park New South Wales. The house mouse reached its maximum 3 years after mining and was associated with bare sand, soil hardness and vegetation structure. The New Holland Mouse reached its maximum 8-9 years after mining, after appearing at the 4-5 year mark and was associated with proportion of heath plants present, vegetation structure, amount of dead plant cover and topsoil depth. They found that this species replacement series in rodents is stretched in time such that the post mining environment (as opposed to the post fire environment) more closely approximates primary rather than secondary succession. Twigg, Fox and Jia (1989) further studied this issue using chronosequence analysis along an old mining path in Myall Lakes National Park. A ‘wave of succession’ moved along the mining path with early colonisation by the House Mouse (*Mus musculus*) an introduced opportunist, followed by the New Holland Mouse (*Pseudomys novaehollandiae*) a native opportunist and finally succeeded by the Common Dunnart (*Sminthopsis murina*) as the regrowth vegetation and hence habitat became more complex. The sequence was similar to that noted for post fire small mammal succession. Twigg and Fox (1991) studied terrestrial lizard fauna in the same area and concluded that while a successional process was underway, the process was proceeding much more slowly than the small mammals. Some species colonised as early as 5 years post mining, but other species were still absent after 15 years. They estimate a period of at least 20 years post mining for the reptile fauna to achieve its pre mining state. Fox (1996) summarises this work as well as the response of small mammals to fire.

In terms of vegetation recovery, Buckney and Morrison (1992) compared the floristic composition of mined and un-mined sand dunes in Myall Lakes National Park from 1982 to 1990. They found that the mined area was different from both adjacent un-mined dunes and the pre mining condition. In fact, the vegetation showed a decreasing similarity over time to the vegetation previously on the site. While species richness and diversity increased during the post mining period, a large proportion of this was attributed to introduced species. McNair (1993) studied post mineral sand mining regeneration with transects undertaken at Salamander Bay in the Port Stephens area and Bridge Hill and Submarine Beach in the Myall Lakes Region. He also studied post silica sand mining regeneration with transects undertaken at Tanilba in the Port Stephens area. He found little resemblance of post mining flora to pre mining flora and an apparent decline in the native plant species in both mineral and silica sand mining flora regeneration with no change after more than 20 years.

Other studies are attempting to compare the differential affects of different types of disturbance. Fox et al. (1996) compared regeneration at 44 sites at Tomago New South Wales in relation to burning, clearing and mineral sand mining. As the study is an interesting contrast between regeneration resulting from different disturbances, it is worth quoting the conclusion section of the paper at length:

> '*The chronosequence data demonstrates that regeneration of cleared or mined sites at Tomago is substantially slower than regeneration following the endogenous disturbance by fire*'…'*The severity of the impact of disturbance on vegetation structure increases from fire to clearing with mining the most severe impact. Seventeen years of regeneration on cleared and sand mined sites at Tomago has not been enough to return the vegetation structure or the soil characteristics to the pre-disturbance state. Understorey height and the amount of vegetation on cleared or mined sites have not achieved the levels in the original forest, although canopy cover does seem to have reached pre-disturbance levels.*'

Jackson and Fox (1996) used chronosequence analysis on 72 ant species from the same 44 sites at Tomago New South Wales to examine whether ant community structure varied with the type of disturbance and time since disturbance. They collected 25 habitat variables at each site covering vegetation structure, floristics, ground cover and soil variables with the key variables being percentage canopy cover of the site, percentage of bare ground and a vegetation index. Their results suggest that fire has a minor effect on the community over time while the impact of clearing and mining is much more severe. Species composition at cleared or mined sites, after 18 years, approaches but does not match controls. The ant species succession seems to closely follow the vegetation succession and hence may be used as a bio-indicator for evaluating the extent of habitat damage and recovery after disturbance.

Mining for gold has also resulted in areas of regrowth vegetation in central and southern New South Wales, although its impact is not easily documented. It is clear though that areas impacted by gold exploration and mining activities in the middle of the 19th century retain many biological values after mining has been abandoned and regrowth initiated. An example from southern New South Wales is the Major's Creek area south of Braidwood which was mined for gold in the middle of last century and consists almost entirely of relatively recent regrowth, but still retains a diversity of native plant species, which include the rare Araluen Gum, *Eucalyptus kartzoffiana* (M. Doherty pers. obs.). Although the composition of the area is not known prior to mining, the present composition appears to be a successful regeneration event to a severe but relatively short-lived impact.

Eastern Australia

Thatcher and Westman (1975) studied succession following mining for mineral sands on North Stradbroke Island. However, the study only investigated the site 5 years after mining. One interesting result was that plots closest to un-mined vegetation showed a greater rate of native vegetation reestablishment due to the availability of propagules. Hill and Phinn (1993) studying Swamp Wallabies (*Wallabia bicolor*) in the same area found that re-vegetated sites were most heavily used for grazing at night at 2 to 4 years post mining where vegetation was shrubby or grassy. Older sites offered little forage and were not utilised. Wallabies rested during the day in adjacent undisturbed eucalypt forest,

Further north, Unwin, Stocker and Sanderson (1988) studied the area around Rossville south of Cooktown in Queensland where alluvial tin mining has been carried out for 100 years. The evidence indicates that natural regeneration followed the cessation of mining on almost all sites. Generally, areas which were eucalypt forest reverted to eucalypt forest and areas that were rainforest reverted to rainforest. They claim an encroachment of rainforest via regeneration in the absence of Aboriginal burning into previously eucalypt dominated areas. However, the evidence presented is not sufficiently detailed to assess the validity of this claim, nor to assess how different the pre and post mining vegetation types are.

Western Australia

Curry and Nichols (1986) surveyed bird species in 5 to 10 year old rehabilitated bauxite mining areas. They found 21 species nesting in the rehabilitation but that 11 other species only nested in adjacent un-mined areas. The main reason for the difference was a lack of suitable hollows for nesting in the young regeneration.

Bell et al. (1990) describe the problems associated with establishing vegetation which is floristically similar to pre-mining vegetation for the Jarrah communities where bauxite is mined and the Kwongan communities where mineral sands are mined. In the first case, topsoil is re-spread after mining, but significant problems arise because the soil seed bank consists primarily of annuals and biennials and germinable seed of the longer lived woody species is hard to obtain. In the second case, canopy stored seed is successfully re spread after mining, but soil seed stores are proving difficult to germinate. Ward et al. (1990) further discuss bauxite mine rehabilitation in the Darling Range and report on research undertaken over a 10 year period. Important factors in returning mined areas to as similar a state as possible to the pre mining condition include using freshly stripped soil rather than stockpiled soil and returning log debris as habitat. They report relatively high proportions of reptile, bird, mammal, ant and collembola species returning to rehabilitated sites. Koch et al. (1996) found that soil handling operations in bauxite mining in Jarrah forest tended to drastically reduce germinable soil seed stores for rehabilitation. They traced soil seed stores at all stages from undisturbed forest which was then cleared and burnt, the soil stockpiled, re-spread and then deep ripped. The final seed content was 16 % of the original forest seed store density. Direct return of topsoil with minimal delays at all stages was recommended as a way of maximising retention of viability of soil stored seed. Roche, Koch and Dixon (1997) found that smoke enhanced seed germination for species in the Jarrah forest and for topsoil used for rehabilitation, with aerosol smoke proving more effective than smoke water. While the effect was demonstrable, the percentage germination of target species was still low. Ward, Koch and Grant (1997) found that for the best way of maximising the contribution of the soil seed store to revegetation of bauxite mines is to collect soil immediately after vegetation clearance in summer and return the soil directly to an area to be rehabilitated, completing all seedbed preparations before autumn rains occur. Grant and Koch (1997) investigated the soil seed store in 12 year old bauxite rehabilitation and found that the seed bank primarily reflected the canopy vegetation but that there was a predominance of annual weeds in this soil seed store.

In relation to sand mining, Bellairs and Bell (1993) discuss seed stores for restoration of species rich Kwongan vegetation. Seed reserves of the dominant woody species were held in the canopy in woody fruit. However, the soil seed stores in the topsoil were species rich with many other species. A combination of topsoil spreading and mulching with pre existing perennial vegetation ensures maximum propagule availability for all species. The possibility that obligate seeding species may be favoured by this treatment rather than the pre mining dominant obligate resprouting species was raised.

Australian Reviews

Majer (1990) reviewed long-term prospects for the recolonisation of fauna onto rehabilitated land, particularly in relation to ant species on mined areas. He found that patterns and rates of recolonisation depend on:

- the nature of the pre-disturbance environment;
- the size and degree of isolation of the rehabilitated area;
- the methods used for rehabilitation;
- climatic factors;
- competitive effects between colonising species
- the taxonomic group concerned and
- the intrinsic properties of the particular system

and suggested that long-term monitoring was necessary to determine successional trends.

3.7 Fragmentation Effects

The volume of literature associated with fragmentation is voluminous both in Australia and overseas. However, the literature on the effects of fragmentation and consequent conservation value of remnants has been concentrated on comparisons between the ‘natural’ fragments and surrounding altered croplands or pasture or else on before and after effects of clearing on the biota in specific remnants. The issue of whether the areas studied have themselves been cleared in the past or have some disturbance history which may confound experimentation is little discussed, as is the problem of habitat heterogeneity. Habitat heterogeneity is an important factor to consider in studies relating fragmentation to the equilibrium theory of island biogeography (Macarthur and Wilson 1967) and subsequent speculation relating to nature reserve design (see Diamond 1975). Margules et al. (1982) critically evaluate these concepts and they argue that:

- the equilibrium theory of island biogeography only concerns itself with the maximisation of species richness above all else;
- habitat is assumed to be homogeneous;

- the theory itself is still unsubstantiated;
- even if the theory is accepted, real islands are nor the same as terrestrial habitat islands.

They urge caution in the use of unsubstantiated concepts and argue that the reliance of the theory on the species-area relationship (first mathematically articulated by Arrhenius in 1921) is also problematic. Boecklen and Gotelli (1984) evaluate the species-area relationship as used in a variety of studies and conclude that it has a low explanatory power and frustrates reliable prediction. They also stress the importance of habitat heterogeneity as being a potentially important but ignored factor in many of these studies and that autecological studies would be a more fruitful approach, particularly in the study of endangered species.

Those papers which did specify some form of disturbance amongst the remnants, irrespective of the effects of the fragmentation events themselves, were concentrated upon in the present review.

New South Wales

Howe et al. (1981) studied bird distributions in small subtropical rainforest remnants near Dorrigo. Although acknowledging that some areas had regrown after clearing, this was not used as a measure in the study and livestock grazing was used as a disturbance factor instead. Size of remnant was the most important factor accounting for species richness, but this was modified by disturbance.

Eby (1991) summarises the small amount of information regarding the role of Grey-headed Flying Foxes as dispersers of rainforest seeds and as pollinators of *Eucalyptus* and other species in the Myrtaceae. Because of their large foraging range and ability to shift camp when fruit or nectar resources become available elsewhere, they can distribute genetic material, both as propagules and as pollen over very large distances. Hence, they could be pivotal (effectively ‘keystone’) species in the maintenance of rainforest remnants and in regeneration processes and in the cross pollination of *Eucalypt* species.

Further south, Dunstan and Fox (1996) studied the effects of fragmentation (island size, isolation and microhabitat) and disturbance on the abundance and species richness of ground-dwelling small mammals in 24 rainforest remnants on the Robertson Plateau, New South Wales. Small mammal species richness was low, but the two native species occurring (*Rattus fuscipes* and *Antechinus stuartii*) were abundant. Overall species richness and abundance decreased significantly with decreasing remnant size and increasing disturbance, and native species on their own responded even more significantly.

Linear impacts may also contribute to habitat fragmentation. Goldingay and Whelan (1997) studied the edge effects of powerline easements through eucalypt forest. While no edge effect was detected, 3 species of native mammal were trapped in the one easement where there was a dense cover of native (but non forest) vegetation. No mammals were trapped in intensively maintained easements. This implies that certain native mammals will utilise regrowth under powerlines, provided there is sufficient cover.

Eastern Australia

Bennett (1987) (see also Bennett 1990a, 1990b, 1993) conducted a study of mammals in a fragmented environment at Naringal in South West Victoria. He found that species richness of remaining mammal assemblages was determined to a significant extent by patch size, habitat richness within patches, grazing by cattle within patches and time since isolation of each patch. Large, diverse, ungrazed, recently formed patches would form one extreme whereas small, homogeneous, grazed, long-time fragmented patches would form the other. Hence any single variable on its own will not be an adequate predictor of mammalian species richness in fragments. Similarly, alteration of any one of the variables individually would be predicted to still have a significant effect on mammalian species richness.

Birds have also been the subject of many studies of fragmentation. Leach and Recher (1993) studied the use by birds of roadside remnants of softwood scrub, which included brigalow regrowth and areas with a significant woody weed understorey, in south eastern Queensland. These linear roadside remnants supported fewer birds than remnant patches but were still of some conservation importance. 40 species, mostly edge species, used the roadside remnants and the largest and most floristically diverse remnants supported the greatest diversity of birds. Grover and Slater (1994) surveyed birds in *Melaleuca quinquinervia* remnants in suburban Brisbane. As with other studies, there was a significant correlation between remnant size and bird species richness. This effect was modified depending on the condition of the understorey. Where the understorey approached a more open condition, remnants became uninhabitable for most forest and understorey species. Habitat and refuges are provided by these remnants for migrant, nesting, locally rare and uncommon species as well as species more dependent on this particular vegetation type.

Kirkpatrick and Gilfedder (1995) in an interesting study surveyed the vegetation in 100 remnants in the agricultural areas of sub humid Tasmania. They found no relationship between size, age and juxtaposition of the remnants and an index of threatened plant species. Threatened plant species could be found in a variety of remnants and some species were only found in remnants of poor integrity. They state that it cannot be expected that areas of high integrity will be coincident with areas supporting threatened plant species and a strategy of preserving remnants of high integrity as well as remnants supporting populations of threatened species is required. Disturbances that favour threatened species do not necessarily favour common species and vice verse. They found that there was a general tendency for the threatened species to be favoured by frequent disturbances.

The effects of powerlines as agents of fragmentation is an emerging field of research. Goosem and Marsh (1997) studied the effects on small mammals of a powerline corridor through rainforest in the wet tropics of Queensland. Although small mammals did not move across the highly disturbed areas of exotic grassland under the powerline, they were detected using regrowth connections along gullies to cross the powerline corridor. In a similar study, Macreadie et al. (1998) surveyed sclerophyll forest east of Melbourne and found five species of native mammals inhabiting regrowth vegetation under a powerline easement. In this instance, the powerline easement vegetation was comprised of three types of heath or gully vegetation and lacked exotic grassy patches. Effectively, this easement had the canopy removed but retained the major understorey components and hence despite frequent slashing, retained essential habitat components for small mammals.

Western Australia

Hobbs (1993) reviewed the scant literature dealing with the changes in ecosystem processes which have occurred as a result of rapid land clearance for agriculture in the wheatbelt of Western Australia, particularly changes occurring in physical and chemical fluxes across the landscape including radiation, wind, water and nutrients. It is speculated that the long term viability of ecosystem processes and hence the maintenance of their biodiversity within remnants will be largely determined by the ‘leakiness’ of the outside agricultural system in terms of its influence on the remnants via the above-mentioned fluxes. The importance of the processes operating both within and surrounding the fragment are stressed.

Australian Reviews

May and Norton (1996) review the influence of fragmentation and disturbance on the potential impact of feral predators (feral cat, fox and wild dog) on native fauna in Australian forest ecosystems and the role of wildlife corridors in particular as mitigating agents in the conservation of biodiversity is reviewed by Wilson and Lindenmayer (1995).

International Reviews

Saunders, Hobbs and Margules (1991) reviewed the biological effects of ecosystem fragmentation using Australian and international literature and discussed the physical effects on remnants of changes in microclimate (radiation fluxes, wind, water flux) and isolation (time since isolation, distance from other remnants, connectivity, changes in the surrounding landscape), They also discussed the operation of modifying influences (remnant size, shape, position in landscape) on these physical effects. Margules (1996) summarises recent key experimental studies from Australia and overseas on the effects of fragmentation with examples from Kansas (agricultural succession) and California (grasslands) in the United States of America and Wog Wog (forest) in Australia. A key observation that is of importance when considering the conservation value of fragments is that ‘continuous’ habitat is actually quite heterogeneous and different remnants will have different biological and physical conditions associated with them because fragmentation has isolated different components of a heterogeneous habitat.

4.0 DISCUSSION

4.1 Conservation Value of Regrowth – Synthesis of Available Information

Regrowth after Clearing and Thinning

The impact of pastoralism and agriculture on Australian vegetation has been extensive and profound. Many studies describe the impact of clearing and thinning on biota but few consider that many areas which are termed remnants today have in fact been cleared at some stage in the past. Despite some examples from semi-arid areas which indicate that there have been some shrub and sapling increases which are deemed undesirable, much of the vegetation now found across Australia has been extensively cleared, thinned or otherwise modified.

The type of regrowth arising from disturbance in closed forest is dependent on the local availability of propagules and the degree of soil disturbance. In the case of a simple clearing, many species will regenerate from rootstocks and the available seed store will form the rest of the available propagules. Despite initial loss of native plant species richness and an increase in exotic species in the short term, native species diversity may again increase in the long term in the absence of disturbance. Where rainforest has been cleared for pasture, regeneration is much slower and there is no guarantee that areas which have gone to pasture will even regenerate back to rainforest, particularly where no mineral soil is exposed. The more similar habitat there is in the vicinity, the more likely there will be propagules available and animals to disperse those propagules. Even short term effects in closed forest systems may last for at least 60 years. In the worst cases, exotic weeds regenerate in gaps and ‘stall’ the successional pathway indefinitely, effectively creating a new vegetation type. Many overseas studies have found that even after time intervals up to 100 years, secondary rainforest is still less species rich than primary rainforest.

Other examples from sclerophyll vegetation types also exhibit a similar phenomena of pasture stalling any further succession or weeds out-competing native species after disturbance, even where soil properties are apparently unaltered. The overseas literature in general also finds that temperate secondary forest is different from temperate primary forest and suggests that the degree of soil disturbance is a major determining factor in the subsequent composition of the regrowth vegetation. Nonetheless, certain rare species such as the potoroo in northern New South Wales and the Striped Legless Lizard in the ACT have been recorded from areas that have been cleared and regrown and even ploughed in historic times in the latter example, but the habitat requirements of such species are little known and the juxtaposition of suitable and marginal habitat may be critical in these instances. Similarly, Koalas have been reported from regrowth vegetation and are apparently capable or re colonising suitable regrowth habitat if local refugia are available through the period of clearing.

The fact that many areas of regrowth vegetation have a diverse weed flora does not necessarily erode their conservation value as it is the mix and relative abundances of native and exotic species which is important, rather than their presence *per se*. Historical management will influence the standing vegetation as well as the composition of the soil seed bank and hence the true potential floristic composition of an area can only be determined if both standing and soil seed bank data are adequately known.

Many studies have incidentally measured the conservation value of regrowth native vegetation by undertaking surveys in areas of regrowth, without necessarily acknowledging that the area under study has been previously cleared. The best example of this is the large amount of survey work undertaken on the Cumberland Plain west of Sydney. Overall, the remnant areas which are essentially all regrowth support a rich and diverse flora and a less diverse fauna but nonetheless have significant conservation value.

The only study undertaken that attempted to directly and experimentally assess the conservation value of regrowth native vegetation was that of Johnson (1981, 1997) in the brigalow belt in Queensland. Even in this instance, the study concentrated on flora and no equivalent faunal studies were undertaken. Johnson was able to clear an area of brigalow and study its regeneration and this was one of the few experimental approaches encountered. He maintained that the conservation value of regrowth brigalow was undiminished in the long term from just one clearing event.

In the more impacted agricultural areas, regrowth is seen entirely in relation to crop or animal production issues and hence is regarded as a problem to be solved rather than as something of habitat value. However, it is apparent that given the scale of impact in agricultural areas, regrowth in many areas is likely to be the only vegetation left which is at least somewhat representative of the original vegetation.

It seems that of all types of regrowth, it is that resulting after clearing that is the most unpredictable in terms of ultimate successional direction. Whether the area in question has been cleared and regrown or cleared and ploughed and regrown will determine the availability of propagules on site and hence the species that regenerate. The more soil disturbance there is and the longer the gap between clearance and cessation of impact, the less likely that native plants will be able to regenerate. Conversely, and importantly, the fact that there is any regrowth of native species on a site itself implies a lesser degree of impact than those sites which remain as exotic pasture or weeds, in the absence of further disturbance. Examples from the semi arid mallee region reinforce the point that the greater the soil physical disturbance, the less likely regrowth will occur. Hence the conservation value of regrowth from agricultural activities will be very dependent on how long the area has been cleared and or cultivated.

Regrowth after Fire

The assessment of the conservation value of vegetation after a regime of control burning is still in its infancy given the lack of long term studies and data. Conceptually, areas which have a history of control burning will in theory be structurally and floristically different from those areas that have not undergone such a regime, but the length of viability of the seed bank under these conditions is not adequately known and while there may be permanent changes at the site level, given the patchiness of fires, there may be a different response at the landscape level. Certainly, areas which have had very frequent fires are most likely to be adversely affected. Evidence suggests that both small mammals and ants are also adversely affected by frequent fire and also in the case of mammals, dependent on the size of the patch remaining and the amount of surrounding suitable habitat and hence the conservation value of areas with a frequent burning history may be lower for small mammals.

Regrowth after Cessation of Grazing

The work that has been done on regrowth after the cessation of grazing shows that there is a slow recovery of values in most areas, the harsher the climate, the slower the recovery process. Alpine and subalpine areas in New South Wales and Victoria are still recovering from the effects of grazing (and burning) and overall, herbaceous species diversity is increasing. However, some areas that have suffered massive soil loss and trampling etc. will be in a permanently degraded state. There is evidence from temperate areas to suggest that while less productive sites may take longer to recover from a grazing impact, the more productive sites suffer a greater degree of change to both structure and composition. The length of grazing will also determine the soil seed bank composition and long grazed areas may have little additional native species in the soil seed bank. In the semi arid zone, the most successful species at regenerating after a grazing disturbance are those species which are known as ‘woody weeds’ to graziers. The studies investigated reinforce the point that severe soil disturbance will have the greatest impact and may lead to different or stalled successional pathways. It is unclear which groups are most affected from previous grazing activities.

Regrowth after Logging

As with fire, no adequate experimental studies have been undertaken to assess the long term effects of logging and the subsequent value of regrowth arising from such activities. A variety of management practices have been evaluated and differing responses recorded from the flora and fauna. Many plant species are able to resprout from storage organs or seed and can effectively re occupy a site soon after logging, although changes in the overstorey composition have been noted where selective logging has been attempting to favour one species or where ‘timber stand improvement’ has been undertaken. However, the results from studies undertaken using a variety of mensurative approaches imply that logging *per se* is not as great an impact as the interactive effects of logging and fire. The exception to this are species of hollow dependent fauna and also mesic plant species both of which are not favoured by short rotation lengths. Previously logged areas are therefore most likely to suffer from a loss of conservation value as regards hollow dependent species.

Regrowth after Mining

Where mining operations either remove or totally reorganise surface materials, regrowth can be expected to either be very different from pre mining operations or else stall at a certain point in a successional pathway. Long term studies have found a successional sequence of small mammals as time since mining increases implying increased habitat complexity in relation to vegetative cover over time. Although this sequence is very similar to that noted from fire, it is a much slower process. Ant species have also been noted to follow a similar successional pathway. Although seed ecology in relation to rehabilitation is increasingly being studied, there are still difficulties in establishing much of the pre-mining flora in the rehabilitated areas. Once the soil seed bank has been disrupted in some way, it is difficult to re-establish in the short term. However, there is much greater scope for rehabilitation of mined areas which were in a natural or semi natural state prior to disturbance than there is of rehabilitating areas which have been cleared and cultivated for many years. Techniques such as rapid topsoil spreading from areas about to be mined to freshly mined areas can assist in the regrowth process.

Fragmentation Effects

Many fragmentation studies incorporate some form of disturbance rating into their investigations, but much work on the effects of habitat fragmentation may be confounded by the fact that areas being compared are likely to have had radically different disturbance histories or else some form of disturbance that may have eliminated more sensitive species early on. Most of these studies have no before impact measures of flora and fauna diversity. Disturbance, which can be partially related to the state regrowth vegetation, has been shown to reduce small native mammal diversity but studies from Tasmania have found that the occurrence of threatened plant species bore no relationship to size, age or juxtaposition of remnants and that some threatened plant species were only found in low value remnants. It may be the case that disturbances which favour rare species do not favour common species and vice versa and a dual approach to conservation may be required conserving both high integrity remnants and those which support populations of rare species. Some threatened plant species have been found to be favoured by frequent disturbance and it is thought that these species require the creation of frequent gaps by such agents as fire to successfully grow, flower and reproduce. This is thought to be the case with threatened species in grassland habitats.

Fragmentation effects from powerline easements and the utilisation of regrowth vegetation within these areas is an emerging area of investigation. However, the main point that is already discernible from the literature is that it is not the fragmentation effect *per se* that is important on the flora and fauna but the suitability of the regrowth habitat for these species. The study of fragmentation effects without recourse to an investigation of the specific habitat requirements of the species under investigation may therefore give misleading and confounding results.

Synthesis

Due to the heterogeneous nature of regrowth native vegetation and the lack of detailed studies, it is difficult to make generalisations about conservation value. However, the key points that emerge from the literature are:

- very few studies attempt to measure the conservation value of regrowth *per se* and there is a very large knowledge gap because of this;
- key disturbances resulting in regrowth are clearing and thinning, fire, grazing, logging and mining;
- fragmentation will further modify the effects of these key disturbances;
- regrowth vegetation is a complex manifestation of a disturbance and successional interaction which may or may not produce a form of vegetation similar to the pre disturbance community;
- exposed mineral soil, propagule availability and cessation of a major disturbance are critical requirements to achieve any form of regrowth;
- short term clearing impacts will not affect the regrowth process to the same degree as severe soil modification will (ploughing, fertilising, pasture improvement);
- in order of major disturbances taken as single factors and their effects on the conservation value of subsequent regrowth, the sequence from most to least impact can be represented as:

  cultivation > clearing > grazing > mining > burning > logging > ‘unaltered’

- synergistic effects between the major disturbances and their history will further complicate this pattern as, for example, an area that has been cultivated for a considerable period and subsequently mined will suffer such fundamental change that regrowth of native vegetation *per se* will be impossible;
- regrowth may be primary, secondary or even tertiary in origin;
- areas ‘representative’ of a vegetation type / community will be difficult to define due to the difficulty of defining a ‘natural’ analog;
- while exotic weed species may be present in regrowth areas, this will only be critical where they are forming a significant part of the biomass and hindering the regeneration of native species;
- regrowth can be the habitat of common species or rare and threatened species but no adequate predictor of the probability of the relative proportions of rare to common species exists due to the historical uniqueness of most areas of regrowth;
- there is some evidence that certain threatened species are favoured by frequent disturbance, but this is not universally true;
- the effects of disturbance will have differential effects on plant and animal species in general, notwithstanding individual differences among species. Many plants have a greater number of traits that will allow them to persist under disturbance – foremost among these is their modular nature which allows resprouting. Animals generally rely on recolonisation after disturbance, which relies on source and sink populations. Fragmentation will greatly affect the recolonisation process.

4.2 Importance of Regrowth Areas to the Maintenance of Biodiversity

The importance of regrowth areas to the maintenance of biodiversity will be proportional to the amount of the vegetation type already fully cleared or otherwise irrevocably developed. In a vegetation type that has been almost entirely cleared such as the White Box woodlands of Central Western New South Wales, any area of regrowth will assume some conservation significance. Specific details are required if a particular site has to be assessed. If on the other hand one was to consider regrowth in Hawkesbury sandstone vegetation in the Sydney Region, then regrowth areas on average would be assumed to be of far less conservation significance. Once again, specific site information would be required before a final decision could be made, due to the possibility of rare or significant species occurring on the site.

Regrowth should be seen as part of the continuum of states of a vegetation type and depending which associated species are being considered, a full spectrum of age classes may be required in some vegetation types in order to fully maintain biodiversity locally, regionally or nationally. There is no doubt that regrowth areas will be of some value for some species at some point in time. Whether rare or significant species occur at specific points in a successional pathway will unfortunately be species specific and no general pattern of occurrence has yet been observed, other than the fact that many such species occur in unique and restricted combinations of rainfall, temperature and geology. It follows that it can never be said that a given patch of regrowth native vegetation has ‘no’ conservation value, even if it is only habitat for widespread species. An area such as the Cumberland Plain may provide one of the best areas to investigate how to assess the conservation value of regrowth in relation to biodiversity conservation.

Given the long history of land use on the Cumberland Plain, there are few if any areas of native vegetation left that could be called pristine or fully natural. Most existing remnants of native vegetation on the Cumberland Plain have been previously cleared or thinned in the past and regenerated and may consist of secondary or even tertiary regrowth. The key factor in assessing the natural heritage values of these areas will be whether they now function as self replacing stands of vegetation, or in effect, whether they adequately perform ecosystem functions such as energy capture, nutrient cycling or soil retention. That is, do the canopy and understorey species regenerate sufficiently over time and interact with a functional soil system such that the stand of vegetation has some long term viability – a range of canopy and understorey species successfully regenerating with little weed invasion. It is apparent from the literature that the most important contributing factor to both the native species composition and the potential for weed invasion is a lack of major soil disturbance, both historically and at the present time. It seems clear from the literature reviewed that areas can be mechanically cleared, grazed or burnt and thus become disturbed, but if these impacts are short lived or of low intensity, the native vegetation can recover to varying degrees, depending on the disturbance regime imposed.

However, if the soil is disturbed in some more fundamental and direct way such as by mechanical cultivation, the addition of fertilisers or other forms of pasture improvement, the ability of native species to regenerate or recolonise is severely impaired. Some native herbs and grasses or other opportunistic species do persist even in these heavily disturbed areas, but most of the biomass in these instances is composed of exotic pasture and weed species. These areas could also in theory be regenerated with native species but with much greater effort as there is no soil stored seed and little input of propagules, particularly if the area is isolated from other remnants. Exotic and native herbivore pressure is also a factor in this capacity for regeneration, although this pressure is probably less important than the soil disturbance factor. In between these two cases are those areas which have a canopy composed of native species but a heavily disturbed understorey. This latter situation is more often the case with isolated trees in paddocks, where scattered timber has been left but the pasture has been improved for grazing.

On the Cumberland Plain, because the disturbance history of any given remnant stand of native vegetation may be unique and the concept that any given stand can be representative is probably erroneous. It is therefore inappropriate to try and allocate priorities to tiny patches of these vegetation types based on perceived notions of naturalness or their state of degradation. Effectively, a threshold point has been passed beyond which any area of remaining vegetation of that type must assume at least initially some conservation value. This could relate as a first approximation to those vegetation types which are represented by less than the nominal 15% of original extent recommended for the Comprehensive, Adequate and Representative (CAR) reserve system currently being put forward as part of the Comprehensive Regional Assessment (CRA) process. In the case of such poorly protected vegetation types as exist on the Cumberland Plain, it is the sum total of what is left that will contribute to long term conservation of plant species and communities, so assigning priority amongst what little is left, seems a misdirected exercise and one that will inevitably lead to further clearing and degradation of these vegetation types. Hence, establishing a hierarchy of conservation significance may be appropriate for widespread vegetation types but amongst small remnants of uncommon vegetation types, this approach is likely to be unproductive.

There are many factors to consider when determining the relative conservation value of a vegetation remnant and apart from condition, the use of vulnerable species may also be of use. However, the remaining areal extent of the vegetation type in question is of primary importance as a factor because beyond some lower limit, the presence of vulnerable species in one remnant versus their absence in another becomes less significant than the fact that the vegetation type generally has been so extensively cleared that any remnant assumes some importance simply because it is a remnant of the original vegetation.

What is important is adequate representation of the vegetation type in terms of area and species composition and this may be achieved by larger or smaller areas. However, no one area can be expected to be fully representative of the vegetation type, given stochastic factors such as fire and other disturbance and the natural variation of vegetation with environment. What needs to be avoided is the implied assumption that greater species richness is ‘better’, that is, that the site with the largest number of species overall or the largest complement of vulnerable species is ‘better’ than a possibly less diverse neighbour and that therefore the less diverse remnant is of no importance. This is not to say that a large number of regionally significant species found on a site is not significant, but that, logically, further subdivision of a remnant into smaller and smaller parcels for comparative purposes will always result in one area that is less ‘diverse’ than another and so on *ad infinitum*. There is often no clear benchmark to compare back to, to gauge what is in fact representative and what is anomalous. This is also a particular problem when a comparison is made between vegetation types where one may be inherently more species rich than another.

Hence, in the case of the Cumberland Plain Woodlands and Castlereagh Woodlands the lower limit of comparison has probably been reached such that all remnants are important and have some, probably high, conservation value. Given that the gradual attrition of what is left on private land still continues, remnants remaining on Commonwealth or State land for example assume an even greater importance, although the *Threatened Species Conservation Act, 1995* now affords greater protection to species and communities regardless of tenure. However, prioritising within these larger remnants, beyond the most grossly physically disturbed areas – that is, fully cleared and/or cultivated with no regeneration - is an exercise that guarantees further loss of these already threatened vegetation types and the restriction of populations of plants and animals to only a few key areas with attendant problems with the long term maintenance of these populations.

Process is the critical factor in the interpretation of the value of regrowth native vegetation. That is, the maintenance of ecosystem processes despite some form of past disturbance and the ability of the system to self perpetuate a suite of native species without significant interference. Of course, there is a fine line between the existing static measurement of the present conservation value of an area versus the dynamic ability of that area to be rehabilitated or restored to a higher value over time. Hence, while fire and exotic species management will probably be required whether an area is regrowth or not, there is the possibility that controlling these factors may enhance conservation value or restore degraded areas. Possibly, the best way of gauging the potential for restoration is whether the area of regrowth vegetation is relatively stable and not degrading over time, as measured by loss of species, continued invasion by exotic species and reciprocal loss of native species, or loss of soil resources. Debate as to how similar the area is to its pre-disturbance state in terms of floristic and faunal composition then becomes a secondary consideration, especially given the expectation that areas will almost always change in structure and composition after disturbance, at least in the short term.

Thus, conservation value of regrowth vegetation may be interpreted at a functional, structural or compositional level and the status of each level will have different implications for different taxa. Hence, while a functioning system will have a high conservation value overall, it will be especially important for native soil biota. By way of contrast, a structurally complex site may lack a fully functioning native soil system and be composed of a mixture of native and exotic species yet still provide important habitat for fauna, even threatened fauna. In relation to flora, an area may not be structurally complex enough to support an array of native fauna but may still reflect a compositional complexity of plant species or even simply conserve one threatened plant species, despite or in some cases because of, past disturbance.

Unfortunately, there is no simple generalisation that can be made from the literature in relation to the interaction between species richness, the occurrence of threatened species, structural complexity and successional stage as this interaction depends on the autecology of the species involved but also, more fundamentally, on the individual history of the area of regrowth under consideration.

4.3 Time Scale of Restoration via Regrowth

The time scale of restoration via regrowth, as posed by the Scientific Committee, may be an inappropriate question to address. This is because it begs the question: restore to what condition ? Pre European; pre Aboriginal ? In most if not all cases there is no benchmark state to measure against as all vegetation is disturbed to a greater or lesser degree and some areas will not have examples of ‘natural’ vegetation at all. That is not to say that an ‘analog’ site of some sort may not be able to be found – a type of vegetation that is decided as the end point, but it becomes problematic to talk of time scales in the expectation that the regrowth vegetation is necessarily heading in a certain successional direction. There are many examples where regrowth is different from surrounding vegetation but is nonetheless composed of native species and in an apparently stable state. The appropriate question to first ask is what present conservation value does the area have and is that likely to change in the foreseeable future. The trajectory or successional pathway of regrowth vegetation is likely to be dictated by a suite of local biological conditions conditioned by a number of stochastic events. In many instances, it will be difficult if not impossible to know whether the regrowth vegetation being assessed is more closely approximating primary rather than secondary succession, due to gross soil modifications and hence whether the vegetation should be expected to have a predictable end point.

The time scale of many successional processes may be measured in hundreds or even thousands of years and therefore the potential to predict how long it may take for a successional pathway to be ‘stabilised’ and restoration ‘completed’ does not appear to be great. The utilisation of the present state of any regrowth vegetation by biota may be all that can be measured in the short term.

Many examples exist of ‘stalled’ successions which are apparently stable over time, but given soil disturbance factors, these areas may not be so much stalled as different from the original vegetation. Examples of apparently stable but stalled successions not mentioned in the literature include patches of regrowth *Acacia* spp. on the east coast of New South Wales- *A. mearnsii*, *A. parramattensis* etc. on previously cleared areas (M.

Doherty pers. obs.), stable *Poa* spp. grasslands in thinned and grazed areas of the tablelands and the self perpetuating stands of ‘woody weeds’ of the semi-arid zone.

As to the relative ‘recoverability’ of overstorey versus understorey components, this will be particularly dependent on individual stand history. However, seed bank status and re-sprouting abilities will be a prime driver in recoverability. As time from disturbance to an opportunity to regrow lengthens, only those species with a high site ‘tenacity’ via some form of propagule retention will be able to recover. As a general observation, species of *Eucalyptus* and *Acacia* can germinate and establish even in highly modified pasture so long as there is some soil disturbance and an opportunity, such as ‘spelling’ from grazing, that allows growth beyond the browse line. This phenomenon is readily observable in many paddocks on the coast and tablelands of New South Wales and is facilitated by the retention of canopy species after clearing, grazing and pasture improvement. However, even in these instances, the long term viability and value of stands of individual eucalypts or wattles in the face of changed soil conditions and continued grazing or pasture improvement is questionable, as evidenced by the degree of tree dieback of both adult individuals and young regenerating seedlings and saplings. Landsberg et al. (1990) single out nutrient enrichment as the likely primary cause of rural dieback, both in terms of increased insect herbivory and overall ecosystem functioning. Only a cessation and possible decrease in nutrient levels would alleviate this problem.

Understorey components traditionally are fully cleared in pastoral and agricultural areas and hence their recoverability is much more difficult given the fact that all adult plants are normally eliminated. However, there are exceptions to this and species within the genus *Kunzea* (such as *Kunzea ambigua* in the Sydney area and *Kunzea ericoides* and *Kunzea parvifolia* on the Southern Tablelands) show a remarkable site tenacity through clearing and grazing and have a ‘woody weed’ status in areas where rough pasture has been abandoned (M. Doherty pers. obs.). Given the lack of data on seed bank viability, it remains an open ended question as to how long a disturbance such as cultivation must occur for, before the native soil stored seed becomes fully depleted.

4.4 Mechanisms of Persistence and Recovery after Disturbance:

The literature contains scant information specifically dealing with mechanisms of recovery for regrowth vegetation other than in a general sense. The major exception to this is the study by Johnson (1981, 1987) of Brigalow (*Acacia harpophylla*) in Queensland. This species is a re-sprouter and has the capacity to sucker *en masse* after a single clearing event. However, most other studies dealing with regrowth are assessing it post regeneration and hence mechanisms of recovery are not explicitly dealt with. Where small fragments are cleared, the possibilities of recolonisation by either flora or fauna become remote. The internal disturbance regime within the remnant will also be exacerbated by the patch size of the remnant and edge effects associated with small remnants. A further complicating factor is that the suite of available biota to recolonise is now larger then before and consists not only of local native species but of feral animals and exotic weeds. The relative potential contribution of different types of plant and animal responses to persistence and recovery is discussed below.

Flora

Soil Stored Seed Bank Harpur (1977) uses the term ‘genetic memory to describe what benefits a buried seed bank provides for a species. However, he also states that in many instances, this memory is short term as the majority of germinants in the absence of disturbance are from the previous one or two years crop. This of course is in the absence of enforced dormancy mechanisms and even in those instances of enforced dormancy, dormancy can be short or long term and stimulated to different degrees by different sorts of disturbance. Hence, hard seeded *Acacia* seeds may have their dormancy broken in the short term by a hot fire or in the longer term by gradual tinning of the seed coat in the soil. Other species such as Alpine Ash (*Eucalyptus delegatensis*) only have a short dormancy broken by cold winter temperatures enabling germination the next summer. Conversely, where soil disturbance is absolute as where an area has been ploughed for many years, it would only be a species that had the dual characteristics of having a soil seed bank with a long enforced dormancy that may be able to survive – a set of characteristics not known for any species of native plant. Soil that has been heavily disturbed by activities such as ploughing would be expected to carry a small or non existent seed bank of native species but a large seed bank of exotic weeds and pasture species. However, given the genetic variation found within species, it is also to be expected that species will have a proportion of dormant and non dormant seed types within the seed bank as a ‘bet hedging’ strategy.

Canopy Stored Seed Bank Unlike a soil stored seed bank, a canopy stored seed bank is much more vulnerable to clearing and particularly ploughing activities. Such species are unlikely to possess seeds with a long viability and may be predicted to become extinct after changes in disturbance regimes, particularly fire intervals less than the maturation period of the species or a sequence of clearing and cropping or grazing events which kill the adult population and do not allow for any regeneration.

Regrowth from Lignotuber, Basal Sprouts, Root Sprouts, Epicormic Buds Genetic memory can also be observed in clonal species which sucker or resprout in some way after disturbance, particularly fire. These species in many cases are more able to resist major disturbance and in many of the less diverse remnants, it may be predicted that those species remaining are likely to be those which have re-sprouting abilities, especially from woody rootstocks. Although many orchids and the native Yam Daisy (*Microseris lanceolata*) have underground storage organs and hence re sprouting abilities, they are reliant on the ability of the plant to photosynthesise each spring and under intense grazing pressure, these species cannot replace their starch reserves and eventually die. Similarly, although the grass species *Themeda australis* re sprouts after fire, it is not tolerant of heavy grazing pressure and will become locally extinct if overgrazed.

Wind or Animal Dispersal into the Site As disturbance becomes more intense and the soil more disturbed, the possibilities of persistence at the site lessen and colonisation may become reliant on dispersal of propagules into the area from suitable habitat elsewhere in the surrounding landscape. Most members of the Asteraceae are wind dispersed, but may still require a certain type of disturbance to successfully colonise an area, even in the short term.

Fauna

Survival in Situ (Refugia in the Area) Unlike plants, animal species are much less likely to survive in situ after a major disturbance. In the case of fire, some mammal species such as wombats are able to retreat to burrow systems or in the case of macropods, avoid the fire front in low to moderate fires. Provided that food is not limiting in the post fire environment, these species may persist on the site. Similarly, many bird species can avoid the fire front and move elsewhere. However, mammals such as koalas and the bulk of the soil litter fauna cannot survive in situ, even after a fire. The major factor in local survival in these instances is some sort of local refugia. However, in the case of clearing, habitat for most animal species will be totally removed and persistence on site is impossible.

Dispersal and Recolonisation. Given the difficulties of survival in situ for many animal species after a major or prolonged disturbance, dispersal and recolonisation abilities become important factors in the maintenance of animal populations at a site. Inability to disperse and recolonise due to habitat fragmentation and predation by exotic predators may have led to a situation where suitable habitat has regrown, but fauna has been unable to persist. In many instances, the conservation value of an area for fauna may need to take into account not only what fauna is actually on the site but also the ability of that site to conserve reintroduced fauna if deemed appropriate.

5.0 CONCLUSION

Conservation assessment, whether it is of areas of regrowth native vegetation or not, is problematic. Margules and Usher (1981) reviewed criteria used in assessing wildlife conservation potential and argued that the various criteria used could initially be divided into two groups – a ‘political’ group of criteria (threat of human interference, availability, educational use, amenity value etc.) and a ‘scientific’ group. They further divided the scientific group into three categories (p. 104):

Criteria which depend upon assessment during a site visit	Diversity Area
Criteria which require extensive survey work in the surrounding biogeographic region for their assessment	Rarity Naturalness Representativeness
Criteria which require appropriate case histories on the other sites for their assessment	Recorded History Potential Value Ecological fragility

All of these approaches require either the existence of or the ability to collect detailed site data. Austin and Margules (1986) discussed various components of these evaluation criteria and argue that if representativeness is to be used to select representative samples of the environment, an appropriate environmental stratification is necessary and that this criterion will be most important in areas where many of the species may well be undescribed. Criteria such as diversity and rarity are thought to be more important in geographical areas where the biota are well known.

The criterion of ‘naturalness’ is the problematic in its implementation. Anderson (1991) suggests that ‘naturalness’ can be defined as the way a system in question would function in the absence of human influence and stresses that naturalness is not a binary quality but that it exists as a continuum between complete naturalness and complete unnaturalness. He suggests three indices with which naturalness may be quantified, when used together:

1. the degree to which the system would change if humans were removed;
2. the amount of cultural energy required to maintain the functioning of the system as it currently exists; and
3. the complement of native species currently in an area compared with the suite of species in the area prior to settlement.

The usage of Index 1 is strictly hypothetical and being essentially hypothetical, is of very little value However, if applied to the Australian context, both pre-settlement Aboriginal and post settlement European impacts would need to be considered. Index 2 is in theory a measurable quantity and would be measured against the degree of change induced in a system when physical inputs of material and energy from humans are withdrawn, provided that the ‘functioning’ of the system could be defined and measured. Index 3 is in theory the most easily measurable quantity as a before and after measurement although it suffers from the likely problem of a lack of pre-settlement (pre-European) biological information A ‘best estimate’ may be possible and is certainly more tractable and realistic than a pre-Aboriginal 'best estimate'. Anderson also mentions a fourth possible index, suggested by Rapport (1989) as a measure of ecosystem 'health' and integrity which measures the proportion of native species in a total assemblage (that is, the number of native species divided by the number of native plus exotic species). The suggested fourth index does not take account of the biomass or relative abundance of exotic species - an area could have a large number of weed species all of which are small and of little ecological consequence in which case it would be calculated as being less intact than an area which is dominated by one or two species of weed which have a large biomass and which are exercising greater environmental control.

Sprugel (1991) is more cautious in his approach in attempting to define 'naturalness'. He cites examples from North America indicating a variety of situations in which the vegetation is not in equilibrium and suggests that it is ill-advised to identify a point in time as epitomising the 'natural' state, particularly for non-equilibrium systems. He rightly points out that in a non-equilibrium system the concept of *the* natural vegetation or disturbance regime is flawed, notwithstanding our inability to predict what might have happened in the absence of humans. He suggests four basic points about vegetational equilibria:

1. many types of natural vegetation are far less stable than they appear to be;
2. small or transient environmental changes can cause large and long-lasting vegetation changes;
3. every point in time is special;
4. because of vegetational instability, it may be impossible to define "the" natural vegetation or "the" natural disturbance regime in many areas.

He does not advocate that the notion of 'natural' vegetation or ecosystem processes be totally abandoned but that there are a range of potential states for the vegetation in any given area. Implicit in this assessment is the rejection of the concept of a 'climax' community for any given area and the acceptance of the concept of multiple successional pathways.

Taylor (1990) also discusses the concept of 'naturalness' but from an Australian landscape perspective. He argues that it is fruitless to try and distinguish between human and non human impacts on the vegetation in terms of 'naturalness' or to assume that there is any *qualitative* difference between Aboriginal and European ecological impacts on Australia's biota. However, he argues that there certainly is a *quantitative* difference in ecological impact such that post-settlement human impact forms a major disjunction along a continuum of human impact on Australia's biota since at least the late Pleistocene.

The post settlement landscape can thus be broadly split into 'natural landscapes' and 'human dominated landscapes' where the latter is characterised by the relatively new phenomenon of fragmentation of the vegetation due to broad acre agriculture and the dominance of exotic vegetation. He suggests that exotic vegetation in human dominated landscapes consists of three different types, although by his definition, only some regrowth vegetation would fall into the last category:

1. adventive vegetation (weedy)
2. cultivated vegetation (gardens, parks etc)
3. relict vegetation (degraded native vegetation - native canopy, exotic understorey)

and conversely that natural vegetation can be characterised by the presence of native species both in the canopy layer and in the understorey layer. As this is a landscape level approach, it gives no indication of how the conservation value or degree of modification of natural vegetation can be assessed at a finer scale and therefore the relative conservation value of a given patch of natural or indeed relict vegetation. It cannot be assumed that relict vegetation has *no* conservation value even if regeneration is not apparent.

It is apparent that most approaches in theory require some form of comparison of the post disturbance biota with other stands of the same ‘type’ that are less disturbed or undisturbed - the use of chronosequences or analog sites. Ideally, an experimental approach would be the most powerful, such as comparison of the post disturbance biota to some pre disturbance benchmark, as measured on the actual site - a ‘before-after-control-impact’ (‘BACI’) design (Stewart-Oaten and Murdoch 1986). However, the areas under consideration have already undergone their disturbance and would therefore only be amenable to a ‘space-for-time’ approach with the assumption that areas compared were a) similar before impact and b) had similar disturbance histories (see Pickett 1989).

It seems clear that a large component of the assessment of the conservation value of regrowth vegetation will in practice have to be a measure of its existing value for flora and fauna. There is a large body of literature dealing with the issue of habitat complexity and heterogeneity and it appears that this may be one fruitful avenue to pursue when attempting to assess the conservation value of regrowth stands of native vegetation.

For example, Dickman (1991) studied trees as nesting and foraging sites for 12 species of small native ground-dwelling mammals in 13 study areas between 1978 and 1990 in the forests in southeastern and southwestern Australia. He found that trees used for foraging were generally large, mature and with a complex system of branches and that over half of all nest/shelter sites were in trees, logs or litter. Catling and Burt (1995) presented the results of studies undertaken in 13 areas on the mid south coast of NSW between 1989 and 1992. They measured ground-dwelling mammal distribution and abundance in relation to basal area of trees, foliage nutrient levels and habitat complexity score. Previous work indicates that on a local scale where there is relative homogeneity in floristic composition, structural components of the forest are important. However Catling and Burt found that at the regional scale, composition of the ground-dwelling mammal fauna in south-eastern forests is determined by the complexity of the understorey, more so than nutrient status. Previous work also suggests that population sources generally are forest associations with high site productivity and the sinks are associations with low productivity. For arboreal fauna a threshold in nutrient status exists below which some species cannot persist regardless of structure whereas for small mammals, a threshold exists in forest structure below which they cannot persist regardless of nutrient status.

They conclude that a significant reduction in understorey complexity would result in a decrease in diversity and abundance of small and medium-sized mammals and an increase in large grazing mammals.

Further to this work, Cork and Catling (1996) reviewed, synthesised and drew together general trends from studies investigating the relationships between the distributions of arboreal and ground-dwelling mammals and environmental, structural and leaf compositional variables in the eucalypt forests of north and south eastern New South Wales. Studies on arboreal marsupials comprise two broad categories in terms of the explanatory variables which appear to be important:

1. studies suggesting nutrient status is the prime determinant of habitat quality
2. studies suggesting that structural variables may be equally or more important

These two explanatory themes can be seen as consistent with a hierarchical model whereby above a nutritional or phytotoxicological threshold structural and climatic variables become more important in explaining the distribution and abundance of arboreal marsupials. Structural variables such as habitat complexity alone have been found to be the most important predictor of ground-dwelling mammals. Hence, climatic or regional level measurements will not be an adequate predictor of species distribution and abundance at the local level, where structure becomes the most important factor and hence factors such as disturbance (from fire or logging) also become important determinants of species distribution and abundance.

Provided some soil or rock substrate is left exposed, colonisation by vegetation of some type is inevitable and whether this process is regarded as primary or secondary succession will ultimately depend on the previous state of that particular habitat. Regrowth vegetation will occur in many forms, as exotic weeds in an agricultural landscape or native species in a largely intact patch of forest. Disturbance of some sort ultimately mediates this process. The structural complexity and species composition may differ from the pre disturbance vegetation, but whether this is a short or long term phenomenon will be dependent on the specific circumstances of the regrowth. As well as physical clearing and cultivation activities, grazing and burning regimes will also influence the composition of regrowth.

Ultimately, the impact on soil seems crucial in determining pathways of succession, via seed bank dynamics and nutrient cycling. The interval between clearing and regrowth may also see significant soil erosion or salinisatioin such that the soil properties change and subsequently influence the type of vegetation that can re-establish. American studies have often related depth of erosion in old-fields to the depth of previous ploughing and hence the vegetation establishing on the old-field may be growing on B rather than A soil horizons and would therefore be expected to be different from the pre disturbance vegetation, although Walker (1986) maintains that land degradation through loss of the A horizon may be reversible whereas loss of the B horizon may mean that degradation is not reversible on a human time scale. Russell and Isbell (1986) provide an overview of the impact of major forms of land use in relation to Australian soils.

The fact that the phrase ‘only regrowth’ is used to denote an absence of conservation value in areas that have been disturbed and regrown can be seen to be misleading, as the implications of this review are that if there is regrowth of native vegetation on a site then there is at least some direct link back to the original vegetation via retained, albeit in a modified form, ecosystem processes and ‘genetic memory’. Where soil disturbance is massive and ongoing, no regrowth will occur. Many ex-intensively cultivated areas are stable ‘synthetic’ communities of weeds and pasture species as all soil seed stores have been exhausted. Grass is particularly notable for its competitive abilities and can block out tree and shrub regeneration for long periods, particularly in the absence of grazing.

It can therefore be strongly argued that any patch of regrowth vegetation will have *some* conservation value, as even agricultural and urban landscapes provide habitat for some native species. It is a matter of whether the value is of local, regional or national significance. The conservation value of regrowth vegetation can be assessed on at least three major levels:

- **compositional importance** e.g. as individual species within a vegetation type including threatened species; as a vegetation type;
- **structural importance** e.g. as fauna habitat
- **functional importance** e.g. as a functioning native ecosystem;

and either one or more of these levels may be important with any given patch of regrowth. Depending on the status of these three levels, regrowth may be more or less ‘natural’ or to some degree ‘synthetic’ (Bridgewater 1990) and can probably only be regarded as having little or no conservation value if it is totally dominated by exotic species and bears no similarity at all to ‘natural’ vegetation.

Therefore, conservation value exists as a continuum from areas totally cleared, ploughed and devoid of native vegetation in a human dominated landscape to those areas comprised of vegetation essentially in a natural landscape. There can be no absolute measure of conservation value and it must be seen that conservation value will always be a relative term, depending on the context of any given area of regrowth - its disturbance history, the amount of the vegetation type left etc. All values may not be contained within one area of regrowth and values may be spread across a number of sites with varying levels of disturbance. Values may also change in time - there is a spatial and temporal context to the conservation value of a given area of regrowth vegetation. Unfortunately for the Scientific Committee, the literature covering the field is not large and those studies that are most relevant to the scope of the review reinforce the view that individual site history is the major determinant in the conservation value of regrowth vegetation and detailed site information is required for evaluation. An approach to determine the conservation value of regrowth native vegetation is outlined in Chapter 6.

6.0 RECOMMENDATIONS

6.1 Evaluation Criteria

The following approach is put forward to assist the Scientific Committee in evaluating the conservation value of areas of regrowth vegetation. While the approach in theory requires a detailed level of information, steps can be flagged where there is no available information and this will identify specific knowledge gaps. Given the heterogeneous nature of regrowth vegetation in relation to space, time and history, there is no one simple method that can be used to assess the conservation value of a given patch of regrowth. At any step of the process, the Committee may be satisfied that the area under consideration does have high conservation value in which case all steps may not need to be undertaken. The approach assumes that a field inspection will be undertaken or that detailed information will be supplied to the Scientific Committee by another party.

The following guidelines should enable the Scientific Committee to gather adequate information for the evaluation of the conservation value of regrowth vegetation on a case by case basis. The evaluation process needs to consider:

Current State (Compositional Value):

- determine whether any flora or fauna of significance occurs on the site and if so determine its conservation status;
- determine native plant species richness and cover / biomass;
- determine exotic plant species richness and cover / biomass;
- determine native animal species richness and abundance;
- determine exotic animal species richness and abundance;

History and Habitat (Structural Value):

- determine the degree of previous major disturbance – how many years of control burning, how many times cleared, how many times cultivated and for how long;
- determine time since last major disturbance;
- determine if overstorey and understorey components are present;
- assess habitat complexity at the site;

Viability (Functional Value):

- determine the functionality of the soil-litter interface to gauge the viability of long term ecosystem processes. Measures such as litter quality and depth, soil organic matter and soil seed bank composition may be important;
- determine existing land use and surrounding land use and current and potential impacts and influences;

Context:

- place the vegetation into an available classification. Vegetation maps may or may not be available for areas under assessment, even if classifications are available;
- place the vegetation in a regional context. This will involve assessing which areas are environmentally similar to the area in question based on at least rainfall, climate, lithology, aspect and soil if known, as well as any vegetation maps;
- calculate the areal extent of the vegetation type or environmental unit;
- determine the reservation status of the vegetation type or environmental unit;

While this information should result in a stand alone assessment of an individual area, some analog site may still need to be chosen for comparative purposes.

In the absence of comprehensive data, an adaptive but conservative approach is warranted and it will probably be necessary to treat each case on its own merits in the absence of general principles. Unfortunately, the composition of a patch regrowth native vegetation will be as heterogeneous as its land use history has made it and it is therefore difficult to be predictive about trends in composition, structure or function of such stands.

6.2 Further Research – Gaps in Knowledge

As with many areas of ecology, the most crucial research need is for long term monitoring of flora and fauna to establish trends in time and space. Space–for-time substitution studies while more practical, will always suffer from the lack of pre-disturbance knowledge for each site. A variety of multidisciplinary techniques can assist in overcoming this problem, such as forest history and dendrochronology but there is no substitute for a well designed before and after / control and impact study.

While there is a tradition of old-field studies in England and the United States, the lack of old-field studies in Australia is not too surprising given our poor soils and short history of cultivation, as there tend to be few abandoned and regenerating fields to study. Nonetheless, there are areas that have a history of disturbance and which have been cleared and regenerated at least once in recent times. For example, the larger area within which the Wog Wog habitat fragmentation experiment is being undertaken on the south coast of New South Wales was cleared just after the turn of the century. However, the vegetation successfully regenerated because after clearing the land, the owner became involved in the First World War and apparently never returned to the property (C. Margules pers. com.). Other areas of dry sclerophyll vegetation near Goulburn which must have been regrowth from an older clearing event have recently been re-cleared and regrown in the space of a 10 year period (M. Doherty pers. obs.). Many areas seem to undergo waves of settlement and often when marginal properties change hands, new owners often re-clear vegetation to ‘improve’ the grazing or cropping capacity of the property. Hence, the concept of primary, secondary and tertiary regrowth is applicable in these instances.

The spate of clearing being undertaken in the western part of the Central Division and the eastern part of the Western Division over the past decade may also provide an opportunity for studying the effects of clearing on subsequent regrowth. However, such studies will need to be undertaken on a biogeographic basis and adequately stratified by vegetation type (even if broad) within climatic regions of interest. Unfortunately, for many areas, we will never know their relatively recent environmental history and whether they are in fact regrowth of some relatively recent origin or not, as many native plant species, including eucalypts, are difficult to age accurately.

Although studies on the conservation value of regrowth native vegetation are few and far between, it is the invertebrates which have been least studied in relation to their contribution to both decomposition and nutrient cycling and as pollinators of plants in relation to disturbance. Whether soil system functionality is maintained after major disturbance is critical to an evaluation of the long term viability of regrowth vegetation.

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Wimbush, D.J. and Costin, A.B. (1979c). Trends in vegetation at Kosciusko III. Alpine range transects., 1959-1978. *Aust. J. Bot.* **27(6)**:833-871.

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Woinarski, J.C.Z. (1989). The vertebrate fauna of Broombush *Melaleuca uncinata* vegetation in north-western Victoria, with reference to effects of Broombush harvesting. *Aust. Wild. Res.* **16**: 217-238.

Yates, C.J. and Hobbs, R.J. (1997a). Temperate eucalypt woodlands: a review of their status, processes threatening their persistence and techniques for restoration. *Aust. J. Bot.* **45**: 949-973.

York, A. (1996). Long-term effects of fuel reduction burning on invertebrates in a dry sclerophyll forest. Chapter 14, pp. 163-181 in: *Fire and Biodiversity. The Effects and Effectiveness of Fire Management.* Proceedings of the Conference held 8-9 October 1994, Footscray, Melbourne. Biodiversity Series, Paper No. 8. Biodiversity Unit. Department of the Environment, Sport and Territories, Canberra.

8.0 APPENDICES

APPENDIX 1: Core Regrowth References Spreadsheet

AUTHOR & YEAR	TITLE & CITATION	DISTURBANCE	REGROWTH TYPE	BIOTA	COUNTRY	STATE or EQUIVALENT	AREA
Abdulhadi, R. & Lamb. D. 1988.	Soil seed stores in a rainforest succession *Proc. Ecol Soc. Aust.* **15**: 81-87.	Regrowth after clearing.	Subtropical Rainforest.	Vegetation.	Australia.	Queensland.	South east Queensland - Lamington National Park.
Allen, R.B., Partridge, T.R., Lee, W.G. & Efford, M. 1992.	Ecology of *Kunzea ericoides* (A. Rich.) J. Thompson (Kanuka) in east Otago, New Zealand. *N.Z. J. Bot*. **30**: 135-149.	Regrowth after clearing.	Shrubland.	Vegetation.	New Zealand.	Otago.	South Island, North of Dunedin.
Barnett, J.L., How, R.A. & Humphreys, W. 1977.	Small mammal populations in pine and native forests in north-eastern New South Wales. *Australian Wildlife Research* **4**: 233-240.	Pine Plantation	Formerly Wet Sclerophyll Forest and Sub Tropical Rainforest.	Small Mammals.	Australia.	New South Wales.	North eastern New South Wales - Clouds Creek.
Barnett, J.L., How, R.A. & Humphreys, W. 1978.	The use of habitat components by small mammals in eastern Australia. *Aust. J. Ecol.* **3**: 277-285.	Pine Plantation	Formerly Wet Sclerophyll Forest and Sub Tropical Rainforest.	Small Mammals.	Australia.	New South Wales.	North eastern New South Wales - Clouds Creek.
Barron, P., Bishop, G. & Dalton, G. 1996.	Regeneration of degraded mallee vegetation using direct seeding *Aust. J. Soil & Water Cons*. **9(2)**: 40-44.	Regrowth after degradation.	Mallee.	Vegetation.	Australia.	South Australia.	Northern South Australia - Northern Murray Mallee.
Barry, S.J. 1984.	Small mammals in a south-east Queensland rainforest: the effects of soil fertility and past logging disturbance *Aust. Wild. Res.* **11**: 31-39.	Regrowth after logging.	Sub-tropical Rainforest.	Small mammals.	Australia.	Queensland.	South east Queensland - Cooloola.
Bell, D.T., Vlahos, S. & Bellairs, S.M. 1990.	Seed ecology in relation to reclamation: lessons from mined lands in Western Australia. *Proc. Ecol. Soc. Aust.* **16**: 531-535.	Regrowth after mining.	Jarrah Forest and Kwongan Shrubland	Vegetation	Australia	Western Australia.	North of Perth - Eneabba; East of Perth - Darling Range
Bellairs, S.M. & Bell, D.T. 1993.	Seed stores for restoration of species-rich shrubland vegetation following mining in Western Australia. *Rest. Ecol*. **1(4)**: 231-240.	Regrowth after sand mining.	Kwongan Shrubland.	Vegetation.	Australia.	Western Australia.	North of Perth - Eneabba.
Bennett, A.F. 1990.	Land use, forest fragmentation and the mammalian fauna at Naringal, south-western Victoria. *Aust. Wild. Res*. **17**: 325-347.	Regrowth after clearing, thinning.	Open Forest, Woodland.	Mammals.	Australia.	Victoria.	South western Victoria - Naringal.
Bennett, A.F. 1990.	Habitat corridors and the conservation of small mammals in a fragmented forest environment. *Land. Ecol.* **4(2/3)**: 109-122.	Regrowth after clearing, thinning.	Open Forest, Woodland.	Small Mammals.	Australia.	Victoria.	South western Victoria - Naringal.

Bennett, A.F. 1993.	Microhabitat use by the long-nosed potoroo, Potorous tridactylus, and other small mammals in remnant forest vegetation of south western Victoria. *Wildl. Res.* **20**: 267-285.	Regrowth after clearing, thinning.	Open Forest, Woodland.	Small Mammals.	Australia.	Victoria.	South western Victoria - Naringal.
Benson, D.H. 1992.	The natural vegetation of the Penrith 1:100000 map sheet.*Cunninghamia.* **2(4)**: 541-596.	Regrowth after clearing, thinning.	Open Forest, Woodland.	Vegetation.	Australia.	New South Wales	West of Sydney
Benson, D.H. & Howell, J. 1994.	The natural vegetation of the Sydney 1:100000 map sheet.*Cunninghamia.* **3(4)**: 679-787.	Regrowth after clearing, thinning.	Open Forest, Woodland.	Vegetation.	Australia.	New South Wales	Sydney
Benson, J.S. & Redpath, P.A. 1998	The nature of pre-European native vegetation in south-eastern Australia: a critique of Ryan, D.G., Ryan, J.R. and Starr, B.J. (1995) The Australian Landscape – Observations of Explorers and Early Settlers*Cunninghamia* **5(2)**: 285-328.	Regrowth after clearing, thinning, fire.	Open Forest, Woodland.	Vegetation.	Australia.	Queensland, New South Wales, Victoria.	South eastern Australia
Bird, J.F. 1978.	The nineteenth-century soap industry and its exploitation of intertidal vegetation in eastern Australia.*Aust. Geog.* **14**: 38-41.	Regrowth after clearing.	Mangrove, Littoral, Dry Sclerophyll Forest.	Vegetation.	Australia.	Queensland, New South Wales, Victoria, South Australia, Tasmania.	Various.
Blankespoor, G.W. 1991.	Slash-and-burn shifting agriculture and bird communities in Liberia, West Africa. *Biol. Con.* **57**: 41-71.	Regrowth after clearing, fire.	Tropical Rainforest.	Birds.	Liberia.	Grand Cape Mount.	Western Liberia - Sinje area.
Bradstock, R.A., Tozer, M.G. & Keith, D.A. 1997.	Effects of high frequency fire on floristic composition and abundance in a fire-prone heathland near Sydney*Aust. J. Bot.* **45**: 641-655.	Regrowth after fire.	Heathland.	Vegetation.	Australia.	New South Wales	North of Sydney - Brisbane Waters National Park.
Buckney, R.T. & Morrison, D.A. 1992.	Temporal trends in plant species composition on mined sand dunes in Myall Lakes National Park, Australia. *Aust. J. Ecol.* **17**: 241-254.	Regrowth after mining.	Dry Sclerophyll Forest - *Eucalyptus pilularis* .	Vegetation.	Australia.	New South Wales.	Central Coast - Myall Lakes National Park.
Calaby, J.H. 1966.	*Mammals of the Upper Richmond and Clarence Rivers, NSW.* Division of Wildlife Research Technical Paper No. 10. CSIRO, Canberra.	Regrowth after clearing.	Dry Sclerophyll Forest, Wet Sclerophyll Forest.	Mammals.	Australia.	New South Wales.	Northern New South Wales - Richmond and Clarence Rivers.
Calder, W. 1986.	*Peninsula Perspectives.* Jimaringle Publications, Melbourne.	Regrowth after clearing.	Dry Sclerophyll Forest, Heathland.	Vegetation.	Australia,.	Victoria.	Mornington Peninsula.
Cambage, R.H. 1923.	Plant invasion of a denuded area.*J. Roy. Soc. NSW* . **LVII**: 334-336.	Regrowth after fill extraction.	Dry sclerophyll forest on Hawkesbury Sandstone.	Vegetation.	Australia.	New South Wales.	Eastern New South Wales Bargo.

Cary, G.C. and Morrison, D.A. 1995.	Effects of fire frequency on plant species composition of sandstone communities in the Sydney region: combinations of inter-fire intervals. *Aust. J. Ecol.* **20**: 418-426.	Regrowth after fire.	Dry sclerophyll forest on Hawkesbury Sandstone.	Vegetation.	Australia.	New South Wales.	Sydney.
Catling, P.C. 1991.	Ecological effects of prescribed burning practices on the mammals of southeastern Australia. pp. 353-363 in: Lunney, D.L. (ed.). *Conservation of Australia's Forest Fauna.* Surrey Beatty and Sons, Sydney.	Regrowth after fire.	Dry Sclerophyll Forest, Wet Sclerophyll Forest, Heathland.	Small Mammals.	Australia.	New South Wales.	Chaelundi SF, Jervis Bay, Kosciusko NP, Nadgee NR.
Catling, P.C. and Burt, R.J. 1995.	Studies of the ground-dwelling mammals of Eucalypt Forests in south-eastern New South Wales: the effect of habitat variables on distribution and abundance. *Wild. Res.* **22**: 271-288.	Regrowth after fire.	Dry Sclerophyll Forest, Wet Sclerophyll Forest, Heathland.	Small Mammals.	Australia.	New South Wales.	Eden area.
Christensen, P.E. and Abbott, I. 1989.	Impact of fire in the eucalypt forest ecosystem of southern Western Australia: a critical review. *Australian Forestry* **52(2)**: 103-121.	Regrowth after fire.	Dry Sclerophyll Forest (Jarrah), Wet Sclerophyll Forest (Karri).	Animals, Vegetation.	Australia.	Western Australia.	East of Perth.
Christensen, P.E. and Kimber, P.C. 1975.	Effect of prescribed burning on the flora and fauna of south-west Australian forests. *Proc. Ecol. Soc. Aust.* **9**: 85-106.	Regrowth after fire.	Dry Sclerophyll Forest (Jarrah), Wet Sclerophyll Forest (Karri).	Animals, Vegetation.	Australia.	Western Australia.	East of Perth.
Clark, S.S. 1975.	Effects of hazard-reduction burning on populations of understorey plant species on Hawkesbury sandstone. *Aust. J. Ecol.* **13**: 473-484.	Regrowth after fire.	Heathland.	Vegetation.	Australia.	New South Wales.	Woronora Plateau.
Clarke, P. and Benson, D. 1988.	The natural vegetation of Homebush Bay – two hundred years of changes. *Wetlands (Australia)* **8(1)**: 3-15.	Regrowth after clearing.	Mangrove, Saltmarsh, Dry Sclerophyll Forest.	Vegetation.	Australia.	New South Wales.	Sydney.
Cork, S. J. and Catling, P. C. 1996.	Modelling distributions of arboreal and ground-dwelling mammals in relation to climate, nutrients, plant chemical defences and vegetation structure in the eucalypt forests of southeastern Australia. *Forest Ecology and Management.* **85(1-3)**: 163-175.	Regrowth after fire, logging.	Dry Sclerophyll Forest, Wet Sclerophyll Forest.	Arboreal and Ground Mammals.	Australia.	New South Wales.	South eastern Australia.
Croft, M., Goldney, D. & Cardale, S. 1997.	Forest and woodland cover in the Central Western Region of New South Wales prior to European settlement. pp. 394-406 (Chapter 73) in: P. Hale & D. Lamb. (eds.). *Conservation Outside Nature Reserves.* University of Queensland, Brisbane.	Regrowth after clearing.	Grassy Open Forests.	Vegetation.	Australia.	New South Wales.	Central Tablelands.
Curry, G.N. 1991.	The influence of proximity to plantation edge on diversity and abundance of bird species in an exotic pine plantation in north-eastern New South Wales. *Wild. Res.* **18**: 299-314.	Pine Plantation.	Formerly Wet Sclerophyll Forest and Sub Tropical Rainforest.	Small Mammals.	Australia.	New South Wales.	North eastern New South Wales - Clouds Creek.

Curry, P.J. & Nichols, O.G. 1986.	Early regrowth in rehabilitated bauxite minesites as breeding habitat for birds in the Jarrah forest of south-western Australia*Aust. For.* **49 (2)**: 112-114.	Regrowth after mining and rehabilitation.	Dry sclerophyll forest - Jarrah.	Birds.	Australia.	Western Australia.	South-west Western Australia - Jarrahdale.
Dick, R. 1993.	*The Vegetation of the Wombeira Land System on the Floodplains of the Culgoa, Birrie and Narran Rivers in NSW – November 1990.* Occasional Paper No. 13. NPWS NSW, Sydney.	Regrowth after disturbance.	Woodland.	Vegetation.	Australia.	New South Wales.	North western New South Wales - Culgoa, Birrie and Narran Rivers.
Dick, R. and Andrew, D. 1993.	*A Vertebrate Fauna Survey of the Culgoa and Birrie River Floodplains in NSW 1990-1992.* Occasional Paper No. 14. NPWS NSW, Sydney.	Regrowth after disturbance.	Woodland.	Animals.	Australia.	New South Wales.	North western New South Wales - Culgoa, Birrie and Narran Rivers.
Dickman, C. R. 1991.	Use of trees by ground-dwelling mammals: implications for management. pp. 125-36 in: Lunney, D. (ed.).*Conservation of Australia's Forest Fauna.* Royal Zoological Society of New South Wales, Mosman.	Regrowth after disturbance.	Dry Sclerophyll Forest, Wet Sclerophyll Forest.	Ground Dwelling Mammals.	Australia.	Various.	Various.
Dixon, S. 1892.	The effects of settlement and pastoral occupation in Australia upon the indigenous vegetation.*Trans. Proc. Rep. Roy. Soc. S.A* . **XV**: 195-206.	Regrowth after clearing, grazing, weeds.	Various.	Vegetation.	Australia.	Various.	Various.
Duncan, A.M.R. 1995.	*Use of Silvicultural Regrowth by Fauna.* Report to Forestry Tasmania and Department of Primary Industry and Energy, Canberra.	Regrowth following logging - clearfelling and partial logging in dry eucalypt forest and clearfelling in wet eucalypt forest.	Dry eucalypt forest in eastern Tasmania and wet eucalypt forest in southern Tasmania.	Bats, Pygmy Possums, Lizards and the Tasmanian Bettong.	Australia.	Tasmania.	Eastern and southern Tasmania.
Dunstan, C.E. & Fox, B.J. 1996.	The effects of fragmentation and disturbance of rainforest on ground-dwelling small mammals on the Robertson Plateau, New South Wales, Australia. *J. Biogeog* . **23**: 187-201.	Regrowth after clearing, thinning, grazing.	Temperate Rainforest.	Small Mammals.	Australia.	New South Wales.	Southern Tablelands - Robertson Plateau.
Duyker, E. 1983.	Land use and ecological change in Central New South Wales*J. Roy. Aust. Hist. Soc.* **69(2)**: 120-132.	Regrowth after change in fire regimes.	Semi-arid Woodlands.	Vegetation.	Australia.	New South Wales.	Central New South Wales.
Ellis, R.C & Graley, A.M. 1987.	Soil chemical properties as related to forest succession in a highland area in north-east Tasmania .*Aust. J. Ecol.* **12**: 307-317.	Succession after cessation of burning.	12 vegetation types in a mix of cool temperate rainforest, wet eucalypt forest,*Acacia* and *Leptospermum* scrubs, grassland and wetland.	Vegetation.	Australia.	Tasmania.	Northern Tasmania - Mt. Maurice Plateau.

Floyd, R.B. 1980.	Density of *Wallabia bicolor* (Desmarest) (Marsupialia: Macropodidae) in eucalypt plantations of different ages *Aust. Wildl. Res.* **7(3)**: 333-337.	Regrowth after fire.	Coastal Dry Sclerophyll Forest.	Small Mammals.	Australia.	New South Wales.	North Coast - Myall Lakes National Park.
Fox, B.J. 1996.	Long-term studies of small-mammal communities from disturbed habitats i eastern Australia. pp. 467-501 (Chapter 15) in: M.L. Cody & J.A. Smallwood. (eds.). *Long-term Studies of Vertebrate Communities* . Academic Press, New York.	Regrowth after mining and burning.	Dry Sclerophyll Forest, Woodland and Heath.	Small Mammals.	Australia.	New South Wales.	North Coast - Myall Lakes National Park.
Fox, B.J. & Fox, M.D. 1984.	Small-mammal recolonisation of open-forest following sand mining *Aust. J. Ecol.* **9**: 241-252.	Regrowth after mining.	Coastal Dry Sclerophyll Forest.	Small Mammals.	Australia.	New South Wales.	North Coast - Myall Lakes National Park.
Fox, B.J., Fox, M.D., Taylor, J.E., Jackson, G.P., Simpson, J., Higgs, P., Rebec, L. & Avery, R. 1996.	Long-term studies of small-mammal communities from disturbed habitats i eastern Australia. pp. 467-501 (Chapter 15) in: M.L. Cody & J.A. Smallwood. (eds.). *Long-term Studies of Vertebrate Communities* . Academic Press, New York.	Regrowth after disturbance.	Open-forest, Low open-forest.	Vegetation.	Australia.	New South Wales.	Central Coast - Tomago Sandbeds, north of New castle.
Fox, B.J. & McKay, G.M. 1981.	Small mammal responses to pyric successional changes in eucalypt forest. *Aust. J. Ecol* . **6**: 29-41.	Regrowth after fire.	Coastal Dry Sclerophyll Forest.	Small Mammals.	Australia.	New South Wales.	North Coast - Myall Lakes National Park.
Fox, M.D. 1988.	Understorey changes following fire at Myall Lakes, New South Wales. *Cunninghamia.* **2(1)**: 85-95.	Regrowth after fire.	Coastal Dry Sclerophyll Forest.	Vegetation.	Australia.	New South Wales.	North Coast - Myall Lakes National Park.
Friend, G.R. 1979.	The response of small mammals to clearing and burning of eucalypt forest south-eastern Australia. *Australian Wildlife Research* **6**: 151-163.	Clearing and burning for pine plantation establishment.	Formerly Wet and Dry Sclerophyll Forests.	Small Mammals.	Australia.	Victoria.	Eastern Victoria - Traralgon, Boola Boola State Forest.
Friend, G.R. 1980.	Wildlife conservation and softwood forestry in Australia: some considerations. *Australian Forestry* **43**: 217-224.	Pine Plantation.	Various.	Vegetation and fauna.	Australia.	Various.	Various.
Friend, G.R. 1982.	Mammal populations in exotic pine plantations and indigenous eucalypt forests in Gippsland, Victoria *Australian Forestry* **45**: 3-18.	Pine Plantation.	Formerly Wet and Dry Sclerophyll Forests.	Mammals.	Australia.	Victoria.	Eastern Victoria - Traralgon, Boola Boola State Forest.
Gepp, B.C. 1976.	Bird species distribution and habitat diversity in an exotic forest in South Australia. *Australian Forestry* **39**: 269-287.	Pine Plantation.	Formerly Dry Sclerophyll Forest.	Birds.	Australia.	South Australia.	South Australia - southern Mt. Lofty Ranges.
Gibson, N. & Kirkpatrick, J. 1989.	Effects of the cessation of grazing on the grasslands and grassy woodlands the Central Plateau, Tasmania. *Aust. J. Bot.* **37**: 55-63.	Regrowth after cessation of grazing.	Grassy Woodlands.	Vegetation.	Australia.	Tasmania.	Central Plateau.

Goldingay, R., Daly, G. and Lemckert, F. 1996.	Assessing the impacts of logging on reptiles and frogs in the montane forest of southern New South Wales. *Wild. Res.* **23**: 495-510.	Regrowth after logging.	Dry Sclerophyll Forest, Wet Sclerophyll Forest.	Reptiles, Frogs.	Australia.	New South Wales.	Queanbeyan area - Tallaganda State Forest.
Goldingay, R.L. & Whelan, R.J. 1997.	Powerline easements: do they promote edge effects in eucalypt forest for small mammals. *Wildl. Res*. **24**: 737-744.	Regrowth after clearing for powerline easements.	Wet Sclerophyll Forest, Dry Sclerophyll Forest.	Small Mammals.	Australia.	New South Wales.	South Coast - Bulli Tops, Currambene State Forest, Yerriyong State Forest.
Goosem, M. and Marsh, H. 1997.	Fragmentation of a small-mammal community by a powerline corridor through tropical rainforest. *Wildl. Res.* **24**: 613-629.	Regrowth after clearing for powerline easements.	Tropical Rainforest.	Small Mammals.	Australia.	Queensland.	North Queensland - Wet Tropics.
Grant, C.D. & Koch, J.M. 1997.	Ecological aspects of soil seed-banks in relation to bauxite mining. II. Twelve year old rehabilitated mines. *Aust. J. Ecol*. **22**: 177-184.	Regrowth after mining.	Dry Sclerophyll Forest - Jarrah.	Vegetation.	Australia.	Western Australia.	Darling Plateau, south of Perth - Jarrahdale, Huntley and Willowdale.
Grover, D.R. & P.J. Slater. 1994.	Conservation value to birds of remnants of *Melaleuca* forest in suburban Brisbane. *Wildl. Res*. **21**: 433-444.	Regrowth after clearing.	*Melaleuca* Forest.	Birds.	Australia.	Queensland.	South eastern Queensland Brisbane.
Hall, E.A.A., Specht R.L. & Eardley C.M. 1964.	Regeneration of the vegetation on Koonamore vegetation reserve, 1926-1962. *Aust. J. Bot.* **12**: 205-264.	Regrowth after clearing, grazing.	Semi arid woodland and shrubland.	Vegetation.	Australia.	South Australia.	North eastern South Australia - Koonamore Station.
Hannon, N.J. & Evans, O.D. 1963.	The regeneration of plant cover on a denuded sandstone area. *Proc. Linn. Soc. NSW.* **LXXXVIII**: 47-53.	Regrowth after fill extraction.	Dry Sclerophyll Forest on Hawkesbury Sandstone.	Vegetation.	Australia.	New South Wales.	Eastern New South Wales Bargo.
Hickey, J.E. 1994.	A floristic comparison of vascular species in Tasmanian oldgrowth mixed forest with regeneration resulting from logging and wildfire. *Aust. J. Bot.* **42**: 383-404.	Regrowth after logging, fire.	Cool Temperate Rainforest / Wet Sclerophyll Forest.	Vegetation.	Australia.	Tasmania.	North western, Central and Southern Tasmania.
Hill, G.J.E. & Phinn, S.R. 1993.	Revegetated sand mining areas, Swamp Wallabies and remote sensing: North Stradbroke Island, Queensland.. *Aust. Geog. Stud.* **31(1)**: 3-13.	Regrowth after mining.	Dry Sclerophyll Forest.	Vegetation, Swamp Wallaby.	Australia.	Queensland.	North Stradbroke Island.
Hopkins, M.S. 1981.	Disturbance and change in rainforests and the resulting problems of functional classification. pp. 42-52 (Chapter 5) in: A.N. Gillison & D.J. Anderson. (eds.). *Vegetation Classification in Australia.* CSIRO/ANU Press, Canberra.	Regrowth after clearing, logging.	Tropical and Subtropical Rainforest.	Vegetation.	Australia.	New South Wales, Queensland.	Various.

Hopkins, M.S. 1990.	Disturbance - the Forest Transformer pp. 40-52 in: Webb, L.J. & Kikkawa, J. (eds.). *Australian Tropical Rainforest. Science-Values-Meaning.* CSIRO, Melbourne.	Regrowth after anthropogenic and non-anthropogenic disturbance.	Tropical Rainforest.	Vegetation.	Australia.	Queensland.	Eastern Queensland.
Hopkins, M.S. & Graham A.W. 1984.	Viable soil seed banks in disturbed lowland tropical rainforest sites in North Queensland. *Aust. J. Ecol.* **9**: 71-79.	Regrowth after clearing, grazing.	Tropical Rainforest.	Vegetation.	Australia.	Queensland.	North Queensland.
Howe, R.W., Howe, T.D. & Ford, H.A. 1981.	Bird distributions on small rainforest remnants in New South Wales. *Aust. Wildl. Res*. **8**: 637-651.	Regrowth after clearing.	Subtropical Rainforest.	Birds.	Australia.	New South Wales.	North eastern New South Wales - Dorrigo Plateau.
Jackson, G.P. & Fox, B.J. 1996.	Comparison of regeneration following burning, clearing or mineral sand mining at Tomago, NSW: II. Succession of ant assemblages in a coastal forest. *Aust. J. Ecol.* **21**: 200-216.	Regrowth after disturbance.	Open-forest, Low open-forest.	Ants.	Australia.	New South Wales.	Central Coast - Tomago Sandbeds, north of New castle.
James, T. 1997.	*Native Flora of Western Sydney.* Urban Bushland Biodiversity Survey. Stage 1: Western Sydney. NSW Biodiversity Survey Program. NSW NPWS, Sydney.	Regrowth after disturbance.	Woodland, Dry Sclerophyll Forest.	Vegetation.	Australia.	New South Wales.	Western Sydney.
Johnson, R.W. 1981.	Choice of attributes to study succession in Brigalow (*Acacia harpophylla*) communities. pp. 66-77 (Chapter 7) in: A.N. Gillison & D.J. Anderson. (eds.). *Vegetation Classification in Australia.* CSIRO/ANU Press, Canberra.	Regrowth after clearing.	Semi-arid Woodlands/Shrublands - *Acacia harpophylla* .	Vegetation.	Australia.	Queensland.	Theodore.
Johnson, R.W. 1997.	The impact of clearing on brigalow communities and consequences for conservation. pp. 359-363 (Chapter 67) in: P. Hale & D. Lamb. (eds.). *Conservation Outside Nature Reserves.* Centre for Conservation Biology, University of Queensland, Brisbane.	Regrowth after clearing.	Semi-arid Woodlands/Shrublands - *Acacia harpophylla* .	Vegetation.	Australia.	Queensland.	Theodore.
Jones, H., Recsei, J., Delaney, R., Barker, C., Williams, S. and Chessman, B. 1997.	*Native Fauna of Western Sydney.* Urban Bushland Biodiversity Survey. Stage 1: Western Sydney. NSW Biodiversity Survey Program. NSW NPWS, Sydney.	Regrowth after disturbance.	Woodland, Dry Sclerophyll Forest.	Fauna.	Australia.	New South Wales.	Western Sydney.
Kavanagh, R.P. & Bamkin, K.L. 1995.	Distribution of nocturnal forest birds and mammals in relation to the loggin mosaic in south-eastern New South Wales, Australia. *Biol. Con.* **71**: 41-53.	Regrowth after logging.	Wet and Dry Sclerophyll Forest.	Nocturnal Birds, Nocturnal Mammals.	Australia.	New South Wales.	South Coast - Eden area.
Kavanagh, R.P., Debus, S., Tweedie, T. & Webster, R. 1995.	Distribution of nocturnal forest birds and mammals in north-eastern New South Wales: relationships with environmental variables and management history. *Wildl. Res.* **22**: 359-377.	Regrowth after logging.	Wet and Dry Sclerophyll Forest.	Nocturnal Birds, Nocturnal Mammals.	Australia.	New South Wales.	North Coast - Glen Innes to Coffs Harbour.
Keith, D.A. 1996.	Fire-driven extinction of plant populations: a synthesis of theory and review of evidence from Australian vegetation. *Proc. Linn. Soc. NSW* **116**: 37-78.	Regrowth after fire.	Various.	Vegetation.	Australia.	Various.	Various.

Kellas, J.D., Jarrett, R.G. and Morgan, B.J. 1988.	Changes in species composition following recent shelterwood cutting in mixed eucalypt stands in the Wombat Forest, Victoria *Aust. For.* **51(2)**: 112-118.	Regrowth after logging.	Dry Sclerophyll Forest.	Vegetation.	Australia.	Victoria.	Wombat State Forest.
Kirkpatrick, J.B. & Gilfedder, L. 1995.	Maintaining integrity compared with maintaining rare and threatened taxa in remnant bushland in subhumid Tasmania. *Biol. Cons.* **74**: 1-8.	Regrowth after clearing, grazing, thinning.	Dry Sclerophyll Forest.	Vegetation.	Australia.	Tasmania.	Subhumid Central Eastern Tasmania.
Kirschbaum, S.B. & Williams, D.G. 1991.	Colonisation of pasture by *Kunzea ericoides* in the Tidbinbilla valley, ACT, Australia. *Aust. J. Ecol.* **16**: 79-90.	Regrowth after clearing.	Shrubland.	Vegetation.	Australia.	Australian Capital Territory.	Tidbinbilla Valley.
Koch, J.M., Ward, S.C., Grant, C.D. and Ainsworth, G.L. 1996.	Effects of bauxite mine restoration operations on topsoil seed reserves in the Jarrah forest of Western Australia. *Rest. Ecol.* **4(4)**: 368-376.	Regrowth after mining.	Dry Sclerophyll Forest.	Vegetation.	Australia.	Western Australia.	East of Perth.
Kooyman, R.M. 1996.	*Growing Rainforest. Rainforest Restoration and Regeneration.* Greening Australia / State Forests of New South Wales, Brisbane.	Regrowth after clearing.	Rainforest.	Vegetation.	Australia.	Queensland, New South Wales.	South eastern Queensland, north eastern New South Wales.
Landsberg, J., Morse, J. and Khanna, P. 1990.	Tree dieback and insect dynamics in remnants of native woodlands on farms. *Proc. Ecol. Soc. Aust.* **16**: 149-165.	Regrowth after clearing.	Woodland.	Vegetation.	Australia.	New South Wales.	Various.
Leach, G.J. & Recher H.F. 1993.	Use of roadside remnants of softwood scrub vegetation by birds in south eastern Queensland. *Wild. Res.* **20**: 233-249.	Regrowth after clearing.	Softwood Scrub.	Birds.	Australia.	Queensland.	South eastern Queensland Marburg district.
Liangzhong, Z. & Whelan, R.J. 1993.	Natural reforestation of abandoned farmland: the role of soils *Aust. Geog.* **24(2)**: 14-25.	Regrowth after clearing.	Dry Sclerophyll Forest.	Vegetation.	Australia.	New South Wales.	Central Coast - Cordeax Catchment south of Sydney.
Loeb, R.E. 1989.	The ecological history of an urban park. *J. For. Hist.* **July**. 134-143.	Regrowth after clearing.	Oak-Chestnut-Walnut-Hickory.	Vegetation.	United States of America.	New Jersey.	Seton Falls Park, the Bronx, New York.
Loyn, R.H., Fagg, P.C., Piggin, J.E., Morton, A.G. and Tolhurst, K.G. 1983.	Changes in the composition of understorey vegetation after harvesting eucalypts for sawlogs and pulpwood in East Gippsland *Aust. J. Ecol* . **8**: 43-53.	Regrowth after logging.	Dry Sclerophyll Forest.	Vegetation.	Australia.	Victoria.	East Gippsland.
Lunney, D., Curtin, A. & Matthews, A. 1995.	The Status of Koalas in NSW. pp. 73-78 in: Australian Koala Foundation. *Proceedings on a Conference on the Status of the Koala in 1995 incorporating the Fourth National Carers Conference.* AKF, Brisbane.	Regrowth after clearing.	Various.	Koala.	Australia.	New South Wales.	Central and eastern New South Wales - Iluka, Gunnedah, Eden, Coffs Harbour, Port Stephens.

Lunney, D.L. & Leary, T. 1988.	The impact on native mammals of land-use changes and exotic species in tl Bega District, New South Wales, since settlement *Aust. J. Ecol.* **13**: 67-92.	Impacts of clearing.	Various.	Mammals.	Australia.	New South Wales.	South Coast - Bega District.
Lunt, I.D. 1990.	The soil seed bank of a long-grazed *Themeda triandra* grassland in Victoria. *Proc. Roy. Soc. Vic.* **102(1)**: 53-57.	Regrowth after cessation of grazing.	Temperate Grassland - *Themeda triandra (australis)* .	Vegetation.	Australia.	Victoria.	West of Melbourne - Derrimut Grassland Reserve.
Lunt, I.D. 1997a.	The distribution and environmental relationships of native grasslands on the Lowland Gippsland Plain, Victoria: an historical study *Aust. Geog. Stud* . **35(2)**: 140-152.	Regrowth after clearing, cultivation.	Grasslands - *Themeda triandra* (*australis*).	Vegetation.	Australia.	Victoria.	Eastern Victoria - lowland Gippsland Plain.
Lunt,, I.D. 1997b.	Tree densities last century on the lowland Gippsland Plain, Victoria *Aust. Geog. Stud.* **35(3)**: 342-348.	Regrowth after clearing, thinning.	Open Forest, Woodland.	Vegetation.	Australia.	Victoria.	Lowland East Gippsland.
Lunt, I.D. 1997c.	Germinable soil seed banks of anthropogenic native grasslands and grassy forest remnants in temperate south-eastern Australia *Plant Ecology* **130**: 21-34.	Regrowth after clearing, thinning.	Grassland.	Vegetation.	Australia.	Victoria.	Lowland East Gippsland.
Macreadie, J., Wallis, R.L. and Adams, R. 1998.	A small mammal community living in a powerline easement at Bunyip Stat Park, Victoria. *Vic. Nat.* **115(4)**: 120-123.	Regrowth after clearing, thinning.	Heathland, Dry Sclerophyll Forest.	Small mammals.	Australia.	Victoria.	East of Melbourne.
Maher, M. 1995.	*A Thin Line: Should Densities of Coolibah and Black Box be Controlled in the Western Division of New South Wales ?* Unpublished Report. Western Lands Commission, Sydney.	Regrowth after clearing, thinning.	Woodland.	Vegetation.	Australia.	New South Wales.	Noreth western New South Wales.
Majer, J.D. 1990.	Rehabilitation of disturbed land: long-term prospects for the recolonisation of fauna. *Proc. Ecol. Aust.* **16**: 509-519.	Regrowth after clearing, thinning.	Various.	Fauna.	Australia.	Various.	Various.
Margules, C.R. 1996.	Experimental fragmentation. pp. 128-137 in: J. Settele; C.R. Margules, P. Poschlod & K. Henle. (eds.) *Species Survival in Fragmented Landscapes.* Kluwer Academic.	Regrowth after clearing.	Dry Sclerophyll Forest, grassland.	Vegetation, Fauna.	Australia, United States of America.	New South Wales, Kansas, California.	South eastern New South Wales - Wog Wog; Kansas - Lawrence; California - Davis.
Matlack, G.R. 1994.	Plant species migration in a mixed-history forest landscape in eastern North America. *Ecology* **75(5)**: 1491-1502.	Regrowth after clearing.	Oak-Chestnut Forest.	Vegetation.	United States of America.	Delaware, Pennsylvania.	Piedmont Zone.
Matlack, G.R. 1997a.	Four centuries of forest clearance and regeneration in the hinterland of a large city. *J. Biogeog.* **24**: 281-295.	Regrowth after clearing.	Winter deciduous hardwood forest (Oak-Hickory).	Vegetation.	United States of America.	Delaware.	Eastern Delaware - Wilmington.
Matlack, G.R. 1997b.	Land use and forest habitat distribution in the hinterland of a large city *J. Biogeog.* **24**: 297-307.	Regrowth after clearing.	Winter deciduous hardwood forest (Oak-Hickory).	Vegetation.	United States of America.	Delaware.	Eastern Delaware - Wilmington.

McIntyre, S. & Barrett, G.W. 1992.	Habitat variegation, an alternative to fragmentation. *Cons. Biol.* **6(1)**: 146-147.	Regrowth after clearing, grazing.	Temperate Grasslands.	Vegetation.	Australia.	New South Wales.	Northern Tablelands - New England area.
McNair, D.L. 1993.	*Aspects of Flora Regeneration Following Mineral and Silica Sand Mining. Port Stephens and Myall Lakes Region, New South Wales.* Unpublished Report. Department of Biological Sciences, University of Newcastle, Newcastle.	Regrowth after mining.	Heathland, Dry Sclerophyll Forest.	Vegetation.	Australia.	New South Wales.	Port Stephens, Myall Lakes National Park.
Mitchell, P.B. 1991.	Historical perspectives on some vegetation and soil changes in semi-arid New South Wales. *Vegetatio* **91**: 169-182.	Regrowth after clearing.	Woodland.	Vegetation, Soil.	Australia.	New South Wales.	Western Division.
Morgan, J.W. 1998.	Patterns of invasion of an urban remnant of a species-rich grassland in southeastern Australia by non-native plant species. *J. Veg. Sci.* **9**: 181-190.	Regrowth after clearing.	Grassland.	Vegetation.	Australia.	Victoria.	North west of Melbourne.
Morrison, D.A., Cary, G.J., Pengelly, S.M., Ross, D.G., Mullins, B.J., Thomas, C.R. and Anderson, T.S. 1995.	Effects of fire frequency on plant species composition of sandstone communities in the Sydney region: inter-fire interval and time since fire. *Aust. J. Ecol.* **20**: 239-247.	Regrowth after fire.	Heathland, Dry Sclerophyll Forest.	Vegetation.	Australia.	New South Wales.	Sydney.
Morrison, D.A., McLuskey, L. & Houstone, M.A. 1995.	Long-term revegetation of a denuded area in the Sydney region. *Cunninghamia* **4(1)**: 45-62.	Regrowth after fill extraction.	Dry Sclerophyll Forest on Hawkesbury Sandstone.	Vegetation.	Australia.	New South Wales.	Eastern New South Wales Bargo.
Murphy, A. and Ough, K. 1997.	Regenerative strategies of understorey flora following clearfell logging in the Central Highlands, Victoria. *Aust. For.* **60(2)**: 90-98.	Regrowth after logging.	Dry Sclerophyll Forest, wet Sclerophyll Forest.	Vegetation.	Australia.	Victoria.	Central Highlands.
Neave, H.M. & Tanton, M.T. 1989.	The effects of grazing by kangaroos and rabbits on the vegetation and the habitat of other fauna in the Tidbinbilla Nature Reserve, Australian Capital Territory. *Aust. Wild. Res.* **16**: 337-351.	Regrowth after clearing.	Shrubland and Grassland.	Vegetation.	Australia.	Australian Capital Territory.	Tidbinbilla Nature Reserve.
Neumann, F.G. 1978.	Insect populations in eucalypt and pine forests in north-eastern Victoria. *Australian Forest Research* **8**: 13-24.	Pine Plantation.	Formerly Dry Sclerophyll Forest.	Insects.	Australia.	Victoria.	North eastern Victoria - Myrtleford.
Neumann, F.G. 1979.	Beetle communities in eucalypt and pine forests in north-eastern Victoria. *Australian Forest Research* **9**: 277-293.	Pine Plantation.	Formerly Dry Sclerophyll Forest.	Beetles.	Australia.	Victoria.	North eastern Victoria - Myrtleford.
Nieuwenhuis, A. 1987.	The effect of fire frequency on the sclerophyll vegetation of the West Head, New South Wales. *Aust. J. Ecol.* **12**: 373-385.	Regrowth after fire.	Heathland, Dry Sclerophyll Forest.	Vegetation.	Australia.	New South Wales.	Kuringai Chase National Park.

Onans, J. & Parsons R.F. 1980.	Regeneration of native plants on abandoned mallee farmland in south-eastern Australia. *Aust. J. Bot.* **28**: 479-493.	Regrowth after cessation of grazing.	Mallee.	Vegetation.	Australia.	Victoria.	North Western Victoria - Central Mallee (Piangil-Annuello).
Ough, K. and Murphy, A. 1996.	The effect of clearfell logging on tree-ferns in Victorian Wet Forest. *Aust. For.* **59(4)**: 178-188.	Regrowth after logging.	Wet Sclerophyll Forest.	Vegetation.	Australia.	Victoria.	Toolangi State Forest.
Peterken, G.F. & Game M. 1984.	Historical factors affecting the number and distribution of vascular plant species in the woodlands of Central Lincolnshire. *J. Ecol.* **72**: 155-182.	Regrowth after clearing.	"Ancient" and "Recent" Woods.	Vegetation.	England.	Lincolnshire.	Central Lincolnshire - Wragby.
Prober, S.M. and Thiele, K.R. 1993.	The ecology and genetics of remnant grassy White Box woodlands in relation to their conservation. *Vic. Nat.* **110(1)**: 30-36.	Regrowth after clearing.	White Box Woodlands.	Vegetation.	Australia.	New South Wales.	Western Slopes.
Pulsford, I.F., Banks, J.C.G. and Hodges, L. 1992.	Environmental history: an example from the White Cypress Pine forests in the Australian Alps. *Revue de Geographie Alpine* **2-3 LXXX**: 65-95.	Regrowth after changed fire regimes and cessation of grazing.	White Cypress Pine Forests.	Vegetation.	Australia.	New South Wales.	South eastern New South Wales - lower Snowy River Valley.
Pulsford, I.F., Banks, J.C.G. & Hodges, L. 1993.	Land use history of the White Cypress Pine forests in the Snowy Valley, Kosciusko National Park. pp. 85-104 in: Dargavel, J. & Feary, S. (eds.). *Australia's Ever Changing Forests II*. CRES / ANU, Canberra.	Regrowth after changed fire regimes and cessation of grazing.	White Cypress Pine Forests.	Vegetation.	Australia.	New South Wales.	South eastern New South Wales - lower Snowy River Valley.
Read, J. & Hill, R.S. 1983.	Rainforest invasion onto Tasmanian old-fields. *Aust. J. Ecol.* **8**: 149-161.	Regrowth after clearing.	Temperate Rainforest.	Vegetation.	Australia.	Tasmania.	Guildford Plateau.
Roche, S., Koch, J.M. & Dixon, K.W. 1997.	Smoke enhanced seed germination for mine rehabilitation in the southwest of Western Australia. *Rest. Ecol.* **5(3)**: 191-203.	Regrowth after bauxite mining.	Dry Sclerophyll Forest - Jarrah.	Vegetation.	Australia.	Western Australia.	South of Perth - Jarrahdale, Huntley and
Saunders, D.A. 1974.	The occurrence of the white-tailed black cockatoo, *Calyptorhynchus baudinii* in *Pinus* plantations in Western Australia. *Australian Wildlife Research* **1**: 45-54.	Pine Plantation.	Formerly Jarrah forest.	White-tailed Black Cockatoo.	Australia.	Western Australia.	Western Australia - Perth area.
Smith, B.E., Marks, P.L. & Gardescu, S. 1993.	Two hundred years of forest cover changes in Tompkins County, New York. *Bull. Torr. Bot. Club* **120(3)**: 229-247.	Regrowth after clearing.	Forest.	Vegetation.	United States of America.	New York.	Tompkins County.
Suckling, G.C. & Heislers A. 1978.	Populations of four small mammals in radiata pine plantations and Eucalypt forests of north-eastern Victoria. *Australian Wildlife Research* **5**: 305-315.	Pine Plantation.	Formerly Dry Sclerophyll Forest.	Small Mammals.	Australia.	Victoria.	North eastern Victoria - Myrtleford.
Suckling, G.C. 1982.	Value of reserved habitat for mammal conservation in plantations. *Australian Forestry* **45**: 19-27.	Pine Plantation	Formerly Wet and Dry Sclerophyll Forests.	Mammals.	Australia.	Victoria.	Eastern Victoria - Traralgon.

Thatcher, A.C. & Westman, W.E. 1975.	Succession following mining on high dunes of coastal southeast Queenslan *Proc. Ecol. Soc. NSW* **9**: 17-33.	Regrowth after mining.	Coastal Dry Sclerophyll Forest.	Vegetation.	Australia.	Queensland.	North Stradbroke Island.
Turner, I.M., Wong, Y.K., Chew, P.T. & Ibrahim, A. 1997.	Tree species richness in primary and old secondary tropical forest in Singapore. *Biodiv. Cons.* **6**: 537-543.	Regrowth after clearing.	Tropical Rainforest.	Vegetation.	Singapore.	_	Central Catchment Nature Reserve.
Twigg, L.E. & Fox, B.J. 1991.	Recolonisation of regenerating open forest by terrestrial lizards following sand mining. *Aust. J. Ecol.* **16**: 137-148.	Regrowth after mining.	Coastal Dry Sclerophyll Forest.	Lizards.	Australia.	New South Wales.	North coast - Myall Lakes National Park.
Twigg, L.E., Fox, B.J. & Jia, L. 1989.	The modified primary succession following sand mining: a validation of the use of chronosequence analysis *Aust. J. Ecol.* **14**: 441-447.	Regrowth after mining.	Coastal Dry Sclerophyll Forest.	Small mammals.	Australia.	New South Wales.	North coast - Myall Lakes National Park.
Tyndale-Biscoe, C.H. and Calaby, J.H. 1975.	Eucalypt forests as refuge for wildlife *Aust. For.* **38(2)**: 117-133.	Regrowth after logging.	Wet Sclerophyll Forest.	Mammals.	Australia.	New South Wales.	Various.
Tyndale-Biscoe, C.H. and Smith, R.F.C. 1969.	Studies on the marsupial glider, Schoinobates volans (Kerr). III. Response t habitat destruction. *J. Anim. Ecol.* **38**: 651-659.	Regrowth after logging.	Wet Sclerophyll Forest.	Arboreal Mammals.	Australia.	New South Wales.	Tumut area.
Unwin, G.L., Stocker, G.C. & Sanderson, K.D. 1988.	Forest successions following European settlement and mining in the Rossville area, north Queensland. *Proc. Ecol. Soc. Aust.* **15**: 303-305.	Regrowth after clearing, mining.	Tropical Rainforest.	Vegetation.	Australia.	Queensland.	South of Cooktown - Rossville area.
Wahren, C.H.A., Papst, W.A. and Williams, R.J. 1994.	Long-term vegetation change in relation to cattle grazing in subalpine grassland and heathland on the Bogong High Plains: an analysis of vegetation records from 1945-1994. *Aust. J. Bot.* **42**: 607-639.	Regrowth after cessation of grazing.	Subalpine Grassland and Heathland.	Vegetation.	Australia.	Victoria.	Bogong High Plains.
Wang, L. 1997.	The soil seed bank and understorey regeneration in Eucalyptus regnans forest, Victoria. *Aust. J. Ecol.* **22**: 404-411.	Regrowth after clear-felling and aerial seeding.	Wet Sclerophyll Forest - *Eucalyptus regnans* .	Vegetation.	Australia.	Victoria.	Central Highlands - Toolangi State Forest.
Ward, S.C., Koch, J.M. & Grant, C.D. 1997.	Ecological aspects of soil seed-banks in relation to bauxite mining. I. Unmined Jarrah forest. *Aust. J. Ecol* . **22**: 169-176.	Regrowth after mining.	Dry Sclerophyll Forest - Jarrah.	Vegetation.	Australia.	Western Australia.	Darling Plateau, south of Perth - Jarrahdale, Huntley and Willowdale.
Ward, S.C., Koch,. J.M. and Nichols, O.G. 1990.	Bauxite mine rehabilitation in the Darling Range, Western Australia *Proc. Ecol. Soc. Aust.* **16**: 557-565.	Regrowth after mining.	Dry Sclerophyll Forest - Jarrah.	Vegetation.	Australia.	Western Australia.	Darling Plateau, south of Perth - Jarrahdale, Huntley and Willowdale.
Webb, G.A. 1995.	Effects of logging on lizards in eucalypt forest at Eden, New South Wales. *Aust. For.* **58(4)**: 155-159.	Regrowth after logging.	Dry Sclerophyll Forest.	Lizards.	Australia.	New South Wales.	South Coast - Eden.

Webb, L.J., Tracey, J.G. and Williams, W.T. 1972.	Regeneration and pattern in the subtropical rain forest *J. Ecol.* **60**: 675-695.	Regrowth after clearing.	Tropical Rainforest.	Vegetation.	Australia.	Queensland.	North Queensland - Wet Tropics.
Whitney, G.G. & Foster, D.R. 1988.	Overstorey composition and age as determinants of the understorey flora of woods of central New England *J. Ecol.* **76**: 867-876.	Regrowth after clearing.	Hemlock-White Pine-Northern Hardwoods.	Vegetation.	United States of America.	Massachusetts and New Hampshire.	Worcester and Cheshire Counties.
Williams, K. and Kukolic, K. 1991.	Fauna of the ACT's Native Grasslands. pp. 11- 19 in: R. Falconer (ed.). *The ACT's Native Grasslands.* Proceedings of a Workshop held at the Conference Room of the National Museum of Australia, Canberra. Conservation Council of the South East Region and Canberra Inc., Canberra.	Regrowth after clearing and grazing.	Grassland.	Fauna.	Australia.	Australian Capital Territory.	Northern ACT.
Willson, M.F. and Chrome, F.H.J. 1989.	Patterns of seed rain at the edge of a tropical Queensland rain forest *J. Tropic. Ecol* . **5**: 301-308.	Regrowth after clearing.	Tropical Rainforest.	Vegetation.	Australia.	Queensland.	North Queensland - Wet Tropics.
Wilson, B.A. 1996.	Fire effects on vertebrate fauna and implications for fire management and conservation. Chapter 11, pp. 131-147 in: *Fire and Biodiversity. The Effects and Effectiveness of Fire Management.* Proceedings of the Conference held 8-9 October 1994, Footscray, Melbourne. Biodiversity Series, Paper No. 8. Biodiversity Unit. Department of the Environment, Sport and Territories, Canberra.	Regrowth after fire.	Various.	Vertebrates.	Australia.	Various.	Various.
Wimbush, D.J. and Costin, A.B. 1979a.	Trends in vegetation at Kosciusko I. Grazing trials in the subalpine zone, 1957-1971. *Aust. J. Bot.* **27(6)**:741-787.	Regrowth after cessation of grazing.	Alpine communities.	Vegetation.	Australia.	New South Wales.	Kosciusko NP.
Wimbush, D.J. and Costin, A.B. 1979b.	Trends in vegetation at Kosciusko II. Subalpine range transects, 1959-1978 *Aust. J. Bot* . **27(6)**: 789-831.	Regrowth after cessation of grazing.	Subalpine Grassland, Heathland and Woodland.	Vegetation.	Australia.	New South Wales.	Kosciusko NP.
Wimbush, D.J. and Costin, A.B. 1979c.	Trends in vegetation at Kosciusko III. Alpine range transects., 1959-1978. *Aust. J. Bot.* **27(6)**: 833-871.	Regrowth after cessation of grazing.	Subalpine Grassland, Heathland and Woodland.	Vegetation.	Australia.	New South Wales.	Kosciusko NP.
Woinarski, J.C.Z. 1979.	Birds of a Eucalyptus plantation and adjacent natural forest *Australian Forestry* **42**: 243-247.	Eucalypt Plantation.	Formerly Dry Sclerophyll Forest.	Birds.	Australia.	Victoria.	Eastern Victoria - Lysterfield Reservoir.
Woinarski, J.C.Z. 1989.	The vertebrate fauna of Broombush *Melaleuca uncinata* vegetation in north-western Victoria, with reference to effects of Broombush harvesting. *Aust. Wild. Res.* **16**: 217-238.	Regrowth after cutting and thinning.	Broombush.	Amphibians, Reptiles, Birds, Mammals.	Australia.	Victoria.	North western Victoria - Big Desert, Little Desert and Sunset Country.

York, A. 1996.	Long-term effects of fuel reduction burning on invertebrates in a dry sclerophyll forest. Chapter 14, pp. 163-181 in:*Fire and Biodiversity. The Effects and Effectiveness of Fire Management.* Proceedings of the Conference held 8-9 October 1994, Footscray, Melbourne. Biodiversity Series, Paper No. 8. Biodiversity Unit. Department of the Environment, Sport and Territories, Canberra.	Regrowth after fire.	Dry Sclerophyll Forest.	Invertebrates.	Australia.	New South Wales.	North Coast.

APPENDIX 2: Other Papers of Potential Relevance

OLD-FIELD SUCCESSION

Auken OW and vanBush JK. 1985.
Secondary succession on terraces of the San Antonio River. Bulletin of the Torrey Botanical Club. 112(2): 158-166.

Abstract: Old field sites on the flood plain terrace of the San Antonio R., Texas were recolonised by woody vegetation within 5 yr. after disturbance. In stands aged about 30 yr. or more, Celtis laevigata had the greatest total av. b.a. Ulmus crassifolia, Acer negundo, Carya illinoensis, U. americana and Bumelia lanuginosa were important secondary species in mature stands aged < more than > 150 yr.

Battaglia LL, Keough JR and Pritchett DW. 1995.
Early secondary succession in a southeastern U.S. alluvial floodplain. Journal of Vegetation Science. 6(6): 769-776.

Abstract: Species number, turnover and early successional patterns were examined over the first 5 yr. of old-field succession in a former bottomland hardwood forest in Louisiana. Number of species, measured by walk-through surveys, increased up to year 3, but decreased in years 4 and 5. Species turnover in 20 quadrats indicated that species invasions remained high throughout the study, while losses of species were initially high but declined. Detrended Correspondence Analysis (DCA) on species cover in each year showed the existence of a compositional gradient that could be significantly related to relative altitude (an indirect measure of the hydrological gradient), in years 2-5. DCA of the pooled 5-yr. species cover data showed greater compositional changes in lower altitude quadrats, and those higher altitude quadrats dominated by the woody vine (Campsis radicans) remained similar over time.

Bigwood DW. 1984.
The seed bank of an old field: comparison with extant vegetation, spatial distributions of component species, and a comparison of sampling techniques. Dissertation Abstracts International, B (Sciences and Engineering). 45(5): 1366B.

Abstract: The vegetation of an old field in Prince George's County, Maryland was sampled in the late spring and early autumn of 1980. Analysis revealed that the field was in transition from an aster/golden rod/broomsedge stage to a stage dominated by trees and shrubs. The seed bank of the field was composed primarily of annual and short-lived perennial species, many of which had low cover abundance values or were not present in the vegetation; tree and shrub seeds were poorly represented. Detailed studies of blocks of soil from the field revealed that the seeds of most individual species generally had clustered distributions in the soil; there was no indication of vertical movement of seeds through the soil. Spatial distributions of seeds were generally governed by environmental factors. Large numbers of small samples were necessary for precise estimates of seed numbers in soil.

Brakenhielm S. 1977.
Vegetation dynamics of afforested farmland in a district of south-eastern Sweden. Acta Phytogeographica Suecica. No. 63. 116pp.

Abstract: Vegetational changes during the succession from an Agropyron repens/Agrostis gigantea old-field succession and a Lolium perenne/Poa trivialis/Cynosurus cristatus sward towards Picea abies forest during 1966-74 are described; during this period the areas were grazed and browsed by moose (Alces alces), roe deer (Capreolus capreolus) and hares (Lepus timidus and L. europaeus).

Brandt CA and Rickard WH. 1994.

Alien taxa in the North American shrub-steppe four decades after cessation of livestock grazing and cultivation agriculture. Biological Conservation. 68(2): 95-105

Abstract: The distribution of alien species, particularly vegetation, was investigated in a 800-km < sup(2) > sagebrush (Artemisia tridentata) steppe on the Columbia River Plain, Washington State, which had been protected from grazing and agricultural development since 1944. Parts of the site had been disturbed mechanically or by herbicide application, for reasons including construction and groundwater monitoring. Recently disturbed areas were dominated by the alien annuals Salsola kali, Sisymbrium altissimum, Lactuca serriola and Ambrosia acanthicarpa. Old-field habitats were almost entirely composed of the alien annual grass Bromus tectorum. The dominant alien plant species in undisturbed areas were B. tectorum, S. kali and Draba verna. B. tectorum and D. verna could set seed in undisturbed habitats, while S. kali and S. altissimum seldom reached maturity in this environment and relied on good seed dispersal from disturbed sites. No alien mammals were found in the shrub steppe, and only native birds nested in undisturbed habitat.

Brown VK Hendrix SD and Dingle H. 1987.
Plants and insects in early old-field succession: comparison of an English site and an American site. Biological Journal of the Linnean Society. 31(1): 59-74.

Abstract: The plant and insect communities of early, secondary succession beginning with bare ground in sites in the UK and Iowa, USA, shared a number of characteristics. Both sites had similar temporal patterns of plant species cover and species richness, but overall species richness was greater at the British site. Annuals dominated both sites during the first year of succession and were largely replaced by perennials in the 2nd year. Monocotyledons were more abundant at the British site, especially in the 2nd year. The Old World site was dominated by native and the New World site by alien plant species. The insect herbivore load, including Hemiptera, Coleoptera, Orthoptera, Lepidoptera and Hymenoptera, was greater at the former site, when expressed in terms of structural complexity of the vegetation, suggesting that there may be major differences in the influence of herbivores on the direction and rate of succession at the 2 sites.

Burton PJ and Bazzaz FA. 1991.
Tree seedling emergence on interactive temperature and moisture gradients and in patches of old-field vegetation. American Journal of Botany. 78(1): 131-149.

Abstract: In laboratory studies, seeds of tree species commonly invading old-fields in Illinois (Fraxinus americana, Gleditsia triacanthos, Morus rubra, Platanus occidentalis and Prunus serotina) were germinated at 8 temperatures from 5 < degrees > to 40 < degrees > C, and 6 moisture levels (2% to 18% gravimetric moisture content). For most species, total seedling emergence and emergence rate exhibited approximate bivariate Gaussian response surfaces. Emergence of all species, except Gleditsia, was much more sensitive to differences in temperature than to differences in moisture. Species differed considerably in their response breadths across the interactive gradients, with moisture response bearing little relation to temperature response. In field studies during 1985-87 near Urbana, Illinois, seeds of Acer saccharum, Crataegus mollis, F. americana, G. triacanthos, M. rubra and P. serotina were sown into old-field vegetation patches dominated by 8 different plant species, across 3 different soils. Acer and Morus emergence exhibited no significant difference among vegetation patches. Emergence of other tree species differed among patch types, but identity of the vegetation (often early successional) most conducive to emergence typically varied from year to year. Emergence of most species responded more strongly to vegetation than to soil series. High Fraxinus and Prunus emergence was associated with dampened temperature ranges, while high Crataegus emergence was associated with low amounts of plant litter. Despite great variability, vegetation differences could predict tree seedling emergence better than year-to-year or soil differences. Extrapolations from the laboratory experiments predicted approximate rates of overall seedling emergence in the field, but prevailing temperature and moisture differences between plant neighbourhoods alone were not sufficient to explain observed differences in seedling emergence between these patches.

Burton PJ and Bazzaz FA. 1995.
Ecophysiological responses of tree seedlings invading different patches of old-field vegetation. Journal of Ecology. 83(1): 99-112.

Abstract: Performance of seedlings of Acer saccharum, Fraxinus americana, Gleditsia triacanthos and Prunus serotina was examined in eight old-field vegetation patch types and in control plots with no competition in Illinois. Measurements of seedling gas exchange, water potential. foliar N, and specific leaf area were related to microenvironmental conditions and to seedling growth and survival. Among vegetated patch types, predawn leaf water potentials and midday photosynthetic rates of tree seedlings were highest in short-statured and shallow-rooted patches of Poa pratensis, and lowest under established trees and shrubs where both soil moisture and subcanopy irradiance were reduced. For seedlings of all tree species, photosynthetic rates per unit leaf area averaged 21-28% of that measured in control seedlings free of competition. Irradiance and photosynthesis both varied significantly among patch types, and photosynthesis was more strongly correlated with irradiance than with other variables. In all species, photosynthesis under full light was strongly correlated with photosynthesis measured under ambient light. Ambient photosynthesis most closely approached photosynthetic capacity in late-successional species (Acer > Fraxinus > Prunus > Gleditsia). Shade-tolerance thereby enhanced potential for late-successional species to invade established plant communities. Ratio of net photosynthesis to stomatal conductance in tree seedlings was decreased in competitive environments dominated by Solidago and other fast-growing herbs. Reduced water use efficiency appeared to be caused by competitively induced nitrogen limitations. Some competitive environments thus reduced both soil moisture and photosynthetic water use efficiency of tree seedlings. Measurements of photosynthesis and foliar nitrogen were good indicators of long-term seedling growth, but not of survival. The complex interaction of light, moisture and nitrogen availability varied distinctly among old-field vegetation patches, and invading tree species differed in their ability to cope with these compound stresses. Such differences can explain differential tree seedling growth rates in old-field vegetation, but densities of trees found germinating and surviving from year to year depended on other factors.

Campbell BM Attwell CAM Hatton JC Jager P deGambiza J Lynam T Mizutani F and Wynter P. 1988.
Secondary dune succession on Inhaca Island, Mozambique. Vegetatio. 78(1-2): 3-11.

Abstract: Old field succession was studied on coastal dunes supporting tropical evergreen forest on Inhaca Island, Mozambique. Plots of 10 < multiply > 10 m were sited in three successional stages and in relatively undisturbed forest. Woody species increased in number during succession; leptophylls were most frequent in younger vegetation, whereas microphylls and mesophylls were most frequent in forest. Grasses, shrubs and forbs dominated initially following abandonment, and shrubs persisted as dominants in the three early successional stages. The initial floristic composition model was generally supported by the pattern of species sequences, with many forest species entering early in the succession. Of the few species conforming to the relay floristic model, many were grasses and forbs of the forest understorey. Similarity between plots of equivalent vegetation age indicated that, at least in early succession, there was linearity in the successional pathway; there was no evidence for divergence or multiple pathways. In early succession, no accumulation was detected in either soil organic matter or extractable nutrients, thus providing little support for the facilitation model of succession. It is stressed that the findings are probably scale-dependent.

Dean WRJ and Milton SJ. 1995.
Plant and invertebrate assemblages on old fields in the arid southern Karoo, South Africa. African Journal of Ecology. 33(1): 1-13.

Abstract: A survey of the vegetation and ground insects of old fields in the arid southern Karoo, South Africa, indicates that perennial plant assemblages may take many decades to re-establish old cultivated lands that were abandoned from 17 to > 50 years ago. Recently disturbed sites were characterised by annual plants and an insect assemblage dominated by the ant Anoplolepis steingroeveri, a carnivore and scavenger. A greater diversity of insects was associated with perennial plants. In general, numbers of invertebrates were positively correlated with the diversity of perennial plant species and plant cover, and were negatively correlated with total plant and annual plant diversity. Granivorous ants increased in abundance and scavenging ants decreased markedly in abundance with increasing age of the old field. Beetles and weevils were least common on the youngest old field and most abundant on the intermediate old field but were not significantly correlated with plant cover. Planthoppers (Homoptera) differed significantly in relative abundance on the three old field sites and were correlated with perennial plant cover, a trend also shown by detritivores. Spiders showed an increase in abundance with increasing age of the old field, and the most important family in this group was the Ammoxenidae, with two species that are specialist termite predators.

Glitzenstein JS Canham CD McDonnell MJ and Streng DR. 1990.
Effects of environment and land-use history on upland forests of the Cary Arboretum, Hudson Valley, New York. Bulletin of the Torrey Botanical Club. 117(2): 106-122.

Abstract: Vegetation data were obtained from 76 circular plots (0.05 ha) randomly located within the forest. Environmental data collected at each plot included slope, aspect, canopy openness, soil texture and nutrients, topographic position, and presence of exposed rock; gravimetric soil moisture was determined weekly during 1985 for 25 plots. Land-use history came from historical records, stone-fence locations, stand ages, an old aerial photograph and soils data. Vegetation analyses identified 3 major community types. One group of stands, dominated by chestnut oak (Quercus prinus) and northern red oak (Q. rubra) occurred on steep, rocky, upper slope sites never cleared for agriculture. Distinct vertical stratification of dominant canopy species in these stands is consistent with a probable history of intensive selective cutting early in this century. Both of the other major community types occurred primarily on abandoned agricultural land. Stands dominated by white oak (Q. alba), black oak (Q. velutina) and pignut hickory (Carya glabra) tended to occur on lower slopes on rocky, nutrient poor sites probably derived from abandoned pastures. The significantly more open canopy in these stands, less distinct vertical stratification of canopy trees and a diverse herbaceous understorey frequently including grasses and sedges, also suggests very gradual invasion of these forests onto old pasture sites. The 3rd major vegetation type, dominated by red maple (Acer rubrum) and white pine (Pinus strobus), tended to occur on finer textured, less rocky old field sites abandoned from cultivation. Comparison of current vegetation with witness tree data from early land survey records suggests that the white oak/black oak/hickory type was prevalent on lower slope sites before forest clearing, but has declined in importance relative to the red maple type during the past 100 yr. of abandonment of land from agriculture.

Goldberg DE and Gross KL. 1988.
Disturbance regimes of midsuccessional old fields. Ecology, USA. 69(6): 1677-1688.

Abstract: The dynamics of natural gaps in vegetation in permanent plots in 3 old field communities including Bromus inermis, Phleum pratense and Agropyron [Elymus] repens as dominants on mesic areas were monitored for 3 years. Total area of gaps with exposed soil was very low, with < less than > 0.2% of the area of each field in gaps < more or = > 10 cm diam. Most gaps were small; only 5-21% of all gaps found were < more or = > 20 cm diam. Most (95%) of the new gaps were created by animal activity, with moles [Scalopus aquaticus] being the most common disturbance agent. There was considerable variation in disturbance and closure rates over space and time that resulted in differences in the availability of gaps within fields, among fields, among seasons, and among years. Within each field, disturbance rates were higher but closure rates tended to be lower in more xeric areas of the field, resulting in higher availability of gaps in the more xeric areas at each census. Within each year, both disturbance and closure rates were higher during the growing season than during the winter. These 2 trends seemed to balance each other, resulting in little change in the availability of gaps over the year. Disturbance rates did not differ among years, but closure rates were higher in a year with higher precipitation, resulting in a lower availability of gaps in the wetter year. Overall these gaps appeared to be too rare and too small to play an important role in the persistence of the dominant perennials in the old-field communities studied, many of which required large gaps to establish from seed. However, they could be important for the persistence of annuals with seed banks in these communities. Such gaps could also influence the rate of succession in these fields by influencing the pattern of colonisation by woody plants.

Gough MW and Marrs RH. 1990.
A comparison of soil fertility between semi-natural and agricultural plant communities: implications for the creation of species rich grassland on abandoned agricultural land. Biological Conservation. 51(2): 83-96.

Abstract: Soils were collected from several community types at 6 UK locations, including semi-natural grassland, scrub, woodland, arable fields and improved grassland on clay, sandstone and limestone parent substrates. Soil fertility was assessed by chemical analysis and plant bioassay techniques. Under greenhouse conditions, P availability was the main limiting factor to plant growth on the soils collected. Extractable P levels in the arable, improved grassland and in some of the scrub and woodland soils collected were significantly higher than in adjacent semi-natural grassland soils. It may therefore be necessary to reduce P availability in the soil before species-rich grassland can be successfully established and maintained on old field sites produced by 'set-aside' or extensification schemes, and in conservation management programmes where late successional vegetation is removed.

Hanks JP. 1972.
A comparison of old-field succession in four areas of the eastern United States. Bulletin of the Torrey Botanical Club. 99(6): 278-286.

Abstract: Presents an analysis of earlier work on succession from abandoned fields to forests on the inner and outer coastal plains and Piedmont of New Jersey and the Piedmont of North Carolina. The number of introduced species decreased with age since abandonment, while that of native species increases. The life-form spectra of corresponding series are very similar in all the areas and there are some similarities in species composition, but almost none in the dominant species. The increasing differences between the series in different areas as succession proceeds is related to the decline of introduced species and to changing site conditions following agricultural abandonment.

Harrison JS and Werner PA. 1984.
Colonisation by oak seedlings into a heterogeneous successional habitat. Canadian Journal of Botany. 62(3): 559-563.

Abstract: Establishment of Quercus velutina and Q. alba seedlings was studied during 1976-81 on an old field abandoned in 1951 in Michigan. Results suggested that oaks first established on bare ground but then survived only if surrounding vegetation invaded the microsite.

Holt RD Robinson GR and Gaines MS. 1995.
Vegetation dynamics in an experimentally fragmented landscape. Ecology. 76(5): 1610-1624.

Abstract: In spatially heterogeneous habitat, plant community change may reflect spatially localised population-level processes that are sensitive to the size of an average habitat patch. However, local species turnover can also be determined by initial conditions and large-scale processes, in which case patch size effects may be overridden. To examine the role of patch size in directing secondary succession, a newly abandoned agricultural field in NE Kansas was subdivided into an array of experimental patches (32, 388, and 5000 m2, grouped to sample equivalent portions of the field), and the resident plant and animal communities were recorded at regular intervals. The general course of change in all patches over a 6-year period followed a trajectory typical of old-field succession, toward increasing dominance by longer lived and larger plant species. The same group of species that dominated at the start of the study continued to dominate after 6 years, although in very different proportional abundances. Larger patches were more species rich than their smaller counterparts, and had a higher proportion of nonshared species, but the additional species were transient and low in abundance. Spatial heterogeneity in vegetation, measured as local community dissimilarity, increased in all patches but to a lesser extent in the largest patches, where censuses of nearby permanent quadrats indicated less divergence over time. At a population level, the strongest effect of patch size was that local populations of clonal species were more prone to disappear from the smallest patches. Nevertheless, summary measures of temporal community change did not reflect significant differences in localised species turnover. It is concluded that patch size does not markedly affect the rate or pattern of early secondary succession, at the scales imposed in this experiment.

Inouye RS Allison TB and Johnson NC. 1994.

Old field succession on a Minnesota sand plain: effects of deer and other factors on invasion by trees. Bulletin of the Torrey Botanical Club. 121(3): 266-276

Abstract: Invasion of old fields by trees occurs much more slowly at the Cedar Creek Natural History Area, Minnesota, than is typical of most areas in the eastern and central USA. Many fields abandoned from agriculture > 50 yr. ago lack a tree canopy. Trees, saplings and seedlings were tagged, mapped and measured during 1988-92; most tagged individuals were red oak (Quercus rubra). Tree density, height and average distance from the forest margin were all positively correlated with time since field abandonment. Most saplings > 20 cm tall were browsed by white-tailed deer (Odocoileus virginianus) during winter. Tree growth was significantly greater inside deer exclosures, although the difference in growth rate of trees inside and outside exclosures was less than expected. Pocket gophers also caused substantial mortality over time. Drought also caused excess mortality in 1988. Removal of herbaceous vegetation around saplings increased stem diameter growth, but fertiliser application had no effect. It was concluded that nutrient-poor soils, slow growth rates, herbivory and climatic factors probably all contribute to the slow invasion of Cedar Creek old fields by trees.

Inouye RS Huntly NJ Tilman D Tester JR Stillwell M and Zinnel KC. 1987.
Old-field succession on a Minnesota sand plain. Ecology. 68(1): 12-26.

Abstract: Vegetation and soils were sampled in 22 old fields ranging in age from 1 to 56 yr. since abandonment. Soil nitrogen concentration increased significantly with field age. Vegetation cover, total aboveground plant biomass, and litter cover increased significantly with soil nitrogen. Light penetration to the soil surface was negatively correlated with total plant biomass. Field age and soil nitrogen concentration were used as independent variables in simple regression and partial correlation analyses to determine the relative importance of such time-dependent processes as dispersal vs. the availability of a limiting resource (nitrogen) as predictors of patterns in species richness or the abundance of various plant groups. Species richness per field and within-field heterogeneity in species composition increased with field age. Local species richness decreased with increasing soil nitrogen. Cover of annuals and introduced species decreased with field age and nitrogen; however, annuals contributed an important part of total vegetative cover even in 25-yr.-old fields. Cover of perennials and woody species increased with soil nitrogen and field age. Although the fields were bordered by woods, woody species contributed < less than > 15% cover even in the oldest fields. For several plant groups the relationship between cover and soil nitrogen within individual fields was the opposite of that among all fields. These patterns suggest that while soil nitrogen is an important determinant of local species composition and abundance, dispersal and colonisation, which are dependent on field age, determine which species are present in a field.

Lavorel S Lepart J Debussche M Lebreton JD and Beffy JL. 1994.
Small scale disturbances and the maintenance of species diversity in Mediterranean old fields. Oikos. 70(3): 455-473.

Abstract: In three Mediterranean old fields (1, 7 and 15 years after the last ploughing), located in Montpellier, small scale disturbances (0.25 m2) by glyphosate associated with or without litter removal and scratching of the top 3 cm of the soil were generated in Oct. 1988, Dec. 1988 and Mar. 1989. Subsequent changes in cover, species richness (including weedy species) and composition were observed over the two following vegetation cycles (until May 1990), and compared to the dynamics in undisturbed samples. The identity of the colonisers for each disturbance date were compared to the soil readily-germinable seed content, sampled simultaneously to the disturbances. The species richness of the samples within the fields increased in the first year after disturbance. Within-field heterogeneity for taxonomic composition was unchanged, but species turnover was increased by disturbances. The dynamics of species richness and composition followed consistent patterns in the three fields. These patterns were strongly related to the seasonal rainfall distribution and clearly linked to the germination timings of the species and to seed bank composition. The identity of species depending on season and treatment were independent between fields. The effects of small scale disturbances on patterns of species establishments and replacements depended on their timings. Disrupting the dominance of autumn established grasses and legumes by disturbances allowed the germination of annual forbs and for spring establishment of perennials. These species were otherwise present as understorey species or in the seed bank. Results of these experiments provide an insight into the mechanisms of maintenance of species diversity in Mediterranean old field systems. Asynchronous small-scale disturbances appear to be effective in maintaining diversity as a result from the interplay of differences in regeneration niches, lottery for establishment, and the incidence of different conditions in time and space.

Leps J. 1987.
Vegetation dynamics in early old field succession: a quantitative approach. Vegetatio. 72(2): 95-102.

Abstract: The vegetation on a newly abandoned field in the Bohemian Karst, Czechoslovakia was analysed yearly and classified on the basis of frequency of dominants and on floristic data (TWINSPAN). Transition matrices were constructed and evaluated and an ordination of quadrats provided supplementary information. The first 4 years of succession was nearly unidirectional with the rate of succession decreasing with time. Floristic composition changed more rapidly than the performance of the dominant species, which included Papaver rhoeas, Galium aparine, Bromus sterilis, Artemisia vulgaris and Achillea millefolium. The influence of early vegetation composition on further development of the plant community was relatively weak.

Maltitz GP vonWyk GF vanEverard DA Von Maltitz GP and Van Wyk GF. 1996.
Successional pathways in disturbed coastal dune forest on the coastal dunes in north-east KwaZulu-Natal, South Africa. South African Journal of Botany. 62(4): 188-195.

Abstract: The floristic composition and structure of secondary dune forest, established on old lands and in grassland, was investigated on the coastal dunes of the NE coast of KwaZulu-Natal. Two distinctly different pathways from disturbance to forest were identified. One is typified by an even aged stand of Acacia karroo, the other by bush clumps in a grassland matrix. The bush clumps are initiated around a single tree, normally Syzygium cordatum, which then acts as a nurse for the establishment of other woody species. The species composition and structure of the bush clumps were the same, regardless of whether the area where it established was identified as an old field or grassland. The bush clumps had a substantially higher density of both woody plants and woody species than did the A. karroo stands.

Maycock PF and Guzikowa M. 1984.
Flora and vegetation of an old field community at Erindale, southern Ontario. Canadian Journal of Botany. 62(11): 2193-2207.

Abstract: Qualitative and quantitative descriptions are given of slow succession in a stable old field, 5.4 ha in extent, that had been undisturbed for at least 50 yr.

Maycock PF and Guzikowa M. 1984.
Flora and vegetation of an old field community at Erindale, Southern Ontario. Canadian Journal of Botany. 62(11): 2193-2207.

Abstract: A stable 5.4-ha old field undisturbed for 50 years was studied for presence and frequency and estimated cover of various spp. in 1-m < sup(2) > quadrats. Of the total flora of 118 spp., 99 were found in the communities studied and only 61 had measurable cover. Agropyron [Elymus] repens, Vicia cracca and Poa pratensis were major dominants followed by Solidago altissima, Phleum pratense and Hieracium pratense. Native spp. (52%) outnumbered introduced spp. (48%) but the latter had a much greater cover. Spp. distribution was correlated with soil moisture and with different stages of succession toward forest which varied with position in the field.

Nepstad DC Uhl C and Serrao EAS. 1991.
Recuperation of a degraded Amazonian landscape: forest recovery and agricultural restoration. Ambio. 20(6): 248-255.

Abstract: Ranching and logging operations are transforming the moist tropical forests of the eastern Amazonian landscape into a mosaic of pastures and regrowth forests. The process is illustrated by reference to the Paragominas region of Para state, an area which has been ranched and logged for < more than > 20 yr. The new ecosystems of this region are agriculturally unproductive, biologically impoverished, and far more inflammable than the mature forests they replace; hydrological differences between the new and old systems are unknown and potentially large. In the absence of fire, the forest regrows on abandoned sites, accumulating biomass and species at a rate that is inversely related to the intensity of use prior to abandonment. Forest regrows slowest on those rare abandoned pastures that were once scraped with bulldozers. The grass- and shrub-dominated old fields that form on some of these sites resist forest regrowth because of numerous barriers to tree establishment and growth. These barriers have been studied in detail in an old field at Fazenda Vitoria (Vitoria Ranch), 6.5 km NW of Paragominas town, and include low propagule availability, seed and seedling predation, seasonal drought, and root competition with old field vegetation. Knowledge of these barriers provides a basis for developing inexpensive techniques (1) to restore agricultural productivity in old fields by planting tree-based agricultural systems or (2) to restore forest regenerative capacity in old fields by establishing trees that attract seed-carrying animals and ameliorate harsh environmental conditions. The first technique (an agroforestry option) has been used by Brazilian farmers of Japanese descent and involves planting fruit, nut and timber tree seedlings, whose growth may be enhanced by establishing them in a hole filled with loose soil and decaying organic matter in a weed-free area of 50-cm radius. Using this planting method at Fazenda Vitoria promoted fruiting of several species within 1 yr. of planting (e.g. Anacardium occidentalis [A. occidentale], Bixa orellana and Byrsonima crassifolia). Slower growing fruit and nut trees were robust 2 yr. after planting (e.g. Bertholletia excelsa and Spondias mombim [S. mombin]) and even some timber species exceeded 4 m in height (e.g. Swietenia macrophylla and Cedrela odorata). The second technique involves planting 'island-forming' tree species that grow rapidly in full sun and produce fleshy fruits soon after planting, preferably establishing them at short intervals from the forest edge to the centre of the old field, so that seed carrying animals penetrate far into the old field. An example of such a species is Stryphnodendron pulcherrimum. These restoration techniques will be needed over large areas of Amazonia if current attempts to reform degraded pastures fail.

Puerto A and Rico M. 1988.
Influence of tree canopy (Quercus rotundifolia Lam. and Quercus pyrenaica Willd.) on old field succession in marginal areas of central-western Spain. Acta Oecologica, Oecologia Plantarum. 9(4): 337-358

Abstract: A joint study was made of old field succession and the influence of tree canopy in an impoverished dehesa zone with mixed Q. rotundifolia/Q. pyrenaica communities in NW Salamanca province. The successional series was 9 old fields 0-20 yr. old, used for livestock grazing (beef steers and sheep) after the abandonment of cereal cultivation. Three specimens of each tree species were selected in each age plot for an assessment of floristic and soil parameters under, at the edge of, and outside the tree crowns in a north-south orientation. Analysis of the results (which are given in detail) showed that convergence between succession and the influence of the tree canopy was clear for the soil variables but less so for the floristic variables. Separately, there was a relation between the vegetation and the soil. The tree influence accelerated the successional process, especially initially, for Q. pyrenaica; this influence was particularly noticeable in the areas under the crowns and in the projection of the edge of the crowns over north-oriented soils. The variations in diversity and its components of richness and equitability, and the generalised increase in herbaceous cover, characterised the different successional series detected. It is suggested that any improvement strategies in these areas should favour the woody species with the greatest contributions, the abandonment of cultivation, a better structuring of the territory, erosion control, and provision of a reserve of sufficient (and stable) nutrients.

Purata SE. 1986.
Transect analysis as a basis for comparing stages of old-field succession in a tropical rain forest area of Mexico. Tropical Ecology. 27(2): 103-122.

Abstract: Forty old fields (from recently abandoned to 30-yr.-old communities) with different management histories were sampled using transects crossed perpendicularly. Sampling and data analysis are described in detail and evaluated. In general, no internal gradients were found which could be interpreted in terms of management history. However, time since abandonment did not provide a complete explanation of successional development at each site, so it is suggested that management history is a factor in determining succession.

Roberts TL and Vankat JL. 1991.
Floristics of a chronosequence corresponding to old field-deciduous forest succession in southwestern Ohio. II. Seed banks. Bulletin of the Torrey Botanical Club. 118(4): 377-384.

Abstract: Seed banks were studied in a chronosequence of 5 stands near Oxford, Ohio: 2- and 10-yr-old herb-dominated old fields; a 50-yr-old savanna-like old field; and 90-yr-old and old-growth broadleaved forests. Species richness, species diversity and density of seed banks generally decreased with successional age. Percentages of annuals and biennials (and short-lived perennials) generally decreased while that of perennial herbs increased with successional age. Seeds of woody plants were absent from the youngest stands.

Schmidt W. 1988.
An experimental study of old-field succession in relation to different environmental factors. Vegetatio. 77: 1-3.

Abstract: Old-field succession on sterilised sand and loam was studied under different water and nutrient regimes. Within one month, moss (Bryophyte) and phanerogam species appeared on all experimental plots but further succession was rather varied. Salix species established quickly on loam and formed within 3 years a shrub layer up to 3 m in height. On sand, woody plant species were observed only at high groundwater level sites. On loam, the old-field succession from short-living therophytes to long-living phanerophytes of clearings and woodlands proceeded very quickly. In contrast, on sand, therophytes, hemicryptophytes and herbaceous chamaephytes of ruderal and grassland communities were still dominant after three years. A high groundwater level as well as mineral fertilisation had variable effects on this succession. The highest amount of biomass was measured on the three loamy soils where shrub layers were well developed. In comparison with data published elsewhere, the above-ground biomass of 2.2-2.8 kg DM m < sup(< minus > 2) > and the below-ground biomass up to 7.2 kg DM m < sup(< minus > 2) > were both high. Over the three years, the vegetation on sandy soils accumulated between 1.2 and 5.1 g N m < sup(< minus > 2) > per year and on loamy soils between 17.1 and 24.7 g N m < sup(< minus > 2) > per year.

Schott GW and Hamburg SP. 1997.
The seed rain and seed bank of an adjacent native tallgrass prairie and old field. Canadian Journal of Botany. 75(1): 1-7.

Abstract: The ability of a grassland to regenerate following disturbance depends on the presence of seeds of native plants and the ability of the seeds to germinate. To examine whether the presence or absence of plant propagules influences re-establishment of tallgrass prairie on abandoned agricultural lands, the seed rain and soil seed bank across a transition from native tallgrass prairie to unmanaged successional grassland (old field) in Kansas was sampled. The native prairie seed rain was seven times greater than that of the old field, richer in species (33 vs. 27), and more diverse (diversity index 0.96 vs. 0.73). In addition, the native tallgrass prairie seed bank was three times as dense as the old-field seed bank and contained the seeds of more species (23 vs. 19), but had a lower index than did the old field (0.81 vs. 1.08). One species, Sphenopholis obtusata, present in the prairie, was observed dispersing to the old-field plot, but was absent in the old-field plot; this observation suggests that at least some species are unable to establish on the old-field plot. Thus, the ability of a native grassland to re-establish may be limited by the dispersal ability of native species and the ability to establish once dispersed.

Sietman BE Fothergill WB and Finck EJ. 1994.
Effects of haying and old-field succession on small mammals in tallgrass prairie. American Midland Naturalist. 131(1): 1-8.

Abstract: Land use practices have created a mosaic of habitats that in some ways resemble the presettlement prairie mosaic. To examine the effects of land use practices on habitat use by small mammals, trapping was done in native, hayed and old-field prairies in E-central Kansas. Relative abundance of all small mammals was highest in the old field and lowest in the hayfield. The high relative abundance of Sigmodon hispidus and Peromyscus leucopus in the old field may be explained by heterogeneity of vegetation, and prevalence of forbs and woody plants. Microtus ochrogaster [Pitymys ochrogaster] and Blarina hylophaga had higher relative abundance in the native prairie than the other species, possibly due to higher vegetation cover. The low relative abundance of small mammals in the hayfield suggests the importance of vertical structure and canopy cover of vegetation, particularly for M. ochrogaster and S. hispidus. Land use mosaic may affect the structure and composition of small mammal communities in a fashion similar to that of the natural prairie mosaic.

Tatoni T and Roche P. 1994.
Comparison of old-field and forest revegetation dynamics in Provence. Journal of Vegetation Science. 5(3): 295-302.

Abstract: A study was made of vegetation changes on cultivation terraces after abandonment (considered as secondary succession), and vegetation responses after clear felling (considered as regeneration) at sites in Provence, France. Species were grouped in life form and dynamic categories in order to infer dynamic patterns. By applying the Shannon diversity index to these characteristics, an index of functional diversity was obtained. Regenerative succession was considered here as a particular case of secondary succession, characterised by a fast vegetative regeneration of the dominant woody species, which controls the succession of the understorey species. Post-agricultural succession and forest regeneration succession show a similar relation between the diversity index and a forest index, indicating the relative amount of forest species. It appeared that the old-field dynamics resemble the deciduous oak (Quercus) forest regeneration after the woody species have established. The species diversity at the end of the post-agricultural succession and in the forest is controlled by the nature of the dominant tree species.

Tatoni T Magnin F, Bonin G and Vaudour J. 1994.
Secondary successions on abandoned cultivation terraces in calcareous Provence. I- Vegetation and soil. Acta Oecologica. 15(4): 431-447.

Abstract: Vegetational and soil changes in cultivation terraces after land abandonment were studied in France. Dynamic patterns are demonstrated by a correspondence analysis conducted on the floristic data. Changes in vegetation features (species richness, growth forms, dynamic gradient and biogeographic types) and in pedological factors are studied along the main dynamic gradient to characterise the succession patterns. Without disturbance, abandoned terraces are quickly recolonised by forest vegetation. The characteristics of dynamics patterns agree with the results already obtained in many studies on secondary successions. In the upper horizon of the soils, the organic matter contents increase along the old field succession. However, wild fires can lead to the occurrence of low open shrublands, as well as soil alteration, particularly in the lower horizon and granulometry.

Trebino HJ Chaneton EJ and Leon RJC. 1996.
Flooding, topography, and successional age as determinants of species diversity in old-field vegetation. Canadian Journal of Botany. 74(4): 582-588.

Abstract: The spatial pattern of plant richness and diversity was studied along topographic gradients in two pairs of plots with 3 and 4 versus 9 and 10 years of abandonment from cultivation, in the Inland Pampa of Argentina. Vegetation in each plot was sampled for species cover every 10 m along a transect running parallel to the maximum local slope. Observations began after 2 years of unusually severe floods and continued for over 6 years. Community richness and diversity both increased with topographic height only the first year after flooding, in young and old successional plots. Richness and diversity decreased over time in upper and intermediate topographic positions, converging toward lesser values observed in lower positions. A transient peak in diversity occurred in lower topographic positions several years after flood disturbance. Species richness was similarly constrained by flooding stress and successional development. Thus, maximum diversity occurred at an early stage of succession in upper, infrequently flooded sites. Spatial and temporal patterns of plant diversity in this successional system did not generally conform with predictions from intermediate disturbance models. It is proposed that control of species diversity in old-field vegetation changed with time since flooding from physical stress to strong biotic interactions.

Vankat JL. 1991.
Floristics of a chronosequence corresponding to old field-deciduous forest succession in southwestern Ohio. IV. Intra- and inter-stand comparisons and their implications for succession mechanisms. Bulletin of the Torrey Botanical Club. 118(4): 392-398.

Abstract: Vegetation, seed banks and post-disturbance vegetation were compared for a chronosequence of 5 stands near Oxford, Ohio: 2- and 10-yr-old herb-dominated old fields; a 50-yr-old savanna-like old field; and 90-yr-old and old-growth broadleaved forests. Results are discussed in relation to succession mechanisms.

Vankat JL and Carson WP. 1991.
Floristics of a chronosequence corresponding to old field-deciduous forest succession in southwestern Ohio. III. Post-disturbance vegetation. Bulletin of the Torrey Botanical Club. 118(4): 385-391.

Abstract: Revegetation of plots 1.5 < multiply > 1.5 m was examined during the first season after disturbance (by severing roots and rhizomes, and turning the topsoil) in a chronosequence of 5 stands near Oxford, Ohio: 2- and 10-yr-old herb-dominated old fields; a 50-yr-old savanna-like old field; and 90-yr-old and old-growth broadleaved forest. Results are discussed in relation to the hypotheses that, in comparison with early stages, post-disturbance vegetation of later successional stages will have lower species richness and diversity, reduced plant abundance, and lower relative number and abundance of annuals and biennials, but higher values for perennial herbs and woody plants.

Vankat JL and Snyder GW. 1991.
Floristics of a chronosequence corresponding to old field-deciduous forest succession in southwestern Ohio. I. Undisturbed vegetation. Bulletin of the Torrey Botanical Club. 118(4): 365-376.

Abstract: In order to characterise vegetation changes during succession, site factors, vegetation and flora were determined for a chronosequence of 5 stands near Oxford, Ohio: 2- and 10-yr-old herb-dominated old fields; 50-yr-old savanna-like old field; and 90-yr-old and old-growth broadleaved forests. The flora in each stand is tabulated.

Warning D. 1996.
The development of vegetation and soil on abandoned fields in the Luneburger Heide national park. Results of a chronosequence analysis. Tuexenia. No. 16: 451-495.

Abstract: The vegetation of selected old fields in the Luneburger Heide National Park (NW Germany) is described and classified and its succession was investigated. The cover of various life forms and phytosociological groups was also calculated. The development of vegetation in abandoned fields was mainly determined by management after farming. In the early succession, less than 20 years after farming had ceased, stands of the Festuca rubra-Agrostis capillaris community covered most of the fields. Such vegetation was promoted by sheep grazing early in the succession. The development of heath on former fields is also discussed. In the course of time, an Ah-horizon was built up within the Ap-horizon in stands of the Festuca rubra-Agrostis capillaris community and an organic layer was formed in heath. In later succession after the termination of farming, the soil acidity rose and a change in the pH depth profile was noticed. The possibility of impoverishment over time due to phosphorus decline, is discussed.

REGENERATION / REGROWTH / REMNANTS

Catteral, C.P. and Kingston, M. 1993.
Remnant bushland of south east Queensland in the 1990's. Its distribution, loss, ecological consequences and future prospects. Institute of Applied Environmental Research, Griffith University / Brisbane City Council, Brisbane.

Comment: Spatial distribution and extent only. No information on quality.

Forestry Commission of Tasmania. 1993.
Survey of Regeneration on Private Lands.

Comment: Essentially area figures only. No discussion of conservation value of regrowth *per se*.

Sherwood, J.; Cumming, K; Stagnitti, F. and Anderson, R. 1992.
Understorey Revegetation Project. Tower Hill State Game Reserve. Report prepared for DCE Victoria. Winsearch Ltd., Melbourne.

Comment: Area totally cleared between 1850 and 1961. Overstorey replanted from 1960's. Present trial to investigate tube stock versus direct seeding for re-establishment of the understorey. No discussion of conservation value of regrowth *per se*.

Tracey, J.G. 1986.
Trees on the Atherton Tableland: Remnants, Regrowth and Opportunities for Planting. CRES Working Paper 1986/35. CRES, ANU, Canberra.
Comment: Briefly describes floristic composition of some regrowth stands as part of larger discussion, with some discussion on weed problems. No discussion of conservation value of regrowth *per se*.

SOIL SEED BANKS

Amezaga I and Onaindia M. 1997.
The effect of evergreen and deciduous coniferous plantations on the field layer and seed bank of native woodlands. Ecography 20 (3): 308 - 318.

Abstract. Vegetation and seed bank changes due to the replacement of a native woodland 29 yr ago by coniferous plantations (evergreen coniferous Pinus radiata and deciduous coniferous Larix kaempferi) were studied in a replicated experiment in the Basque Country, northern Spain. In the vegetation the species richness was lower in both coniferous plantations than in the native woodland but there was no significant difference in species richness between the two coniferous plantations. The highest similarity between the vegetation and the seed bank was in the P. radiata plantations (0.51). There was higher vegetation similarity between the native woodland and the larch plantation (0.65) than that with the pine plantation (0.58). Seed bank species richness was higher in the arch plantation than in the native woodland but species richness in the seed bank did not differ between the coniferous plantations. The seed bank showed no difference in the species similarity between the plantations and the native woodland. This was mainly due to the similarity between the broad ranged species. In the coniferous plantations the vegetation diversity was lower than in the native woodland; however, in the seed bank the diversity was higher. Coniferous plantations affected mainly the shade-tolerant and shade-intolerant vernals (Caltha palustris, Galium odoratum, Heleborus viridis and Saxifiaga hirsuta), which disappeared from the field layer of plantations while the shade-intolerant not vernals were favoured by the plantations (Blackstonia perfoliata, Danthonia decumbens, Deschampsia flexuosa, Hypericum androsaemum, Holcus lanatus, Lotus corniculatus and Plantago lanceolata). There was no significant difference in vegetation or seed bank between the two types of coniferous plantations.

Anderson UV. 1995.
Succession and soil development in man-made coastal ecosystems at the Baltic Sea. Nordic Journal of Botany. 15(1): 91-104.

Abstract: Koge Bay Seaside Park, south of Copenhagen, was created in 1978 as a coastal area for recreation and coast protection. The soil was made of marine material from the Baltic Sea, with no organic matter or seed bank. Primary succession was first assessed in 1980, and further surveys were made in 1992 and 1993. A few woody and grass species were planted and sown, but all other species depended on natural dispersal. Species number in permanent 10 x 10 m plots increased from 26 in 1980 to 91 in 1993, and it is suggested that the number is still increasing. Most of the halophytic and weedy species which initially colonised the area had disappeared by 1993. Early stages of primary succession included establishment of many legumes. Compared with 1980, in 1992-93 the percentage of annuals and seashore plants had decreased and the number of species adapted to wind dispersal increased. Rather than the expected salt meadow, the area has developed into a landscape dominated by small groves and grasslands of an urban common type.

Bertiller MB. 1996.
Grazing effects on sustainable semiarid rangelands in Patagonia: the state and dynamics of the soil seed bank. Environmental Management. 20(1): 123-132.

Abstract: The composition of the germinable seed bank was studied in four vegetation states (grazed and ungrazed uplands and slopes) of the Festuca pallescens grasslands in semiarid Patagonia during four years in order to test whether aboveground vegetation states resulting from different combinations of grazing and topography are reflected in different states of the germinable seed bank. The size of the total and dicot germinable seed bank was positively related to the total cover in each state. Dicots dominated all germinable seed bank states. Carex patagonica increased its cover as well as its germinable seed bank under grazing disturbance. Grazing did not reduce the germinable seed bank of perennial grasses in uplands where the grazing pressure is lower than slopes. In slopes the germinable seed bank of perennial grasses was significantly reduced by grazing. A reduction of the length of the grazing period in late spring increased the germinable seed bank of perennial grasses both in upland and slope. These results are interpreted in the frame of a model of management techniques where grazing exclusion during late spring and late summer increases the seed bank of perennial grasses and promotes their establishment in uplands. The artificial addition of seeds of perennial grasses and the manipulation of the soil surface in order to increase 'safe sites' appear as management alternatives that deserve further evaluation to improve plant re-establishment in slopes.

Buckley GP Howell R and Anderson MA. 1997.
Vegetation succession following ride edge management in lowland plantations and woods. 2. The seed bank resource. Biological Conservation 82 (3): 305 - 316.

Abstract. The composition and distribution of the buried soil seed bank was examined across the edges of lowland plantations and woods in southern England from which portions of the tree canopy were removed. Species most frequently germinating in soil samples were those with known or suspected persistent soil seed banks, which included a number of ancient woodland indicators. Both the number of individuals and species were stimulated by the cutting treatments, especially in the areas cleared of trees, where initial germination temporarily depleted the seed bank. Recharge followed rapidly over successive growing seasons, with several species showing consistently strong zonation across the edge gradient. These results suggest that edge management has a positive role in restoring and maintaining populations of seed bank species in plantations and neglected coppice woods, but the frequency of cutting needs to be carefully balanced against the requirements of other, less mobile species of both permanently open and shady habitats.

Eriksson O. 1996.
Regional dynamics of plants – a review of evidence for remnant, source-sink and metapopulations. Oikos 77 (2): 248 - 258.

Abstract. Despite a long tradition in plant ecology of studies of patch dynamics, recent developments of models for large scale dynamics in source-sink and metapopulations have largely focused on animals. In contrast to mobile unitary animals, many plants resist extinction, even under conditions where only a part of the life cycle can be maintained. This model of remnant population dynamics adds to the two commonly recognised source-sink and metapopulations dynamics. A review of the literature suggests that all three types of dynamics are common in plants. Regional dynamics are related to life-cycle characteristics determining dispersal ability and longevity of life cycle stages. Short-lived or highly habitat specialised plants with good dispersal tend to build up metapopulations, i.e. systems of local populations and non-occupied but potentially suitable sites, interconnected with dispersal, and in a continuous flux of local colonisation and extinction. At the other extreme, long-lived plants with clonal propagation, or plants with extensive seed banks, tend to build up remnant population systems, in which many local populations persist over periods long enough to bridge unfavourable phases of successional development, intervening periods of favourable conditions. Source-sink populations are a special case of metapopulations, in the sense that they comprise both persistent refuge populations and ephemeral populations maintained by dispersal. It is suggested that a concept of local population inertia in remnant population systems, scales to higher level phenomena of vegetation inertia, and to community stabilisation (through enhanced recovery after perturbations). Such an inertia may contribute to explain cases of exceptionally high species diversity, and lack of pronounced mass extinctions of plants in the fossil record.

Granstrom A. 1982.
Seed banks in five boreal forest stands originating between 1810 and 1963. Canadian Journal of Botany. 60(9): 1815-1821.

Abstract: The viable seed content of soil samples from five coniferous forest stands in northern Sweden, aged 16-169 years, was determined by germination trials. The soil samples were separated into three organic horizons and two mineral horizons. Seedlings of 15 phanerogam species emerged, representing densities of 239-763 seeds/m < sup(2) > in the soils from the different stands. Luzula pilosa and Vaccinium myrtillus dominated the seedling counts for all stands. The depth distributions of the seeds varied with both plant species and forest stand. Most seeds were found at various depths in the humus layer, but in one stand an appreciable seed density of Luzula pilosa was present in the mineral soil. Most of the seedlings belonged to plant species present in the vegetation or with good means of dispersal. The depth distribution data, however, suggest that Luzula pilosa in particular may have a persistent seed bank. The role of persistent seeds in the vegetational composition of the boreal forest is discussed.

Jankowskablaszczuk M and Grubb PJ. 1997.
Soil seed banks in primary and secondary deciduous forest in Bialowieza, Poland. Seed Science Research 7 (3): 281 - 292.

Abstract. Germination over 3 years was followed in 25 soil samples of 31 x 31 x 5 cm each from primary and secondary stands in Bialowieza forest, Poland. The number of seedlings emerging and the number of species declined over the 3 years. In year 1 the mean densities of emerging seedlings for the primary and secondary stands were similar (2142 m(-2) and 2488 m(-2) respectively); in year 3 the difference was greater (248 vs. 498 m(-2)) but not statistically significant. The trend reflected the greater longevity of the seed bank species characteristic of the secondary forest. Two functional groups of herb and shrub species were distinguished in the seed bank based on (a) frequency as adults in the present vegetation, and (b) relative abundance in the seed banks of primary and secondary forest. Group A species need large-scale gaps in the tree canopy; most have very small seeds (0.15 mg mean dry mass) and are very persistent in the soil. Group B species benefit from single-treefall gaps in the tree canopy, but appear to be suited primarily to gaps in the canopy of the herb layer and in the root layer made mainly by animals; their seeds are not as small (mostly 0.15 mg) and not as persistent in the soil. Group B species made up 86% of the seedlings emerging over 3 years in soil from the primary stand, and 56% of those from the secondary stand. In the laboratory all five Group B species tested showed some inhibition of germination in darkness, but only one showed unequivocal inhibition by far-red-enrichment of low irradiance light.

Jefferson RG and Usher MB. 1989.
Seed rain dynamics in disused chalk quarries in the Yorkshire Wolds, England, with special reference to nature conservation. Biological Conservation. 47(2): 123-136.

Abstract: The species composition of the seed input or 'rain' of two disused chalk quarries is described; these sites were known to have botanical conservation interest. There was a close qualitative correlation between the species composition of the seed rain and the existing flowering plant community; the flowering plant community was more closely related to the seed rain than to the soil seed bank. Very few species were present in the seed rain that were absent from the quarry vegetation. The importance of seed rain for the management of terrestrial habitats for nature conservation is discussed.

Kiirikki M. 1993.
Seed bank and vegetation succession in abandoned fields in Karkali Nature Reserve, southern Finland. Annales Botanici Fennici. 30(2): 139-152.

Abstract: The vegetation of 3 abandoned fields in Karkali Nature Reserve developed without human impact for 21 years. In 1967, the 1st summer after abandonment, permanent sample plots were set up to study vegetation succession; these were inspected every 5th year. In autumn 1988 and 1989, soil samples were collected in order to study the composition and germination of the seed bank. The composition of the seed bank was correlated with the successional vegetation cover. The av. size of the seed bank was 50 < thin > 000 viable seeds/m < sup(2) > to a depth of 25 cm. The most abundant taxa were Gnaphalium uliginosum [Filaginella uliginosa], Juncus spp., Hypericum spp., Sagina procumbens and Veronica serpyllifolia, species common in the early stages of succession. Seeds of 17 species were found to have remained viable for 5-21 years. Analysis of the vertical structure of the seed bank was shown to be a useful means of evaluating which seeds arrived before and which after abandonment of the fields.

Kinucan RJ and Smeins FE. 1992.
Soil seed bank of a semiarid Texas grassland under three long-term (36-years) grazing regimes. American Midland Naturalist. 128(1): 11-21.

Abstract: Species composition and density of the readily germinable soil seed bank of 3 long-term grazing treatments (heavy continuous, moderate deferred rotation and ungrazed exclosure) were determined for a summer and spring period for a semiarid grassland of the W. Edwards Plateau, Texas. Total seed densities (2252-4409 seeds/m < sup(2) >) did not differ among grazing treatments, but varied seasonally. Species composition varied among treatments. Heavy continuous grazing had a high proportion of early-seral, annual-dicot taxa, whereas the ungrazed treatment had a high proportion of late-seral, perennial-monocot taxa. Seeds of late-successional midgrass species (e.g., Bouteloua curtipendula, Eriochloa sericea) were not stored in the soil of any treatment and appeared to be transient. Many other species appeared to maintain persistent seed banks, including seeds of the current mid-successional dominant shortgrass, Hilaria belangeri. Similarity of composition between germinable seeds in the soil and existing plant communities was low. It was concluded that the soil seed bank is a primary control of secondary succession in these grasslands, and absence of late-successional species in the seed bank impairs the rate of succession.

Kotanen PM. 1996.
Revegetation following soil disturbance in a California meadow: the role of propagule supply. Oecologia. 108(4): 652-662.

Abstract: Artificial soil disturbances were created by excavating or burying pre-existing grassland vegetation in a natural meadow present in a forest opening. In the first experiment, disturbance intensity (depth) was varied in order to investigate the consequences for revegetation when numbers of surviving propagules (dormant seeds and bulbs) were altered. In the second experiment, the timing of disturbance was varied, to investigate the consequences when disturbed sites experienced differing exposures to seasonal patterns of clonal growth and seed dispersal. The experiments were sampled from 1991 to 1993, and their results interpreted using measurements of the seed bank, the bulb bank, and the seed rain. In the first (depth) experiment, bulbs declined in abundance with burial depth and were scarcer in deeper excavations. In contrast, numbers of annual graminoids initially showed no trends with respect to disturbance depth. These results reflect the depth distributions of the seed and bulb banks. Since bulbs occur deeply in the soil, progressively deeper disturbances left fewer survivors. Similarly, perennial graminoids could grow through the shallowest burials. In contrast, since the annual-graminoid-dominated seed bank is concentrated near the soil surface, disturbance depth mattered less to these species: any disturbance removing the surface layer was equally destructive. In the second (timing) experiment, more annual graminoids initially occurred in older plots. This result reflects seasonal patterns of seed production: plots exposed to more of the annual-graminoid-dominated seed rain supported higher densities of annual graminoids as a result. In subsequent years, the vegetation of most plots in both experiments was increasingly dominated by annual graminoids, again as a consequence of their great abundance in the seed rain. These results indicate that interactions between soil disturbances and sources of propagules play an important role in controlling early stages of succession in newly created gaps. They also suggest that disturbance may play different roles in communities characterised by species with different reproductive strategies. Understanding sources of colonists will improve the ability to predict the effects of disturbance.

Lagroix-McLean R and King JR. 1989.
Buried viable seeds in the Alberta foothills under high intensity low frequency grazing and the resemblance to seed rain. pp. 1067-1068. Proceedings of the XVI International Grassland Congress, 4-11 October 1989, Nice, France. Association Francaise pour la Production Fourragere. Versailles, France.

Abstract: Field experiments were conducted on a Canadian native rangeland to describe seed bank and seed rain and to evaluate the impact of high intensity low frequency grazing on seed rain and the correlation with the bank. Species number and species abundance varied on a yearly basis. The most abundant dicotyledons in the seed bank were Artemisia frigida and Androsace septentrionalis in both years and soil strata. Juncus sp. comprised the major portion of the monocotyledon seed bank in 1985, while in 1986, due to increased seed production and a later sampling date, Koeleria macrantha was most prevalent. Seed rain was not a good indicator of the seed bank or vice versa. Seed rain consisted largely of grasses such as Koeleria macrantha and dicotyledons from the families Compositae and Cruciferae. Species observed in the seed rain were not always present in the seed bank. Conversely, other species abundant in the seed bank occurred only rarely in the seed rain. Festuca scabrella [F. altaica subsp. hallii], a desirable forage grass observed on the site, was not found in either the seed bank or seed rain.

McClanahan TR and Wolfe RW. 1993.
Accelerating forest succession in a fragmented landscape: the role of birds and perches. Conservation Biology. 7(2): 279-288.

Abstract: In order to determine the effectiveness of bird perches (snags) in reclaiming forested landscapes, seed dispersal, seed bank storage and recruitment of bird-dispersed plants were studied for 7 yr on a central Florida mined site with clay-rich soil undergoing primary succession. Data collection included seed dispersal for 20 continuous months, analysis of the total and germinable seedbanks, and recruitment 1 and 2 yr after a fire destroyed perches and burned vegetation. Seed fall beneath perches was 150 < multiply > that on control plots (no perches). Bird-dispersed seeds were not found in seed banks away from perches. The recruitment of bird-dispersed plants was 1.4 and 2.0 plants/m < sup(2) > , respectively, 1 and 2 yr after the fire. Less than 0.06% of the dispersed seeds survived to become seedlings. Species composition shifted between seed fall and seedlings, with small-seeded early-successional shrubs and herbs becoming relatively more common than the desired large-seeded, late-successional trees. Perches attracted birds, and had a higher abundance and diversity of bird-dispersed plants under them, suggesting that they may enhance plant diversity in primary succession.

Milberg P. 1995.
Soil seed bank after eighteen years of succession from grassland to forest. Oikos. 72(1): 3-13.

Abstract: The vegetation and seed bank were studied in an 18-year-old replicated experiment with grazed and ungrazed plots in a semi-natural, perennial grassland in southern Sweden. In the ungrazed plots, a tall (16-20 m) and dense tree layer had developed. There were fewer plant species growing in ungrazed plots than in grazed plots, but the difference was not significant. However, the number of species per square metre was significantly lower in ungrazed plots. Hence, on a smaller scale, the ground vegetation had become less diverse, but on a larger scale few species had been lost. In the seed bank, a few species lost from the vegetation were still present as seeds in the soil, but in most cases species lost were not recorded in the seed bank. Seeds of species that had colonised plots over the 18 years were evenly distributed in the soil between the upper (0-4 cm) and lower (4-8 cm) sampling depths. Most of the seeds of species that had disappeared from plots were deep in the soil. Hypotheses about changes in the seed bank during secondary succession, predicting decrease in species richness and seed density, were not confirmed.

Morgan P and Neuenschwander LF. 1988.
Seed-bank contributions to regeneration of shrub species and clear-cutting and burning. Canadian Journal of Botany. 66(1): 169-172.

Abstract: The species composition in the seed bank and the understorey of undisturbed stands was compared with the species composition of shrub communities that were established 2 yr after clear felling and autumn broadcast burning of dense forests of the Thuja plicata/Clintonia uniflora habitat type in northern Idaho. Total density of shrub seeds was 1511 < +- > 1896 seeds/m < sup(2) > with densities for individual shrub species in the range 1 < +- > 3 to 690 < +- > 1728 seeds/m < sup(2) > . Shrub species were classified into 3 groups in relation to their reliance on seed banks for post-fire regeneration. 'Obligate' species relied on seed banks and were absent from or rarely flowered in the understorey of the undisturbed stand. 'Nonreliant' species regenerated by sprouting alone and no seedlings were found although seeds were found in seed-bank samples. 'Opportunistic' species regenerated as seedlings and sprouts. Canopy cover of Ceanothus sanguineus increased with severity of the fire. Failure to appreciate the contribution of shrub seed banks to regeneration could result in poor predictions of species response to disturbance.

Partridge TR. 1989.
Soil seed banks of secondary vegetation on the Port Hills and Banks Peninsula, Canterbury, New Zealand, and their role in succession. New Zealand Journal of Botany. 27(3): 421-435.

Abstract: Soil seed banks at 21 sites covered with poor quality pasture, bracken fernland, scrubland of broom or gorse and various forest types were examined by germinating seed in soil samples. At most sites the composition of upper and lower soil layers was similar. Persistent, deeply buried seed banks of Cytisus scoparius, Ulex europaeus and more rarely Sophora microphylla were discovered at 7 sites, 4 of which lacked that particular species in the aboveground vegetation, and are thus considered to be of a former vegetation type. Forest sites tended to have more seeds and more species represented in the soil seed bank. Although an average of only 35% of the species in the seed bank were represented above ground at the sampling point, this rose to 60% within 5 m, and 72% within 10 m of that point. Those species further away were mostly widespread pasture weeds, even within forest sites, and were interpreted as being recently dispersed and transient. Large quantities of Juncus spp. in some sites were believed to be transported by water movement through the soil. Some species, including certain site dominants, were poorly or never represented in the soil seed bank. It was suggested that the seed bank has an important role in establishing the initial floristic composition following disturbance but differential seedling survival, resprouting and competition probably help in maintaining the pre-disturbance vegetation at non-forest sites. Where forest is disturbed, especially by burning, there is the potential for a completely different vegetation to develop from the seed bank.

Putwain PD and Gillham DA. 1990.
The significance of the dormant viable seed bank in the restoration of heathlands. Biological Conservation. 52(1): 1-16.

Abstract: The dormant viable seed bank of heathland dwarf shrub species was investigated in several different heather moorland soils from sites in the UK. Soil was incubated in a warm, moist environment for periods of up to 12 months. Generally there was a high density of viable seeds of Calluna vulgaris, Erica cinerea and Erica tetralix and several other heathland species. At all sites, a substantial portion of the seed bank (usually more than 90%) of all the species occurred in the upper 40 mm of the soil. This upper soil layer also contained a 'bud bank' of certain species (e.g. Molinia caerulea and Vaccinium myrtillus) which was equally important for subsequent regeneration of these species. When heathland is disturbed by mineral extraction, construction operations and installation of pipelines, it is essential that the seed-rich topsoil is carefully conserved to enable subsequent restoration to be successfully achieved. Since the seed bank is concentrated in a relatively shallow upper soil layer, it is important that only the upper 40-50 mm is removed. A greater depth of soil removal only dilutes the seed bank and reduces the usefulness of the separately stripped topsoil as a source of plant propagules.

Stieperaere H and Timmerman C. 1983.
Viable seeds in the soils of some parcels of reclaimed and unreclaimed heath in the Flemish district (Northern Belgium). Bulletin de la Societe Royale de Botanique de Belgique. 116(1): 62-73.
Abstract: A survey of the viable seeds in the surface soil (1.5 to 5 cm depth) of Flemish heathlands, ranging from neglected coppice to agricultural grassland on reclaimed heath, was conducted. The most abundant seeds in the unreclaimed heathland soils belonged to Juncus effusus, J. bulbosus, Erica tetralix and Calluna vulgaris. The most abundant seeds in the reclaimed heath soils were Poa trivialis, P. annua, Alopecurus geniculatus, Ranunculus repens and J. bufonius. The species present in the seed bank of unreclaimed heathland soils survived in soils of 20-year-old improved grassland, but were absent from grasslands reclaimed before 1940. The composition of the above ground vegetation was closely correlated with that of the buried viable seeds, although there was only a limited quantitative similarity between them.

Ungar IA and Woodell SRJ. 1996.
Similarity of seed banks to aboveground vegetation in grazed and ungrazed salt marsh communities on the Gower Peninsula, South Wales. International Journal of Plant Sciences 157 (6): 746 - 749.

Abstract. Seed bank and aboveground species composition of four salt marsh plant communities on the Cower Peninsula, South Wales, were compared. Puccinellia maritima was the dominant or codominant species in the vegetation on all of the marshes investigated. Two of the marshes were ungrazed (Oxwich, Three Cliffs Bay), one lightly grazed by horses (Cwm Ivy), and one heavily grazed by sheep (Landimore). Two annual species, Salicornia europaea and Suaeda maritima, accounted for less than 15% of the plant cover in the four salt marshes, but their seeds accounted for over 60% of the seed bank in the Cwm Ivy, Oxwich, and Landimore marshes. The two annuals comprised 100% of the seed bank of the heavily grazed marsh, but only 13.6% of the total plant cover. Ungrazed and lightly grazed marshes had percentage similarities between seed bank and plant cover ranging from 1.7% to 12.3%, while the grazed marsh had a value of 13.7%. An unweighted pair group mean cluster analysis indicated that three of the four plant communities formed a cluster at 55% for vegetation and 65.3% for seed banks. However, because the dominant perennial grass species P. maritima did not produce a persistent seed bank, none of the plant communities formed clusters with their seed banks.

Willems JH. 1988.
Soil seed bank and regeneration of a Calluna vulgaris community after forest clearing. Acta Botanica Neerlandica. 37(2): 313-320.

Abstract: After tree cutting at the margin of a deciduous forest on acid gravel deposits in South Limburg, Netherlands, a C. vulgaris community re-established as a result of germination from the soil seed bank, the greater part of which probably originated from heathland vegetation which was present on the site until half a century ago. The number of viable seeds of C. vulgaris present in the soil varied tremendously in time and space. The maximal density found was approx. 300 seeds per dm < sup(2) > to a depth of 20 cm.

Young KR Ewel JJ and Brown BJ. 1987.
Seed dynamics during forest succession in Costa Rica. Vegetatio. 71(3): 157-173.

Abstract: Abundance and floristic composition of seeds were compared on the Florenica Norte forest (which developed after coffee plantations were abandoned) by germinating seeds in the soil, measuring seed input for 3 yr, and monitoring the earliest colonists in a forest clearing. In the soil, there were 6800 viable seeds/m < sup(2) > in 3.3-yr-old vegetation, 9500 in 11-yr-old vegetation and 7000 in 75-yr-old forest. Input was 10 < thin > 000 seeds/m < sup(2) > in young successional vegetation and 3700 in the forest. Deforestation stimulated germination of most seeds in the surface soil. Recruitment of seedlings from the soil seed bank greatly outnumbered that from post-disturbance seed rain and sprouts.