TECHNICAL REPORT 18

July 2005

Effects of Stock Grazing on Biodiversity Values in Temperate Native Grasslands and Grassy Woodlands in SE Australia: A Literature Review

DR IAN D. LUNT

Wildlife Research and Monitoring
PO Box 144
Lyneham ACT 2602

building our city
building our community

ACT Government

environment ACT

ISSN: 1320 - 1069

ISBN: 0 642 60341 3

Published by Arts, Heritage & Environment. A full listing of the Reports produced by Environment ACT is on page 59.

Website: www.cmd.gov.au
Enquiries: Phone 13 22 81

A report commissioned by Environment ACT.

This document should be cited as:

Lunt, I.D. 2005. Technical Report 18. *Effects of Stock Grazing on Biodiversity Values in Temperate Native Grasslands and Grassy Woodlands in SE Australia: A Literature Review*. Environment ACT, Canberra.

Printed on recycled paper

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

LIST OF TABLES

LIST OF FIGURES

<u>PART A — INTRODUCTION</u>

1. INTRODUCTION

This review considers the impacts of stock grazing on biodiversity values in temperate grassy ecosystems in southern Australia. Its aim is to assist grazing management of temperate lowland native grasslands and grassy woodlands in areas of the Australian Capital Territory (ACT) where conservation is a primary management objective.

Historically, stock grazing has caused enormous damage to many Australian ecosystems. Most remnant grassy ecosystems in southern Australia have been grazed by stock in the past, and their current composition is, to varying extents, a legacy of past grazing activities. However, notwithstanding the negative impact of earlier grazing regimes, there is increasing recognition that stock grazing may provide a useful tool for maintaining biodiversity values in some cases. For example, grazing stock are currently being used to maintain biodiversity values in two newly declared national parks in New South Wales and Victoria (Oolambeyan and Terrick Terrick National Parks) and in the Gungahlin and Dunlop Grassland Reserves in the ACT. On the other hand, there is no scientific dispute that grazing stock continue to degrade ecological values in other areas, such as alpine grasslands in Victoria.

These examples are not contradictory. They highlight that different grazing regimes have different ecological outcomes in different ecosystems. In the ACT, as in many other regions of southern Australia, stock grazing has the potential to both enhance and degrade ecological values, depending on where and how it is implemented. Few ecologists or conservation managers would today debate whether fire *per se* is 'good' or 'bad'. Instead, considerable energy is being devoted to understanding how different *fire regimes* affect ecological attributes in different ecosystems. Similarly, if we wish to maximise the opportunity to use grazing stock as a useful tool to achieve biodiversity conservation outcomes, then grazing ecology must be recognised as a complex field, in which outcomes will vary depending upon the ecosystem in question and the grazing regime being implemented.

This review describes how grazing stock affect temperate grassy ecosystems in south-eastern Australia, and provides an ecological framework to enable managers to understand *how* grazing regimes affect conservation values. The review covers the following broad topics.

- **Part A – Introduction**
  - Report introduction and a brief overview of temperate grassy ecosystems in the ACT (Chapters 1–2).

- **Part B – Principles for grazing management in conservation areas**
  - An overview of management objectives for conservation areas in the ACT (Chapter 3).
  - An introduction to grazing strategies and how different grazing strategies affect grassy ecosystems (Chapter 4).
  - A series of principles to guide decisions about whether grazing is likely to an appropriate management regime in any particular area and, if it is deemed to be appropriate, how grazing should be managed to minimise adverse effects on conservation values (Chapter 5).

- **Part C – Literature review: How stock grazing affects biodiversity values in temperate native grasslands and grassy woodlands in SE Australia**
  - An overview of ecological concepts describing how grazing affects natural ecosystems, and how plants respond to grazing. This section is based predominantly on the international literature (Chapters 6–8).
  - A description of the historical effects of grazing stock, and of the effects of grazing exclusion, on temperate grassy ecosystems in Australia (Chapters 9–11).

2. TEMPERATE GRASSY ECOSYSTEMS IN THE ACT

The following information draws heavily from recently published conservation strategies for lowland native grasslands and woodlands in the ACT (ACT Government 2004a,b). The ACT is within the South Eastern Highlands Bioregion of Australia (Thackway & Cresswell 1995). Grasslands and woodlands in the ACT share a similar landscape context to temperate grassy ecosystems across south-eastern Australia: most of the landscape has been cleared or altered for cropping and grazing in the past, and remaining remnants are usually small, isolated and often highly degraded (Sivertsen & Clarke 2000; Lunt & Bennett 2000). The degree of utilisation and degradation increases with increasing agricultural productivity, so ecosystems on fertile plains tend to be more highly degraded and less well reserved than those on steeper, less fertile hill slopes

(Landsberg 2000). In addition to past agricultural development, expanding urbanisation is increasingly dominating landscape processes within the ACT, as in other capital cities.

Lowland temperate grasslands and woodlands are highly degraded and depleted across their range, and a number of communities that occur in the ACT are listed under various state and commonwealth conservation acts, *viz*.:

- 'Yellow Box–Red Gum Grassy Woodland' is listed as an endangered ecological community under the ACT *Nature Conservation Act 1980.*
- 'White Box–Yellow Box–Blakely's Red Gum Woodland' is listed as an endangered ecological community under the NSW *Threatened Species Conservation Act 1995.*
- 'Grassy White Box Woodland' is listed under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999.*
- 'Natural Temperate Grassland of the Southern Tablelands of New South Wales and the ACT' is listed under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999.*
- 'Natural Temperate Grassland' is listed as an endangered ecological community under the under the ACT *Nature Conservation Act 1980.*

Four major grassy woodland ecosystems occur in the ACT (ACT Govt 2004a):

- Tablelands Brittle Gum Dry Forest dominated by *Eucalyptus macrorhyncha* (Red Stringybark), *E*. *rossii* (Scribbly Gum) and *E*. *mannifera* (Brittle Gum) which occurs on steep stony hillslopes.
- Tablelands Dry Shrubby Box Woodland, variously dominated by *E. goniocalyx* (Bundy), *E. nortonii* (Mealy Bundy), *E. polyanthemos* (Red Box), *E. bridgesiana* (Apple Box) and *E. dives* (Broad-leaved Peppermint), which occurs on lower hillslopes where it intergrades with Yellow Box–Red Gum Grassy Woodland.
- Tablelands and Slopes Yellow Box–Red Gum Grassy Woodland, dominated by *E. melliodora* (Yellow Box), *E*. *blakelyi* (Blakely's Red Gum) and *E*. *bridgesiana* (Apple Box), which occurs on mid- and low hillslopes of 600-900 m elevation.
- Tablelands Valley Snow Gum Grassy Woodland dominated by *E. pauciflora* (Snow Gum) and *E. rubida* (Candle Bark), which occurs on lower slopes, often in areas of cold air drainage. This ecosystem often intergrades with Natural Temperate Grassland.

The ACT lowland native grassland strategy describes natural temperate grassland as:

> '*a native ecological community that is dominated by native species of perennial grasses. There is also a diversity of other native herbaceous plants (forbs) present. An important characteristic of the community is that it is naturally treeless, or has less than 10% projective foliage cover of trees, shrubs and sedges in its tallest stratum*' (ACT Government 2004b, p. 3).

Five grassland associations occur in the ACT: '*Austrodanthonia* Grassland', 'Dry *Themeda* Grassland', '*Austrostipa* Grassland', 'Wet *Themeda* Grassland' and '*Poa labillardieri* Grassland' (Sharp 1997, ACT Government 2004b). *Austrodanthonia* Grassland occurs on well drained, skeletal soils and Dry *Themeda* Grassland on well drained loamy soils. *Austrostipa* grassland is thought to have been derived from degraded Dry *Themeda* Grassland. Wet *Themeda* Grassland occurs in moist to poorly drained sites, and *Poa labillardieri* Grassland in poorly drained areas and along drainage lines (Sharp 1997, ACT Government 2004b). In addition, secondary (or derived or disclimax) grasslands occur, which are derived from cleared Yellow Box–Red Gum Grassy Woodlands.

Reflecting their long history of utilisation (especially for stock grazing), all lowland grassland and woodland communities in the ACT have been altered in various ways since European settlement. Remnants range from relatively intact sites, which are thought to resemble closely their original pre-European condition, to highly degraded sites dominated by exotic species, with few, sparse native species. Highly degraded woodlands often consist of scattered paddock trees above exotic pastures or crops (ACT Government 2004a,b).

PART B — PRINCIPLES FOR GRAZING MANAGEMENT IN CONSERVATION AREAS

3. CONSERVATION MANAGEMENT OBJECTIVES

Clear goal setting is a requisite for successful conservation planning (Possingham 2001). Decisions about whether to implement any disturbance regime for conservation purposes are best guided, not by whether such a regime is ‘natural’, but whether it is likely to best achieve the management goals at the site in question. The ACT Lowland Woodland Conservation Strategy (ACT Government 2004b, p. 84) lists three primary goals for woodland conservation:

- Protection goal (woodland): Conserve in perpetuity all types of Lowland Woodland communities in the ACT, as viable and well-represented ecological systems.
- Protection goal (fauna and flora): Conserve in perpetuity, viable, wild populations of all Lowland Woodland flora and fauna species in the ACT, and support regional and national efforts towards conservation of these species.
- Management goal: Manage and rehabilitate Lowland Woodlands across all tenures with appropriate regeneration, restoration, and reinstatement practices.

A similar series of goals have been described for lowland temperate grassland communities in the Draft ACT Lowland Native Grassland Strategy (ACT Government 2004b, p. 86). Additionally, both strategies contain many specific goals for threatened species management, and management plans for individual reserves contain many site-specific conservation goals. For example the management goal for the Goorooyarroo section of the Canberra Nature Park is, ‘to conserve & enhance grassland, scrub, woodland & forest communities, with emphasis on restoring the understorey…’ (Environment ACT 2004, unpubl. document, p. 1).

3.1 Management strategies

As shown in the objectives listed above, community and species conservation is the principal management goal for grasslands and woodlands in reserves and other site of high conservation value in the ACT. In attempting to conserve grassland and woodland communities, managers commonly implement more specific management strategies, which are thought to be consistent with broad ‘community conservation’ objectives. Common strategies for maintaining biodiversity in grassland and woodland remnants include:

- Maintaining ecosystem processes (e.g. natural drainage patterns).
- Maintaining or promoting woodland structural diversity (e.g. shrub or tree recruitment).
- Maintaining a particular ground vegetation structure (e.g. dense or open grassland).
- Maintaining fauna habitat, including rare species. Often this is achieved by manipulating vegetation structure using disturbances such as fire or grazing.
- Maintaining small-scale native plant diversity.
- Controlling exotic plant and animal species, sometimes by manipulating disturbance regimes to promote natives and discourage exotics.
- Maintaining or promoting specific rare plant species.

These objectives are typically implemented at site scales. At larger scales, regional conservation strategies enable complementary objectives to be implemented across the landscape (as detailed in ACT Government 2004a,b). Thus, identical outcomes are not necessarily desired in every site.

3.2 Ecological role of stock grazing

Stock grazing may serve a number of economic, social and land management roles, including providing an economic return to the grazier or land management agency, helping to achieve fire management objectives (by depleting grass biomass and fuel loads), or by creating habitat conditions for particular plants or animals. This review considers only the ecological impacts of stock grazing, not social or economic issues, and biodiversity conservation is assumed to be the primary land management objective.

4. USING STRATEGIC GRAZING

Terms describing grazing techniques — including grazing strategies, tactics, systems and methods — are defined and used in many different ways in the grazing literature. In the most general (and rather uninformative) sense, a grazing method can be defined as, ‘a defined procedure or technique of grazing management based on a specified period of grazing and/or period of nongrazing which is designed to achieve a specific objective’ (Vallentine 2001, p. 447). Under this definition, grazing ‘methods’ may be implemented within paddocks and more complex grazing ‘systems’ (involving stock movements amongst paddocks) may be implemented across multiple paddocks within a property or reserve. Grazing strategies can be altered in three main ways, by manipulating:

- the type of grazing animal (e.g. sheep, cattle, kangaroos or goats);
- stocking intensity (animal numbers); and
- the timing of grazing, especially in relation to rest periods.

These approaches focus on management decisions about animal movements. At a larger scale, grazing patterns can also be manipulated by changing paddock infrastructure, such as the layout of fences and watering points.

4.1 Grazing management objectives

In commercial pasture management, grazing strategies may be implemented for at least three different reasons: to maximise animal production, to maximise pasture growth rates in the short-term, and to control pasture composition over the longer-term (Kemp 2000, Saul & Chapman 2002). From a biodiversity conservation perspective, the first two reasons are largely irrelevant. There is no obvious reason to optimise pasture growth rates. Maximising animal productivity (and consequent economic returns) is also of less significance, provided that basic animal health is maintained. Thus, the principle reason for implementing a specific grazing management strategy is to influence vegetation structure and composition over the long-term.

As described in Chapter 3, grazing may be implemented for biodiversity conservation in order to: reduce grass biomass to maintain small-scale plant diversity, control exotic species, promote or control tree and shrub establishment, manipulate relative abundances of particular species (e.g. dominant native and exotic grasses) and to maintain vegetation structure for animal habitat. All of these objectives involve attempts to influence vegetation structure and composition over the long-term.

4.2 Recommended grazing strategies for conservation management

A number of documents provide 'best practice' principles for managing grazing stock to conserve grassy ecosystems in Australia (Lunt 1991, Barlow 1997, Ross 1999, Eddy 2002, McIvor 2002, Nadolny *et al*. 2003, Dorrough *et al*. 2004b, DCE undated). The suggested principles can be summarised as follows:

1. Grazing stock should not be introduced to high quality remnants that have not been grazed historically.
2. Grazing managers should aim to promote a spatially variable, structurally complex grassland structure; uniformly short, closely-cropped 'grazing lawns' are undesirable.

3. Continuous grazing should be avoided wherever possible. Intermittent grazing, interspersed with rest periods, is preferred.
4. Within seasonal or annual periods, the longer the rest period the better. Intensive grazing over short periods (mob or crash grazing) interspersed by lengthy rest periods is commonly advocated.
5. Sites should be rested (i.e. stock should be removed) when desired native plants are flowering and setting seed in spring and early summer.
6. Supplementary feed should not be used, and stock should be moved when animal health cannot be maintained.
7. Fertilisers should not be applied and exotic pasture species should not be sown. These activities are likely to have more serious adverse impacts on biodiversity patterns than grazing alone.

It should be stressed that the amount of relevant research varies greatly amongst these principles. In particular virtually no information is available to support (or disprove) principle four.

4.3 Using grazing strategies to manipulate vegetation composition

The above principles provide a simple framework for conserving biodiversity (or sustainably managing native pastures) in grazed systems. They are relevant where management does not aim towards any particular species composition. Instead they address the simple question: if grazing stock are used to reduce biomass levels in order to maintain conservation values, how can potential adverse outcomes be minimised?

However, grazing strategies can also be used to modify vegetation composition in particular directions, by promoting desirable species (or species groups) and disadvantaging undesirable species. In Australia, this approach has been widely promoted by advocates of sustainable pasture management (e.g. Lodge & Whalley 1989, Lodge *et al*. 1998, Kemp *et al*. 1996). Targeted grazing strategies have been used to control undesirable pasture weeds (e.g. Friend & Kemp 2000, Grace *et al*. 2002) and to increase the proportion of palatable, nutritious pasture species over unpalatable species of low nutritional value (Lodge *et al*. 1999).

In targeted grazing strategies, heavy grazing (often in conjunction with other management activities) is applied during sensitive phases (‘weak points’) in the life cycle of undesirable species, thereby causing their decline. Plants tend to be susceptible to heavy grazing when they are germinating, seedlings, regenerating from buds or flowering, since energy reserves are consumed to support growth during these periods (Kemp *et al*. 1996, Kemp 2000). Where desired and undesired species co-exist, grazing strategies can be used to promote desired species and to diminish undesirable species, if desired and undesired species have different weak points or growth cycles.

Targeted grazing strategies have not commonly been used in Australia to achieve biodiversity conservation objectives. Notable examples include recent attempts to restore the vegetation composition of degraded riverine forests by manipulating the season of grazing (Leslie 2000), and to control weeds in degraded grasslands using a combination of burning and crash grazing (Tscharke 2001). However, long-term outcomes from these recent trials are not yet available.

Targeted grazing strategies have considerable potential to assist biodiversity conservation in grassy ecosystems. However, the following features are required for their successful implementation.

- Specific management objectives must first be developed (e.g. deplete exotic annual grasses and promote summer-growing native perennial grasses).
- Information must be available on the phenologies and likely 'weak points' of desired and undesired taxa.
- Desired and undesired species must differ in phenology, and there must be a clear (and wide enough) window of opportunity to allow inter-specific differences to be capitalised upon.
- Adequate infrastructure must exist to control grazing stock to achieve targeted interventions (relatively small paddocks may be required).
- Stocking levels must be high enough to achieve desired outcomes during the grazing period.
- Adequate expertise and resources must be devoted to stock management, as there is a high risk of adverse outcomes if stock are poorly supervised.
- The effects of grazing strategies on non-target native and exotic species must be assessed. This point is particularly important given the absence of information of the effects of grazing strategies on biodiversity patterns.

4.4 Potential to implement targeted grazing strategies

Targeted grazing strategies have the greatest potential to promote biodiversity in moderately degraded grassy remnants which contain abundant natives and exotics. In high quality remnants where few exotics are abundant, grazing strategies may require little more than removing stock when native species are flowering and setting seed. At the other extreme, in heavily degraded sites, native plants may occur too sparsely to recover following grazing-induced reductions in exotic species. To achieve sustainable outcomes, declines in exotics must be matched by increases in native species or apparent improvements in condition are likely to be short-lived.

Targeted grazing strategies have considerable potential to achieve positive ecological outcomes in the following circumstances:

- In sites containing abundant exotic annuals, strategic grazing may be used to deplete the cover of exotic annuals and promote native perennials.
- In sites containing a mixture of summer-growing natives (e.g. *Themeda*) and 'cool-season' species (exotics and natives), strategic grazing may be used to influence the proportions of these two species groups, depending upon management objectives at the site.
- In sites containing woody species, strategic grazing may be used (in conjunction with other activities) to promote or control recruitment of woody species.

It is important to remember that, in most grassy ecosystems, native and exotic species both include a wide range of growth-forms and phenologies, with considerable ecological overlap. Thus, in most circumstances grazing strategies are unlikely to be able to promote *all* native species over *all* exotic species. Nevertheless they have considerable potential to enable managers to manipulate the abundances of specific species (or species groups) in many instances.

4.5 Infrastructure and management requirements

The key issue for grazing managers is not whether continuous or short-duration grazing (or indeed any other grazing strategy) is theoretically 'better' for any particular site, but whether either option can be reliably implemented in a manner that is likely to achieve the desired outcomes. *The biggest practical constraint on achieving ecosystem management objectives using grazing animals is the degree of control that can be exerted over animal movements*.

The degree of control that can be exerted over animal movements increases with the intensification of grazing infrastructure, especially fences; more fences enable more control. Grazing strategies have the lowest potential to achieve desired outcomes in large areas that contain a variety of ecosystems and no internal fencing, especially if stocking levels are relatively light.

To control animal movements, fences should separate:

- different topographical units (e.g. slopes, flats and waterways);
- different vegetation types;
- different vegetation states (e.g. intact and degraded areas that differ greatly in composition and structure); and
- high quality or grazing-sensitive areas (e.g. wetlands and stream banks).

In practice, intensive infrastructure is incompatible with many social and ecological objectives for conservation reserves, as well as economic constraints faced by conservation managers. Thus, in large reserves in particular, the potential to achieve desired outcomes from strategic stock grazing is likely to be constrained by a relatively low degree of control over livestock movements.

In areas where internal fencing does enable stock to be rotated amongst internal paddocks, it must be realised that stock rotations cannot achieve positive outcomes in all places at all times. For example, if stock are removed from an area in spring to encourage native plants to flower, then they will need to be housed somewhere else during this period. In some cases, it may be possible to remove stock from the entire grazing area. However, if this is not possible, then some parts of the area (presumably those of lower conservation significance) may have to be subjected to sub-optimal grazing regimes during this period.

5. GRAZING MANAGEMENT PRINCIPLES

Managers of commercial grazing properties and conservation reserves have different management options. On commercial properties grazing exclusion is not a viable management option except in small areas, and compromises may often be necessary to meet production and conservation goals. By contrast, in conservation reserves, total stock exclusion is a viable management option. Stock grazing is only likely to be used as an ecological management tool in reserves if it achieves positive conservation outcomes that cannot reliably be attained using other practical methods. Furthermore, in contrast to commercial properties, even if grazing stock have *no* perceptible negative impacts on biodiversity patterns, then they are likely to be removed from conservation reserves, not retained. Conservation reserves may also be grazed by stock for other political or social reasons, but this typically involves an explicit trade-off between conservation objectives and other social objectives, as in alpine grazing (Griffiths 1996).

Because of these differences in management goals and options, managers of conservation reserves tend to ask different questions about stock grazing than do managers interested in sustainable management of native pastures or rangelands. Sustainable pasture managers and rangeland ecologists frequently ask, '*how can grazing be managed to minimise adverse environmental outcomes?*' The underlying assumption is that some form of stock grazing will (or should) continue in the area concerned.

By contrast, reserve managers invariably first ask, '*is stock grazing necessary and able to achieve desired conservation outcomes?*' If stock grazing is unlikely to achieve desired outcomes, or if these outcomes can be more easily achieved using other practical techniques, then stock grazing is unlikely to be considered as a useful management option. Thus, for managers of conservation reserves, the question, 'how can grazing best be managed?' only needs to be addressed in cases where: (1) it has been ascertained that stock grazing does have the potential to achieve positive conservation outcomes; or (2) political or social constraints prevent stock removal despite acknowledged negative impacts on biodiversity.

In this section, a number of principles are suggested to guide the management of stock grazing in areas managed for biodiversity conservation. These principles firstly address the question 'when is grazing appropriate?', and secondly, 'how can grazing best be implemented?' The first question is more relevant to conservation reserves than commercial properties, whereas the second question applies across all land tenures. The principles build upon the conceptual frameworks and empirical results summarised in Part C of this report, the literature review. An underlying assumption is that the principle management objective is to maintain biodiversity at regional scales rather than to maximise diversity within every remnant.

5.1 When is grazing appropriate?

The following principles relate only to the presence or absence of grazing stock, not to the development of refined grazing strategies (which is addressed under the later question, 'how can grazing best be implemented?').

At least three major ecological issues need to be addressed when considering whether grazing is an appropriate tool to achieve biodiversity conservation objectives: grazing history, landscape context and expected small-scale biodiversity responses.

Grazing history

1. Since ungrazed refugia are extremely rare in Australia, intact remnants that have escaped stock grazing over the past century should remain ungrazed. Other forms of ecosystem management (e.g. burning) should be considered where necessary.
2. Continuation of grazing in long-grazed areas is unlikely to lead to rapid ecosystem changes, unless implemented at clearly inappropriate intensities. However, ongoing grazing may contribute to ongoing, long-term declines of some species or ecosystem functions.
3. The removal of grazing stock may lead to substantial changes (positive or negative) if existing stocking levels are high, especially in productive sites.

Landscape context

4. If the regional landscape is relatively intact, then grazing in localised areas may enhance landscape diversity patterns, but only if some native species are promoted by grazing. If most 'increaser' species are exotic, then the net impact is likely to be negative.
5. Provided that grazing promotes at least some native 'increaser' species, then landscape diversity may be maximized by implementing a range of grazing regimes. By contrast, if no (or very few) native species are promoted by grazing, then spatial variations in grazing intensity cannot promote diversity; instead grazing will lead to losses of native species.
6. If the regional landscape is predominantly grazed, then the protection or establishment of grazing refugia (or implementation of novel grazing regimes) may enhance regional biodiversity patterns.
7. In all cases, appraisals of grazing impacts need to be tempered by the conservation objectives for the area in question. For example, 'increaser' species may not be valued in fragmented conservation reserves if these species are abundant in the wider landscape (e.g. common wallaby-grasses or galahs). In this case, reserves may function best by conserving 'decreaser' species that have been depleted elsewhere across the grazed landscape.

Reserve scale issues

8. Many reserves contain a variety of vegetation types. If grazing impacts are to be controlled, then managers must be able to control stock movements between vegetation types and landscape units. Thus, different vegetation types must be isolated by fences or other mechanisms. If stock movements cannot be controlled, then desired outcomes may not be achieved where grazing is required, and undesired outcomes may occur in places where grazing is not required.

9. If stock movements amongst vegetation types cannot be controlled, then the decision on whether grazing is permitted should be based on potential impacts on the most significant or most sensitive attributes present. For example, in the Riverina grazing strategy (Leslie 2000), grazing stock were removed from areas containing sensitive wetlands unless the wetlands could be fenced to exclude stock, regardless of possible positive impacts in other, less significant ecosystems. This approach recognises that unavoidable trade-offs between grazing impacts may occur when stock movements cannot be controlled.

10. Grazing stock can transport seeds of environmental weeds. Dispersal of ingested seeds can be minimised by temporarily quarantining new stock. However, in general stock should not be moved from low to high quality vegetation to minimise the potential for spreading environmental weeds.

Vegetation type scale

11. The principal mechanism by which grazing promotes small scale diversity of herbaceous plants in productive ecosystems is by reducing dominant grasses and permitting less competitive species to coexist. In productive areas where grass biomass rapidly accumulates, grazing may help to promote small-scale plant diversity, if the dominant grasses are palatable to grazing stock.

12. In some instances, soil disturbances created by grazing stock may promote regeneration of particular native plants, including some rare or threatened species. However, in general, soil disturbance is likely to promote exotic plants with large soil seed banks.

13. In some cases, grazing may play a useful role by preventing dense recruitment of trees and shrubs (native or exotic) which could deplete ground layer diversity or adversely affect fauna habitat. A number of cases exist where native shrubs have regenerated densely following removal of grazing stock. Whether these changes are deemed positive or negative will depend on the reserve management aims. However, in many temperate woodlands, the opposite situation exists, and current grazing levels are preventing desirable recruitment of ageing woodland trees.

14. In some cases, grazing may be a practical way to maintain a suitable vegetation structure for significant fauna that prefer open ground vegetation (e.g. Plains Wanderers; Baker-Gabb 1993, 1998). Especially in fragmented remnants, grazing may be more useful than burning to maintain habitat for threatened fauna if it results in a lower level of disturbance-induced mortality. For example, burning is often considered undesirable in grasslands containing Striped Legless Lizard since it causes high mortality (Webster *et al*. 1992).

If the above circumstances do not apply, then grazing is unlikely to promote plant diversity. Instead, negative or neutral outcomes might be expected.

The flowchart presented in Figure 1 integrates the above principles. It is intended to guide decisions about grazing management in a wide variety of environments and ecosystems, recognising that temperate grassy ecosystems often occur in a mosaic with other ecosystems.

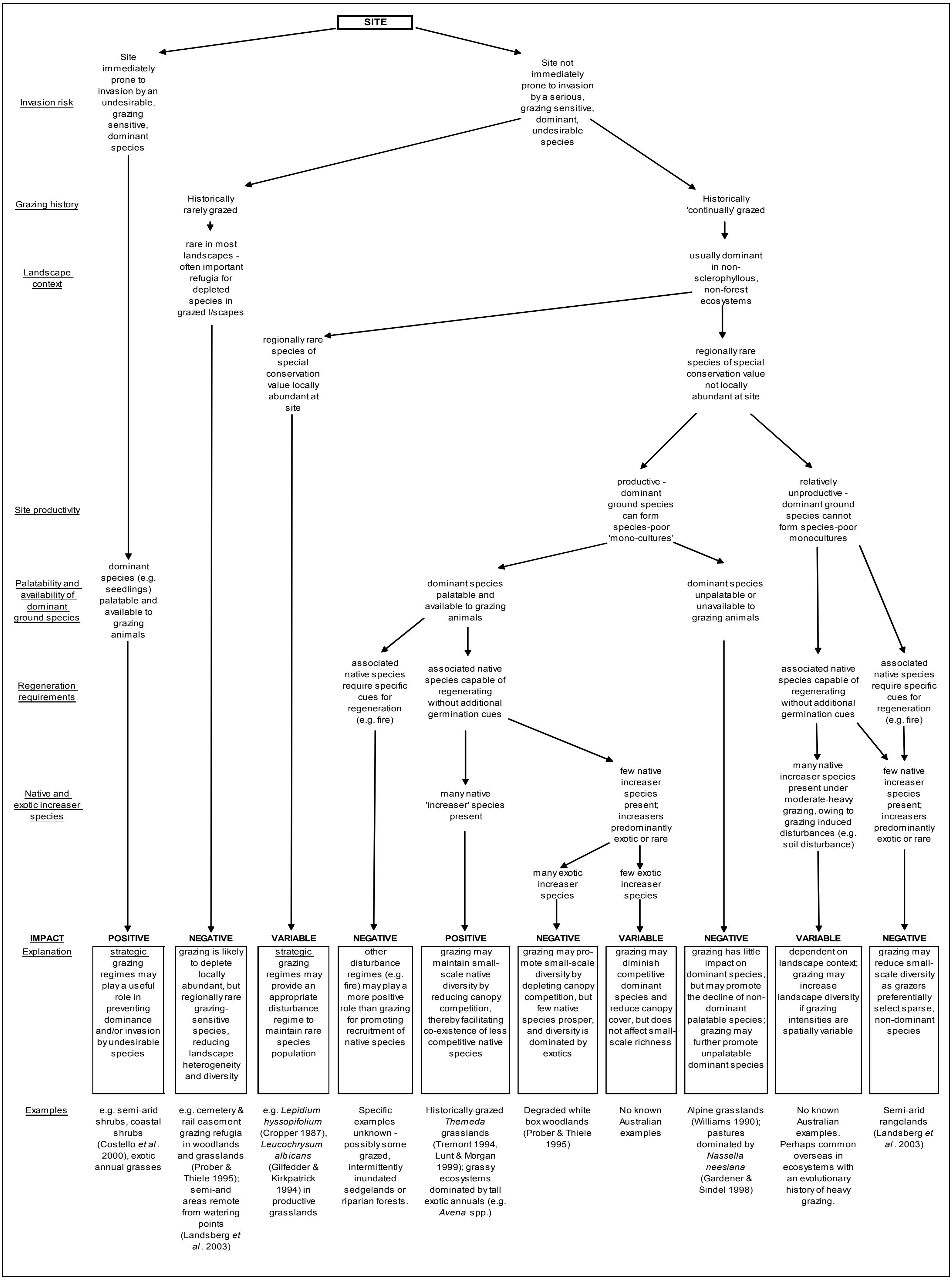

Figure 1: Decision tree to help predict the effects of stock grazing on plant diversity and conservation values

5.2 How can grazing be implemented?

As noted in Chapter 4, there are only a small number of principles to guide grazing management for biodiversity conservation within grassy ecosystems. These are summarised below. In addition to these general guidelines, local circumstances and goals will strongly affect the management strategies used in particular sites.

Type of grazing animal — stock or native herbivores

It is often suggested that grazing should be undertaken using native herbivores (e.g. grey kangaroos) rather than grazing stock. The practicality of native herbivore management differs greatly, largely according to reserve size and location.

Since kangaroos are native animals, kangaroo conservation is a key management objective in most grassy ecosystems. However, kangaroos are often difficult to control in small isolated grassland and woodland remnants, especially in urban areas. Stock can be easily moved or sold when not needed. By contrast, kangaroos cannot easily be mustered and culling is often socially unacceptable. With few constraints on population growth, kangaroo numbers in many urban remnants may be expected to increase to ecologically damaging levels.

Regardless of subtle differences in grazing behaviour, from a management perspective the key difference between grazing with stock and kangaroos in small remnants is that stock grazing can be controlled to achieve desired ecological outcomes, whereas kangaroo grazing cannot easily be controlled. For this reason is it recommended that kangaroos not be introduced to small grassy remnants for the purpose of *helping to achieve habitat management goals*.

Stocking levels

Extremely low and high stocking levels should be avoided. Other things being equal, grazing selectivity is greatest at low stocking levels, since stock are not forced to eat less palatable food. Low stocking levels are likely to cause a decline in palatable plants, perhaps with minimal impact on broader ecosystem attributes such as grass cover or biomass (especially if dominant grasses are rank and unpalatable). In contrast to low stocking levels, the dangers of prolonged grazing at high stocking levels are well known. However, high stocking levels for short periods of time (e.g. ‘crash grazing’) may be a useful strategy to reduce biomass levels whilst minimising selective consumption of preferred plant species.

Spelling

Continuous grazing (set-stocking) should be avoided where possible. Continuous grazing is likely to promote the gradual depletion of grazing sensitive species since it provides few opportunities for grazing sensitive species to avoid or recover from grazing. Seasonal or annual spelling enables species to recover from defoliation and to build up energy reserves.

Where possible, stock should be removed from high quality remnants in spring and early summer to enable native plants to flower and set seed. However, this approach is also likely to promote many exotic species, and may not be appropriate in highly degraded sites. Whilst little information is available, rotating stock at periods greater than 1 year (e.g. 12 months grazing followed by 12 months spelling), might enable periodic reductions in litter and annual weeds, whilst allowing native species to regenerate during ungrazed periods.

Associated management

Fertilisers should not be applied to native vegetation, and exotic pasture species should not be introduced. Many of the adverse impacts on biodiversity of stock grazing in production areas are caused by activities commonly associated with grazing, rather than with grazing itself. Fertilisation, introduction of exotic pasture species and artificial feeding are all likely to reduce biodiversity values.

Targeted grazing tactics

There is considerable potential to develop targeted grazing strategies to enhance vegetation composition in degraded grassy ecosystems by promoting desired natives over undesired exotics. However, these techniques require good management infrastructure (e.g. small grazing areas), stock management expertise and close supervision, and in most cases, considerable experimental work (or adaptive management trials) to develop new strategies to achieve specific management goals.

PART C — LITERATURE REVIEW: HOW STOCK GRAZING AFFECTS BIODIVERSITY VALUES IN TEMPERATE NATIVE GRASSLANDS AND GRASSY WOODLANDS IN SE AUSTRALIA

6. HOW GRAZING ANIMALS AFFECT NATURAL ECOSYSTEMS

The daily activities of grazing animals affect ecosystems in three major ways:

- Grazing animals eat plant parts, thereby directly removing vegetation and altering ecological processes within remaining vegetation.
- The feet of grazing animals directly affect soils, by breaking soil surface crusts, compacting soils and encouraging erosion (Noble & Tongway 1983, Yates *et al*. 2000, Greenwood & McKenzie 2001).
- Animal wastes (urine, faeces and carcasses) redistribute nutrients within ecosystems. Nutrients consumed in eaten plants are deposited within relatively small parts of the landscape, often at high local concentrations (Taylor *et al*. 1984).

In addition to these three primary impacts, grazing animals also influence other important ecosystem processes such as seed dispersal (e.g. Brown & Carter 1998). Plant ecologists often group the above processes into two simpler groups: (1) the direct impacts of herbivory (losses of plant parts); and (2) indirect (environmental) impacts (e.g. soil changes). These two processes are not independent and interact considerably: soil changes affect subsequent plant growth, and reductions in plant cover by herbivory affect soils, as witnessed by scalds and erosion.

6.1 Plant consumption

The most obvious impact of grazing animals is the consumption of plant parts. Grazing animals do not eat all foods equally, and some species are utilised before others. Selectivity works at many spatial sales. Free-ranging grazing animals can select the landscape they move through, the topographical zone they spend time in, and the specific plant species and plant parts that they consume (Senft *et al*. 1987, Bailey *et al*. 1996, Frank *et al*. 1998). Fenced paddocks prevent managed stock from moving across the wider landscape, but even in small paddocks, stock tend to utilise some areas and some species more heavily than others.

Grazing selectivity is a highly complex process. Selectivity differs amongst animal species (e.g. horses eat different foods to rabbits, when possible) and amongst individuals, and is strongly influenced by the variety of plant material available. Some species may be strongly avoided in some circumstances, but avidly consumed in others, especially if no alternative foods are available. The degree to which grazing animals actively select some plant species (or parts) over others can be expressed by a selectivity ratio, which equals the proportion of a particular plant species in the diet divided by the proportion that the plant species contributes to the available herbage (Vallentine 2001).

Table 1: Attributes that influence the palatability of plants to grazing stock (from Vallentine 2001, pp. 269 & 275).

High palatability	**Low palatability**
High succulence	Low succulence; high percent dry matter
High crude protein, sugars & fat	High fibre, lignin & silica; low magnesium, phosphorus
Low secondary plant metabolites (e.g. phenols, tannins)	High secondary plant metabolites
High digestibility	Low digestibility
High leaf: stem ratio	Low leaf: stem ratio
Few seed stalks	Abundant seed stalks
New growth or regrowth	Old growth
Leaves fine and tender	Leaves coarse and tough
Twigs small and open-spaced	Twigs thick, closely entwined, sharp-tipped
High accessibility	Low accessibility
Not thorny or spiny	Possess thorns, spines or awns

Palatability refers to the 'combination of plant characteristics that stimulates animals to prefer one forage over another' (Vallentine 2001, p. 262). Palatability differs amongst species, amongst plants within a species, amongst plant parts, and changes seasonally, and is influenced by a wide variety of plant attributes (Table 1).

The degree of selectivity is influenced by the availability of food plants, which is itself influenced by stocking rates. Selectivity is typically high under low stocking rates, as grazing animals need only consume highly palatable species with little impact on non-preferred species (Friend & Kemp 2000; Vallentine 2001).

6.2 Mechanical damage to soils and plants

The feet of moving grazing animals exert great pressure on soils (Noble & Tongway 1983, Bennett 1999). This pressure can break soil crusts, compact soils, and erode fragile soil types. Grazing animals affect soils through their daily movement, and also by actively digging to obtain subterranean foodstuffs (e.g. tubers).

Australian ecosystems did not evolve with large herds of ungulate animals, so Australian soils were greatly affected by the introduction of exotic stock. Many accounts describe the soft, spongy, boggy nature of Australian soils at the time of first settlement, and the rapid changes to soils that were caused by grazing stock (Gale & Haworth 2002, Gale 2003). The degree of soil damage varies greatly amongst soil types. Especially in riparian areas, soil damage from grazing stock affects many larger-scale ecosystem processes, such as drainage patterns, nutrient flows, water quality and aquatic species composition (Robertson 1997, Jansen & Robertson 2001).

6.3 Nutrient cycling

The third major way in which grazing animals affect ecosystems is by redistributing nutrients. Grazing animals consume plants over large areas, and deposit nutrient-rich wastes in localised areas. Animal behaviour patterns affect the spatial distribution of deposition sites. The tendency of sheep to camp in localised places (e.g. on high ground and beneath large trees) results in extremely high concentrations of nutrients in localised areas. Increases to soil nitrogen and phosphorus levels strongly affect plant composition, and promote exotic species over native species (McIntyre & Lavorel 1994, Prober *et al*. 2002).

The combination of selective plant consumption, damage to soils and redistribution of nutrients can have profound impacts on ecosystem processes at large and small scales. The most extreme examples include large-scale erosion owing to removal of vegetation and damage to sensitive soils, especially in drought periods.

7. HOW STOCK GRAZING AFFECTS PLANT DIVERSITY PATTERNS

Plant diversity varies at different spatial scales. Some ecosystems have high diversity at small scales (alpha diversity) but low diversity at larger scales (landscape or gamma diversity). Temperate grassy ecosystems in southern Australia vary greatly in richness at small scales, with maximum levels exceeding 80 species in a 30 m^2 quadrat (Lunt 1990a, McIntyre & Martin 2001). However, species turnover tends to be relatively small at large regional scales; most species are widespread, and occur in many regions on a range of geologies (McIntyre 1992, Prober 1996). Grazing impacts also vary across spatial scales. Grazing may promote diversity at small scales but diminish diversity at larger, regional scales (Chaneton & Facelli 1991, Landsberg *et al*. 2002; see below for more details). Consequently, the effects of grazing on plant diversity can be complex.

The international grazing literature contains many examples in which stock grazing, and grazing exclusion, has had positive, negative or neutral impacts on plant diversity. In an attempt to understand this diversity of outcomes, a number of conceptual models have been developed to help address the question: *under what circumstances does grazing (or other disturbances) promote or diminish plant diversity* (e.g. Grime 1973, 1979, Milchunas *et al*. 1988, Milchunas & Lauenroth 1993, Olff & Ritchie 1998). These models highlight a number of factors as being important predictors of grazing impacts on plant diversity in temperate grassy ecosystems:

- the evolutionary history of plant-herbivore interactions (or prior grazing history);
- site productivity (which is influenced by soil fertility and water availability);
- the relative palatability of dominant and sub-ordinate species;
- characteristics of the grazing regime (e.g. grazing animal, stocking intensity and continuity); and
- the spatial scale of disturbance regimes and ecological studies.

Each of these factors is discussed in more detail below.

7.1 Evolutionary history of grazing

In some parts of the world, native vegetation has evolved under heavy grazing pressure from large herds of migratory herbivores (e.g. African savannahs and American tall-grass prairies, which were grazed by bison). By contrast, Australia (and other areas including the Argentinian pampas and grasslands and woodlands of eastern USA) did not support large populations of large mammalian herbivores before the introduction of European stock (Mack & Thompson 1982, Mack 1989). Mammalian herbivores obviously occurred in Australia before European settlement (e.g. macropods), but population numbers were lower than post-settlement stock levels, owing to restricted and unreliable water supplies, predation by dingoes, and perhaps seasonal feed shortages prior to clearing and the introduction of fertilisers and exotic annual grasses and legumes (Calaby & Grigg 1989).

The introduction of grazing stock had a greater impact on natural ecosystems in regions with no evolutionary history of heavy grazing, than in regions which evolved under heavy grazing pressure for two reasons. In regions that have experienced heavy grazing pressure over millennia: (a) disturbance regimes did not necessarily change greatly following the introduction of stock (e.g. cattle and bison have similar effects on soils and plants); and (b) plant species had previously evolved a range of adaptations to withstand heavy grazing. By contrast, in regions without an evolutionary history of grazing: (a) grazing stock created novel disturbance regimes which rapidly affected soils and vegetation, and (b) few plant species had evolved traits to withstand heavy grazing pressure (although traits evolved under other selection pressures may have afforded some protection against grazing; Coughenour 1985). The paucity of heavy grazing prior to the introduction of European stock made Australian ecosystems (including soils) far more susceptible to major changes following the introduction of grazing stock.

7.2 Site productivity

Grazing impacts are strongly affected by site productivity levels. Grime (1973, 1977) proposed that grassland dominance and diversity patterns reflected underlying site productivity gradients. If they remain undisturbed, productive grasslands can quickly become dominated by a small number of large species (often grasses). Small-scale plant diversity then declines since smaller plants cannot co-exist beneath the dense grass and litter. In these sites, disturbances such as grazing can promote small-scale diversity by reducing competition for light from dominant species and providing opportunities for recruitment. The importance of using disturbances such as fire and grazing to regularly deplete the biomass of vigorous grasses (such as *Themeda triandra*, Kangaroo Grass) has long been recognised in the grassland conservation literature in Australia (e.g. Stuwe & Parsons 1977, Tremont & McIntyre 1994, Lunt & Morgan 2002).

By contrast, unproductive sites cannot support a large biomass of vigorous, dominant grasses. Instead, large gaps and open ground may be common. In these sites, grazing cannot promote small-scale diversity by reducing shoot competition, as shoot competition is not constraining diversity. Instead, in unproductive sites grazing (and other disturbances) may have little impact on diversity or may reduce diversity, either by selectively removing palatable species or by reducing carbohydrate reserves from already stressed populations.

The important influence of site productivity on grazing impacts on small-scale plant diversity has been highlighted in a number of recent grazing models. Milchunas *et al*. (1988) suggested that grazing impacts on diversity and ecosystem structure reflected two major factors: evolutionary history of grazing and ‘environmental moisture’ (as determined by climate and annual net primary productivity, ANPP). Milchunas and Lauenroth (1993) analysed hundreds of datasets (mostly from North America) to uncover global relationships between grazing impacts and various ecosystem attributes. They found that grazing (or more precisely, grazing removal) had the strongest impact on species composition in productive sites and in sites with a long evolutionary history of grazing. From an Australian perspective, this suggests that grazing exclusion is likely to cause more substantial changes to species composition and dominance in productive, rather than unproductive, grassy ecosystems.

In an influential recent paper, Olff and Ritchie (1998) suggested that grazing by large and small herbivores would have different impacts on plant diversity under different levels of nutrient and water availability; thus, different outcomes were expected in dry/fertile, dry/infertile, wet/fertile and wet/infertile areas. However this model assumes that fertile soils have experienced high grazing pressure over evolutionary periods, so many of the hypothesised mechanisms are not relevant to Australian grassy ecosystems. From an Australian perspective, it seems more appropriate (and practical) to compare grazing outcomes across generalised productivity gradients (which integrate soil moisture and nutrient levels) as suggested by Grime (1973, 1977) and Milchunas and Lauenroth (1993), rather than to adopt the more complex and mechanistically inappropriate model suggested by Olff & Ritchie (1998).

It is important to note that none of these models consider the evolutionary importance of disturbance regimes other than grazing; an evolutionary history of frequent burning is completely ignored. Temperate grassy ecosystems in Australia are generally considered to have experienced a major change in disturbance regimes following European settlement. Prior to settlement, fire is thought to have been the major disturbance regime affecting ecosystem composition and structure. Since settlement, grazing has replaced burning as the predominant disturbance regime in grassy ecosystems in south-eastern Australia (Lunt 1995, Hobbs 2002). Burning and grazing can both increase small-scale diversity in productive ecosystems (by reducing shoot competition), but the two regimes would be expected to select for very different plant traits (e.g. Lunt 1997a,b). Milchunas *et al*. (1988, p.100) parenthetically noted that their model may not apply in burnt ecosystems, since '*frequent fires or other disturbances may maintain a plant community at its potentially peak diversity. The additional effect of grazing would decrease diversity by causing a shift towards population reduction*.'

7.3 Relative selectivity of dominant and sub-ordinate species

A basic assumption of the above models is that grazing animals reduce the biomass of the dominant grasses. If grazing animals preferentially select smaller sub-ordinate species rather than dominant species, then the suggested increase in diversity following grazing of productive sites is unlikely to eventuate; instead a decline is diversity may occur. The importance of grazing selectivity is apparent where pastures have become dominated by unpalatable dominant grasses, such as *Nassella trichotoma* (Serrated Tussock). Continued grazing pressure in such paddocks further reduces associated species, which are more palatable and nutritious than *Nassella* (Campbell 1998). Reduced competition from other species further promotes seedling recruitment of

Nassella, leading to continued dominance by an unpalatable dominant in an increasingly species-poor pasture (Campbell 1998).

7.4 Characteristics of the grazing regime

Grazing impacts are strongly affected by attributes of the grazing regime, including type of grazing animal (or animals), stocking numbers, seasonality of grazing and spelling, and other factors. These factors are explored more fully in Chapter 4. Much of the Australian conservation literature on the historical impacts of grazing has described stock grazing regimes in an extremely simple way (see Chapter 9). Regional surveys have (by necessity) categorised relative grazing intensities into broad categories, such as 'absent', 'low intensity', 'moderate' and 'high intensity'. These categories are rarely quantified and rarely incorporate other attributes of grazing regimes. As discussed in Chapter 4, strategic grazing studies have demonstrated that subtle differences in grazing regimes (e.g. season of resting) can have substantial impacts on vegetation composition. More generally, the absence of a standardised method for describing grazing regimes in grazing studies greatly constrains attempts to develop a general understanding of grazing impacts on vegetation (McIntyre *et al*. 2003, Chapter 10).

7.5 Spatial scales

The effects of grazing on diversity are scale-dependent, and different outcomes may be observed depending on the scale that is investigated (Olff & Ritchie 1998). For instance, herbivores may increase diversity at the small-scale (by reducing competition or providing niches for regeneration) but might reduce diversity at larger scales by selectively depleting species that are sensitive to grazing. Landsberg *et al*. (2002) illustrated this process in central Australia, as did Chaneton and Facelli (1991) in Argentina.

Spatial scale is important to consider in fragmented landscapes consisting of remnants that differ in composition and degree of degradation. In this context, conservation managers might aim to promote different suites of species in different sites, rather than attempting to maximise plant diversity in every site, in order to maximise diversity at the regional scale (Lunt 1995, McIntyre *et al*. 2003). Thus, grazing management should ideally be considered within the wider context of conserving biodiversity within a regional mosaic of complementary management regimes and biodiversity objectives.

7.6 Integrating historical and productivity based models

Two of the above frameworks have received considerable attention in the literature on grazing impacts in temperate Australian grassy ecosystems: (a) evolutionary and historical exposure to stock grazing; and (b) site productivity and resultant competition. These two frameworks have been described separately above, but it is valuable to integrate the two to highlight the different processes that each framework considers.

A simple conceptual model is used to help synthesise the two frameworks (Figure 2a,b). This model is based on the simple hypothesis that, in ecosystems not exposed to heavy stock grazing over evolutionary periods, increases in post-settlement grazing intensity will lead to ongoing reductions in ecological condition, as shown in Figure 2a. The shape of the curve shown in Fig. 2a varies amongst regions (McIntyre & Martin 2001), but the general trend of declining condition is widely found (see Chapter 10).

The circles in Figure 2a represent successively degraded ecosystem states resulting from increasing grazing intensities since European settlement. State 1 is the most intact state and State 5 is the most degraded. If these patterns were documented from a survey of existing sites, then State 1 would include refuge sites that have rarely been grazed by stock since settlement (e.g. cemeteries), and State 5 represents over-grazed paddocks.

Thus, Figure 2a illustrates the hypothesised ecosystem response when grazing stock are introduced to ecosystems with little evolutionary experience of heavy stock grazing. The general trend is for ongoing decline in ecosystem condition as grazing intensity increases. The Y axis in Figure 2a may represent any number of ecological attributes, including small-scale native plant diversity.

Figure 2: **Conceptual model to highlight the contrasting contexts of studies which (a) document historical impacts of increasing grazing intensity, and (b) experimentally compare grazing regimes within an existing degradation state. See text for explanation of symbols.**

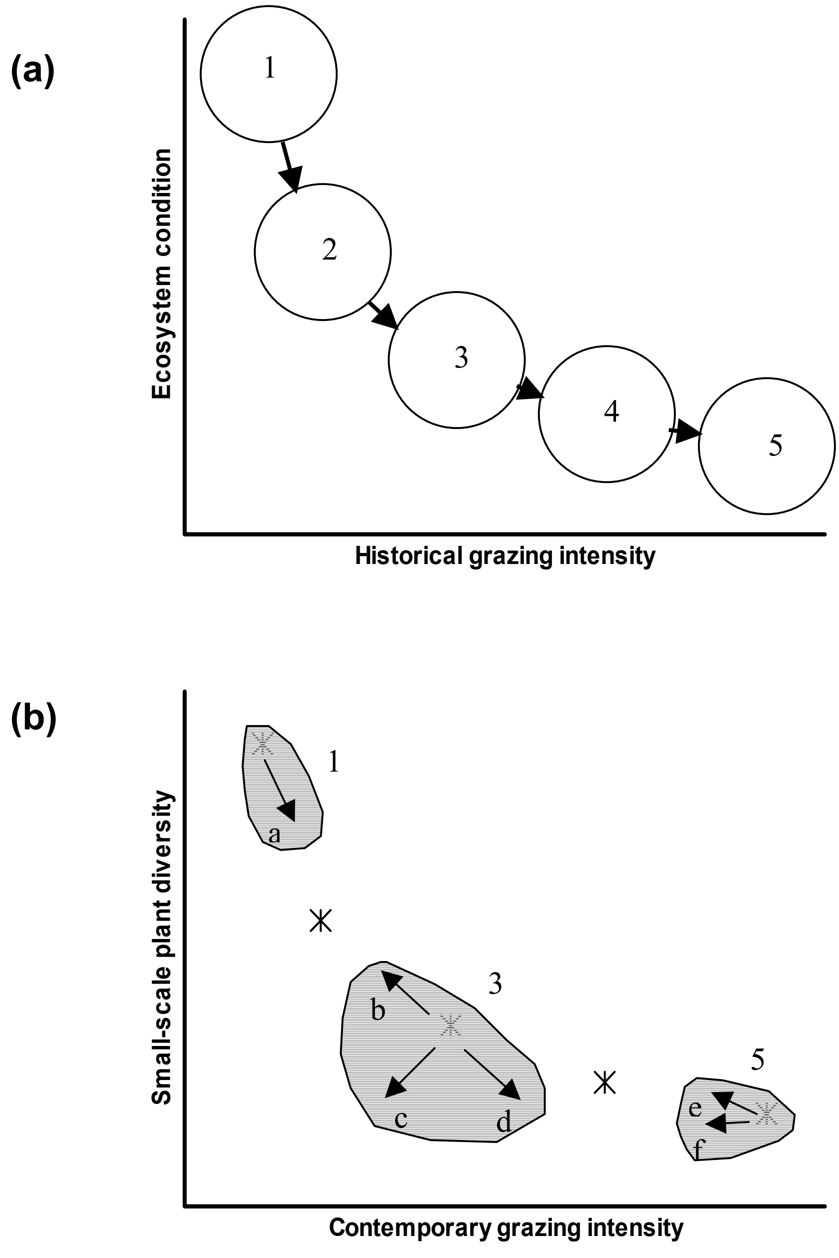

Figure 2b integrates the historical framework from Figure 2a with potential diversity responses following changes in contemporary (recent or future) grazing intensities in sites of differing productivity. The asterisks in Figure 2b mark the centre of each of the circles in Figure 2a. The arrows in Figure 2b illustrate potential changes in small-scale diversity of native plants following newly applied changes to historical grazing regimes; rising arrows show an increase in native diversity and downward arrows show a decline. Shaded polygons show the range of changes that might occur following changes to grazing intensities in each ecosystem state.

Figure 2b highlights that novel changes in grazing regimes can be expected to have different effects on ecosystem conditions (especially small-scale diversity) depending upon: (i) the degree of historical degradation that a site has been subjected to (or put another way, depending upon the initial condition of the vegetation); and (ii) site productivity levels. In high quality sites (shaded area 1), increases in historical grazing intensity are expected to lead to declines in native diversity (Arrow a) as grazing sensitive species are likely to decline.

In moderately degraded sites (shaded area 3), a wide range of outcomes is possible. Increases in historical grazing intensity (Arrow d) may lead to further declines in native diversity, owing to continued reductions of grazing-sensitive species. However, reductions in grazing intensity (Arrows b & c) could lead to an increase or decrease in diversity, depending on site productivity and plant competition. In productive sites, reduced grazing pressure may further reduce small-scale native diversity (Arrow c), owing to competitive exclusion from dominant plants. By contrast, in unproductive sites, reduced grazing pressure may potentially have positive effects on native diversity (Arrow b), by reducing selective herbivory of palatable natives.

In highly degraded sites (shaded area 5), reduced grazing pressure could lead to a minor increase in native plant diversity (Arrow e) or a relatively stable state (Arrow f). However, substantial improvements in native plant diversity are unlikely as most native species are likely to be locally extinct (Yates & Hobbs 1997). Within the range of grazing intensities that would be sensibly be implemented, further declines in native plant diversity may not be possible, regardless of changes to grazing intensities.

These models also highlight the different processes that are documented in two different types of grazing research: (1) regional surveys of historical impacts of grazing regimes; and (2) experimental manipulations of contemporary grazing regimes (Chapter 9). Regional surveys of the effects of historical grazing regimes document the impact of increasing grazing intensities on a flora with little evolutionary exposure to heavy stock grazing, as shown in Figure 2a. Clearly, the patterns observed will vary depending on the range of grazing histories observed (i.e. whether all states 1–5 are sampled or just some states). In particular, historical impacts are likely to be under-estimated if intact refugia (State 1) are not sampled.

By contrast, experimental manipulations of grazing regimes compare the effects of contemporary grazing regimes within a particular ecosystem state, which itself is often degraded (especially in southern Australia). Experimental manipulations document observed responses within each of the shaded ranges shown in Figure 2b. The conclusions drawn from grazing experiments within a particular degradation state (e.g. State 3) cannot easily be extended to other states that differ in their historical exposure to stock grazing (e.g. State 1 or 5).

In closing this chapter, the following two points must be emphasised:

- Even if historical grazing regimes have adversely affected biodiversity patterns, this does not mean that current grazing regimes are having adverse impacts. Current grazing regimes may differ in type or intensity from historical regimes (they may be more or less intense) and/or current degraded ecosystem states may be more stable under current grazing regimes than the ‘original’ unaltered ecosystems were.
- Experimental studies of grazing regimes within pastures (or degraded grassy ecosystems) may show that certain grazing regimes have positive conservation outcomes (e.g. strategic grazing may be better than no grazing). This does not imply that grazing has had positive impacts historically, or that grazing does not damage other ecosystems states (i.e. other unstudied degraded states). Once again, current grazing regimes may differ in type or intensity from historical regimes and current degraded ecosystems states may be more stable under current grazing regimes than the ‘original’ unaltered ecosystems were.

8. GRAZING RESISTANCE AND PLANT TRAITS

Plant species differ in their ability to establish, grow and reproduce under specific grazing regimes; some species decline, whilst others prosper. Grazing resistance has been defined as ‘the relative ability of plants to survive and grow in grazed systems’ (Briske 1996, p. 37). Plants that are resistant to grazing possess avoidance mechanisms, which reduce the likelihood of being grazed, and/or tolerance mechanisms, which increase plant growth after grazing occurs (Briske 1996). Thus, species that increase under grazing are likely to: (a) be grazed less severely (i.e. avoid grazing); (b) grow more rapidly after grazing events (i.e. tolerate grazing better); or (c) possess combinations of both mechanisms.

Tolerance mechanisms include the location and availability of buds which enable plants resprout after grazing, and internal physiological processes that promote active growth after plants are grazed (Briske 1996). Many avoidance mechanisms pose a heavy cost to plants. For example, if more resources are devoted to producing chemical repellents, then less energy is available for growth, resulting in slower growth rates. Thus, there is likely to be a substantial trade-off between investment in avoidance mechanisms and competitive ability (Briske 1996).

Plants with high resistance to grazing pressure commonly possess a number of traits (Table 2). In particular, grazing-resistant species tend to have short-life cycles, a low, creeping habit, vegetative propagation, unpalatable foliage, and/or regenerative buds at or below ground level. Grazing resistant species will not necessarily possess all of these features, but most possess a selection.

Notably, all of these traits relate to ways in which plants *avoid* grazing, rather than to ways in which they *tolerate* it. Equally as importantly, virtually all of these traits relate to *direct* effects of grazing – i.e. to ways in which plants avoid being eaten by grazing stock. None of these traits necessarily describe mechanisms for coping with the many indirect changes which grazing causes, such as soil disturbance or nutrient changes.

Traits that confer resistance to grazing did not necessarily evolve in response to historical grazing pressure. Many features which confer resistance to grazing (including annual life-forms and the ability to die back to ground-level during dry periods) are likely to have evolved to enable plants to withstand other environmental factors (e.g. drought), but also happen to be useful adaptations to survive grazing. In particular, many of the adaptations which enable plants to survive grazing are valuable adaptations against drought (Coughenour 1985).

Table 2: Traits commonly possessed by plants with high resistance to grazing pressure (after McIntyre *et al*. 1999).

Short life-span, rapid life-cycle
Short time to first reproduction
Low height
Scrambling, twining or mat-forming habit
Wide lateral spread
High degree of morphological plasticity
Dormant buds at or below ground-level
Unpalatable or toxic compounds
Plants hairy or prickly
Leaves tough, sclerophyllous
Leaves small
Inflorescence low, not prominent
Plants difficult to uproot

Considerable attention has been devoted to the identification of grazing-resistant traits and functional groups of plant species which share similar traits. Despite the value of these generalisations (as highlighted by Table 2), attempts to further refine our understanding of grazing resistant traits have proved frustrating for a number of reasons (Landsberg *et al*. 1999; McIntyre *et al*. 1999):

- Plants experience a wide variety of disturbances as well as variable climate. Consequently, they must possess features to withstand all of these interacting influences, not just grazing.
- Selective pressures do not relate to individual traits, but to the overall genome of a species. Since the overall genetic composition includes a range of compromises, perfect adaptations is never possible.
- Grazing impacts are, to some extent, context specific (Vesk & Westoby 2001). Different grazing regimes will select for different plant traits (Westoby 1999), as will different competitive interactions between plants in different environments.
- Direct and indirect grazing impacts may select for different traits. A particular plant trait may be disadvantageous in relation to some indirect grazing impacts (e.g. soil changes) even though it may be beneficial in relation to direct grazing impacts (herbivory).

To date, the simplest synthesis of the effects of grazing on plant traits is that grazing tends to promote herbaceous plants that are short-statured, short-lived, with large seed banks or vegetative reproduction, at the expense of tall, upright, long-lived species.

9. HOW ECOLOGISTS HAVE STUDIED GRAZING IMPACTS

Before describing how stock grazing has affected temperate grassy ecosystems in Australia (Chapter 10), it is important to first describe how ecologists have studied grazing impacts, as different types of studies address different types of questions. Ecologists have studied how grazing affects vegetation patterns in three main ways, by undertaking:

- Surveys to compare the effects of different historical grazing regimes across a range of sites, such as regional surveys or fence-line comparisons (e.g. Prober 1996, Fensham *et al*. 1999).
- Experiments to compare the effects of different contemporary grazing regimes, such as grazing exclusion or tactical grazing experiments (e.g. Austin *et al*. 1981, Wahren *et al*. 1994, Lodge *et al*. 1999, Garden *et al*. 2000).
- Experiments to determine how grazing affects ecosystem processes (such as competition, recruitment or seed bank dynamics) to enhance our understanding of *how* and *why* grazing impacts occur (e.g. Clarke 2002, Li *et al*. 2003, Alcock & Hik 2004).

9.1 Surveys of historical grazing effects

Many studies of the effects of historical grazing regimes have been undertaken in Australia (Figure 2). These studies document *long-term, large-scale* grazing impacts. Conclusions about the effects of historical grazing intensities are highly contingent on the range of degradation states studied (Figure 2a). Consequently, when interpreting regional surveys, it is important to consider the range of historical regimes that was sampled, as this varies greatly amongst studies (Table 3).

Table 3: Comparison of the range of grazing histories documented in different studies of historical grazing impacts

Grazing classes: (1) refugia ‘never or rarely grazed’ by stock since European settlement (e.g. cemeteries, rail easements); (2) areas subject to ‘intermittent or light grazing’ over the past 50 years or more, which are likely to have experienced more intensive grazing previously (e.g. roadsides, travelling stock reserves, many public reserves); (3) ‘lightly grazed’ paddocks subjected to more-or-less continuous, low intensity grazing; and (4) ‘heavily grazed’ paddocks subjected to more-or-less continuous, high intensity grazing. Grazing classes have been interpreted from information provided in each paper. Question marks indicate that some treatments that cannot confidently be allocated to particular classes.

Study	Region	Vegetation	Grazing classes			
			1	2	3	4
Prober (1996)	NSW-Qld to Vic	white box woodlands	■	■		
Lunt (1997a)	E Victoria	grassy woodlands	■	■		
Fensham & Skull (1999)	N Qld tropical/subtropical	basalt woodland	■		■	
Benson (1994)	NSW S Tablelands	temperate grasslands	■	■	■	
Prober *et al.* (2002)	Central NSW	white box woodlands	■	■	■	
McDougall & Kirkpatrick (1994)	SE Australia	temperate grasslands	■	■	■	
Stuwe & Parsons (1977)	W Victoria	basalt grasslands	■	■	■	
Biddiscombe (1953)	Central NSW (Trangie)	temperate woodlands	■	■	■	■
Clarke (2003)	NSW N Tablelands	temperate grassland & woodlands	■	■	■	■
Moore (1953)	NSW SE Riverina	temperate & semi-arid woodlands	■	■	■	■
Pettit *et al.* (1995)	South-west W Australia	Mediterranean woodlands	■	■	■	■
Prober & Thiele (1995)	Central NSW	white box woodlands	■	■	■	■
Gilfedder & Kirkpatrick (1998)	Tasmanian midlands	woodlands	?	■	■	
Fensham (1998)	Qld Darling Downs	subtropical grassland & woodland	?	■	■	?
Bromham *et al.* (1999)	Central Victoria	temperate woodlands		■	■	?
Dorrough *et al.* (2004a)	NSW S Tablelands	basalt grasslands		■	■	?
Benson *et al.* (1997)	NSW Riverine Plain	temperate / semi-arid grasslands	?	■	■	■
McIntyre & colleagues	SW Queensland	sub-tropical woodlands	?	■	■	■
McIntyre & colleagues	NSW N Tablelands	temperate grassy woodlands	?	■	■	■
Fensham *et al.* (1999)	Central Queensland	subtropical grassland		■	■	■
Scott & Whalley (1982)	NSW N Tablelands	temperate woodlands		■	■	■
Garden *et al.* (2001)	NSW Central-South T/lands	temperate grassland & woodlands			■	?
Roe (1947)	NSW N Tablelands	temperate woodlands & forests			■	?
Magcale Macandog Whalley 1994	NSW N Tablelands	temperate woodlands / pastures			■	■
Munnich *et al.* (1991)	Central NSW (Goulburn)	temperate woodlands / pastures			■	■
Robinson *et al.* (1993)	Central NSW (Goulburn)	temperate woodlands / pastures			■	■
Robinson & Dowling (1976)	NSW N Tablelands	temperate woodlands / pastures			■	■
Sanford *et al.* (2003)	SE & SW Australia	temperate woodlands / pastures			■	■

For example, some studies have compared vegetation patterns between continuously grazed paddocks and grazing refugia; sites that have rarely been grazed since European settlement, such as cemeteries and rail easements (e.g. Stuwe & Parsons 1977, Prober 1996). These studies provide the most accurate information on the effects of grazing on the 'original' grassy ecosystems (but see caveats in Chapter 10).

By contrast, other studies have compared patterns between continuously grazed paddocks and areas that are currently ungrazed or lightly grazed, but which are known to have experienced more intensive grazing in the past, such as roadsides (e.g. Dorrough *et al*. 2004a). In many parts of southern Australia, current grazing intensities on public land (e.g. roadsides, travelling stock reserves (TSRs) and other reserves) are considerably lower than in the past, owing to the use of vehicles rather than drovers to move stock, and ongoing restrictions of grazing on public land. Studies which use roadsides and bushland reserves as lightly grazed or ungrazed benchmarks are likely to under-estimate the magnitude of post-settlement grazing impacts to some extent, as these reserves are likely to have been grazed more intensively in the past.

9.2 Grazing experiments

In contrast to surveys of historical grazing impacts, experimental studies compare the effects of contemporary grazing regimes, usually within one ecosystem type, which itself is often degraded (especially in southern Australia). Experimental studies typically document short-term, small-scale grazing impacts, as long-term, large-scale experiments are difficult to organise and fund. Experimental studies do not show whether historical grazing has had positive, negative or neutral impacts. They only compare the effects of the studied grazing regimes, within the studied ecosystem state.

The third type of study (experiments to determine how and why grazing affects ecosystem processes) greatly enhance our ability to understand *why* different grazing regimes have different outcomes.

10. HISTORICAL IMPACTS OF STOCK GRAZING ON TEMPERATE GRASSY ECOSYSTEMS

The historical impact of stock grazing on Australian grassy ecosystems has been documented in many studies (Table 3). Virtually all studies have compared vegetation attributes amongst a range of land tenures which differ in known (or assumed) grazing histories, such as cemeteries, road reserves, travelling stock reserves, bushland reserves and grazed pastures. Given the absence of quantitative records of vegetation composition at the time of European settlement, this is the only practical method to document the effects of over 150 years of stock grazing, and to compare vegetation outcomes across a range of grazing intensities. Alternative approaches to document successive changes within individual sites (such as Witt *et al*.'s (2000) analyses of dung beneath shearing sheds) have limited potential for extrapolation across broader landscapes.

This approach has a number of assumptions, including the following.

- All land units originally contained similar vegetation, and differences in current composition relate to post-settlement management rather than natural biophysical attributes. Many studies test this assumption by measuring selected environmental attributes at sites.
- Grazing intensity before European settlement was light, and similar to that in the most lightly grazed, 'reference' sites.
- The vegetation in land units with a history of light (or no) grazing most closely resembles the 'original' pre-settlement condition.
- Stock grazing patterns have historically differed in a consistent way amongst land tenures. Historical variations in grazing intensity within land tenures are often acknowledged, but the relative intensity of grazing amongst tenures is assumed to have remained stable over time.
- Other management activities have not varied greatly across land tenures. Consequently, stock grazing is the most important management activity affecting vegetation that varies amongst land tenures.

A major limitation of regional studies of historical grazing impacts is that minimal information on past stocking regimes is usually available. Consequently, terms such as 'grazing intensity' are (by necessity) defined in a relative rather than absolute manner within each study. This makes it difficult to answer the question, 'is the *moderate* grazing history in one study comparable to the *light*, *moderate* or *heavy* grazing history in another study?' This question is even more problematic when results are compared across regions as European settlement patterns and early grazing regimes differed greatly amongst regions.

Because of this problem, only broad generalisations of grazing impacts are possible when comparing findings amongst studies and regions. It is possible to compare general differences between 'low' and 'high' grazing intensities across studies, but it is not possible to compare effects of more subtle variations in grazing intensity (e.g. differences between 'low' and 'intermediate' intensities). Attempts to undertake detailed meta-analyses – for example, to investigate the generality of the intermediate disturbance hypothesis – are futile. From a practical perspective, regional studies of historical grazing impacts have not helped the development of quantitative (or even indicative) bounds of acceptable stocking levels for current management, since actual past stocking levels are usually unknown and have usually varied greatly over time within each treatment.

10.1 Milton Moore's model of grazing impacts

In the mid-1900s, a series of integrated models of grazing impacts in temperate grassy ecosystems was developed by Milton Moore and colleagues (Moore 1959, 1962, 1964, 1967, 1973, Moore & Biddiscombe 1964). Moore's framework focussed on changes to dominant grasses and weeds, and provided less information on native herbs. Subsequent studies have greatly refined many of the trends described by Moore – especially by describing changes to floristic composition (e.g. Prober & Thiele 1995) – and have highlighted many regional deviations from these trends. Nevertheless, Moore's general trends are still widely accepted and reprinted (e.g. Landsberg 2000). In various papers, Milton Moore (1964, 1967, 1973) presented a number of complicated, regional variations on the general theme illustrated in Figure 3. All of these sequences included the following three general features.

- The gradual replacement under increasing grazing intensity of tall understorey species by shorter species.
- The gradual replacement of long-lived perennial species by short-lived species, including many annuals.
- Since most native grasses are perennial, and many exotic grasses and legumes are annual, the above change also corresponded with the gradual replacement of native plants by exotic species.

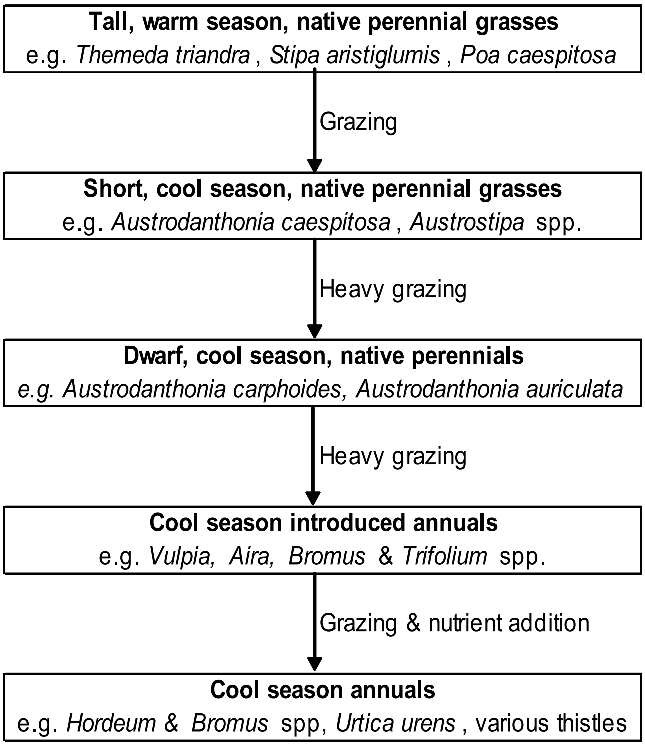

Figure 3: Sequential changes in vegetation composition resulting from increasing grazing intensity in temperate grassy ecosystems in southern Australia (based on Moore 1967)

General features of R.M. Moore's model have been confirmed by many regional studies from southern Australia (C.W.E. Moore 1953, Biddiscombe 1956, Stuwe & Parsons 1977, McIntyre & Lavorel 1994a,b, McIntyre *et al*. 1995, Prober & Thiele 1995, Prober 1996, Lunt 1997a,b, Clarke 2003, Dorrough *et al*. 2004a). The magnitude of the ecological changes induced by heavy grazing in southern Australia is extraordinary: in many areas perennial dominated systems have been almost totally replaced by exotic annuals (e.g. Prober & Thiele 1995).

By contrast, grazing has had lower impacts in sub-tropical and tropical grassy ecosystems in northern Australia, where diverse native communities have persisted under moderate grazing intensities for over 100 years (Fensham 1998; McIntyre & Martin 2001). Nevertheless, even in northern Australia, many native species are now largely confined to small parts of the landscape that escape regular grazing, such as roadsides and reserves (Fensham 1998, McIntyre *et al*. 2002, 2003). The contrast in the degree of grazing impacts between northern and southern Australia has led some researchers to suggest that many of the trends that are often attributed to heavy grazing in southern

Australia may actually represent the cumulative impacts of a wide range of landscape disturbances, including grazing, agricultural development, fragmentation, eutrophication, and other disturbances (Prober 1996, McIntyre & Martin 2001).

10.2 Case studies from south-eastern Australia

Prober & Thiele (1995) gathered the most comprehensive dataset on the effects of grazing on woodland composition in winter-rainfall areas of southern Australia. Sequential changes in grass dominance, from *Themeda triandra* and *Poa sieberiana*, through *Austrodanthonia* – *Austrostipa* species to grazing tolerant natives (e.g. *Bothriochloa macra*) and exotic annuals were observed. Native species richness declined and exotic species richness increased with increasing grazing intensity. Species richness (measured at patch scales) did not increase under intermediate grazing intensities.

More recently, Prober *et al*. (2002) compared soil conditions between different degradation states dominated by different native and exotic species. They found that soil nutrient levels and compaction differed amongst the different degradation states, but not necessarily in a linear fashion. Thus different grazing management regimes appear to have produced an array of different soil and vegetation states rather than the linear uni-directional degradation sequence proposed by R.M. Moore. The potential complexity of grazing impacts on native pastures was comprehensively illustrated by Lodge and Whalley (1989).

In a recent study of historical grazing impacts on the NSW Southern Tablelands, Dorrough *et al*. (2004a) compared grassland composition amongst three tenure-based grazing intensity states: frequently grazed paddocks, infrequently grazed TSRs and rarely grazed roadsides. Increasing grazing pressure resulted in a decline in the richness of forbs and tall native plants (> 25 cm high), and an increase in the richness of annual species, most of which were exotic. Native species richness was similar in infrequently grazed TSRs and rarely grazed roadsides, but declined under frequent grazing in paddocks. An older study from southern Victoria (Stuwe & Parsons 1977) compared plant composition amongst rail-line grazing refugia, roadsides and lightly grazed paddocks (which still supported *Themeda* dominance). Many native species were significantly more frequent in rail easements than in roadsides and paddocks. Rail-line remnants were significantly richer in native species than roads and paddocks, which – in contrast to the findings by Dorrough *et al*. (2004a) – had similar native and exotic richness, although they differed in composition.

Grazing impacts have been intensively studied in summer-rainfall dominated, temperate grassy ecosystems in the New England region of northern New South Wales (Lodge & Whalley 1989, McIntyre & Lavorel 1994a,b, McIntyre *et al*. 1995, Clarke 2003, Reseigh *et al*. 2003). In general, these studies show similar but less dramatic responses to studies from winter-rainfall areas in southern Australia. Many native species have persisted under higher stocking levels than in southern Australia, and exotic annuals are less dominant in many degraded sites. Native pastures in the New England region are dominated by native species rather than exotic annuals, and many exotic pasture species do not persist in the region (Lodge & Whalley 1989).

McIntyre and Lavorel (1994a) compared historical grazing effects across a number of land tenures in the New England area, including grazed pastures, intermittently grazed reserves and TSRs, ungrazed reserves, and rarely grazed roadsides (which experienced more soil disturbance than other reserve types). They found that the richness of total, native and rare plant species was significantly lower in grazed pastures and in roadsides subject to soil disturbance than in less intensively grazed reserves. Additionally, the richness of rare species was greatest in ungrazed reserves. Nevertheless grazed pastures still contained many native species, and contributed greatly to regional biodiversity conservation. A life-form analysis of the same dataset (McIntyre *et al*. 1995) showed that the diversity of plant life forms was greatest in sites subject to low intensity grazing; heavy grazing promoted annual species and species with flat rosettes and small, mobile seeds. Similar patterns were recorded from the same region by Clarke (2003) and Reseigh *et al*. (2003), who found that continuous grazing led to a decline in richness (at the plot scale) of all native growth forms except grasses; many native perennial grasses proved more persistent than native forbs.

Thus, despite regional variations, the general effect of increasing grazing intensity in temperate grassy ecosystems in southern Australia has been the replacement of tall, native, long-lived, perennial species by short-statured, short-lived, annual and exotic species. Nevertheless, many grazed native pastures still contain a diverse mix of native species and contribute substantially to regional biodiversity conservation.

10.3 Tree and shrub recruitment

The above studies have focused on grazing responses of herbaceous ground plants. However, temperate woodlands contain many species of native trees and shrubs. In temperate woodlands, continual grazing for over a century has prevented regeneration of ageing paddock trees, resulting in the restriction of localised tree regeneration and many native shrubs to infrequently grazed areas such as roadsides and reserves (e.g. Moore 1953, Bennett *et al*. 1994; Clarke 2003).

Many native pastures in temperate woodlands are now dominated by old eucalypts with limited recruitment of new cohorts. As old trees senesce, these regions are gradually being converted to open treeless grasslands (Saunders *et al*. 2003). This pattern stands in stark contrast to the promotion of tree and shrub regeneration in heavily grazed areas in semi-arid regions (e.g. Noble 1997). Isolated paddock trees are extremely important for fauna conservation (Bennett *et al*. 1994; Fischer & Lindenmayer 2002; Lumsden & Bennett 2005), and considerable efforts have been given in recent decades to fencing remnant vegetation on grazing properties to promote regeneration of trees and shrubs (e.g. McDonald 2000, Spooner *et al*. 2002).

11. EFFECTS OF GRAZING EXCLUSION

Given the negative effects of historical stock grazing in Australia, stock are often removed from newly declared conservation reserves, for good ecological reasons. Indeed there appears to be little if any ecological basis for maintaining stock grazing in many Australian ecosystems, such as heathlands, shrubby mountain forests, many semi-arid ecosystems and alpine grasslands (e.g. Gibson & Kirkpatrick 1989, Williams 1990, Cheal 1993, Wahren *et al*. 1994, Tiver & Andrew 1997, Bridle & Kirkpatrick 1999, Pettit & Froend 2001, Henderson & Keith 2002).

In lowland temperate grassy ecosystems, exclusion of grazing stock has had mixed ecological outcomes (e.g. Tremont 1994 c.f. Spooner *et al*. 2002). However it must be stressed that decisions about whether grazing-induced vegetation changes are 'good' or 'bad' will depend on the management objectives of the site in question. For example, promotion of shrub regeneration may be considered positive in some situations but negative in others.

As described earlier, the exclusion of grazing stock is likely to have different effects in different ecosystems, and different effects on different species within the one ecosystem. In particular, different responses might be expected in productive and unproductive areas (Grime 1973, 1979, Milchunas *et al*. 1988, Milchunas & Lauenroth 1993, Olff & Ritchie 1998).

In productive sites, grazing removal might be expected to:

- promote recruitment and survival of grazing sensitive species;
- reduce recruitment of species that require regeneration niches created by stock, such as soil disturbances or localised areas with elevated nutrients (e.g. sheep camps);

- reduce recruitment of species that require open canopy conditions (i.e. canopy gaps) for regeneration;
- promote mortality of less competitive plants, due to increased competition from vigorous dominant species; and
- promote recruitment of species that regenerate beneath grass litter.

By contrast, in unproductive sites, grazing removal might be expected to:

- promote recruitment and survival of grazing sensitive species; and
- reduce recruitment of species that require regeneration niches created by stock, such as soil disturbances or high nutrient patches.

As noted earlier (Chapter 7), grazing exclusion is more likely to reduce small-scale plant diversity in productive sites than in unproductive sites (Grime 1973, 1979). Indeed, in unproductive sites, removal of grazing stock may be expected to enhance small-scale plant diversity, by reducing selective grazing of palatable species.

Vegetation changes may occur more rapidly after grazing stock are removed in productive than unproductive sites owing to faster growth rates of dominant grasses, trees and shrubs in productive areas (Milchunas & Lauenroth 1993). Similarly, ground vegetation may change more rapidly following grazing exclusion in open grasslands than in dense grassy woodlands or forests, since dense trees commonly restrict the growth of ground plants, especially in productive areas (Holmgren *et al*. 1997, Scanlan 2002).

The degree of vegetation recovery following grazing exclusion will also vary according to the initial degree of degradation. Post-grazing recovery might be expected to be considerably weaker and slower in highly degraded areas dominated by exotic species with few natives, especially if soil conditions have changed (Yates & Hobbs 1997, Prober *et al*. 2002). Furthermore, many native herbs in temperate grassy ecosystems do not form persistent soil seed banks, so they cannot regenerate following grazing exclusion if they have long been eliminated from the standing vegetation (Lunt 1990b, Morgan 1998a).

The following section summarises the findings from a range of Australian studies on the effects of grazing exclusion in temperate grassy ecosystems. Research findings are described in relation to the ecological mechanisms listed above. This section of this review is intended to be illustrative rather than comprehensive, given the large amount of research that has been conducted on these topics.

11.1 Exclusion enhances recruitment and survival of grazing-sensitive species

Many studies have documented enhanced recruitment or survival of grazing-sensitive species following exclusion of stock and feral animals, especially for trees and shrubs in semi-arid woodlands and eucalypts in temperate woodlands (e.g. Crisp & Lange 1976, Crisp 1978, Chesterfield & Parsons 1985, Windsor 2000). Stock commonly restrict eucalypt regeneration (Semple & Koen 2001, Li *et al*. 2003, Allcock & Hik 2004), leading to increasingly old eucalypt populations in many pastoral regions (Reid & Landsberg 2000, Windsor 2000). Fencing isolated trees and remnant bushland commonly enhances eucalypt recruitment, although recruitment is often sporadic (Cluff & Semple 1994, Clarke 2002, Spooner *et al*. 2002).

In addition to promoting recruitment, removal of grazing stock may also enhance flowering and seed production of palatable species. Dorrough and Ash (2004) found that grazing stock greatly reduced flower and seed production of the daisy, *Leptorhynchos elongatus* and speculated that stock exclusion during the flowering period would enhance the long-term persistence of this species.

Over the long term, enhanced establishment of grazing-sensitive species can lead to increases in native plant diversity following the removal of grazing stock. In a 7 year grazing exclusion study in south-west Western Australia, Pettit and Froend (2001) found that native plant diversity continued to increase after stock were removed, and species composition gradually became more similar to high quality reference sites. Total plant cover (and hence shoot competition) was relatively low (< 50%) in the study sites, and there was no evidence of increasing competition from dominant grasses.

In general, grazing exclusion is likely to promote recruitment and survival of many grazing sensitive native species, provided that the propagules of these species persist or can disperse into the ungrazed area, and provided that recruitment does not require soil disturbance and is not constrained by increased grass competition (see below). However, grazing exclusion may also encourage regeneration of palatable weed species. For example, Tiver *et al*. (2001) found that regeneration of the exotic tree, *Acacia nilotica* (Prickly Acacia) was controlled by sheep (but not cattle) grazing.

11.2 Exclusion enhances mortality due to increased competition

Many regional studies have documented reduced species diversity in ungrazed and undisturbed grasslands and woodlands (Stuwe & Parsons 1977, McIntyre & Lavorel 1994b, Tremont 1994, Dorrough *et al*. 2004), and have attributed this pattern to increased competition in undisturbed sites. In productive grasslands, shoot competition from dominant grasses can reduce plant diversity by enhancing mortality of less competitive plants as well as by restricting recruitment of new individuals (see below). Increased competition from vigorous grasses can lead to changes in the life-form composition of associated species, as small species are out-competed and the cover of taller species increases (Tremont 1994, Lunt & Morgan 1999a).

Whilst this process is widely accepted in the Australian literature on grassland conservation management, no long-term experimental studies are available which unequivocally illustrate reductions in diversity due to enhanced mortality of existing plants in undisturbed areas. However, considerable anecdotal information exists describing reductions in rare species following the abandonment of regular biomass removal (e.g. Scarlett & Parsons 1982, 1990, Cropper 1993, Morgan 1995).

A number of studies have demonstrated reduced vigour, flower and seed production of grassland herbs beneath thick grass litter (e.g. Lunt 1994, Morgan 1997, Coates *et al*. submitted). Restrictions in vigour are not restricted to small herbs. In productive grasslands, the dominant grass *Themeda triandra* senesces under dense litter, resulting in dramatic changes to grassland dominance and structure (Morgan & Lunt 1999).

Dense shrubs can also reduce ground plant richness. Costello *et al*. (2000) found that small-scale richness of grassland plants declined with increasing time beneath recently established stands of *Acacia sophorae* (Coast Wattle). On average 38% of species disappeared after 10 years beneath *Acacia* plants and 76% disappeared after 20 years. Only a small group of shade tolerant, rhizomic grasses and sedges could persist in the long-term beneath *Acacia* shrubs.

Thus in general, in productive sites dominated by dense grasses (native or exotic), the small-scale diversity of native plants is likely to decline if grazing and other disturbances are removed for extended periods.

11.3 Exclusion reduces recruitment of species that require open gaps for regeneration

Competition from the existing grass sward is a major factor constraining plant recruitment in productive grassy ecosystems (Grime 1973, Burke & Grime 1996). Thick grass limits recruitment of grassland and woodland herbs and trees, and recruitment may be promoted by removing grass and litter (Withers 1978, Morgan 1997, 1998b). However, this mechanism is only likely to occur in productive areas where the ground layer is dominated by large native perennial grasses (or other herbs) or by dense swards of tall exotics (e.g. *Avena*, *Bromus*, *Paspalum* and *Phalaris* species). Reductions in diversity due to reduced opportunities for seedling regeneration have not been documented in long-term grazing exclusion studies in unproductive areas where vigorous grasses do not dominant (e.g. Pettit *et al*. 1995, Pettit & Froend 2001, Kenny 2003). Instead, native species diversity often increases after grazing is removed from unproductive areas owing to increases in grazing sensitive species (see above).

11.4 Exclusion reduces recruitment of species that require regeneration niches created by stock

In addition to creating gaps in the plant canopy by eating dominant plants, grazing stock can create specific regeneration niches for some plant species by disturbing the soil and creating small fertile patches, especially in sheep camps. Stock exclusion would reduce soil disturbance and prevent further increases in nutrient levels in sheep camps (although high nutrient levels are likely to persist for long periods).

Sheep grazing increases nutrient levels in localised areas, especially in sheep camps (Taylor *et al*. 1984). Sheep camps are invariably dominated by exotic species (Prober *et al*. 2002) with few natives (e.g. *Urtica incisa*; Harden 1990). Consequently, it seems unlikely that many (if any) native species will decline following grazing exclusion because of the elimination of sheep camps. At any rate, elevated nutrients levels are likely to persist for lengthy periods.

Pyrke (1993) found that small soil disturbances by bettongs and bandicoots promoted the establishment of a number of woodland herbs in Tasmania, including some threatened species. However no species were completely dependent on diggings for regeneration. Similarly, regeneration of the native daisy *Leucochrysum albicans* (which is endangered in Tasmania) is promoted by soil disturbances created by grazing stock, leading Gilfedder & Kirkpatrick (1994) to conclude that Tasmanian populations of *L. albicans* would decline if grazing was removed.

In temperate grassy ecosystems, soil disturbances commonly promote exotic weeds rather than native species (McIntyre & Lavorel 1994a,b). This occurs because many exotics have larger seed banks than most native species (Lunt 1990b, Morgan 1998a), and because soil disturbance increases nutrient levels which favour many exotics (Wijesuriya & Hocking 1999, Prober *et al*. 2002). With some exceptions (e.g. *L. albicans*), it appears unlikely that most native species will be greatly disadvantaged by the removal of soil disturbances created by stock or by the elimination of sheep camps following grazing exclusion. Instead, reductions in soil disturbance and nutrient levels may diminish recruitment of some exotic species. In most woodlands, soil will continue to be disturbed by native animals (e.g. choughs, echidnas, kangaroos and wallabies).

11.5 Exclusion enhances recruitment in thick leaf litter

In productive sites, grazing exclusion commonly promotes the formation of a thick layer of dead grass litter (see Fig. 2 in Tremont & McIntyre 1994). Thick grass litter generally inhibits seed germination and seedling establishment (Facelli & Pickett 1991), but does promote establishment of some species, including the exotic annual grasses, *Bromus tectorum* and *B. mollis* (Heady 1956, Evans & Young 1970 cited in Facelli & Pickett 1991). A number of exotic species have been found to increase in abundance in long-undisturbed *Themeda* grasslands (including *Bromus racemosus*, *Holcus lanatus*, *Hypochoeris radicata* and *Plantago* species; Tremont 1994, Lunt and Morgan 1999b), which suggests that these vigorous, non-rhizomic and non-stoloniferous weeds can successfully establish from seedlings in thick grass and litter. By contrast there appears to be no evidence that seedling establishment of native plants is promoted by thick grass litter. Instead, thick litter is known to inhibit establishment of many native species (see above). Thus, the formation of a thick litter layer following grazing exclusion is unlikely to promote many natives. Instead, it may enhance the establishment of a number of vigorous exotic species.

11.6 Synthesis

The above examples document a range of ways in which grazing exclusion can affect plant populations and community composition. As can be seen, outcomes are often context dependent. As a broad generalisation, grazing exclusion might be expected to lead to positive ecological outcomes in relatively unproductive ecosystems. These include:

- grasslands, grassy woodlands and forests on infertile, shallow or skeletal soils;
- grassy woodlands and forests in which trees constrain grass biomass levels and prevent dominant grasses from outcompeting smaller herbs; and
- other ecosystems on unproductive soils that occur amongst grassy ecosystems within managed areas.

By contrast, total grazing exclusion might be expected to have negative ecological outcomes in productive grassy ecosystems, including:

- open grasslands on fertile, well watered soils; and

- degraded grasslands and woodlands dominated by vigorous weeds (particularly if these weeds are relatively palatable to grazing stock).

Once again it must be stressed that ecological outcomes must be assessed in relation to the management aims for the site in question. Changes to management regimes should be considered carefully, especially in areas supporting rare and threatened species. Furthermore, these generalisations are framed solely in terms of a simple dichotomy between ‘grazing’ and ‘exclusion’. Different outcomes may be obtained if targeted grazing strategies are utilised (Chapter 4) or if stock are replaced by other disturbance regimes (e.g. ecological burning).

12. LITERATURE REVIEW OVERVIEW

This review has described the effects of stock grazing on biodiversity values in temperate, lowland grassy ecosystems in southern Australia. A number of conceptual models have been developed to address the question: ‘under what circumstances does grazing promote or diminish plant diversity?’ Important predictors of grazing impacts on plant diversity include: (*a*) evolutionary history (or prior grazing history); (*b*) site productivity; (*c*) the relative palatability of dominant and sub-ordinate species; (*d*) characteristics of the grazing regime, and (*e*) the spatial scale of disturbance regimes and ecological studies.

Australian ecosystems did not evolve with intensive grazing from large ungulates. Consequently, they were far more susceptible to damage from grazing stock than were ecosystems in many other countries. The introduction of grazing stock in the 19th century caused enormous damage to Australian soils and vegetation. Heavy grazing caused tall, long-lived, perennial, native grasses and herbs to be replaced by small, short-lived, exotic species, as well as depleting many native shrubs and preventing regeneration of ageing paddock trees. Nevertheless, many grazed native pastures still contain many native species and assist regional biodiversity conservation.

Notwithstanding the negative effects of historical grazing, grazing stock can play a useful role to maintain biodiversity values in certain situations. In particular, grazing stock may enhance small-scale plant diversity in productive grassy ecosystems. In the absence of grazing and other disturbances, productive grasslands can become dominated by large grasses which outcompete smaller plants, reducing plant diversity. In these sites, grazing can promote small-scale diversity by reducing competition. By contrast, stock grazing may have neutral or negative impacts on plant diversity in unproductive sites. The effects of grazing on diversity are scale-dependent, and stock may increase diversity at the small-scale (by reducing competition) whilst simultaneously reducing diversity at regional scales (by selectively depleting grazing-sensitive species).

In deciding whether to use grazing stock to maintain biological values, managers must firstly ask whether stock grazing is necessary and able to achieve desired conservation outcomes, and secondly, how to manage grazing stock to minimise potential adverse environmental outcomes. Site management objectives, grazing history, landscape context and expected small-scale biodiversity responses all need to be taken into account when considering whether grazing is an appropriate management tool. High quality remnants that have rarely been grazed by stock in the past are likely to be the most sensitive to damage from stock, and should not normally be grazed. In general, continuous grazing should be avoided, as should fertilisers, exotic pasture species and artificial feed.

There is considerable potential to restore degraded grassy ecosystems using targeted grazing strategies, in which stock grazing promotes desirable species (e.g. certain natives) and depletes undesirable species (e.g. certain exotics). However, limited control over animal movements due to sparse fencing is likely to constrain outcomes to some extent, especially in large unfenced areas. Targeted grazing strategies are most likely to be useful in moderately degraded grassy remnants that historically have been grazed by stock, and which contain abundant natives and exotics. However, these strategies will require good management infrastructure (e.g. small grazing areas), stock management expertise and close supervision, and considerable experimental work (or adaptive management trials).

Like fire management, grazing management is complex. Grazing stock have different effects on biodiversity in different ecosystems and under different stocking regimes. Whilst stock may often provide a useful tool to maintain biodiversity values in temperate lowland grassy ecosystems, they are known to degrade many other ecosystems, including shrubby forests and alpine grasslands.

13. REFERENCES

ACT Government (2004a). *Woodlands for Wildlife. ACT Lowland Woodland Conservation Strategy. Action Plan No. 27*. Environment ACT, Canberra.

ACT Government (2004b). *A Vision Splendid of the Grassy Plains Extended. Draft ACT Lowland Native Grassland Conservation Strategy. Action Plan No. 28*. Environment ACT, Canberra.

Allcock, K. G. and Hik, D. S. (2004). Survival, growth, and escape from herbivory are determined by habitat and herbivore species for three Australian woodland plants. *Oecologia* 138, 231-241.

Austin, M. P., Williams, O. B., and Belbin, L. (1981). Grassland dynamics under sheep grazing in an Australian Mediterranean type climate. *Vegetatio* 47, 201-211.

Bailey, D. W., Gross, J. E., Laca, E. A., Rittenhouse, L. R. *et. al*. (1996). Mechanisms that result in large herbivore grazing distribution patterns. *Journal of Range Management* 49, 386-400.

Baker-Gabb, D. (1993). Managing native grasslands to maintain biodiversity and conserve the plains-wanderer. *Supplement to Wingspan* 10, 1-8.

Baker-Gabb, D. (1998). Native grasslands and the Plains-wanderer. *Supplement to Wingspan* 8, 1-8.

Barlow, T. (1997). *Grassy Guidelines. A Landowners Guide to Managing Victorian Native Grasslands and Woodlands.* Trust for Nature, Melbourne.

Bennett, A. F., Lumsden, L. F., and Nicholls, A. O. (1994). Tree hollows as a resource for wildlife in remnant woodlands: spatial and temporal patterns across the northern plains of Victoria, Australia. *Pacific Conservation Biology* 1, 222-235.

Bennett, M. B. (1999). Foot areas, ground reaction forces and pressures beneath the feet of kangaroos, wallabies and rat-kangaroos (Marsupialia: Macropodoidea). *Journal of Zoology* 247, 365-369.

Benson, J. S. (1994). The native grasslands of the Monaro region: Southern Tablelands of NSW. *Cunninghamia* 3, 609-650.

Benson, J. S., Ashby, E. M., and Porteners, M. F. (1997). The native grasslands of the Riverine Plain, New South Wales. *Cunninghamia* 5, 1-48.

Biddiscombe, E. F. (1953). A survey of the natural pastures of the Trangie district, New South Wales, with particular reference to the grazing factor. *Australian Journal of Agricultural Research* 4, 1-28.

Biddiscombe, E. F., Hutchings, R. J., Edgar, G., and Cuthbertson, E. G. (1956). Grazing management of natural pastures at Trangie, New South Wales. *Australian Journal of Agricultural Research* 7, 233-247.

Bridle, K. L. and Kirkpatrick, J. B. (1999). Comparative effects of stock and wild vertebrate herbivore grazing on treeless subalpine vegetation, eastern Central Plateau, Tasmania. *Australian Journal of Botany* 47, 817-834.

Briske, D. D. (1996). Strategies of plant survival in grazed systems: a functional interpretation. In *The ecology and management of grazing systems*. (Eds J. Hodgson and A. W. Illius.) pp. 37-67. CAB International, Wallingford UK.

Bromham, L., Cardillo, M., Bennett, A. F., and Elgar, M. A. (1999). Effects of stock grazing on the ground invertebrate fauna of woodland remnants. *Australian Journal of Ecology* 24, 199-207.

Brown, J. R. and Carter, J. (1998). Spatial and temporal patterns of exotic shrub invasion in an Australian tropical grassland. *Landscape Ecology* 13, 93-102.

Burke, M. J. W. and Grime, J. P. (1996). An experimental study of plant community invasibility. *Ecology* 77, 776-790.

Calaby, J. H. and Grigg, G. C. (1989). Changes in macropodoid communities and populations in the past 200 years, and the future. In *Kangaroos, Wallabies and Rat-kangaroos. Vol. 2*. (Eds G. Grigg, P. Jarman, and I. Hume.) pp. 813-820. Surrey Beatty & Sons, Chipping Norton NSW.

Campbell, M. H. (1998). Biological and ecological impact of serrated tussock (*Nassella trichotoma* (Nees) Arech.) on pastures in Australia. *Plant Protection Quarterly* 13, 80-86.

Chaneton, E. J. and Facelli, J. M. (1991). Disturbance effects on plant community diversity: spatial scales and dominance hierarchies. *Vegetatio* 93, 143-155.

Cheal, D. C. (1993). Effects of stock grazing on the plants of semi-arid woodlands and grasslands. *Proceedings of the Royal Society of Victoria* 105, 57-65.

Chesterfield, C. J. and Parsons, R. F. (1985). Regeneration of three tree species in arid south-eastern Australia. *Australian Journal of Botany* 33, 715-732.

Clarke, P. J. (2002). Experiments on tree and shrub establishment in temperate grassy woodlands: seedling survival. *Austral Ecology* 27, 606-615.

Clarke, P. J. (2003). Composition of grazed and cleared temperate grassy woodlands in eastern Australia: patterns in space and inferences in time. *Journal of Vegetation Science* 14, 5-14.

Cluff, D. and Semple, W. S. (1994). Natural regeneration: in 'mother natures' own time. *Australian Journal of Soil and Water Conservation* 7, 28-33.

Coates, F., Lunt I.D. & Tremblay, R.L. (submitted). The effect of fire, rainfall and herbivory on emergence and flowering in a threatened terrestrial orchid from south-eastern Australia, *Prasophyllum correctum* D.L. Jones, and implications for grassland habitat management. *Biological Conservation*, in review.

Costello, D. A., Lunt, I. D., and Williams, J. E. (2000). Effects of invasion by the indigenous shrub *Acacia sophorae* on plant composition of coastal grasslands in south-eastern Australia. *Biological Conservation* 96, 113-121.

Coughenour, M. B. (1985). Graminoid responses to grazing by large herbivores: adaptations, exaptations, and interacting processes. *Annals of the Missouri Botanical Garden* 72, 852-863.

Crisp, M. D. (1978). Demography and survival under grazing of three Australian semi-desert shrubs. *Oikos* 30, 520-528.

Crisp, M. D. and Lange, R. T. (1976). Age structure, distribution and survival under grazing of the arid zone shrub *Acacia burkittii*. *Oikos* 27, 86-92.

Cropper, S. (1987). Ecological notes and suggestions for conservation of a recently discovered site of *Lepidium hyssopifolium* Desv. (Brassicaceae) at Bolwarrah, Victoria, Australia. *Biological Conservation* 41, 269-278.

Cropper, S. (1993). *Management of Endangered Plants*. CSIRO, Melbourne.

Department of Conservation and Environment (undated). *Native Grassland Management in the Melbourne Area*. Department of Conservation and Environment, Melbourne.

Dorrough, J. and Ash, J. (2004). The impact of livestock grazing on the persistence of a perennial forb in a temperate Australian grassland. *Pacific Conservation Biology* 9, 302-307.

Dorrough, J., Ash, J., and McIntyre, S. (2004). Plant responses to livestock grazing frequency in an Australian temperate grassland. *Ecography* 27, 798-810.

Dorrough, J., Yen, A., Turner, V., Clark, S. G., Crosthwaite, J., and Hirth, J. R. (2004). Livestock grazing management and biodiversity conservation in Australian temperate grassy landscapes. *Australian Journal of Agricultural Research* 55, 279-295.

Eddy, D. (2002). *Managing Native Grassland: A Guide to Management for Conservation, Production and Landscape Protection*. Worldwide Fund for Nature Australia, Sydney.

Evans, R. A. and Young, J. (1970). Plant litter and establishment of alien annual weed species in rangeland communities. *Weed Science* 18.

Facelli, J. M. and Pickett, S. T. A. (1991). Plant litter: its dynamics and effects on plant community structure. *Botanical Review* 57, 1-32.

Fensham, R. J. (1998). The grassy vegetation of the Darling Downs, south-eastern Queensland, Australia. Floristics and grazing effects. *Biological Conservation* 84, 301-310.

Fensham, R. J., Holman, J. E., and Cox, M. J. (1999). Plant species responses along a grazing disturbance gradient in Australian grassland. *Journal of Vegetation Science* 10, 77-86.

Fensham, R. J. and Skull, S. D. (1999). Before cattle: a comparative floristic study of *Eucalyptus* savanna grazed by macropods and cattle in north Queensland, Australia. *Biotropica* 31, 37-47.

Fischer, J. and Lindenmayer, D. B. (2002). The conservation value of paddock trees for birds in a variegated landscape in southern New South Wales. 2. Paddock trees as stepping stones. *Biodiversity & Conservation* 11, 833-849.

Frank, D. A., McNaughton, S. J., and Tracy, B. F. (1998). The ecology of the earth's grazing ecosystems. *Bioscience* 48, 513-521.

Friend, D. A. and Kemp, D. R. (2000). Grazing management methods. In *Australian Weed Management Systems*. (Ed B. M. Sindel.) pp. 139-159. R.G. and F.J. Richardson, Melbourne.

Gale, S. J. (2003). Making the European landscape: early contact environmental impact in Australia. *Geography's New Frontiers. Geographical Society of New South Wales Conference Papers* 17*,* 7-16.

Gale, S. J. and Haworth, R. J. (2002). Beyond the limits of location: human environmental disturbance prior to official European contact in early colonial Australia. *Archaeology in Oceania* 37, 123-136.

Garden, D. L., Dowling, P. M., Eddy, D. A., and Nicol, H. I. (2001). The influence of climate, soil, and management on the composition of native grass pastures on the Central, Southern, and Monaro Tablelands of New South Wales. *Australian Journal of Agricultural Research* 52, 925-936.

Garden, D. L., Lodge, G. M., Friend, D. A., Dowling, P. M., and Orchard, B. A. (2000). Effects of grazing management on botanical composition of native grass-based pastures in temperate south-east Australia. *Australian Journal of Experimental Agriculture* 40, 225-245.

Gardener, M. R. and Sindel, B. M. (1998). The biology of *Nassella* and *Achnatherum* species naturalized in Australia and the implications for management on conservation lands. *Plant Protection Quarterly* 13, 76-79.

Gibson, N. and Kirkpatrick, J. B. (1989). Effects of the cessation of grazing on the grasslands and grassy woodlands of the central plateau, Tasmania. *Australian Journal of Botany* 37, 55-63.

Gilfedder, L. and Kirkpatrick, J. B. (1994). Climate, grazing and disturbance, and the population dynamics of *Leucochrysum albicans* at Ross, Tasmania. *Australian Journal of Botany* 42, 417-430.

Gilfedder, L. and Kirkpatrick, J. B. (1998). Factors influencing the integrity of remnant bushland in subhumid Tasmania. *Biological Conservation* 84, 89-96.

Grace, B. S., Whalley, R. D. B., Sheppard, A. W., and Sindel, B. M. (2002). Managing saffron thistle in pastures with strategic grazing. *Rangeland Journal* 24, 313-325.

Greenwood, K. L. and McKenzie, B. M. (2001). Grazing effects on soil physical properties and the consequences for pastures: a review. *Australian Journal of Experimental Agriculture* 41, 1231-1250.

Griffiths, T. (1996). *Hunters and Collectors: the Antiquarian Imagination in Australia*. Cambridge University Press, Cambridge.

Grime, J. P. (1973). Competitive exclusion in herbaceous vegetation. *Nature* 242, 344-347.

Grime, J. P. (1979). *Plant Strategies and Vegetation Processes*. John Wiley and Sons, Chichester, UK.

Harden, G. J. (1990). *Flora of New South Wales, Volume 1*. NSW University Press, Kensington NSW.

Heady, H. F. (1956). Changes in a California annual plant community induced by manipulation of natural mulch. *Ecology* 37, 798-812.

Henderson, M. K. and Keith, D. A. (2002). Correlation of burning and grazing indicators with composition of woody understorey flora of dells in a temperate eucalypt forest. *Austral Ecology* 27, 121-131.

Hobbs, R. (2002). Fire regimes and their effects in Australian temperate woodlands. In *Flammable Australia: The Fire Regimes and Biodiversity of a Continent*. (Eds R. Bradstock, J. Williams, and A. M. Gill.) pp. 305-326. Cambridge University Press: Cambridge UK.

Holmgren, M., Scheffer, M., and Huston, M. A. (1997). The interplay of facilitation and competition in plant communities. *Ecology* 78, 1966-1975.

Jansen, A. and Robertson, A. I. (2001). Relationships between livestock management and the ecological condition of riparian habitats along an Australian floodplain river. *Journal of Applied Ecology* 38, 63-75.

Kemp, D. R. (2000). Managing grassland composition with grazing. In *Balancing Conservation and Production in Grassy Landscapes. Proceedings of the Bushcare Grassy Landscapes Conference*. (Eds T. Barlow and R. Thorburn.) pp. 145-152. Environment Australia: Canberra.

Kemp, D. R., Dowling, P. M., and Michalk, D. L. (1996). Managing the composition of native and naturalised pastures with grazing. *New Zealand Journal of Agricultural Research* 39, 569-578.

Kenny, S. (2003). *Effects of Grazing Exclusion on Understorey Vegetation in River Red Gum Forests and Ephemeral Wetlands in Millewa State Forest, NSW*. Unpubl. Honours thesis, School of Environmental & Information Sciences, Charles Sturt University, Albury.

Landsberg, J. (2000). Status of temperate woodlands in the Australian Capital Territory Region. In *Temperate Eucalypt Woodlands in Australia: Biology, Conservation, Management and Restoration*. (Eds R. J. Hobbs and C. J. Yates.) pp. 32-44. Surrey Beatty & Sons, Chipping Norton NSW.

Landsberg, J., James, C. D., Maconochie, J., Nicholls, A. O., Stol, J., and Tynan, R. (2002). Scale-related effects of grazing on native plant communities in an arid rangeland region of South Australia. *Journal of Applied Ecology* 39, 427-444.

Landsberg, J., James, C. D., Morton, S. R., Muller, W. J., and Stol, J. (2003). Abundance and composition of plant species along grazing gradients in Australian rangelands. *Journal of Applied Ecology* 40, 1008-1024.

Landsberg, J., Lavorel, S., and Stol, J. (1999). Grazing response groups among understorey plants in arid rangelands. *Journal of Vegetation Science* 10, 683-696.

Leslie, D. (2000). *Grazing Strategy for Riverina Region Native Forest Management System*. State Forests of New South Wales, Deniliquin.

Li, J., Duggin, J. A., Grant, C. D., and Loneragan, W. A. (2003). Germination and early survival of *Eucalyptus blakelyi* in grasslands of the New England Tablelands, NSW, Australia. *Forest Ecology and Management* 173, 319-334.

Lodge, G. M., Gogel, B. J., Cullis, B. R., and Archer, K. A. (1999). Effects of grazing, slashing and burning on *Aristida ramosa* and sheep productivity in northern New South Wales. *Australian Journal of Experimental Agriculture* 39, 685-698.

Lodge, G. M. and Whalley, R. D. B. (1989). *Native and Natural Pastures on the Northern Slopes and Tablelands of New South Wales*. NSW Agriculture and Fisheries, Sydney.

Lodge, G. M., Gogel, B. J., Cullis, B. R., and Archer, K. A. (1999). Effects of grazing, slashing and burning on *Aristida ramosa* and sheep productivity in northern New South Wales. *Australian Journal of Experimental Agriculture* 39, 685-698.

Lodge, G. M., Scott, J. M., King, K. L., and Hutchinson, M. D. (1998). A review of sustainable pasture production issues in temperate native and improved pastures. *Animal Production in Australia* 22, 79-89.

Lumsden, L. F. and Bennett, A. F. (2005). Scattered trees in rural landscapes: foraging habitat for insectivorous bats in south-eastern Australia. *Biological Conservation* 122, 205-222.

Lunt, I. D. (1990a). Species-area curves and growth-form spectra for some herb-rich woodlands in western Victoria, Australia. *Australian Journal of Ecology* 15, 155-161.

Lunt, I. D. (1990b). The soil seed bank of a long-grazed *Themeda triandra* grassland in Victoria. *Proceedings of the Royal Society of Victoria* 102, 53-57.

Lunt, I. D. (1991). Management of remnant, lowland grasslands and grassy woodlands for nature conservation: a review. *Victorian Naturalist* 108, 56-66.

Lunt, I. D. (1994). Variation in flower production of nine grassland species with time since fire, and implications for grassland management and restoration. *Pacific Conservation Biology* 1, 359-366.

Lunt, I. D. (1995). European management of remnant grassy forests and woodlands in south-eastern Australia - past, present and future? *Victorian Naturalist* 112, 239-249.

Lunt, I. D. (1997a). Effects of long-term vegetation management on remnant grassy forests and anthropogenic native grasslands in south-eastern Australia. *Biological Conservation* 81, 287-297.

Lunt, I. D. (1997b). A multivariate growth-form analysis of grassland and forest forbs in south-eastern Australia. *Australian Journal of Botany* 45, 691-705.

Lunt, I. and Bennett, A. F. (2000). Temperate woodlands in Victoria: distribution, composition and conservation. In *Temperate Eucalypt Woodlands in Australia: Biology, Conservation, Management and Restoration*. (Eds R. J. Hobbs and C. J. Yates.) pp. 17-31. Surrey Beatty and Sons: Chipping Norton NSW.

Lunt, I. D. and Morgan, J. W. (1999a). Vegetation changes after 10 years of grazing exclusion and intermittent burning in a *Themeda triandra* (Poaceae) grassland reserve in south-eastern Australia. *Australian Journal of Botany* 47, 537-552.

Lunt, I. D. and Morgan, J. W. (1999b). Effect of fire frequency on plant composition at the Laverton North Grassland Reserve, Victoria. *Victorian Naturalist* 116, 84-90.

Lunt, I. D. and Morgan, J. W. (2002). The role of fire regimes in temperate lowland grasslands of south-eastern Australia. In *Flammable Australia: The Fire Regimes and Biodiversity of a Continent*. (Eds R. Bradstock, J. Williams, and A. M. Gill.) pp. 177-196. Cambridge University Press: Cambridge UK.

Macgale-Macandog, D. B. and Whalley, R. D. B. (1994). Factors affecting the distribution and abundance of *Microlaena stipoides* (Labill.) R.Br. on the Northern Tablelands of New South Wales. *Rangeland Journal* 16, 26-38.

Mack, R. N. (1989). Temperate grasslands vulnerable to plant invasions: characteristics and consequences. In *Biological Invasions: A Global Perspective*. (Eds J. A. Drake, H. A. Mooney, F. diCastri, R. H. Groves, F. J. Kruger, M. Rejmanek, and M. Williamson.) pp. 155-179. John Wiley and Sons: Chichester.

Mack, R. N. and Thompson, J. N. (1982). Evolution in steppe with few, large, hooved mammals. *American Naturalist* 119, 757-773.

McDonald, T. (2000). Extending that little bit further: an interview with Martin Driver and Ian Davidson. *Ecological Management and Restoration* 1, 3-9.

McDougall, K. and Kirkpatrick, J. B. (1994). *Conservation of Lowland Native Grasslands in South-eastern Australia*. World Wide Fund for Nature Australia, Sydney.

McIntyre, S. (1992). Risks associated with the setting of conservation priorities from rare plant species lists. *Biological Conservation* 60, 31-37.

McIntyre, S., Heard, K. M., and Martin, T. G. (2002). How grassland plants are distributed over five human-created habitats typical of eucalypt woodlands in a variegated landscape. *Pacific Conservation Biology* 7, 274-289.

McIntyre, S., Heard, K. M., and Martin, T. G. (2003). The relative importance of cattle grazing in subtropical grasslands: does it reduce or enhance plant biodiversity? *Journal of Applied Ecology* 40, 445-457.

McIntyre, S. and Lavorel, S. (1994a). How environmental and disturbance factors influence species composition in temperate Australian grasslands. *Journal of Vegetation Science* 5, 373-384.

McIntyre, S. and Lavorel, S. (1994b). Predicting richness of native, rare, and exotic plants in response to habitat and disturbance variables across a variegated landscape. *Conservation Biology* 8, 521-531.

McIntyre, S., Lavorel, S., and Tremont, R. M. (1995). Plant life-history attributes: their relationship to disturbance response in herbaceous vegetation. *Journal of Ecology* 83, 31-44.

McIntyre, S., Lavorel, S., Landsberg, J., and Forbes, T. D. A. (1999). Disturbance response in vegetation - towards a global perspective on functional traits. *Journal of Vegetation Science* 10, 621-630.

McIntyre, S. and Martin, T. G. (2001). Biophysical and human influences on plant species richness in grasslands: comparing variegated landscapes in subtropical and temperate regions. *Austral Ecology* 26, 233-245.

McIvor, J. G. (2002). Pastures. In *Managing and Conserving Grassy Woodlands*. (Eds S. McIntyre, J. G. McIvor, and K. M. Heard.) pp. 61-77. CSIRO, Collingwood.

Milchunas, D. G. and Lauenroth, W. K. (1993). Quantitative effects of grazing on vegetation and soils over a global range of environments. *Ecological Monographs* 63, 327-366.

Milchunas, D. G., Sala, O. E., and Lauenroth, W. K. (1988). A generalized model of the effects of grazing by large herbivores on grassland community structure. *American Naturalist* 132, 87-106.

Moore, C. W. E. (1953). The vegetation of the south-eastern Riverina, New South Wales. II. The disclimax communities. *Australian Journal of Botany* 1 , 548-567.

Moore, R. M. (1959). Ecological observations on plant communities grazed by sheep in Australia. *Monographiae Biologicae* 8, 500-513.

Moore, R. M. (1962). Effects of the sheep industry on Australian vegetation. In *The Simple Fleece: Studies in the Australian Wool Industry*. (Ed A. Barnard.) pp. 170-183. Melbourne University Press, Melbourne.

Moore, R. M. (1964). Ecological effects of grazing on grasslands in south-eastern Australia. *Proceedings of the IXth International Grassland Congress, Brazil* 429-433.

Moore, R. M. (1967). The naturalisation of alien plants in Australia. *I.U.C.N. Publications New Series* 9, 82-97.

Moore, R. M. (1973). South-eastern temperate woodlands and grasslands. In *Australian Grasslands*. (Ed R. M. Moore.) pp. 169-190. Australian National University Press, Canberra.

Moore, R. M. and Biddiscombe, E. F. (1964). The effects of grazing on grasslands. In *Grasses and Grasslands*. (Ed C. Barnard.) pp. 221-235. Macmillan, London.

Morgan, J. W. (1995). Ecological studies of the endangered *Rutidosis leptorrhynchoides*. 1. Seed production, soil seed bank dynamics, population density and their effects on recruitment. *Australian Journal of Botany* 43, 1-11.

Morgan, J. W. (1997). The effect of grassland gap size on establishment, growth and flowering of the endangered *Rutidosis leptorrhynchoides* (Asteraceae). *Journal of Applied Ecology* 34, 566-576.

Morgan, J. W. (1998a). Composition and seasonal flux of the soil seed bank of species-rich *Themeda triandra* grasslands in relation to burning history. *Journal of Vegetation Science* 9, 145-156.

Morgan, J. W. (1998b). Importance of canopy gaps for recruitment of some forbs in *Themeda triandra*-dominated grasslands in south-eastern Australia. *Australian Journal of Botany* 46, 609-627.

Morgan, J. W. and Lunt, I. D. (1999). Effects of time-since-fire on the tussock dynamics of a dominant grass (*Themeda triandra*) in a temperate Australian grassland. *Biological Conservation* 88, 379-386.

Munnich, D. J., Simpson, P. C., and Nicol, H. I. (1991). A survey of native grasses in the Goulburn district and factors influencing their abundance. *Rangeland Journal* 13 , 118-129.

Nadolny, C., Ranclaud, H., Whalley, W., *et al*. (2003). *Grassy Vegetation in North-Western NSW and Guidelines for its Management and Conservation*. Armidale Tree Group Inc: Armidale.

Noble, J. C. (1997). *The Delicate and Noxious Scrub: CSIRO Studies on Native Tree and Shrub Proliferation in the Semi-arid Woodlands of Eastern Australia*. CSIRO, Canberra.

Noble, J. C. and Tongway, D. J. (1983). Herbivores in arid and semi-arid rangelands. In *Australian Soils: The Human Impact*. (Eds J. S. Russell and R. F. Isbel.) pp. 243-270. University of Queensland Press, St Lucia, Queensland.

Olff, H. and Ritchie, M. E. (1998). Effects of herbivores on grassland plant diversity. *Trends in Ecology and Evolution* 13, 261-265.

Pettit, N. E., Froend, R. H., and Ladd, P. G. (1995). Grazing in remnant woodland vegetation: changes in species composition and life form groups. *Journal of Vegetation Science* 6, 121-130.

Pettit, N. E. and Froend, R. H. (2001). Long-term changes in the vegetation after the cessation of livestock grazing in *Eucalyptus marginata* (jarrah) woodland remnants. *Austral Ecology* 26, 22-31.

Possingham, H. P. (2001). *The Business of Biodiversity: Applying Decision Theory Principles to Nature Conservation*. Australian Conservation Foundation, Melbourne.

Prober, S. M. (1996). Conservation of the grassy white box woodlands: rangewide floristic variation and implications for reserve design. *Australian Journal of Botany* 44, 57-77.

Prober, S. M. and Thiele, K. R. (1995). Conservation of the grassy white box woodlands: relative contributions of size and disturbance to floristic composition and diversity of remnants. *Australian Journal of Botany* 43, 349-366.

Prober, S. M., Thiele, K. R., and Lunt, I. D. (2002). Identifying ecological barriers to restoration in temperate grassy woodlands: soil changes associated with different degradation states. *Australian Journal of Botany* 50, 699-712.

Pyrke, A. (1993). *The Role of Soil Disturbance by Small Mammals in the Establishment of Rare Plant Species*. Unpubl. report to Australian National Parks & Wildlife Service, Dept Geography & Environmental Studies, University of Tasmania, Hobart.

Reid, N. and Landsberg, J. (2000). Tree decline in agricultural landscapes: what we stand to lose. In *Temperate Eucalypt Woodlands in Australia : Biology, Conservation, Management and Restoration*. (Eds R. J. Hobbs & C. J. Yates) pp. 127-166. Surrey Beatty & Sons, Chipping Norton NSW

Reseigh, J., Nadolny, C., and Reid, N. (2003). Effects of recent changes in grazing and fertiliser management on species richness of native ground-layer vegetation, Northern Tablelands, New South Wales. In *Proceedings of the Conference on Rural Land Use Change*. pp. 1-9. State of Victoria (DSE), Melbourne.

Robertson, A. I. (1997). Land-water linkages in floodplain river systems: the influence of domestic stock. In *Frontiers in Ecology: Building the Links*. (Eds N. Klomp & I. Lunt.) pp. 207-218. Elsevier: Oxford.

Robinson, J. B., Munnich, D. J., Simpson, P. C., and Orchard, P. W. (1993). Pasture associations and their relation to environment and agronomy in the Goulburn district. *Australian Journal of Botany* 41, 627-636.

Robinson, G. G. and Dowling, P. M. (1976). Management of natural pastures on the Northern Tablelands of New South Wales - a survey. *Australian Rangeland Journal* 1, 70-74.

Roe, R. (1947). *Preliminary Survey of the Natural Pastures of the New England District of New South Wales and a General Discussion of their Problems*. CSIR, Melbourne.

Ross, J. (1999). *Guide to Best Practice Conservation of Temperate Native Grasslands*. World Wide Fund for Nature Australia, Sydney.

Sanford, P., Cullen, B. R., Dowling, P. M., Chapman, D. F., Garden, D. L., Lodge, G. M., Andrew, M. H., Quigley, P. E., Murphy, S. R., King, W. M., Johnston, W. H., and Kemp, D. R. (2003). SGS pasture theme: effect of climate, soil factors and management on pasture production and stability across the high rainfall zone of southern Australia. *Australian Journal of Experimental Agriculture* 43, 945-959.

Saul, G. R. and Chapman, D. F. (2002). Grazing methods, productivity and sustainability for sheep and beef pastures in temperate Australia. *Wool Technology and Sheep Breeding* 50, 449-464.

Saunders, D. A., Smith, G. T., Ingram, J. A., and Forrester, R. I. (2003). Changes in a remnant of salmon gum *Eucalyptus salmonophloia* and York gum *E. loxophleba* woodland, 1978 to 1997. Implications for woodland conservation in the wheat–sheep regions of Australia. *Biological Conservation* 110, 245-256.

Scanlan, J. C. (2002). Some aspects of tree-grass dynamics in Queensland's grazing lands. *Rangeland Journal* 24, 56-82.

Scarlett, N. H. and Parsons, R. F. (1982). Rare plants of the Victorian plains. In *Species at Risk: Research in Australia*. (Eds R. H. Groves and W. D. L. Ride.) pp. 89-105. Australian Academy of Science, Canberra.

Scarlett, N. H. and Parsons, R. F. (1990). Conservation biology of the southern Australian daisy *Rutidosis leptorrhynchoides*. In *Management of Small Populations*. (Eds T. W. Clark and J. H. Seebeck.) pp. 195-205. Chicago Zoological Society, Illinois.

Scott, A. W. and Whalley, R. D. B. (1982). The distribution and abundance of species of *Danthonia* DC on the New England Tablelands (Australia). *Australian Journal of Ecology* 7, 239-248.

Semple, W. S. and Koen, T. B. (2001). Growth rate and effect of sheep browsing on young eucalypts in an anthropogenic *Themeda* grassland. *The Rangeland Journal* 23, 182-193.

Senft, R. L., Coughenour, M. B., Bailey, D. W., Rittenhouse, L. R., Sala, O. E., and Swift, D. M. (1987). Large herbivore foraging and ecological hierarchies. *BioScience* 37, 789-799.

Sharp, S. (1997). *Diversity, Patterns and Processes of Vegetation and Invertebrate Orders in Natural Temperate Grasslands in the Australian Capital Territory*. M.App.Sci. thesis. University of Canberra, Canberra.

Sivertsen, D. and Clarke, P. J. (2000). Temperate woodlands in New South Wales: a brief overview of distribution, composition and conservation. In *Temperate Eucalypt Woodlands in Australia: Biology, Conservation, Management and Restoration*. (Eds R. J. Hobbs and C. J. Yates.) pp. 6-16. Surrey Beatty and Sons: Chipping Norton NSW.

Spooner, P., Lunt, I. D., and Robinson, W. A. (2002). Is fencing enough? The short-term effects of stock exclusion in remnant grassy woodlands in southern NSW. *Ecological Management and Restoration* 3, 117-126.

Stuwe, J. and Parsons, R. F. (1977). *Themeda australis* grasslands on the Basalt Plains, Victoria: floristics and management effects. *Australian Journal of Ecology* 2, 467-476.

Taylor, J. A., Hedges, D. A., and Whalley, R. D. B. (1984). The occurrence, distribution and characteristics of sheep camps on the Northern Tablelands of New South Wales. *Australian Rangeland Journal* 6, 10-16.

Thackway, R. and Creswell, I. D. (1995). *An Interim Biogeographic Regionalisation for Australia*. Australian Nature Conservation Agency: Canberra.

Tiver, F. and Andrew, M. H. (1997). Relative effects of herbivory by sheep, rabbits, goats and kangaroos on recruitment and regeneration of shrubs and trees in eastern New South Wales. *Journal of Applied Ecology* 34, 903-914.

Tiver, F., Nicholas, M., Kriticos, D., and Brown, J. R. (2001). Low density of prickly acacia under sheep grazing in Queensland. *Journal of Range Management* 54, 382-389.

Tremont, R. M. (1994). Life-history attributes of plants in grazed and ungrazed grasslands on the Northern Tablelands of New South Wales. *Australian Journal of Botany* 42, 511-530.

Tremont, R. M. and McIntyre, S. (1994). Natural grassy vegetation and native forbs in temperate Australia: structure, dynamics and life histories. *Australian Journal of Botany* 42, 641-658.

Tscharke, M. (2001). Experiences managing Terrick Terrick National Park. In *Our Valuable Native Grasslands, Better Pastures Naturally. Stipa Native Grasses Association. Proceedings from the Second National Conference*. (Stipa Native Grasses Association: Gulgong NSW.)

Vallentine, J. F. (2001). *Grazing Management*. Academic Press, San Diego.

Vesk, P. A. and Westoby, M. (2001). Predicting plant species' responses to grazing. *Journal of Applied Ecology* 38, 897-90.

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 to 1994. *Australian Journal of Botany* 42, 607-639.

Webster, A., Fallu, R., and Preece, K. (1992). *Action Statement No. 17. Striped Legless Lizard Delma impar*. Department of Conservation and Environment Victoria, Melbourne.

Westoby, M. (1999). The LHS scheme in relation to fire and grazing. In *People and Rangelands Building the Future. Proceedings of the VI International Rangeland Congress Volume 2*. (Eds D. Eldridge and D. Freudenberger.) pp. 893-896. VI International Rangeland Congress Inc., Townsville Queensland.

Wijesuriya, S. and Hocking, C. (1999). Why do weeds grow when you dig up native grasslands? The effects of physical disturbance on available nutrients, mineralisation and weed invasion in grassland soils. In *Down to Grass Roots: Proceedings of a Conference on the Management of Grassy Ecosystems*. (Eds V. Craigie & C. Hocking.) pp. 31-37. Dept Conservation & Natural Resources and Parks Victoria, Melbourne.

Williams, R. J. (1990). Cattle grazing within subalpine heathland and grassland communities on the Bogong High Plains: disturbance, regeneration and the shrub-grass balance. *Proceedings of the Ecological Society of Australia* 16, 255-265.

Windsor, D. M. (2000). A review of factors affecting regeneration of box woodlands in the Central Tablelands of New South Wales. In *Temperate Eucalypt Woodlands in Australia: Biology, Conservation, Management and Restoration*. (Eds R. J. Hobbs and C. J. Yates.) pp. 271-285. Surrey Beatty and Sons, Chipping Norton NSW.

Withers, J. R. (1978). Studies on the status of unburnt *Eucalyptus* woodland at Ocean Grove, Victoria. II. The differential seedling establishment of *Eucalyptus ovata* Labill. and *Casuarina littoralis* Salisb. *Australian Journal of Botany* 26, 465-483.

Witt, G. B., Berghammer, L. J., Beeton, R. J. S., and Moll, E. J. (2000). Retrospective monitoring of rangeland vegetation change: ecohistory from deposits of sheep dung associated with shearing sheds. *Austral Ecology* 25, 260-267.

Yates, C. J. and Hobbs, R. J. (1997). Woodland restoration in the Western Australian wheatbelt: a conceptual framework using a state and transition model. *Restoration Ecology* 5, 28-35.

Yates, C. J., Norton, D. A., and Hobbs, R. J. (2000). Grazing effects on plant cover, soil and microclimate in fragmented woodlands in south-western Australia: implications for restoration. *Austral Ecology* 25, 36-47.

REPORTS PUBLISHED BY ENVIRONMENT ACT

RESEARCH REPORT SERIES

Kukolic, K. 1990. A survey of the vertebrate fauna of Mt Ainslie, Mt Majura and Black Mountain, 1975–76. Research Report 1.

Lintermans, M., Rutzou, T. and Kukolic, K. 1990. The status, distribution and possible impacts of the oriental weatherloach *Misgurnus anguillicaudatus* in the Ginninderra Creek catchment. Research Report 2.

Jones, H. A., Rutzou, T. and Kukolic, K. 1990. Distribution and relative abundance of fish in the Naas-Gudgenby catchment. Research Report 3.

Lintermans, M. and Rutzou, T. 1990. The fish fauna of the Upper Cotter River Catchment. Research Report 4.

Osborne, W. S., Lintermans, M. and Williams, K. D. 1991. Distribution and conservation status of the endangered pink-tailed legless lizard *Aprasia parapulchella* (Kluge). Research Report 5.

Lintermans, M. and Rutzou, T. 1991. The status, distribution and management of the Murray crayfish *Euastacus armatus* in the Australian Capital Territory. Research Report 6.

TECHNICAL REPORT SERIES

Lintermans, M. 1993. The vertebrate fauna of the Gudgenby region, Australian Capital Territory. Technical Report 1.

Ormay, P. and Ingwersen, F. 1993. Management of *Xanthorrhea australis* in Tidbinbilla Nature Reserve. Technical Report 2.

Osborne, W. S. and McKergow, F. V. C. 1993. Distribution, population density and habitat of the pink-tailed legless lizard *Aprasia parapulchella* in Canberra Nature Park. Technical Report 3.

Lintermans, M. 1993. Oriental weatherloach *Misgurnus anguillicaudatus* in the Cotter River : A new population in the Canberra region. Technical Report 4.

Rauhala, M. 1993. Distribution and habitat of the nobby dragon *Amphibolurus nobbi* in the Australian Capital Territory. Technical Report 5.

Rauhala, M. 1993. The reptile, amphibian and mammal fauna of the Stony Creek Nature Reserve, Australian Capital Territory. Technical Report 6.

Rutzou, T. V., Rauhala, M. A. and Ormay, P. I. 1994. The fish fauna of the Tidbinbilla River catchment. Technical Report 7.

Sharp, S. 1994. Lowland native grasslands in the ACT and surrounding region : A review and research strategy for a recovery plan. Technical Report 8.

Driscoll, D.A. 1994. Invertebrates of lowland native grasslands in the Australian Capital Territory : Conservation and research strategies for a recovery plan. Technical Report 9.

Osborne, W.S. and Jones S. R. 1995. Recovery plan for the pink-tailed worm lizard (*Aprasia parapulchella*). Technical Report 10.

Rauhala, M. A. 1995. The reptile, amphibian and mammal fauna of the Gigerline Nature Reserve, Australian Capital Territory. Technical Report 11.

Coulson, G. 1995. Management directions for the striped legless lizard (*Delma impar*) in the Australian Capital Territory. Technical Report 12.

Ormay, P. 1996. Status of the brush-tailed rock wallaby *Petrogale penicillata* in the Australian Capital Territory. Technical Report 13.

Rauhala, M. A. 1997. Frog fauna of the Australian Capital Territory: A review. Technical Report 14.

Lintermans, M. 2000. The Status of Fish in the Australian Capital Territory: A Review of Current Knowledge and Management Requirements. Technical Report 15

Lintermans, M. (in prep.) Partial recovery of the Murray River Crayfish *Euastacus armatus* in the Australian Capital Territory after the implementation of protective management measures. Technical Report 16.

BOOKS

Eddy, D., Mallinson, D., Rehwinkel, R. and Sharp, S. 1999. *Grassland Flora - a field guide for the Southern Tablelands (NSW and ACT).* World Wide Fund for Nature Australia, Australian National Botanic Gardens, NSW National Parks and Wildlife Service, Environment ACT, Canberra.156 pp.

Lintermans, M and Osborne, W.S. 2002. *Wet & Wild: A Field Guide to the Freshwater Animals of the Southern Tablelands and High Country of the ACT and NSW*. Environment ACT, Canberra. 262 pp.