Management Options for Canberra Urban Grasslands

Prepared for Canberra Urban Parks and Places
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CONTENTS

APPENDICES

Terms of Reference

To undertake a literature review on grassland ecology and management and look for principles and alternative management treatments that would apply to different landscapes in the ACT, particularly to those for which Canberra Urban Parks and Places has management responsibility, that is, public land which Urban Open Space in the Territory Plan.

The literature review to focus on:

- rehabilitation of weed infested grassland and woodlands to become native grass dominated systems; and
- re-establishment strategies for native grasses and forbs in highly disturbed sites.

Executive summary

The lands managed by Canberra Urban Parks and Places (CUPP) contribute significantly to the Bush Capital ‘city in the country’ and are valued by the people of Canberra for the ecological services these lands provide. Apart from designated recreation areas such as sports fields, much of the land is grassland consisting of a few widely scattered patches of remnant native grassland in a ‘sea’ of degraded grassland dominated by exotic grasses.

There is scope for shifting the degraded grassland to local native grass and forb dominance. This will increase the level of nature in the City, change vegetation in Urban Parks and Places so it is less fire prone, increase viability of rare and endangered plant and animal populations of the ACT and improve the level of satisfaction by the people of Canberra in their Bush Capital.

In this report the scientific literature was reviewed for knowledge on urban grassland ecology and management and relevant information is synthesised. The literature is separately presented in Appendix B in the form of an annotated bibliography.

The major finding from the review is that knowledge on how the degraded grasslands can be shifted towards native grass and forb dominance is inadequate for present management of these lands. Without this knowledge, it is problematic whether the grasslands in CUPP jurisdiction can be shifted to benefit nature conservation and minimise wildfire occurrences.

1. Canberra as place for nature

Canberra is the Bush Capital ‘city in the country’. A random survey of Canberra residents (ACT Government, 2002) showed five top special things people liked about Canberra; easy to move around, *wide open space/green*, *Bush capital*, fresh unpolluted air and *quiet and peaceful*. In the same survey the 5 top issues that concerned people about a future Canberra were; community well-being, *environment*, movement and interaction, employment and education opportunities and *maintaining and enhancing unique sense of place* (aspects relating to nature are in italics).

These were built into one of the 13 guiding principles for the ACT Government in translating sustainability into practical action (ACT Government, 2003):
Valuing and protecting ecological integrity and biodiversity: recognise that all life has intrinsic value and that ecological processes and biological diversity are part of the irreplaceable life support systems upon which a sustainable future depends.

Canberra was designed to allow people and nature (present as patches and corridors) to co-exist and interact. Australian nature is found in urban land designated as Urban Nature Reserves and Urban Parks and Places in the Territory Plan, and to a lesser extent in the planted native and exotic vegetation of the Parks and Gardens on public land, along roads verges and in residential and business gardens. Most people value these natural and semi-natural areas and the nature they experience whilst motoring, cycling, walking, playing and sitting. People will widely differ in their description and appreciation of nature within the City. However the survey indicates there is a strong demand for a city of nature to be sustained.

The terrestrial ecosystems, on which Canberra is built, were not pristine at the commencement of the city. Aboriginal people, and in recent years farming and pastoral people, greatly modified the vegetation by fire management, grazing of domestic herbivores and vegetation clearing for farming. At European settlement, hills were wooded and the extensive valleys were grassed. These “valley” grasslands have been recognised to be part of the temperate grasslands of Australia (Pryor, 1938). In south-eastern Australia, prior to settlement, there were 2 million ha of natural temperate grasslands. 99.5 per cent of these have now been destroyed or severely modified by clearing and agriculture (McDougall & Kirkpatrick, 1994). With such extensive modification, natural temperate grassland is the most threatened natural plant community in Australia (Parsons, 1994). Therefore an important task for managers of public lands is to rehabilitate these grasslands and restore their ecological value (in terms of nature and fire management) for the enjoyment of people living amongst the patches and corridors of grasslands and wooded grasslands.

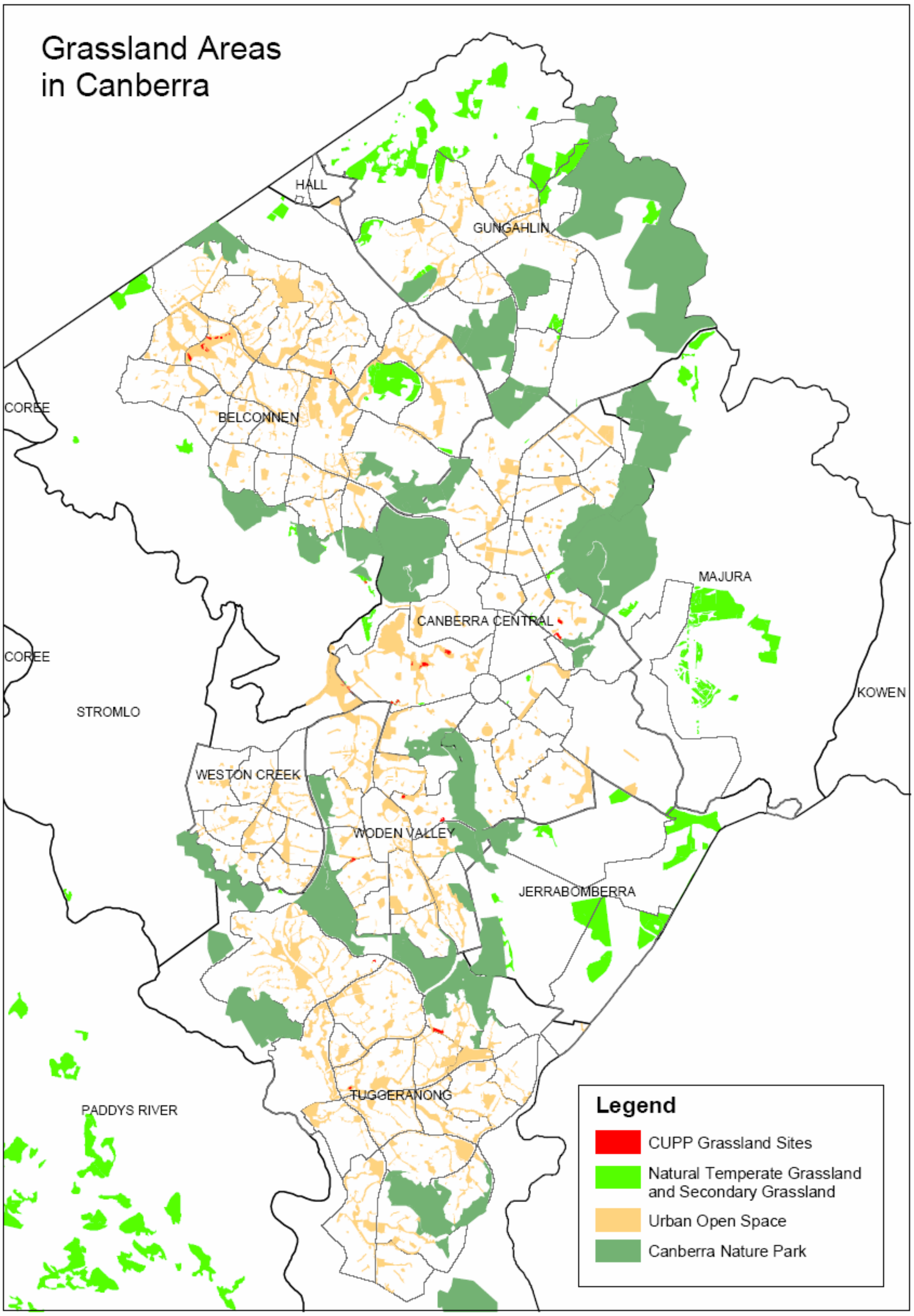

Figure 1: Grassland/woodland areas designated as Urban Open Space and Canberra Nature Park land in Canberra

There were 20,000 ha of natural temperate grassland in the ACT at European settlement (S. Sharp unpublished data). Field surveys undertaken for the ACT Government between 1991 and 1996 revealed this once extensive grassland within the ACT to be highly fragmented and now greatly reduced in area. The natural temperate grassland is now confined to 38 small and isolated patches. About 1000 ha of these patches are in a more or less natural condition and a further 550 ha are in poorer condition. Many patches are in land managed by Canberra Urban Parks and Places (CUPP) - see Figure 1 showing CUPP-managed Urban Open Space and Canberra Nature Park lands. Urban Open Space lands are managed as Town Parks, District Parks, Neighbourhood Parks, Pedestrian Parkland, Lake and Water Features, Semi-natural Open Space, and Native Grassland or Woodland Sites. Each patch of natural temperate grassland is embedded in highly degraded grasslands dominated by weeds (plant species of exotic origin or native species not natural to the area). These isolated patches range in size from <1 ha to 300 ha (Sharp & Shorthouse, 1996). In 1996 the natural temperate grasslands in the ACT were declared endangered and an action plan was developed to conserve the remnants (Action Plan, 1997). In addition to this conservation requirement there is a need to rehabilitate nature land outside of Canberra Nature Parks to enhance urban nature and increase the ecological services of Urban Nature Parks.

The urban grassland ecosystem (natural temperate grassland patches within a predominant matrix of degraded grasslands) comprise many plant and animal species; grasses, forbs, shrubs, trees, vertebrate animals and invertebrate animals. Responses to human activity of the populations of each species have been variable; some have increased in population size, while others have decreased (Dorrough, 1995) or been unaffected. It will take some time to fully document and monitor these changes. Six species so far have been declared endangered or vulnerable within the urban grassland ecosystem; Striped Legless Lizard (*Dema impar*), Grassland Earless Dragon (*Tympanocrystis pinguicolla*), Golden Sun Moth (*Synemon plana*), Perunga Grasshopper (*Perunga ochracea*), Button Wrinklewort (*Rutidosis leptorrhynchoides*) and Ginninderra Peppercress (*Lepidium ginninderrense*). Late in 2004 a Draft ACT Lowland Native Grassland Conservation Strategy (Action Plan No. 28) was released for comment and action plans for conservation of each of the six species named have been developed.

Given natural temperate grassland is the most endangered ecosystem in Australia and given that four animal and two plant species of this ecosystem are endangered or vulnerable in the ACT, it is appropriate for CUPP to review management of the grasslands and grassy woodlands in their jurisdiction. The now fragmented remnant grassland ecosystems, although small, has the potential of higher ecological function and extent to meet the conservation goals set by the ACT Government. Conservation corridors largely exist between areas designated as Urban Nature Parks. The question needs to be addressed as to whether management regimes applied to these intervening lands is appropriate to foster the continuation of nature desired by the people of Canberra and the ACT Government.

It will become apparent in this review that a major problem for managing urban nature lands is incomplete knowledge in some areas on how these urban grassland and grassy woodland systems function and respond to management regimes. Knowledge, although imperfect and likely to remain so for some time, is however, adequate for evaluation of current management regimes.

There is another problem for managers; CUPP-managed land is seen by the people as land that should provide many services. Individuals will have particular and often widely differing views about the importance of each service. Some will see CUPP land for provision of amenity value, for wildfire suppression, for minimisation of deep drainage and recharge to groundwater (Singh, et al., 2003) and so on. All services are important but at times they will be competitive. However, **in this review the provision of Australian nature in the city is taken as a central concept and the management required to support nature in the City is seen to be paramount.**

In many capital cities around the world, Governments are striving for more effective retention of nature in the urban environment and there is considerable intellectual attention given to the issues involved, see (Pickett, et al., 2001). Given the views of Canberra residents, the development of guiding principles for the ACT Government underpinning policy for sustainability in the ACT and knowledge that key floral and faunal components of the temperate grassland ecosystems are missing from much of urban open space in Canberra, the **central aim for CUPP is to conserve nature in the matrix of the urban open space it actively manages** (including playing fields, woodlots and other special purpose areas). This CUPP-managed **land can be viewed as nature corridors connecting the land designated as Nature Reserves** and therefore as additional refuge areas for remnant populations of endangered species in the ACT. As such, their retention and management to maintain ecosystem functionality, is critical to maintaining Australian nature in the City.

A member of the ACT Government's Sustainability Expert Reference Group, Brown, has argued that Canberra could become a world-class sustainable city (Brown 2005). "The ideal of a bush capital, as the firestorm taught us at great cost, means being responsible for how we live in the landscape. The ideal of remaining a prosperous city means accepting responsibility for our own use of social and environmental resources." To this end, it is proposed that CUPP review the management of land under its jurisdiction to see whether the managements are conserving nature in the City of Canberra.

2. Methods used to evaluate effectiveness of management regimes for improving native grass and forb content

There are two methods for evaluating effectiveness of management regimes;
(1) conduct surveys over time to find if the condition of the resource is improving, declining or unchanged or
(2) review literature describing experiments where responses of grassland vegetation to management regimes are compared.
The latter method is used here. The two methods are not mutually exclusive and both have their value.

The first method, conducting repeated surveys over time (say every 5 years) of the ecological status of landscapes, needs to be based on strict protocols for repeated objective measurements. Changes in the ecological status of landscapes can then be established and some conclusions drawn on whether the ecological status of landscapes are changing or remaining the same and whether the management practices are improving or degrading the ecological function of the landscapes. Surveying to evaluate ecological status and function change has been developed by scientists but application is expensive and does not provide the insights required to develop the best alternative management should a management regime cause a degrading change.

The second method of evaluating the management of land is to critically examine knowledge from scientific studies of changes to vegetation when subject to different management regimes. This form of evaluation is essentially a desk top study of the literature available on the responses of vegetation in the ACT or in similar nearby vegetation in south eastern Australia. It is cheap to conduct but has the limitation that knowledge about ecosystem function and plant and animal composition of communities on one landscape may not be directly transferable to others. However, where reservations about generality may be held by the reviewer these are noted and caution given.

3. Evaluation of the effectiveness of management regimes used by Canberra Urban Parks and Places

3.1 mowing and slashing

3.1.1 Background

Portions of CUPP-managed land are mown or slashed by contractors of CUPP. The practice is widespread and the reasons for both patch and edge mowing within the lands appear to be;

- providing cleared vehicular access along fence lines for service and emergency vehicles,
- fuel hazard reduction and
- enhancing pedestrian and cyclist access.

Throughout the world there have been many studies made of the effects of mowing urban and rural grasslands and a study in Ireland by Helden & Leather (2004) is a recent example. This and all other studies show that mowing changes the species composition of grassland and the relative abundance of species. Changes are typically adverse for nature. Here in the ACT there have been only two studies on the responses of native grassland ecosystems to mowing. Further local studies are required.

3.1.2 Mowing regimes for conservation of nature

The effect of five mowing regimes (monthly, two-monthly, three-monthly, annual winter and once only in the winter) on two communities of natural temperate grassland in urban ACT over two years was studied by Chan (1980) for an ANU Masters program. The four dominant grass species in these two grassland communities responded differently to each mowing regime. Amongst the native grass species, *Themeda triandra* and *Stipa bigeniculata* were less tolerant of frequent mowing regimes than *Austrodanthonia* species and *Bothriochloa macra.*

Importantly, Chan found season of mowing had a large effect on the relative abundance of plant species and the number of reproductive tillers on each plant. Mowing at times other than winter, substantially reduced the density of reproductive tillers and hence the seed production from the natural grasslands. This was because many tillers change from vegetative to reproductive mode and begin elevation in the spring and early summer. Mowing at this time greatly reduces seed production. The consequences for this impairment are lower recruitment levels and reduced native grass content of grasslands. Reduced basal area of grasses will also open the grassland plant community to weed invasion.

Examination of reproductive tiller heights of the four dominant native grass species revealed there were species differences in the timing of flowering in the critical October/November period. On this evidence **Chan recommended that should mowing of natural temperate grassland take place, mowing should occur only before and only after periods of active grass growth and associated flowering and seed production, to maintain native grasses.**

Mowing, if sufficiently frequent, will also kill grass plants. Hodgkinson (1976) found monthly defoliation (simulated mowing) reduced vigour of *Austrodanthonia caespitosa* (a native grass and member of a large genus of grass species found in the ACT) plants and killed a high proportion in the summer and in the autumn seasons. Bimonthly defoliation had a similar effect but the death response was lower. The grass *Themeda triandra* similarly can not withstand close frequent mowing (Hodgkinson, et al., 1989).

An important element of the mowing regime is the height of mowing. Hodgkinson (1995) found that for a number of native perennial grasses in semi-arid wooded grasslands, death by grazing occurred when foliage was grazed below 10 cm. Other unpublished studies by this author confirm that **10 cm is a critical height below which grazing/mowing will kill plants of native grass species**, especially when drought occurs during or after mowing/grazing.

In a biodiversity study, part conducted in urban Canberra, Sharp (1997) found the abundance and species richness of invertebrate animals to be highest in natural temperate grasslands dominated by *T. triandra* and in mown grasslands. The later finding was unexpected (because the grasslands comprised many weedy species) and needs confirmation. Sharp recognised that further research is required to inform management actions and that research should focus on a greater understanding of the effects of management on species diversity and include a monitoring component.

Recently, Verrier (2005) reported from a study in a Tasmanian grassland that a 12 year mowing regime of 4 to 6 times mows per year to an approximate height of 7 cm and with removal of slash, produced greater cover of rare or threatened species, greater native cover and less exotic grass cover than a moderate continuously grazed regime. The experimental design used in this study unfortunately severely weakens its value and further research is required to verify this unexpected finding.

In contrast, Kirkpatrick (2004) found that mowing over a 25 year period significantly reduced the plant species richness and native-plant species richness of lowland temperate grassy woodlands in urban Hobart, Tasmania.

3.1.3 Mowing regimes for restoration of nature

The value of mowing strategies for restoring natural values in degraded vegetation has not been adequately studied. In a study of a natural pasture dominated by *Aristida ramosa* in northern New South Wales (Lodge, et al., 1999) slashing in the spring before heavy grazing in summer–autumn reduced the species and increased *Austrodanthonia linkii* density. This marginally relevant study confirms that certain mowing/slashing regimes changes species composition of grassland and mowing regimes may restore degraded grasslands.

Ecologists, Dorrough and Prober, (Dorrough, 1995) (Prober, et al., 2002a) married observations with sound ecological understanding to establish the following mowing protocol which are in keeping with the limited research noted above. The protocols are:

1. Use flail mowers as the preferred cutting tool.
2. Mow to remove litter that will later inhibit native plant growth.
3. Mow 10 cm or higher.
4. Clean mowing equipment to avoid introducing exotic species to other areas.

5. Avoid the peak flowering season to ensure seed set.
6. Minimise mowing frequency to avoid increasing exotic annual grasses.
7. Do not mow when a site is wet to avoid formation of wheel ruts and compacting soil that can lead to exotic species invasion.

In summary, the limited research on effects of mowing temperate grasslands of the ACT suggests that the current mowing regimes applied to Urban Parks and Places land should be reviewed. **Mowing regimes in urban land where patches of natural temperate grassland remain should not involve late spring and summer season mowing as this strongly disadvantages the seed production of native grass species and forbs and mowing height should always exceed 10 cm.**

Mowing for fire hazard reduction may be in conflict with the native plants requirement to reproduce viable seed. Compromise may be possible in some degraded grasslands where it may be important to reduce the density of weedy species as part of restoration managements. A fundamental issue for research is elucidating the mowing regime(s), plus or minus other treatments, which will shift grasslands from exotic to indigenous native grass species dominance.

3.2 prescribed burning

3.2.1 Background

Fire is a natural process in all native vegetation throughout Australia (Hodgkinson, et al., 1984), except for some tropical rainforests. No natural vegetation in Canberra urban land is wildfire free. The addition of exotic weedy grasses (such as *Phalaris aquatica)* and some exotic trees (especially conifers) and shrubs to what were natural temperate grasslands, substantially increases proneness to fire and the intensity of the fires themselves. Native grassland is considerably less fire prone than degraded grassland. The reason for this is that the dominant native grass, *Themeda triandra,* remains green much longer in the fire season than exotic grasses. The latter “hay-off” in late spring/early summer whereas *T. triandra* typically remains green until late summer.

Populations of the native plant and animal species are adapted to survive certain fire regimes (defined by frequency, intensity, season and patchiness) and unless burning takes place their persistence can be in jeopardy. One example of adaptation to fire is enhanced germination of seed exposed to smoke. Seed of many, but not all, plant species is smoke stimulated to germinate (Read & Bellairs, 1999). This explains why fire increases the recruitment of new plants and raises the richness and density of plants in *Themeda triandra* grasslands (Morgan, 2001). Fire frequencies of 5 years appear to be appropriate for management of these native grasslands (Morgan & Lunt, 1999).

These findings have important implications for the maintenance of faunal habitat and the potential for weed invasion in remnant grasslands. **Given grassland and grassy woodland within and surrounding Canberra is fire prone, they should be periodically burnt to maintain species richness and habitat diversity** (Purdie & Slatyer, 1976, Purdie, 1977). Such prescribed burning to maintain ecological function would reduce the wildfire hazard from accumulated fuels. The burning of grassland

and grassy woodlands within and surrounding Canberra does present some logistic and potential health problems (Johnston, et al., 2002). With adequate training of landscape managers these problems can largely be overcome and prescribed burning at appropriate times can be applied safely within the city close to residences and people.

3.2.2 Prescribed fire regimes for restoration of nature

Prescribed fire is a very effective management for changing the botanical composition of plant communities and the habitat for animals. For example, the effect of long-term vegetation managements (rarely burnt, intermittently grazed, frequently burnt, and not grazed) on grassy forest remnants in Gippsland, south-eastern Australia (Lunt, 1997a) indicated management history basically controlled botanical composition. Frequently burnt sites supported a distinctly different and more diverse flora from those rarely burnt.

Fire on its own may be an inappropriate management regime in some situations. Changes in vegetation of remnant *Themeda triandra* grassland in south-eastern Australia followed replacement on stock grazing with intermittent burning at 3-11 year intervals. Most grassland species remained abundant but there was proliferation of tall forbs with wind-blown seeds, including exotic thistles and colonising native forbs after grazing ceased and prescribed fires began. Replacing grazing with intermittent burning did not result in the flora becoming more similar to that of high-quality, species-rich grassland remnants (Lunt & Morgan, 1999).

Several studies in eastern Australia show prescribed fire with and without grazing can significantly change vegetation. Natural pasture dominated by *Aristida ramosa* in northern New South Wales can be changed to palatable native grass dominance by winter or spring burning, and heavy summer grazing (Lodge, et al., 1999). Similarly, in south-eastern Queensland the undesirable *Aristida* spp. which replaces the desirable grass *Heteropogon contortus* can be manipulated by prescribed fire. Burning increases the proportion of *H. contortus* when pastures remain not grazed but not when pastures were grazed, because cattle selectively grazed *H. contortus* after burning. Burning reduced the proportion of *Aristida* spp and other undesirable grasses such as *Bothriochloa decipiens* and *Chloris divaricate* (Orr, et al., 1997). Four to 6 months rest from grazing or a reduced grazing pressure (Orr & Paton, 1997) after fire maintained the changed botanical composition.

Nutrient levels appear to be important in determining the botanical composition of grassland and grassy woodland communities and trees lead to significant heterogeneity in soil fertility, alter the competitive dynamics of grasses and positively influence the richness of the understorey vegetation (Prober, et al., 2002a). This spatial heterogeneity in nutrients has implications for prescribed burning, grazing and slashing management of grassland and grassy woodland.

In summary it can be concluded that fire is natural in the grasslands and grassy woodlands of Canberra and they should, if possible, be deliberately burnt. Prescribed fire is not a substitute for mowing or grazing as it has different effects on vegetation but is an important management in its own right and should be utilised wisely in conjunction with other managements especially mowing and grazing, to increase the species diversity and richness of plant and animal communities.

3.3 grazing

3.3.1 Background

Grazing is a management applied in the past to limited areas of CUPP-managed land, such as Diddams Close Park. Domestic livestock are trucked to and from the paddocks. The purpose of grazing appears to be fire or weed control; there is no stated conservation objective.

Grazing affects many ecosystem processes and knowledge on these is reviewed.

3.3.2 Compaction of soil by grazing livestock

Grazing animals, through hoof action, exert pressure on the ground comparable to that of agricultural machinery (Greenwood & McKenzie, 2001). As a result, soil under pasture can be very compacted. In pastoral systems based on permanent pastures or rangelands, there is little opportunity to ameliorate poor soil physical conditions through tillage. Most soils under grazed pasture, even those managed to minimise soil physical degradation, will be compacted to some extent. However, the magnitude of this compaction is usually small, and limited to the upper 50–150 mm of the soil. Compaction to greater depth, and other changes in soil physical properties, is more likely in wet soils.

The authors consider response of pasture to the poorer soil conditions caused by grazing is difficult to determine, but it is likely to be small compared with the defoliation effects of grazing. They did not review the direct effects of soil compaction on biodiversity but it is likely any effect is minor; most responses would come about by changed botanical composition of grassland communities. Maintenance of a vigorous pasture should be a major aim of grazing management and would also achieve the secondary aim of maintaining acceptable soil physical conditions.

3.3.3 Challenges to biodiversity by grazing livestock

Effect of grazing on biodiversity has been fully reviewed (Dorrough, et al., 2004). “There is an increasing interest in the development of livestock grazing management strategies that achieve environmental sustainability and maintain or improve the long-term production capacity of commercial grazing systems. In temperate Australia, these strategies are generally focussed on reducing perennial pasture decline, soil loss, acidity, and salinity. An additional challenge facing land managers and researchers is developing grazing strategies that also maintain and enhance local and regional biodiversity. However, few studies have assessed the compatibility of management practices for maintaining long-term productivity and biodiversity conservation. We still have only a very basic understanding of the effects of different grazing strategies and pasture management on biodiversity and this is a major impediment to the development of appropriate and compatible best management practice. We argue that although there is an increasing desire to find management strategies that protect and enhance biodiversity without hindering long-term agricultural production, in many cases this may not be possible. Current knowledge suggests that compatibility is most likely to be achieved using low-input systems in low productivity (fragile) landscapes, whereas in highly productive (robust) landscapes there is less opportunity for integration of productive land-use and biodiversity conservation. There is an urgent need for improved communication and collaboration between agronomic and ecological researchers and research agencies to ensure that future programs consider sustainability in terms of biodiversity as well as pasture and livestock productivity and soil and water health."

3.3.4 Weed control by grazing livestock

In a long term study (Lunt & Morgan, 1999) of remnant *Themeda triandra* grassland in south-eastern Australia, where stock grazing was replaced by intermittent prescribed fire, weeds soon established from wind-blown seed. This and other studies support the concept that grazing, if appropriately applied, will control the unwanted weeds.

A common weed in CUPP-managed land is *Phalaris aquatica* developed by CSIRO for improved pastures in the southern Tablelands. Campbell (1988) found that resting pasture from grazing, especially in summer, before or after application of selective herbicides maximised death of this weed grass. In grazing studies on the northern Tablelands (Lodge & Orchard, 2000) and the southern Tablelands (Culvenor & Oram, 1996, Culvenor, 1997, Culvenor, et al., 2002, Virgona, et al., 2000) no seedlings of the species survived grazing and that heavy sheep grazing in either spring or autumn or continuous grazing by sheep would kill many *P. aquatica* plants. Survival of *P. aquatica* plants is highest in nutrient rich areas (Culvenor, 2000).

In summary there is sufficient evidence that **strategic heavy grazing of the degraded grasslands in Urban Parks and Places land could be used to better control weeds especially *P. aquatica.***

3.3.5 Fostering native grasses by grazing livestock

Despite pasture improvement and application of superphosphate in the rural lands of the ACT and surrounding tablelands of NSW, native grasses are common (Garden, et al., 2001). Seventeen genera of native perennial grasses comprising over 35 species were found in an extensive survey. The most common species on the central tablelands were *Austrodanthonia* spp., *Bothriochloa macra*, and *Microlaena stipoides*; on the southern tablelands, *Austrodanthonia* spp. and *M. stipoides*; and on the Monaro, *Poa* spp., *Austrodanthonia* spp., *Themeda triandra*, and *Austrostipa* spp. The significant areas of native grass pastures that were found suggest recolonisation of sown pastures with native grasses will occur under grazing. In another follow-up study (Garden, et al., 2000b) pastoralists were found to undervalue native grass species. Application of superphosphate was found to disadvantage survival of native grasses in sheep grazed pasture land (Garden, et al., 2003). Grazing at other sites in Victoria also maintained short but not tall forbs (Lunt, 1997c).

In summary, at low stocking rates, native grasses and forbs can persist and heavy grazing (probably in autumn after seed set) to deplete competition from tussock grasses, can favour many native forbs and biodiversity in general.

3.3.6 Tactical grazing by livestock

It is now understood that vegetation is never stable, even in the absence of human intervention. Vegetation varies in composition in response to the variable environment. Grazing and fire are the strongest vectors for change (Wilson, et al., 1988). Native grasses however can not withstand continuous grazing and require rest from grazing to persist (Hodgkinson 1989). A probable reason for this weakness of grasses, especially native grasses, is their inability to accumulate sufficient carbohydrate reserves, necessary for regrowth, when defoliation is constant (Boschma, et al., 2003a, Boschma, et al., 2003b).

In several studies, tactical resting from grazing in certain seasons improved the botanical composition of grassland and timing of rest and of grazing was found to be critical to bring about the change (Lodge, et al., 1999, Garden, et al., 2000a, Michalk, et al., 2003). Earlier (Wilson & Hodgkinson, 1991), six principles of grazing management were proposed.

1. Stocking rate (or grazing pressure) is the most important management variable.
2. The essence of grazing systems is the proper timing of resting to favour desirable species, or grazing to inhibit undesirable species.
3. Grazing systems are applied for the benefit of the forage plants rather than the livestock. They reduce animal production unless there is a desirable changed in botanical composition.
4. Pastures containing mixtures of desirable and undesirable species provide the best opportunities for grazing management.
5. Grazing management should be integrated with other management options, particularly with fire.

6. Changes in botanical composition may take a number of years to show advantage, particularly areas where germination and establishment is irregular.

In summary, tactical grazing is a management that has successfully shifted towards or maintained the native grass and forb component of natural grasslands.

Grazing of livestock, especially when in a tactical manner, appears to be an effective vector for desirable botanical change of degraded grasslands. However only some portions of CUPP-managed land can be grazed and this management will have very limited application.

3.4 sowing native grasses for restoration

3.4.1 Background

On CUPP-managed land devoid of native grasses, or where native grasses are in low abundance, sowing of native grass seed quickly increases the density and contribution of native plants in the grassland vegetation. The addition of seed is necessary because the soil seed bank, through earlier land management practices, may not contain the seed of lost species. In a study of soil seed banks in native temperate grasslands and in grassy forest remnants (Lunt, 1997b), each vegetation type was found to have distinctive flora and species. However, each flora (above-ground) had species absent from the below-ground soil seed stores. The study shows that changing the elements of the management regime may not add new species because their seed may not be present in the soil seed store.

3.4.2 Source of seed for sowing

It is not always possible to source seed from local areas. The issue of seed source is of concern because seed obtained from non-local sources may genetically contaminant local populations of the same species. There is considerable genetic variation amongst populations of widely distributed species as shown in genetic studies on the grass *Austranthonia caespitosa* (Hodgkinson & Quinn, 1978, Quinn & Hodgkinson, 1984). For example, reproduction (Hodgkinson & Quinn, 1978) is programmed differently amongst populations. In cool and moist southern temperate habitats, reproduction is programmed by day length and temperature effects on floral initiation and development to coincide with the predictable growing season, whereas in hot northern semi-arid habitats this control is relaxed, so that opportunistic reproduction occurs whenever soil moisture and temperature permit growth.

These and other studies indicate it is preferable to harvest seed for sowing from local populations as these plants will be adapted to survive in the local environment. If only seed of non-local populations of species are available then these may be sown because the cleistogamous reproductive system is common in Australian grasses. Outcrossing does not occur in this system and hence introduced genetic material is not shared with local populations (pers. comm. R.D.B. Whalley). Different reproductive systems prevail in other countries such as North America, where perennial grasses are usually outcrossing auto-polyploids. Here planting non-local seed is likely to alter the genetic structure of nearby remnant populations and potentially influence the associated community and affect ecosystem structure and function in unforeseen ways (Gustafson, et al., 2004). Australian grasses are unique in the world for being predominantly cleistogamous in reproduction system.

Adequate knowledge exists to show that sourcing seed from local areas is desirable. Furthermore, techniques are now available to ensure effective harvesting of native seed of high viability. However **areas within CUPP-managed land where seed of native plants may be collected are not clearly designated nor are there procedures for setting such areas aside and managing them in a way which is**

suitable for maximising seed production.

3.4.3 Adjusting the soil nutrient levels

The levels of soil nutrients, especially nitrogen and phosphorous, are known to be important in determining the botanical composition of grassland. In agriculture, nutrients are added to boost primary productivity (Prober, et al., 2002a) and Urban Open Space land will in general have higher levels of nutrients as a result of widespread pastoralism before suburbs were developed.

The effect of higher nutrient levels on survival of native grasses has been studied here in Canberra. In a glasshouse study (Groves, et al., 2003), native species were unable to compete with introduced plant species even at the lowest nutrient levels studied. In field surveys, (Prober, et al., 2002b, Bolger & Garden, 2003) found that at low nutrient sites, characteristic of grazed remnant vegetation, soils were compacted, acidic and depleted and Aristida *ramosa* or *Austrodanthonia spp.* and *Austrostipa scabra* dominated. At the least compacted and most nutrient rich soils in remnants the species dominating were annual exotics; intermediate soils in remnants were dominated by *Bothriochloa macra* or *Austrostipa bigeniculata*. These studies indicate that the levels of nutrients in the soil need to be determined before seeding with native plant species because if they are high from addition of agricultural fertilisers, survival of the native species would be unlikely in the presence of exotic weeds. There is no known technique to lower soil nutrients apart from repeated burning over a long period of time to volatilise nutrients (not practical) and slashing and removing the cut grass to another location were nutrient build-up is not a problem (possibly practical). Although low soil nutrient levels appears to be important for seeding success, enough knowledge exists to guide selection of sites for seeding management. This is not an area requiring further research.

3.4.4 Methods of sowing

Practitioners of native plant regeneration have worked out ways of sowing and managing seedling establishment. For example, (Stafford, 1991) developed a successful direct seeding technique for kangaroo grass (*Themeda triandra*). The technique involves cutting culms at the commencement of seed shedding in December and immediately broadcasting them over the seeding site. Germination is triggered nine months later by applying herbicides to weed growth and burning the vegetation as soon as it has cured. *Themeda* seedlings emerging in October usually thrive in the warm moist, undisturbed soil.

In addition to knowledge gained by experience and observation there are many published studies on field and glasshouse experiments to elucidate sowing methods. Each is described here in turn because they are usually multi-purpose.

Fertiliser application at sowing is not necessary for success establishment. (Hagon & Groves, 1977) found application of a NPK fertiliser had no effect on emergence or survival of native grasses in the field. Mulching with paper or straw generally increased emergence and mulching with bitumen increased emergence of some species but decreased survival of two species. The authors concluded sowing seed in late spring and using straw mulch would insure satisfactory levels of establishment of native grass seedlings in south-eastern Australia.

Bitumen-coated straw mulch improved germination of *T. triandra* seeds by maintaining high moisture content in the top 2 cm of soil. (Sindel, et al., 1993) found maximum germination was achieved by either de-awning seeds and burying them manually at 1 cm depth or by sowing awned seeds on the soil surface in the vicinity of cracks or stones which allowed up to 96% of the seeds to bury themselves by natural means.

No generalizations can be made about the regeneration niche of herbaceous species groups. (Clarke & Davison, 2004) studied a range of herbaceous species and found short-lived forbs had the highest emergence, followed by perennial grasses; rhizomatous grasses and perennial forbs had the lowest emergence. Soil surface and cover treatments did not markedly enhance emergence in his study. No consistent pattern of enhanced emergence was found for any treatment combination across all species. Seedling survival varied among species, with perennial grasses and short-lived forbs having the highest seedling mortality. All perennial grasses and some short-lived forbs showed increased risk of mortality with grazing.

Seed soil banks need annual replenishment from natural seeding (Lunt, 1995). Seeds of six native forbs – *Arthropodium strictum*, *Bulbine bulbosa*, *Chysocephlum apiculatum*, *Craspedia variabilis* and *Leptorhynchos squamatus* - were sown on and below the soil surface in a closed, native grassland dominated by *Themeda triandra*. Seed quickly lost viability within 12 months indicating that these species, typical of many of the grasslands, form small, transient or short-term seed banks.

Germination and dormancy of seeds of native forbs vary with temperature and light conditions (Willis & Groves, 1991, Morgan, 1998b). Seed germination of seven native herbaceous species common in natural grasslands and woodlands of south-eastern Australia was maximal at 20/10-degrees-C but there were important species differences.

Smoke is an important environmental stimulus for breaking the dormancy of many native grasses (Read & Bellairs, 1999). Seed of species belonged to 14 genera including *Bothriochloa*, *Chloris*, *Cymbopogon*, *Danthonia*, *Dichanthium*, *Digitaria*, *Eragrostis*, *Eriochloa*, *Microlaena*, *Panicum*, *Paspalidium*, *Poa*, *Stipa* and *Themeda* were exposed to smoke and responses differed between genera and between species. For almost half the species, smoke significantly increased the germination percentage.

Grass seedlings do not emerge if buried more than 25 mm (Lodder, et al., 1994). Seedlings of three species of *Austrodanthonia* (*A. linkii* var. fulva, *A. tenuior* and *A. richardsonii*) did not emerge if seeds were buried deeper than 25 mm and at lesser depths, *A. linkii* var. fulva showed greatest tolerance to increasing sowing depth, whilst *A. tenuior* was intermediate and *A. richardsonii* was least tolerant of seed burial.

Seedling recruitment events for herbaceous dicotyledons become rare after 3 years since disturbance of grassland (Morgan, 1998a). Grassland gaps are necessary for establishment of perennial forbs in *Themeda triandra* grasslands. The presence of vegetation *per se* does not affect germination for most species. Survival of seedlings, however, was negatively affected by vegetation, presumably because of low light levels in small gaps. Large canopy gaps (> 300 cm^2), necessary for effective recruitment in this grassland are only created 1 and 2 years after burning and then are only 8–19% of all gaps.

In summary the methods to sow seed of different species for general satisfactory

establishment are well known by practitioners.

3.4.5 Selection of sites for reseeding

(Hobbs & Norton, 1996) has proposed how restoration of locally highly degraded sites may be approached for conservation reasons. Key processes in the restoration management include identifying and dealing with the processes leading to degeneration in the first place, determining realistic goals and measures of success, developing methods for implementing the goals and incorporating them into land-management and planning strategies, and monitoring the restoration and assessing its success.

The landscapes in Town Parks, District Parks, Neighbourhood Parks, Pedestrian Parkland, Lake and Water Features, Semi-natural Open Space and Native Grassland Sites are all potential sites for rehabilitation reseeding. The fragmented nature of many of these areas presents some logistic problems but with small mobile machines they can all be easily treated.

Development of understanding on where in CUPP-managed landscapes should reseeding take place is a priority for research. Procedures for deciding which parts of landscapes are best assigned restoration management by seeding and which are best changed by other managements are required.

3.5 weeding

Weeds are plant species unwanted because they interfere with the objectives for land use at the location. Reasons for not being wanted are usually one or more of the following; listing of the species on the Noxious Plant Register, not indigenous to the locality (whether introduced to Australia or an Australian native not natural to the area) and interference with and suppression of recruitment, growth and reproduction of one or more species native to the area. **Throughout CUPP-managed land weeds are a major problem and an issue for management.** Weed control is often difficult and costly to achieve. However the dividends/rewards for conservation can be high as occurred when Hawthorn and Willow trees were removed from the banks of Ginninderra creek.

Weeds may be controlled by clearing, herbicide application, fire, mowing, and grazing. However mowing and grazing may also be the means of spreading weeds. This happens for Chilean Needle Grass when it is spread to weed-free areas from infested areas by mowers that are not thoroughly cleaned.

There is a large knowledge base available in general for weed management in urban and rural lands. There have been several studies conducted in or near the ACT and these deserve special attention.

Management of the aggressive introduced pasture grass *Phalaris aquatica* is achieved by spraying glyphosate, tetrapion or 2,2-DPA according to a study carried out near Orange, New South Wales (Campbell & Ridings, 1988). Grazing before or after spraying did not increase the death of *P. aquatica* to 2,2-DPA but grazing after spraying reduced death from tetrapion. This method would be appropriate when preparing land for reseeding with native plants.

In a series of experiments, (Hitchmough, et al., 1994) found the grass specific herbicides (ethofumesate, sethoxydim, and fluazifop) had no marked selectivity for grass species. When the herbicides were applied at varying rates to vigorously growing and mature tussocks of native grasses however there was low outright mortality. Canopy dieback, however, ranged from slight to severe indicating that tolerance was not absolute. Fluazifop was trialled in a grassy woodland community north of Melbourne. Under semi-natural conditions canopy dieback occurred amongst all native grasses tested but mortality was low. Regrowth was evident 36 weeks after treatment for all species other than *Poa morrissii* Vick. Grass weed seedling cohorts were competitively controlled with the exception of *Vulpia bromides*. This study indicates that this herbicide may be useful in the management of remnant grassy vegetation.

The weed *Echium plantagineum*, native to the western Mediterranean Basin where it is a common but not dominant, is now widespread in southeast Australia (Grigulis, et al., 2001). Neither grazing nor pasture competition appear to limit seed production or seedling survival of *E. plantagineum* populations at a study site near Canberra. It is thought that an effective approach for the control of *E. plantagineum* in Australia may thus be through the reduction of the seedling establishment fraction. This may be achieved by maintaining significant pasture vegetation cover and reducing the available space for *E. plantagineum* establishment during autumn. This suggests that both grazing and mowing should be avoided in autumn months.

Management of *Hypericum perforatum* L., St John's wort, (not to be confused with Small St John's Wort (*H. gramineum*) which is a native local species) has received some research interest. (Busby, 1997) considered this a very serious problem and that given the level of infestations of St. John's wort in Canberra's open spaces and current management technologies, he suggested the rate of spread may at best be limited but not eliminated. A more promising approach appears to tactical heavy grazing with goats and cattle (Campbell, 1997). If left not grazed *H. perforatum* becomes dominant. Light infestations heavily grazed can be controlled. The most difficult situations for control are heavy infestations in non-grazed land. Grazing of cattle seem more effective than sheep and a mixture of goats and cattle has proved the most effective grazing management system yet devised. Most of the reports on the effects of grazing management on the control of *H. perforatum* have come from observations by graziers. Campbell concludes there is a major need for detailed research into grazing systems to control the weed.

In summary it can be stated with confidence that weeding will remain an important management of CUPP-managed land. Knowledge on best practice for weed management will continue to evolve but there does not appear to be a case for investing in weed research; knowledge can be acquired from elsewhere.

3.6 tree planting and removal

Trees and shrubs have a large influence on the functioning and biodiversity of grassland. They acquire nutrients and water from soil and bedrock beneath the deepest grass roots and “lift” this to the surface soil. They attract many bird species that are not natural to grasslands. They also become “problems to people” when they become mature and senile by dropping limbs. Since trees and shrubs do not occur naturally in grassland they should slowly be removed. People highly value trees in general and so their removal needs to be a slow, undetected process using opportunities such as wildfire hazard reduction, to reduce numbers.

The temperate grassy woodlands are different and here native trees and shrubs dominate. They were once widespread and dominant in many agricultural regions of south-eastern Australia and in the ACT. Most are now highly degraded and fragmented and exist within a context of broad scale landscape degradation. Greater understanding of natural processes in these grassy woodlands is needed to benchmark management and restoration efforts that are now critical for their ongoing survival. Topsoils beneath trees are much more fertile than in open areas and this will account for known species differences under and between trees. Trees are also associated with higher native-plant richness, possibly resulting from their influence on the competitive dynamics of the dominant grasses (Prober, et al., 2002a). **In grassy woodland sections of CUPP-managed land consideration needs to be given to planting trees to establish greater functionality and in grasslands, trees may need to be removed to allow full development of ecological processes typical of grassland.**

3.7 vertebrate pest controls

This is an area outside the expertise of the author but it is an important management to be considered by CUPP especially the control of foxes and rabbits. Foxes predate many of the rare and endangered animals, such as reptiles. Rabbits selectively eat certain grasses and forbs and if their numbers become too high they can degrade grasslands.

3.8 adjacent land uses

All public urban land is today, liable to invasion by exotic plant species. Likelihood of invasion and the species involved will vary greatly depending on whether the seed is blown, deposited by birds, or dumped wittingly or unwittingly as rubbish from urban homes. Closeness of land to the urban edge is significant. The number of exotic species in vegetation in Sydney bush land, for example, was found to decrease with increasing distance from the urban edges (Rose & Fairweather, 1997). Seed in soil at 10 urban bushland sites in northern Sydney (King & Buckney, 2001) confirmed the earlier study and showed that the above-ground vegetation was a poor indicator of the contents of the seed bank for both native and exotic species. Most of the exotic species found in the seed bank were not found in the immediately surrounding vegetation. Furthermore, some exotic species were found in the seed bank at sites where no exotic species were present in the vegetation. The results suggest that it is the lack of suitable conditions that is largely restricting invasion of exotic species to edges of bush land.

Development of vigorous native grassland in Urban Parks and Places will greatly reduce the invasion of exotic plant species from adjacent residential areas.

3.9 monitoring

Earlier, the importance of monitoring the health or functionality of grassland was discussed. It is important to check the success or otherwise of management regimes applied to grasslands and grassy woodlands of Urban Parks and Places. In this review it is not necessary to be prescriptive on this process - ecological status and function survey and evaluation methods are readily available.

4. Concluding comments

There are many land and vegetation managements available to CUPP to use in managing the landscapes in its jurisdiction. There are problems with mowing the grasslands because many populations of the native forbs and grasses appear to be adversely affected by the practice. Mowing therefore, if necessary, needs to be kept to a minimum and judiciously practiced with an eye on the requirements of grasses and forbs to regularly reproduce viable seed for population persistence. Other managements such as prescribed fire and tactical grazing by domestic animals have their place but are not alternatives to mowing.

To quickly move towards sustaining and building nature in the lands managed by CUPP, a research project is necessary to find out how to shift degraded grasslands from exotic plant dominance to local native grass and forb dominance in landscapes of urban Canberra. Assuming the research is successful and the implementation of suitable techniques is achievable then **the benefits to the people of Canberra would be; increased level of nature in the City, reduction in the "long grass" syndrome (connected with snakes, fire proneness and wilderness) fear of people, vegetation in Urban Parks and Places which is less prone to wildfire because native grasses remain green for longer than exotic grasses, increased chance of maintaining viable populations of rare and endangered plant and animal species of the ACT and improved level of satisfaction by the people of Canberra in the Bush Capital 'city in the country'.**

The people of Canberra should be informed of policy and practices for the management of urban grasslands. This needs to be brief and where appropriate, underpinned by reasons for each of the practices.

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Appendix A – Annotated Bibliography

Note: This bibliography, although extensive, may not include some important references and therefore may not be complete. References dealing with research conducted outside the ACT are included if considered relevant.

Boschma SP, Hill MJ, Scott JM, and Rapp GG (2003) The response to moisture and defoliation stresses, and traits for resilience of perennial grasses on the Northern Tablelands of New South Wales, Australia. Australian Journal of Agricultural Research 54:903-916

This field experiment was conducted near Armidale on the Northern Tablelands of NSW but data on perennial grass responses to defoliation and moisture stress is relevant to ACT grasslands because of the species studied. *Phalaris aquatica*, *Festuca arundinacea*, *Dactylis glomerata*, and *Lolium perenne*) and 2 native grass species (*Microlaena stipoides* and *Austrodanthonia richardsonii*) were subjected to 3 moisture regimes (non-stress moisture, moderate drought, and severe drought) and 2 defoliation intensities (severe and moderate).

Severe defoliation stimulated plant growth, resulting in higher harvested herbage mass than from those moderately defoliated. Reproductive development was suppressed by severe drought and reduced by moderate drought. Severe defoliation suppressed flowering of *Dactylis* and *Lolium* at both drought intensities, compared with moderate defoliation. *Phalaris*, *Festuca*, and *Austrodanthonia* were the deepest rooting species during spring–summer, and *Dactylis* the shallowest. All species had similar rooting depths during summer–autumn, with those under severe and moderate drought having the deepest and shallowest rooting, respectively.

Carbohydrate reserves and basal area were important traits for determining plant resilience during spring–summer. During summer–autumn, maintaining basal area and plant biomass through moderate grazing was important for resilience.

Boschma SP, Scott JM, Hill MJ, King JR, and Lutton JJ (2003) Plant reserves of perennial grasses subjected to drought and defoliation stresses on the Northern Tablelands of New South Wales, Australia. Australian Journal of Agricultural Research 54:819-828

The effects of defoliation intensity and drought severity on plant carbohydrate and regrowth of 6 important perennial grasses were investigated. The experiment was conducted under a rain-out shelter at Armidale, NSW, Australia, using 6 perennial grass species (*Phalaris aquatica* cv. Sirosa, *Festuca arundinacea* cv. Demeter, *Dactylis glomerata* cv. Porto, *Lolium perenne* cv. Victorian, *Microlaena stipoides* cv. Shannon, and *Austrodanthonia richardsonii* cv. Taranna) subjected to 3 moisture regimes (non-stress moisture, and moderate and severe drought) and 2 defoliation intensities (moderate and severe) over 2 seasonal sequences (spring–summer and summer–autumn).

The effect of defoliation intensity and drought varied with season. Defoliation intensity had little effect on carbohydrate reserves of all species, except *Festuca*, during summer of the spring–summer experimental season. During the summer–autumn experimental season, severe defoliation reduced the rate of accumulation during the period December–April. Drought affected carbohydrate accumulation and utilisation. Carbohydrates that had been accumulated at the end of spring of the spring–summer experimental season in plants affected by drought were utilised during summer. However, if drought commenced in summer, carbohydrate accumulation continued for 120 days in all species studied, and 180 days in *Lolium* and *Phalaris*. Autumn appeared to be a period when plant reserves were particularly susceptible to stress.

Busby D (1997) Hypericum: current control strategies in the Australian Capital Territory. Plant protection Quarterly 12:101

This review identified the ACT Weeds Strategy as a means of focusing use of resources and creating greater awareness of weeds and their control throughout the ACT. However, given the level of infestations of St. John's wort in Canberra's open spaces and current management technologies, the author considers that the rate of spread may at best be limited but not eliminated.

Campbell MH (1997) Control of *Hypericum perforatum* L. (St John's wort) by grazing management. Plant Protection Quarterly 12:97-99

If an infested pasture is left ungrazed *Hypericum perforatum* (St. John's wort) becomes dominant. If light infestations are heavily grazed it can be controlled. Heavy infestations on arable land can be controlled by ploughing, sowing improved pastures and grazing heavily. The most difficult situations for the control of the weed are heavy infestations in large paddocks on non-arable land. Here the establishment of a for *Phalaris aquatica* based pasture by the aerial spray-sow technique and heavy grazing has proved successful on fertile soils but the high cost and the risk of failure on infertile soils has limited its use. Aerial distribution of *Trifolium subterranean* seed and fertiliser and grazing only when there is an abundance of pasture has reduced ground-cover of *H. perforatum* by 75 per cent. Heavy set stocking of *T. subterranean* - *H. perforatum* pastures with sheep (black or white) has proved successful on light infestations but unsuccessful on heavy infestations. Cattle are more effective than sheep and a mixture of goats and cattle has proved the most effective grazing management system yet devised. Most of the reports on the effects of grazing management on the control of *H. perforatum* have come from observations by producers. There is a major need for detailed research into grazing systems to control the weed, particularly on non-arable land.

Campbell MH and Ridings HI (1988) Tolerance of grazed and ungrazed *Phalaris aquatica* to glyphosate, tetrapion and 2,2-DPA. Australian Journal of Experimental Agriculture 28:747-751

In this study three experiments were carried out near orange, New South Wales, where the tolerance of grazed and ungrazed *Phalaris aquatica* to glyphosate, tetrapion and 2,2-DPA applied at three rates were determined. Tolerance varied considerably. Grazing before or after spraying did not improve the tolerance of *P. aquatica* to 2,2-DPA but grazing after spraying improved its tolerance to tetrapion. Maximum selective effect, on taking into account the optimum time for killing weeds and retaining pasture (*P. aquatica* and *Trifolium subterranean*), could be achieved by applying: tetrapion to *Nassella trichotoma*, *Eragrostis curvula* or *Sporobolus africanus* in late spring or summer; 2,2-DPA to *N. trichotoma* in summer; and glyphosate to *Poa labillardieri* and heavily grazed pasture in summer, provided the weed was actively growing.

Chan CW (1980) Natural grasslands in Canberra: their distribution, phenology and effects of mowing. Diss. Australian National University, p 86

A method of mapping natural grasslands in the Canberra region using infra-red colour and natural colour photography is described. Five grassland types are identified depending on the relative proportions in them of the four native grasses, *Themeda triandra*, *Bothriochloa macra*, *Austrostipa bigeniculata* and *Austrodanthonia* species. The inter-relationships of these grassland types to the habitat and different land uses are discussed.

The phenology of the four major native grass species was studied to help understand the seasonal behaviour. Observations are the four species indicated differing photoperiod requirements, stem and leaf yield and reproductive tillering patterns. *Bothriochloa* grew, flowered and shed seed much later than the other three species. A species list for a Canberra grassland site, together with the flowering times, is presented. The peak of flowering occurred in October-November.

A study was made of the effect of five mowing frequencies on two grassland types. The responses of the four dominant species present were different when subjected to the same sequence of treatments. *Themeda* and *Austrostipa* appeared to be less tolerant of frequent mowing than *Austrodanthonia* or *Bothriochloa*, especially when percent touch basal cover and foliage cover measurements were considered. Mowing periods timed with regard to the seasonal behaviour of these grass species could alter the relative contribution of the species to the grassland.

The presence of grasslands may be seen as a result of many environmental factors such as fire incidence, grazing and climate acting on the vegetation.

Limitations to the study are discussed and proposals for further research suggested.

Management schedules for maintaining five different grassland types in Canberra are recommended. They involve mowing before and after periods of active grass growth.

Clarke PJ and Davison EA (2004) Emergence and survival of herbaceous seedlings in temperate grassy woodlands: Recruitment limitations and regeneration niche. Austral Ecology 29:320-331

These field experiments examined herbaceous seedling emergence and survival in temperate grassy woodlands on the New England Tablelands of New South Wales. Effects of intensity of previous grazing, removal of ground cover by fire or clearing, burial of seeds, grazing and seed theft by ants on seedling emergence and survival were studied. Thirteen species with a range of traits were used in the experiments and their cumulative emergence was compared with laboratory germination studies. Field emergence correlated to laboratory germination but all species had lower emergence in the field. Little natural emergence of native species was observed in the field in unsown treatments. Short-lived forbs had the highest emergence, followed by perennial grasses; rhizomatous graminoids and perennial forbs had the lowest emergence. Soil surface and cover treatments did not markedly enhance emergence suggesting that intertussock spaces were not prerequisites for forb emergence. No consistent pattern of enhanced emergence was found for any treatment combination across all species. Seedling survival varied among species, with perennial grasses and short-lived forbs having the highest seedling mortality. Low mortality rates in the graminoids and rhizomatous forbs appeared partially to compensate for lower seedling emergence. All perennial grasses and some short-lived forbs showed increased risk of mortality with grazing. Differences in emergence and survival of species were related to ground cover heterogeneity, soil surfaces and, to some extent, herbivory. The complexity of these patterns when superimposed on temporal variability suggests that no generalizations can be made about the regeneration niche of herbaceous species groups. Strong recruitment limitation and partitioning of resources in the regeneration niche may reduce competition among native species and explain the high species richness of the herbaceous layer in the temperate grassy communities of eastern Australia.

Culvenor RA (1997) Observations on tillering in cultivars of phalaris under rotational grazing in a year with a summer–autumn drought. Australian Journal of Agricultural Research 48:467-476

Changes in tiller numbers, timing of stem elongation, and tiller survival under summer moisture stress were measured in phalaris (*Phalaris aquatica* L.) within-urban-ACT-pastures rotationally grazed at 15 wethers/ha during a study of the survival and productivity of a semi-winter-dormant cultivar (Australian) compared with 3 winter-active cultivars (Sirosa, Holdfast, Perla Retainer). The semi-winter-dormant cultivar maintained higher tiller numbers per plant and per area than the 3 winter-active cultivars, was later in its reproductive stem development, and was capable of more new tillering early in spring, but could display higher rates of tiller death late in spring. Although stem elongation in Australian started later in 1990, it was no less synchronous than in the winter-active cultivars. However, Sirosa had a higher proportion of elongating tillers than Australian under very infrequent grazing in a supplementary experiment during 1991. Cultivars did not differ in the proportion of tillers that were decapitated during spring 1990.

Perla Retainer displayed higher summer dormancy after rainfall in January 1991 and new tillers of Perla Retainer and Holdfast survived subsequent drought better than tillers of Australian. However, regeneration of the tiller population of Australian after drought ended was enhanced by a slightly higher propensity for tillering during July–September 1991.

Maintaining grazing pressure and frequency in late winter and early spring should enhance tiller survival and improve the resilience of phalaris to episodes of heavy spring grazing. Later reproductive development probably benefits grazing tolerance in semi-winter-dormant cultivars, but the value of selecting for this in winter-active phalaris is uncertain. In areas with harsh summers, higher summer dormancy is required for survival combined with a capacity for tiller survival should growth occur. However, unnecessarily high summer dormancy will reduce the growth of green herbage and, consequently, animal production.

Culvenor RA (2000) Comparison of four phalaris cultivars under grazing: drought survival and subsequent performance under rotational grazing versus set stocking. Australian Journal of Experimental Agriculture 40:1047-1058

Four cultivars of phalaris were evaluated for their ability to survive the severe drought in 1994 in an existing grazing experiment at 2 sites within the ACT. The effect of rotational grazing and set stocking on persistence of phalaris measured as basal cover, pasture composition in spring and animal production from the pastures was assessed over the next 4 years.

Basal cover of all cultivars declined sharply in 1994, but had recovered by August 1995 at a site with a relatively deep soil profile. Recovery was slower at a site with a shallower soil profile. Sirosa declined more in basal cover than Holdfast and Australian at the latter site. All of the cultivars survived the drought well but Sirosa may be more sensitive to overgrazing in drought.

Compared with set stocking, rotationally grazed pastures had a higher proportion of phalaris for all cultivars 2 years after management treatments began, and a higher basal cover for 2 winter-active cultivars after 3 years. Overall, a divergent effect of grazing management on basal cover (management & times; year interaction) was demonstrated. Phalaris basal cover did not decline with set stocking and it was concluded that rotational grazing was beneficial, but not crucial, for the persistence of winter-active phalaris cultivars in this environment. Site factors and their manipulation by management were also important for the persistence of phalaris.

A review of the persistence of phalaris over the entire 9 years of the grazing experiment concluded that all cultivars displayed good persistence under conditions of reasonable soil fertility. The importance of good establishment for a high presence of phalaris in later years was emphasised.

Culvenor RA, Dobbie MJ, Wood JT, and Forrester RI (2002) Selection for persistence under grazing in winter-active populations of the perennial grass, *Phalaris aquatica* L. (phalaris): Selection for persistence in winter-active phalaris. Australian Journal of Agricultural Research 53:1059-1068

Winter-active cultivars of phalaris (*Phalaris aquatica* L.) have the potential to be more productive than semi-winter-dormant cultivars but may be less persistent under the stress of heavy grazing. The feasibility of improving persistence of winter-active phalaris was examined by subjecting plots of half-sib families from several winter-active populations to 2 cycles of heavy grazing pressure by sheep. Because variation among families in initial density influenced final density score in both cycles, persistence was assessed by 2 methods, final density with initial density as a covariate and the ratio of final over initial density.

The selected populations displayed higher density and persistence than control winter-active cultivars. Overall they were considered to indicate that differences in persistence between families were present and heritable. This was supported by the observation that generations of 2 populations selected in Cycle 1 were higher in final density and persistence than the base generations, although differences in persistence as distinct from final density were not always at the $P = 0.05$ significance level.

The ratio of final over initial density scores was considered less appropriate than the covariate method of estimating persistence in this cycle because plots that established at very low density and increased slightly thereafter resulted in high error variance and biased selection towards families that established at low density.

Culvenor RA and Oram RN (1996) Comparison of winter-active phalaris with the Australian cultivar under rotational grazing 1. Basal area and plant density. Australian Journal of Experimental Agriculture 36:277-286

Basal area and plant density in fixed contracts are presented from a grazing trial comparing the persistence of two ‘winter-active’ cultivars (Sirosa, Holdfast) and a breeding population (Perla Retainer) of phalaris (*Phalaris aquatica* L.) possessing high seedling and winter growth rates with the original cultivar Australian. Four replicate pastures, 2 at each of 2 sites near Canberra, were grazed year-round at 15 wethers/ha for three years using a rotational system of management (two weeks on, four weeks off). The first site, The Elms, was located on a slope with shallow, coarse-textured soil; the second, Boundary Creek, was level with deep soil which was very acid in the upper 20 cm. Both sites were fertilised with superphosphate and, except for small areas, were limed before sowing.

Significant mortality was observed at The Elms during the summer-autumn drought after grazing commenced, when plant death was highest for Australian and lowest for Perla Retainer, an erect, summer-dormant population. Basal area of Australian and Sirosa, but not Holdfast and Perla Retainer, subsequently recovered. Australian established and maintained a 50-70 per cent higher basal area due to a 30 - 40 per cent higher area per plant and 15-25 per cent more plants. The cultivars did not differ markedly in persistence measured as stability of basal area. However, Perla Retainer showed less vegetative expansion at the first sight after grazing commenced and was considered less persistent than the cultivars there.

Persistence was correlated with the productivity of individual plots, all cultivars being affected similarly. Regressions which varied with cultivar were derived in which basal area at establishment, but not subsequent changes in basal area under grazing, was positively related to soil fertility factors, mainly phosphorus, potassium and manganese. An association between the initial basal area of Sirosa and soil magnesium levels was also detected at one site. It was concluded from this study, which was conducted in the absence of major drought, that the winter-active cultivars of phalaris can be as persistent as Australian under rotational grazing and with adequate soil fertility, but that interaction with site will occur.

Dorrough J (1995) Grassland conservation in the ACT: an historical perspective. Bogong 16:4-5

The major issues for grassland conservation in at the ACT are briefly reviewed. Grasslands are seen as one of the most disturbed natural ecosystems in south eastern temperate Australia. It is estimated that of the grasslands present at the time of European arrival, less than one percent now remain undisturbed. However, such estimates are hard to make due to the presence of secondary grasslands which develop when woodland is cleared. Most grassland has been grazed, cultivated, pasture improved and invaded by exotic species. Urban grasslands have been decimated by development. Information is given on changes in the distribution of the striped legless lizard as a case study.

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

This excellent review addresses issues to be considered in grazing urban ACT grasslands.

There is an increasing interest in the development of livestock grazing management strategies that achieve environmental sustainability and maintain or improve the long-term production capacity of commercial grazing systems. In temperate Australia, these strategies are generally focussed on reducing perennial pasture decline, soil loss, acidity, and salinity. An additional challenge facing land managers and researchers is developing grazing strategies that also maintain and enhance local and regional biodiversity. However, few studies have assessed the compatibility of management practices for maintaining long-term productivity and biodiversity conservation. We still have only a very basic understanding of the effects of different grazing strategies and pasture management on biodiversity and this is a major impediment to the development of appropriate and compatible best management practice. We argue that although there is an increasing desire to find management strategies that protect and enhance biodiversity without hindering long-term agricultural production, in many cases this may not be possible. Current knowledge suggests that compatibility is most likely to be achieved using low-input systems in low productivity (fragile) landscapes, whereas in highly productive (robust) landscapes there is less opportunity for integration of productive land-use and biodiversity conservation. There is an urgent need for improved communication and collaboration between agronomic and ecological researchers and research agencies to ensure that future programs consider sustainability in terms of biodiversity as well as pasture and livestock productivity and soil and water health.

Eddy DA (2002) Managing native grassland: a guide to management for conservation, production and landscape protection. Sydney, WWF Australia. 21

This excellent guide to managing native grasslands is relevant to urban ACT and is written in a style that managers should find easy to understand.

Garden DL, Dowling PM, Eddy DA, and Nicol HI (2000) A survey of farms on the Central, Southern and Monaro Tablelands of New South Wales: management practices, farmer knowledge of native grasses, and extent of native grass areas. Australian Journal of Experimental Agriculture 40:1081-1088

Results are presented of a survey of pastoral properties on the Central, Southern and Monaro Tablelands of New South Wales carried out during 1991—92. Landholders were interviewed to obtain information on property size, enterprise types, grazing management, tree clearing, fertiliser history and carrying capacity. In addition, familiarity with native grass species, and knowledge of their value were determined. The main grazing enterprises were wool and beef. The most common form of livestock management was continuous grazing. Most properties had been extensively cleared of trees (average cleared area 80%), and there had been a significant amount of disturbance of the original pastures. This varied from 40% of total property area for the Central and Monaro Tablelands to 60% for the Southern Tablelands. The main form of disturbance was cultivation for pasture sowing or fodder cropping. Landholders had used 80% more fertiliser on disturbed areas than on undisturbed areas, with most fertiliser applied on the Southern Tablelands and least on the Monaro Tablelands. The average carrying capacities of undisturbed and disturbed pastures over the tablelands were 4.3 and 7.7 dry sheep equivalents per hectare, respectively. While most landholders were satisfied with the performance of their sown pastures, there was a lack of knowledge of the contribution of native perennial grasses to pasture production. Using survey data, it was estimated that pastures with native grasses as the major components covered a minimum of 1.38 million hectares or 40% of the surveyed area. With such a large contribution to production, there is a need to assist landholders to identify native perennial grasses so that their potential value can be more fully realised.

Garden DL, Dowling PM., Eddy DA, and Nicol HI (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

Pastures on 126 properties on the central, southern, and Monaro tablelands were surveyed to determine their botanical composition. Data on climate, soils, pasture sowing, fertiliser history, and stock management were collected to relate current composition to environmental factors and previous management. Native grass-based pastures were found to be widespread, and in many cases, pastures were dominated by native grasses, despite many decades of pasture improvement. Seventeen genera of native perennial grasses comprising over 35 species were identified. The most common species on the central tablelands were *Austrodanthonia* spp., *Bothriochloa macra*, and *Microlaena stipoides*; on the southern tablelands, *Austrodanthonia* spp. and *M. stipoides*; and on the Monaro, *Poa* spp., *Austrodanthonia* spp., *Themeda triandra*, and *Austrostipa* spp. Soil type was the most important factor affecting species distribution, and other soil attributes such as texture, pH, P, and N were also important. Environmental (rainfall) and management (superphosphate application, stock type, stocking rate) factors also influenced distribution. The significant areas of native grass pastures that were found suggest a decline in sown species and a recolonisation of sown pastures with native grasses. The potential for manipulation of botanical composition of these grasslands is discussed, together with their value for production and sustainability.

Garden DL, Ellis NJS, Rab MA, et al (2003) Fertiliser and grazing effects on production and botanical composition of native grasslands in south-east Australia. Australian Journal of Experimental Agriculture 43:843-859

The effects of application of superphosphate and grazing on production and botanical composition of native grasslands were investigated at 3 locations in the high rainfall zone of south-east Australia. These studies were conducted as part of the Sustainable Grazing Systems Key Program, which investigated various aspects of grassland productivity and sustainability between 1996 and 2001. Grasslands in this study either had high contents of *Themeda triandra* or *Austrodanthonia* spp., or were based on a degraded *Austrodanthonia* spp. grassland with a high content of annual and weedy species. All sites used increasing levels of superphosphate application (nil, low, medium and high) as treatments, with clover being added in some treatments at 1 site, and herbicide in 1 treatment at another site. Grazing (sheep) was continuous at 1 site (with stocking rates matched to pasture productivity) and intermittent at other sites, with grazing being dictated by available herbage between defined trigger points. Climate was monitored and changes in soil P, herbage mass, botanical composition, ground cover and sheep production recorded. Changes in composition resulting from the treatments varied between sites. At the continuously grazed *Austrodanthonia* spp. site, there was a decline in native perennial grasses throughout the experiment and an increase in exotic annual grasses in spring where superphosphate was applied. The grassland at the *T. triandra* site remained relatively stable, which may have been due to the limited amount of grazing applied. The degraded *Austrodanthonia* spp. grassland showed wide seasonal fluctuations in annual species. There were no clear effects of treatments at the latter 2 sites. Sheep production increased with increased superphosphate application at the continuously grazed *Austrodanthonia* spp. site, but there was little effect at the other 2 sites. Recommendations are made for sustainable management of native grasslands depending on their current botanical state.

Garden DL, Lodge GM, Friend DA, Dowling, and Orchard BA (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

Grazing management strategies to alter botanical composition of native pastures were investigated at 4 locations in the high rainfall zone of south-east Australia, including Tasmania. These studies were conducted as part of the Temperate Pasture Sustainability Key Program, which evaluated the effects of grazing management on a wide range of pasture types between 1993 and 1996. Pastures in this study were based on *Aristida ramosa*/*Bothriochloa macra*, *Microlaena stipoides-Austrodanthonia* spp. or *Themeda triandra-Austrodanthonia* spp. Seasonal rests, increased grazing pressure in spring, mob stocking and cutting for hay were compared to continuous grazing at all sites. In addition, specific local treatments were tested at individual sites. Changes in composition resulting from the treatments were minimal at most sites. This may have been due to a combination of the inherent stability of the pastures, the relatively short duration of the experiments, and the drought conditions experienced, which minimised differences between treatments. Some strategies to alter composition of natural pastures are suggested. In the *Aristida-Bothriochloa* pasture there was a general decrease in *Aristida* and an increase in *Bothriochloa*, which was largely unaffected by the type of grazing management applied. The combination of drought conditions and increasing grazing pressure was sufficient to alter composition without specific management strategies being necessary. In the *Themeda-Austrodanthonia* pasture, resting in spring, 12-month rests or cutting for hay (which involved a spring rest) allowed *Themeda* to increase in the pasture. The *Microlaena-Austrodanthonia* pastures were very stable, especially where annual grass content was low. However, certain treatments allowed *Microlaena* to increase, a result which is regarded as being favourable. The major effects in these latter pastures were on undesirable species. *Vulpia* spp. were reduced by resting in autumn and increased spring grazing pressure, while *Holcus lanatus* was increased dramatically by resting in spring and was also increased by resting in autumn or winter, but only when conditions were suitable for growth of this species. In many cases, treatment differences were only expressed following recovery from drought, showing that timing of grazing management to achieve change is critical.

Greenwood KL and McKenzie BM (2001) Grazing effects on soil physical properties and the consequences for pastures: a review. Australian Journal of Experimental Agriculture 41:1231-1250

Grazing animals exert pressure on the ground comparable to that of agricultural machinery. As a result, soil under pasture can be compacted. In grazing systems based on permanent pastures or rangelands, there is little opportunity to ameliorate poor soil physical conditions through tillage. Hence, it is important to understand the effects of grazing on soil physical properties and the consequent effects of these properties on pasture growth and composition.

Most soils under grazed pasture, even those managed to minimise soil physical degradation, will be compacted to some extent. However, the magnitude of this compaction is usually small, and limited to the upper 50–150 mm of the soil. Compaction to greater depth, and other changes in soil physical properties, are more likely in recently tilled or wet soils.

The response of pasture to the poorer soil conditions caused by grazing is difficult to determine, but it is likely to be small compared with the defoliation effects of grazing. Maintenance of a vigorous pasture should be a major aim of grazing management and would also achieve the secondary aim of maintaining acceptable soil physical conditions.

Grigulis K, Sheppard A, Ash J, and Groves R (2001) The comparative demography of the pasture weed *Echium plantagineum* between its native and invaded ranges. Journal of Applied Ecology 38:281-290

Echium plantagineum is native to the western Mediterranean Basin, where it is a common, but not dominant, component of species-rich annual grasslands. Since its introduction into Australia, *E. plantagineum* has spread to infest vast areas of predominantly agricultural land in south-east and south-west Australia, where it can be the dominant pasture species.

To unravel the ecological factors responsible for the high population abundance of *E. plantagineum* in Australia, its demography was compared between sites in the invaded and native ranges. Demographic parameters of *E. plantagineum* populations were estimated at a site near Canberra in south-eastern Australia, and at a site near Evora in southern Portugal. Identical factorial experiments were set up at each site with treatment combinations of the presence or absence of grazing and pasture competition.

The recruitment, survival, fecundity and seed bank dynamics of *E. plantagineum* populations were measured for each of the treatment combinations over 2 years at each site. These data allowed the estimation of demographic parameters describing the proportion of *E. plantagineum* individuals moving from one life-cycle stage to the next.

Seedling establishment fractions were two to five times greater at Canberra than at

Evora, and seed bank incorporation rates were three times greater at Canberra than Evora. These demographic differences were those most likely to play an important role in the greater abundance of *E. plantagineum* in Australia compared with Mediterranean Europe. Neither seed bank survival rates nor seed production differed between populations at Canberra and Evora, while seedling survival rates were always lower at Canberra than at Evora.

Neither grazing nor pasture competition limited the seed production or seedling survival of *E. plantagineum* populations at Evora more than at Canberra.

An effective approach for the control of *E. plantagineum* in Australia may thus be through the reduction of the seedling establishment fraction. This may be achieved by maintaining significant pasture vegetation cover and reducing the available space for *E. plantagineum* establishment during autumn.

Groves RH, Austin MP, and Kaye PE (2003) Competition between Australian native and introduced grasses along a nutrient gradient. Austral Ecology 28:491-498

Seven grass species were grown in monocultures and in multispecies mixtures along a gradient of total nutrient levels that ranged from 1/64 to 16× the normal level of nutrient solution. The seven grasses represented three ecological groups: (i) three perennial species native to Australia (*Themeda triandra*, *Poa labillardieri* and *Danthonia carphoides*); (ii) two introduced annuals (*Vulpia bromoides* and *Hordeum leporinum*); and (iii) two introduced perennials (*Lolium perenne* and *Dactylis glomerata*). We hypothesized that the native grasses would prove less competitive when grown at increased nutrient levels than those introduced from Europe. Results supported the hypothesis. The native species were unable to compete in mixtures even at the lowest nutrient level, where *T. triandra* was the most productive species in monoculture. *Lolium perenne* and *Dactylis glomerata* dominated mixtures at intermediate nutrient levels. The responses of the annual introduced grasses differed in that *Vulpia bromoides* showed an optimum at intermediate nutrient levels in both monoculture and in mixtures, whereas *Hordeum leporinum* dominated at the highest nutrient levels in mixture but was suppressed by *V. bromoides*, *L. perenne* and *D. glomerata* at intermediate levels. The results are discussed in terms of predicting species responses in mixtures from their performance in monocultures as well as in terms of previous observations on the sequential changes in botanical composition of south-eastern Australian grasslands after 150 years of continuous grazing by sheep.

Hagon MW and Groves RH (1977) Some factors affecting the establishment of four native grasses. Australian Journal of Experimental Agriculture and Animal Husbandry 17:90-96

The effects of the fertiliser application, types of mulching and times of sowing on the field germination of seed of four native grasses (*Themeda triandra*, *Bothriochloa macra*, *Austrodanthonia* spp., and *Austrostipa bigenticulata*) are reported. Growth of these species in controlled environments was compared with that of *Lolium perenne* (ryegrass) at 3 temperature regimes and two levels of nutrition.

Application of an NPK fertiliser had no effect on emergence or survival of the native grasses in the field. Mulching with paper or straw increased emergence of all four species and mulching with bitumen increased emergence from *Themeda*, *Bothriochloa* and *Austrodanthonia* seed only, but decreased survival of the two latter species. In both field and controlled environments, germination and seedling growth of *Themeda* and *Bothriochloa* were best when the maximum daily temperatures were greater than 30 degrees, whereas *Austrodanthonia* and *Austrostipa* germinated and grew most satisfactorily when the maximum daily temperatures were about 25 degrees. Growth of *Austrostipa* seedlings in a controlled environment was enhanced by a high level of nutrition but growth of the other species was not.

Sowing seed in late spring and using straw mulch would insure satisfactory levels of establishment of native grass seedlings in the field in south-eastern Australia. Fertiliser application should not be necessary.

Hitchmough JD, Kilgour RA, Morgan JW, and Shears IG (1994) Efficacy of some grass specific herbicides in controlling exotic grass seedlings in native grassy vegetation. Plant Protection Quarterly 9:28-34

In a series of experiments the efficacy of grass specific herbicides (ethofumesate, sethoxydim, and fluazifop) were evaluated for their ability to remove exotic grass seedlings amongst native grasses. In glasshouse seedling trials the three herbicides applied at varying rates to native and exotic species had no marked selectivity. When the same herbicides were applied at varying rates to vigorously growing and mature tussocks of native grasses outright mortality was low in most instances. Canopy dieback, however, ranged from slight to severe indicating that tolerance was not absolute. In the final experiment, fluazifop was trialled in a grassy woodland community north of Melbourne. Under semi-natural conditions canopy dieback occurred amongst all native grasses tested but mortality was low. Regrowth was evident 36 weeks after treatment for all species other than *Poa morrissii* Vick. Grass weed seedling cohorts were competitively controlled with the exception of *Vulpia bromides* (L.) Gray. This study indicates that the herbicide may be useful in the management of remnant grassy vegetation.

Hodgkinson KC (1976) The effects of frequency and extent of defoliation, summer irrigation and fertiliser on the production and survival of the grass Danthonia caespitosa Gaud. Australian Journal of Agricultural Research 27:755-767

The effects of extent and frequency of defoliation on the growth and survival of *Austrodanthonia caespitosa* were measured in a series of field experiments. Additional treatments, of summer irrigation and application of nitrogen and phosphorus fertiliser, were included in some of the experiments to assess how they modified the effects of defoliation.

During the summer, complete defoliation increased the shoot yield of plants which had not been irrigated, but yield was decreased in the irrigated treatments. Frequent, partial defoliation increased yields of irrigated plants but decreased yields of plants not irrigated. Depression of yield was caused by both tiller death and reduced regrowth of individual tillers.

In an experiment lasting two years, plants were completely defoliated monthly, bi-monthly or tri-monthly or left intact, and shoot yields, tillering characteristics and plant survival under the treatments were compared. Monthly defoliation depressed yields and rate of tillering and accelerated the death-rate of plants, particularly during the summer and autumn periods. Plants also died when cut bi-monthly but the rate was lower. Plants irrigated during the first summer generally died at a faster rate than plants not irrigated. Tillering was more rapid during the autumn and early winter months. Midwinter application of fertiliser to plants cut bi-monthly greatly stimulated sheep yields and seed production in the spring but not in the following year.

Examination of tiller apices showed that floral induction took place prior to the beginning of July. Many apices were elevated above the 'grazing level' by early September, and flowering and seed set occurred in October.

Hodgkinson KC, Ludlow, Mott JJ, and Baruch Z (1989) Comparative responses of the savanna grasses *Cenchrus ciliaris* and *Themeda triandra* to defoliation. Oecologia 79:45-52

Two perennial tussock grasses of savannas were compared in a glasshouse study to determine why they differed in their ability to withstand frequent, heavy grazing; *Cenchrus ciliaris* is tolerant and *Themeda triandra* is intolerant of heavy grazing. Frequent defoliation at weekly intervals for six weeks reduced shoot biomass production over a subsequent 14 day regrowth period compared with previously undefoliated plants (infrequent) in *T. triandra*, but not in *C. ciliaris*. Leaf area or *T. triandra* expanded rapidly following defoliation but high initial relative growth rates of shoots were not sustained after 14 days of regrowth because of reducing light utilising efficiency of leaves. Frequently defoliated plants were slower in rate of leaf area expansion and this was associated with reduced photosynthetic capacity of newly formed leaves, lower allocation of photosynthate to leaves but not lower tiller numbers. *T. triandra* appears well adapted to a regime where defoliation is sufficiently infrequent to allow carbon to be fixed to replace that used in initial leaf area expansion. In contrast, *C. ciliaris* is better adapted to frequent defoliation than is *T. triandra*, because horizontally orientated nodal tillers are produced below the defoliation level. This morphological adaptation resulted in a 10-fold higher leaf area remaining after defoliation compared with similarly defoliated *T. triandra*, which together with the maintenance of moderate levels of light utilising efficiency, contributed to the highly feria and shoot weight throughout the regrowth period.

Hodgkinson KC and Quinn JA (1978) Environmental and genetic control of reproduction in *Danthonia caespitosa* populations. Australian Journal of Botany 26:351-364

Seedlings and older plants of five populations of *Danthonia caespitosa* from south-eastern Australia were grown in controlled environments and in a transplant garden to determine the effect of day length, temperature, and vernalization of floral initiation and inflorescence development. The populations were selected from widely separated sites which spanned the latitudinal range (31-42 degrees south) for the species and extended from a hot, semi-arid environment in the north to a relatively cool and moist temperate environment in the south.

Examination of herbarium specimens indicated that seed set could occur as early as mid-September at the northern limit for the species and not before mid-January at the southern limit (Tasmania). In a uniform transplant garden located at Deniliquin (latitude 35 degrees 27 minutes South) plants from the northern side reached anthesis four weeks earlier than plants from southern sites.

Controlled environment experiments revealed that *D. caespitosa* is a long-day plant. Northern populations required a 9.5 hour day length or longer for floral induction compared with 11 hours or longer for southern populations. The number of days in inductive conditions (outside, day length13.5 hours) required for floral initiation was 5-7 for the three most northern populations and 21-25 days for the two southern populations. Inflorescent development (initiation to flag leaf stage) was considerably slower in southern populations.

All but the most northern population responded to the vernalization. Flowering was earlier in temperatures that were optimal for plant growth. At high temperatures (36/31 degrees C day/night) flowering was not significantly delayed for the three most northern populations, but was for the two southern populations, and florets containing caryopses in only the three northern populations.

The results suggest that in cool and moist temperate habitats reproduction of the species is programmed by day length and temperature effects on floral initiation and development to coincide with the predictable growing season, whereas in hot semiarid habitat this control is relaxed, which permits opportunistic reproduction whenever soil moisture and temperature permit growth.

Johnston WH, Koen TB, and Shoemark VF (2002) Water use, competition, and a temperate-zone C4 grass (*Eragrostis curvula* (Schrad.) Nees. complex) cv. Consol. Australian Journal of Agricultural Research 53:715-729

The effects of a perennial C4 grass (*Eragrostis curvula* [Schrad.] Nees. complex cv. Consol) and winter-growing annual pasture on the soil water deficit (SWD) was assessed at 2 sites near Wagga Wagga, NSW. At Site A, newly sown *E. curvula-Trifolium subterraneum* L. pasture was compared with an annual pasture containing *Lolium rigidum* Gaud. and *T. subterraneum*. A mature *E. curvula* pasture sown 10 years previously was compared with an adjacent volunteer annual pasture at Site B.

The annual pasture at Site A had little effect on the SWD at 120 cm depth, but it developed an appreciable SWD at 60 cm on 2 occasions when spring rainfall was well below average. This deficit was not evident the following autumn. When *E. curvula* was present in the pasture, it developed a substantial SWD at 120 cm in summer and autumn. This represented a significant realignment of the water balance that had the potential to reduce deep drainage.

The size of the SWD in autumn determined how rapidly soils reached field capacity in winter. At Site B, *E. curvula* consistently created a deficit of between 108 and 124 mm to 100 cm depth in autumn, compared with 2-106 mm for the annual pasture. The soil profile under *E. curvula* did not reach field capacity until 60-100 days later than the annual pasture. The annual pasture at Site B had a minimal effect on the SWD at 100 cm in 3 of the 4 years of the study.

The camping behavior of sheep at Site A caused *E. curvula* to succumb to competition from *T. subterraneum*, *Hordeum leporinum* Link, and *Cryptostemma calendula* (L.) Druce. Competitive interactions between *T. subterraneum* cv. Junee and *Eragrostis curvula* cv. Consol were therefore investigated in a glasshouse study using the de Wit replacement series methodology. Pots were watered to weight and water usage was recorded under 2 levels of watering [low (restricted watering) and high (watered to field capacity)] that were applied after an establishment period of 6 weeks. Pots were harvested after a further c.12 weeks and above- and below-ground yield of each species determined.

T. subterraneum tended to use water up to the limit of its supply, and as water became less available and in response to increasing atmospheric water demand in spring, it frequently wilted. *E. curvula* rarely wilted; it exhibited water-saving strategies, including leaf waxing and leaf rolling in the heat of the day in response to increasing water demand without necessarily exhausting its water supply.

Both species used water more efficiently (dry matter/kg water used) when its supply was limited. The water use efficiency of monoculture *T. subterraneum* was greater than that of slowly growing *E. curvula*, and both species used water most efficiently when growing alone. *T. subterraneum* was highly competitive against *E. curvula*. Competition resulted from its out-of-phase growth compared with *E. curvula*.

E. curvula has the potential to markedly affect on the water balance. However, it is vulnerable to competition. Managing the flush of growth in spring is an important issue in maintaining a balance between *E. curvula* and winter-growing annual species.

King SA and Buckney RT (2001) Exotic plants in the soil-stored seed bank of urban bushland. Australian Journal of Botany 49:717-720

Native vegetation reserves in urban areas have been invaded by exotic plants, particularly along edges. However, it is not known whether the seeds of exotic plants in the soil-stored seed bank are also largely restricted to edges. Ten urban bushland sites in northern Sydney were randomly selected and the readily germinable, soil stored seed bank examined to assess whether the number of exotic and native species varied with distance from an urban edge. The similarity of the contents of the seed bank and the composition of the above-ground vegetation was also examined. Soil samples were collected from quadrats 0–10, 20–30 and 50–60 m from the edge at each site, then spread on germination trays in a glasshouse and germinated seedlings identified. Soil samples were collected every 3 months for a year. The number of exotic species in the seed bank was found to be highest near urban edges, as was the total number of species. The above-ground vegetation was found to be a poor indicator of the contents of the seed bank, for both native and exotic species. Most of the exotic species found in the seed bank were not found in the immediately surrounding vegetation. Furthermore, some exotic species were found in the seed bank at sites where no exotic species were present in the vegetation. The results suggest that it is the lack of suitable conditions that is largely restricting invasion of exotic species to edges of bushland. The results also highlight the need for seedbank studies to assess the contents of the soil seed bank in urban bushland in order to prevent further invasions of exotic plants.

Lodder MS, Groves RH, and Muller WJ (1994) Early seedling growth of three species of Danthonia as affected by depth of sowing and nutrient supply. Australian Journal of Botany 42:543-554

In an experiment in a controlled environment, seedling emergence of three species of *Danthonia* (*D. linkii* var. fulva, *D. tenuior* and *D. richardsonii*) was measured in response to sowing depth. Seedlings of all three species did not emerge if seeds were buried deeper than 25 mm. At lesser depths, *D. linkii* var. fulva showed greatest tolerance to increasing sowing depth, whilst D. tenuior was intermediate and *D. richardsonii* was least tolerant of seed burial. In a separate experiment, seedlings of *Danthonia linkii* var. fulva and two geographically distinct populations of *D. richardsonii* emerged earlier, grew faster and had a higher biomass than those of D. tenuior in response to nutrient supply. The latter population grew more slowly than the others, but by day 54, the number of emergents of *D. tenuior* had equalled those of the other populations. Nutrient addition had little effect on seedling development, except that by day 54, four times normal nutrient level reduced root growth in all four populations. No population by nutrient interactions were found for either time to emergence or for seedling biomass up to 54 days from sowing. Increases in shoot biomass and the reversal of shoot to root ratios occurred between 41 and 54 days after sowing, by which time seedling establishment of *Danthonia* was complete. Some practical recommendations for field sowings are given based on the results of this and other studies

Lodge GM (2000) Effects of sowing method and competitor species and presence on Phalaris and Austrodanthonia establishment and persistence. Australian Journal of Experimental Agriculture 40:813-832

Two experiments were conducted on plots sown in autumn 1992, at Tamworth in northern New South Wales. The first compared the establishment of 3 perennial grasses when sown as monocultures or with competitors in either broadcast-sown swards or alternate row-sown plots. Sowing rate and species of competitor were also examined as factors affecting perennial grass establishment. Perennial grasses were *Austrodanthonia richardsonii* (synonym *Danthonia richardsonii*) cv. Taranna, *A. bipartita* (synonym *D. linkii*) cv. Bunderra, and *Phalaris aquatica* cv. Sirosa. Competitors were *Trifolium subterraneum* var. *brachycalycinum* cv. Clare, *T. repens* cv. Haifa, and *Lolium rigidum* cv. Wimmera. In spring 1992, competitors were removed from 144 of the 288 plots to prevent them from seeding. A second experiment compared the longer-term (1993–96) dry matter yield and persistence of these perennial grasses under continuous grazing in plots were the competitor was present in year 1 (1992) or in all years (1992–96).

In spring 1992, mean dry matter yield of perennial grass was higher ($P<0.001$) in row-sown plots then those sown by broadcasting. Mean dry matter yield of perennial grass was lowest at low sowing rate, but not significantly different at medium and high sowing rates (about 350 kg DM/ha). Compared with the monocultures, the presence of a competitor reduced mean perennial grass dry matter yields by 48, 69 and 85%, respectively for white clover, subterranean clover and annual ryegrass. Perennial grass plant numbers were highest ($P<0.001$) in the medium and high sowing rates of the monocultures and in white clover competitor plots and lowest ($P<0.001$) in all broadcast-sown plots, where annual ryegrass was the competitor.

By spring 1996, white clover and annual ryegrass had declined to a low level in the pasture in all plots and the only major competitor was subterranean clover (1200 kg DM/ha, 40% plant frequency). Mean dry matter yields were highest ($P<0.001$) for Sirosa in 1993, but with dry conditions in 1994 and continuous grazing they were highest for Bunderra in all other years. The implications of these data for devising sowing strategies to maximise the establishment of perennial grasses and their long-term persistence in this environment are discussed.

Lodge GM (2002) Studies of seed production in two *Austrodanthonia* grass cultivars. Australian Journal of Agricultural Research 53:1197-1202

Studies were conducted in 1993–94 on 2 native grass cultivars, *Austrodanthonia richardsonii* (Link) H.P. Linder (syn. *Danthonia richardsonii* Cashmore) cv. Taranna and *A. bipartita* (Link) H.P. Linder (syn. *D. linkii* Kunth) cv. Bunderra, to quantify the important morphological factors affecting seed production (as measured by seed weight, g/plant). Experiments also examined the influence of nitrogen (N) application and investigated the effects of time and method of harvest on seed production and subsequent germination. For both cultivars, inflorescence and floret number accounted for the highest proportion of the variation in seed production per plant (R2 = 0.873 and 0.686 for Taranna and Bunderra, respectively). Although N applied (0, 25, and 50 kg/ha) at the late vegetative or early flowering stage, or split applications at both times, had no significant effect ($P > 0.05$) on the seed production per plant of Taranna and Bunderra, further studies of N effects are required. In 1993 and 1994, time of inflorescence harvest and method of harvest had no significant effect on inflorescence number and seed production of Taranna and Bunderra and no significant effect on the subsequent germination of Bunderra seed. However, in 1993, harvesting at an early stage of flowering (10% of florets white and fluffy) reduced Taranna seed production by 17% compared with the mean and decreased ($P < 0.05$)

seed germination by about 10%. In 1994, harvesting at early flowering (5% florets white and fluffy) reduced Taranna seed production by a mean of around 55% compared with harvesting at 50% maturity, and subsequent seed germination was also lower ($P < 0.05$) for the early harvest time. Application of 1 L/ha of paraquat (a.i. 200 g/L of paraquat dichloride) at mid-flowering to desiccate the crop in 1993 had no significant effect on the germination of Taranna and Bunderra caryopses. The implications of these data for commercial seed production are discussed.

Lodge GM (2004) Seed dormancy, germination, seedling emergence, and survival of some temperate perennial pasture grasses in northern New South Wales. Australian Journal of Agricultural Research 55:345-355

A series of seed and seedling studies was undertaken in northern New South Wales for the temperate perennial grasses phalaris (*Phalaris aquatica* cv. Sirosa and Australian), tall fescue (*Festuca arundinacea* cv. Demeter), perennial ryegrass (*Lolium perenne* cv. Kangaroo Valley), and 2 wallaby grasses (*Austrodanthonia bipartita* syn. *Danthonia linkii* cv. Bunderra and *A. richardsonii* syn. *D. richardsonii* cv. Taranna). Studies were conducted to determine the level of dormancy in freshly harvested seed and the time required to overcome it, effects of alternating daily temperatures on the germination of non-dormant seed, effect of time-of-sowing on seedling emergence (2 studies) and survival, levels of seed production and soil seedbanks, and the effect of litter cover and soil type on the emergence of Sirosa phalaris seedlings.

Grass species, time, and their interaction all had a significant effect ($P < 0.05$) on both dispersal unit and caryopses germination. One month after harvest, germination of caryopses was lower ($P < 0.05$, 2 and 1%, respectively) for Taranna and Bunderra than for Sirosa (79.5%). In March 1993, germination of the 2 wallaby grasses was also lower ($P < 0.05$) than that of Sirosa. Dormancy of freshly harvested seeds of Sirosa was mainly associated with the structures surrounding the caryopses (7.7 v. 79.5% mean germination), but for Taranna and Bunderra it was related to physiological dormancy of the caryopses.

Germination levels that were not significantly different to the maximum occurred for temperature ranges of 35/30–15/10°C [Sirosa (commercial)], 35/25–15/10°C (Australian phalaris), and 35/30–15/05°C (Kangaroo Valley ryegrass). In contrast, maximum germination of wallaby grasses only occurred for Taranna in the temperature range 25/20–20/10°C, and for Bunderra at 25/15 and 20/15°C.

Seedling emergence in the field was episodic, occurring on only 3 occasions from 1993 to 1996. No seedlings of Sirosa phalaris, Demeter tall fescue, or Kangaroo Valley ryegrass were successfully recruited, but Taranna and Bunderra successfully recruited new plants from natural seedfalls. Whereas seed production of the perennial grasses studied was relatively high (~10 000 seed/m2 in 1992), soil seedbank levels were much lower (generally <1000 seeds/m2). These data were used to indicate the likely successful establishment of sown perennial grasses or by regeneration from natural seedfall.

Lodge GM, Gogel BJ, Cullis BR, and Archer KA (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

Studies were conducted on a natural pasture dominated by *Aristida ramosa* (wiregrass) in northern New South Wales. In each of the 4 studies, treatments were designed to reduce wiregrass presence by grazing, using stocking rates up to 12.5–15.0 dry sheep equivalents (dse/ha) in summer and autumn (1983–88), slashing (1984–86), or burning (2 studies, 1985–88; 1986–88) in spring before heavily grazing in summer–autumn. Effects of these treatments on *A. ramosa* dry matter yield and basal cover, *Danthonia linkii* (wallaby grass) basal cover, sheep liveweight change and fleeceweight were measured for the different time periods. Wool quality was determined from mid-side samples taken in 1983–85.

All treatments reduced *A. ramosa* dry matter yield and basal cover and increased *D. linkii* basal cover, compared with control plots continuously grazed at 5 dse/ha. From 1983 to 1988, A. ramosa dry matter yields in the control plots increased from about 1000 to 3500 kg/ha and its basal cover increased from 7 to 13%. In contrast, *A. ramosa* dry matter yields in heavily grazed, and spring burnt and heavily grazed treatments were <500 kg/ha, with basal cover levels of *A. ramosa* <0.3% while those of *D. linkii* were about 5%. Slashing before heavy grazing (1984–86) also reduced *A. ramosa* dry matter yields and basal cover compared with the control, but higher levels of *A. ramosa* (800 kg/ha dry matter, 1% basal cover) remained at the end of these studies.

Heavy grazing of wiregrass led to significant negative liveweight changes, compared with sheep in control plots. Slashing or burning of wiregrass to remove dead material and increase green leaf before grazing at high stocking rates, markedly reduced rates of liveweight decline. Both grazing at high stocking rate and slashing in spring followed by heavy grazing, significantly reduced the amount of wool grown in the spring–winter period and significantly decreased either wool fibre diameter, strength or point-of-break. In the long term, sheep in wiregrass control plots lost more weight than those in treatment plots at equivalent stocking rates. Results suggest that on-farm control strategies based on late winter or spring burning, and heavy summer grazing should reduce the presence of wiregrass in similar pasture system.

Lodge GM, and Orchard BA (2000) Effects of grazing management on Sirosa phalaris herbage mass and persistence in a predominantly summer rainfall environment. Australian Journal of Experimental Agriculture 40:55-169

Herbage mass, plant frequency and basal cover data collected from September 1993 to August 1996 were used to compare the effects of various seasonal closures with continuous grazing on the persistence of Sirosa phalaris (Phalaris aquatica cv. Sirosa) at 3 sites on the North West Slopes of New South Wales. Sites were on-farm and consisted of up to 10 treatments with 2 replicates and treatments were initially imposed in 2 different years. Pastures were either newly sown (3 years old) and grazed by either sheep or cattle, or degraded (14 years old) and grazed by sheep.

Drought conditions prevailed in 1994–95, confounding the interpretation of the importance of treatments that involved long periods of closure, since significant effects could be attributed to both grazing exclusion and the timing of the closure in relation to plant phenology. However, across all sites and years, fitted values for phalaris herbage mass were generally significantly higher than the continuously grazed control in only 2 treatments: spring closure (at 1 site) and an extended spring closure combined with an autumn closure (at all sites). At the end of these studies phalaris herbage mass in spring–autumn closures was 4–32 times higher than the control plots. These results were confirmed by analysis of initial and final plant frequency data. At all sites, no recruitment of Sirosa seedlings occurred in any treatment.

These data support the hypothesis that for increased persistence in a summer rainfall environment Sirosa phalaris requires some form of grazing management that involves the exclusion of grazing in the critical periods of spring and autumn.

Lunt ID (1995) Seed longevity of six native forbs in a closed *Themeda triandra* grassland. Australian Journal of Botany 43:439-449

Seeds of a six native forbs – *Arthropodium strictum* R.Br., *Bulbine bulbosa* (R. Br.) Haw., *Chysocephlum apiculatum* (labill.) Steetz, *Craspedia variabilis* Everett Doust and *Leptorhynchos squamatus* (Labill.) Less. - were sown on and below the soil surface in a closed, native grassland dominated by *Themeda triandra* Forsskal. Replicate seed lots were recovered after 2, 4, 6, 9 and 12 months, and viability was assessed. Less than 7% of the sown surface seeds of *B. bulbosa*, *B. umbellata*, *C. variabilis* and *L. squamatus*, and less than 10% of a buried seeds of *A. strictum*, *B. umbellatum* and *L. squamatus* remained viable after 12 months. Virtually all losses of Liliaceae seeds were due to germination. Fates of Asteraceae seeds were difficult to assess accurately after 6 months, but germination accounted for most seed losses. Burial significantly promoted longevity of *B. bulbosa*, *C. variabilis* and *L. squamatus* seeds. No obvious relationship existed between seed longevity and taxonomic group (Liliaceae versus Asteraceae) or seed mass, for surface or buried seats; the response of the large-seeded lily, *B. bulbosa*, was most similar to that of the small-seeded daisy, *L. squamatus*. Of the six species, *C. apiculatum* appears to have the greatest potential to accumulate a soil seed bank beneath a closed grass canopy, owing to its small seed size, inhibition of germination beneath a closed canopy, both on and below the source surface, and sustained viability of buried seed. Naturally dispersed seeds of the other five species are likely to form smaller, transient or short-term seed banks.

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

The effect of long-term vegetation management on grassy forest remnants in

Gippsland, south-eastern Australia, was examined by comparing the floristic composition of rarely burnt, intermittently grazed, grassy forest remnants with frequently burnt, ungrazed sites (anthropogenic grasslands). Management history was the dominant factor controlling composition, and all frequently burnt sites supported a distinctly different flora from rarely burnt forest remnants. Frequently burnt sites contained many species that were uncommon or absent from the unburnt forest sites, and vice versa. Both vegetation types are assumed to be derived from an original grassy forest flora which contained all recorded native species. It is hypothesised that the imposition of divergent management regimes in different sites has led to an ecological segregation of native species according to their tolerance to prevailing management. The two vegetation types now make important contributions to regional diversity, thereby illustrating the need to maintain a diversity of ecosystem processes to conserve species diversity at a regional level.

Lunt ID (1997) Germinable soil seed banks of anthropogenic native grasslands and grassy forest remnants in temperate south-eastern Australia. Plant Ecology 130:21-34

Soil seed banks of anthropogenic native grassland and grassy forest remnants on the Gippsland Plain in south-eastern Australia were studied using the seedling emergence method. Intact examples of both ecosystems are rare, owing to extensive agricultural development. Both ecosystems are assumed to have been derived since European settlement from the same original, grassy forest ecosystem. It was hypothesised that species now restricted to grassland remnants might persist in the soil seed bank of forest remnants, and vice versa. This hypothesis was not supported. In total, 25554 seedlings of at least 155 species emerged from forest and grassland seed banks collectively. Small-seeded, annual and perennial herbs were most abundant. Forest seedbanks differed substantially in composition from grassland seedbanks, and both essentially contained a subset of the species in the vegetation. Forest seedbanks contained significantly more species and individuals of annual and perennial native dicotyledons than grassland seedbanks. Seedbanks made a major contribution to local diversity, since many species in the seed bank at each quadrat were not recorded from the vegetation, but only a minor contribution to regional diversity. Species in the seedbank that were absent from all vegetation samples were recorded at few quadrats, except Juncus species, which were widespread and abundant in the seedbank. The apparent absence from forest seed banks of species that are best represented in grassland remnants (and vice versa), suggests that there is little opportunity of recruiting grassland-restricted species in forest remnants by instigating grassland management practices.

Lunt ID (1997) A multivariate growth-form analysis of grassland and forest forbs in south-eastern Australia. Australian Journal of Botany 45:691-705

The growth-form composition of grazed and unburnt, grassy forest remnants and ungrazed, frequently burnt, anthropogenic native grasslands in Gippsland, Victoria were compared, using a multivariate, clustering analysis of the growth-form and life-form attributes of 53 forb species. Groups comprising (1) annual forbs, (2) clambering, repent and decumbent perennials, and (3) rosette perennials and rhizomic ground-cover forbs occurred in significantly more forest than grassland quadrats. One group, mostly containing tall erect geophytes with linear basal leaves, occurred in significantly more grassland than forest quadrats. Grassland quadrats contained significantly more tall forbs (> 20 cm) than forest quadrats, whilst forest quadrats contained significantly more forbs of short to medium height (< 20 cm). There was a significant, positive correlation between plant height and frequency of occurrence in grassland quadrats ($r_s = 0.58$, $P < 0.001$), and a significant, although weak, negative correlation in forest quadrats ($r_s = -0.29$, $P < 0.05$). Short forbs are likely to have been depleted from grassland sites owing to competition from the dominant tussock grass, *Themeda triandra* Forsskal. By contrast, ground cover in forest sites is of relatively low stature, biomass and cover, allowing short forbs to persist. The relative paucity of tall forbs from forest remnants is suspected to be at least partly due to intensive stock grazing in the past.

Lunt ID (2002) Grazed, burnt and cleared: how ecologists have studied century-scale vegetation changes in Australia: Century-scale vegetation changes in Australia. Australian Journal of Botany 50:391-407

Ecological studies of century-scale vegetation changes in Australia were quantitatively reviewed by assessing relevant papers according to a range of methodological and environmental attributes. In general, century-scale vegetation dynamics are rarely studied by Australian ecologists. Most studies of century-scale changes are short-term studies with one sampling period, and few long-term experimental studies exist. Century-scale changes are well documented in open forests, grassy woodlands, tussock grasslands and rainforests, but little information is available from lowland heathlands, herblands or hummock grasslands. Tall open forests and rainforests have received the most comprehensive attention. Five major genres of research were recognised from a multivariate analysis of methodological attributes: (1) single-species tree-ring and fire-scar studies; (2) forest dynamics and age-structure studies; (3) floristic degradation studies (usually caused by stock grazing); (4) archival benchmarking studies; and (5) palynological research. These genres tend to focus on different ecosystems and ecosystem attributes, giving incomplete pictures of vegetation changes even in some well-studied ecosystems. In all genres other than forest dynamics studies, century-scale changes are commonly described by comparing present conditions with a pre-European reference point, and few studies have documented successive vegetation changes within the period of European occupation. Considerable opportunity exists to document long-term ecosystem responses to successive disturbances resulting from European disturbance regimes.

Lunt ID (2003) A protocol for integrated management, monitoring, and enhancement of degraded *Themeda triandra* grasslands based on plantings of indicator species. Restoration Ecology 11:223-230

Lowland temperate grasslands dominated by *Themeda triandra* (kangaroo grass) are an endangered ecosystem in southeastern Australia. Grass biomass must be removed frequently to maintain plant diversity, but few studies of the impacts of different biomass removal techniques have been undertaken, and no rapid monitoring schemes have been developed. Low species densities in many reserves (due to past stock grazing) make it difficult to assess the effects of management regimes on plant diversity. Management impacts could be assessed by planting indicator species in replicated enhancement plots and subjecting these plots to adaptive management trials. A protocol for selecting potential indicator species is described, based on a regional quadrat database, using clearly defined criteria. Potential indicator species need to be conspicuous, easy to identify and abundant in high quality diverse grassland remnants, to have relatively broad ecological tolerances, to occur in sites that are relatively species rich and have a comparatively low cover of dominant exotic species, to commonly persist at low densities in long-grazed reserves, to be responsive to changes in management, and to have been studied ecologically. Only three species from western Victorian grasslands satisfied these criteria: *Calocephalus citreus* (lemon beauty-heads), *Chrysocephalum apiculatum* (common everlasting), and *Leptorhynchos squamatus* (scaly buttons). All are widespread, herbaceous, hemicryptophytic daisies. Despite a number of caveats, the scheme has the potential to provide a more clearly focused framework for grassland ecosystem management than currently exists.

Lunt ID and Morgan JW (1999) 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

Changes in the vegetation composition of a remnant *Themeda triandra* grassland in south-eastern Australia were documented following the replacement on stock grazing with intermittent burning at 3-11- year intervals. The vegetation was initially sampled in 1986, one year after stock was removed, and then 10 years later in the 1996. Most frequently encountered grassland species were abundant in both surveys, although there was little correspondence between species richness at the quadrat scale in 1986 and 1996. Total floristic richness increased slightly over the 10-year period, owing to the proliferation of tall forbs with wind-blown seeds, including exotic thistles and colonising native forbs. Unfortunately, most native 'increases' were 'weedy' species which are not typical or common components of species-rich temperate grassland remnants in southern Victoria. Thus, replacing grazing with intermittent burning has not resulted in the flora becoming more similar to that of high-quality, species-rich grassland remnants, but instead, has promoted a group of ruderal colonisers. The ability to identify factors contributing to particular botanical changes was hampered by the design of the management regimes implemented over the past decade. Suggestions are provided to overcome these difficulties, incorporating principles from adaptive management.

Matthew C (2002) Translocation from flowering to daughter tillers in perennial ryegrass (*Lolium perenne* L.). Australian Journal of Agricultural Research 53:21-28

Recent New Zealand cultivars of *Lolium perenne* often have a high rate of tiller death and replacement in late spring–early summer. A majority of the new tillers are daughter tillers of flowering tillers. Previous research has led to a hypothesis that defoliation may influence the amount of assimilate exported by flowering tillers, and hence the rate of daughter tiller formation.

To test this hypothesis, flowering tillers of *L. perenne*(cv. Ellett) were fed 740 kBq 14CO2 in late spring, then subjected to different light levels and defoliation treatments and harvested a month later, with attached daughter tillers, and radiocarbon allocation to and distribution within the daughter tillers determined. Daughter tiller formation from flowering tillers was greatest where seed heads were decapitated at the flag leaf node, and was reduced when the seed head was left intact or when the seed head was removed at ground level. At harvest, approximately 3.5% of recovered radiocarbon was located in daughter tillers. However, due to the smaller size of the daughter tillers, their specific activities were up to 15% of those in the parent tillers. Moreover, leaf segments of daughter tillers, which had been elongation zones at the time of labelling, exhibited localised specific activity approximately 3 times that in the remainder of the daughter tiller. Increased daughter tiller production by flowering tillers decapitated at the flag leaf node was associated with increased radiocarbon recovery from those daughter tillers.

Michalk DL, Dowling PM, Kemp DR, et al (2003) Sustainable grazing systems for the Central Tablelands, New South Wales. Australian Journal of Experimental Agriculture 43:861-874

Pasture degradation is a major issue in the high rainfall zone (>600 mm) of temperate Australia. Characterised by a decline in the perennial grass component, this degradation is responsible for reduced livestock production and implicated in environmental problems, such as dryland salinity, through changed water-use patterns. This paper reports on a multi-disciplinary research program conducted at Carcoar in central New South Wales, one of 6 sites that comprised the Sustainable Grazing Systems National Experiment. The aim of the experiment was to develop more profitable and sustainable pasture systems by evaluating the impact of changes in the perennial grass component on animal production and water-use patterns. Tactical management strategies were evaluated on naturalised and sown perennial grass pastures and on chicory (*Cichorium intybus*), using a Merino ewe-based first cross lamb enterprise. Data presented showed that grazing deferment over summer, combined with reduced stocking rate, increased perenniality and reduced annual grass weeds compared with continuous grazing. Livestock performance, however, did not always follow trends in available perennial herbage mass. Naturalised and sown pastures were suitable for raising prime lambs, but only chicory had the capacity to finish lambs to market specification without supplementation. With respect to water-use patterns, sown perennial pastures were more successful than naturalised pastures in reducing leakage of water from the root zone, although this seemed to be related mostly to the abundance of the perennial grass in the pasture. From a sustainability perspective, continuously grazed pastures generated higher net cash flows, but had negative environmental impacts, whereas tactically grazed pastures had positive on- and off-farm impacts but lower net cash flows. The implications of these findings for incorporation into future management strategies for sustainable production in high rainfall environments are discussed.

Morgan JW (1998) Comparative germination responses of 28 temperate grassland species. Australian Journal of Botany 46:209-219

The comparative germination biology of 28 perennial species native to the temperate grasslands of southern Victoria was tested using a single temperature regime (20/10C) in either constant darkness or 12 h diurnal white-light conditions. This temperature regime was chosen because it corresponds to the temperature found to produce substantial or optimal germination in other germination studies of grassland plants. Four germination attributes—time to the beginning of germination (germination lag), time taken to achieve 50% of final germination (germination speed –t50), percentage germination in diurnal light conditions and percentage germination in continuous darkness—were calculated for each species and correlated to three plant attributes: plant family, life form and seed weight. Germination lag was short for many species: 50% had a lag of less than 7 days, whilst 96% of species had begun germinating within 28 days. Germination speed was moderately fast for most species: 75% of species had a t50 of less than 28 days. Total percentage germination in diurnal light or continuous darkness was variable (0–98%), but many species (64%) germinated readily (> 50%) in at least one treatment. Twenty-four percent of species had germination substantially inhibited by darkness (i.e. *Acaena echinata*, *Bulbine bulbosa*, *Eryngium ovinum*, *Podolepis* sp. aff. jaceoides, *Velleia paradoxa* and *Wahlenbergia luteola*). No species had its germination promoted by darkness. Few correlations between plant and germination attributes were detected. Seed weight was not correlated with any of the three germination attributes, nor was life form or plant family correlated with germination speed or percentage germination in the light or dark. Germination lag, however, was significantly associated with plant family and, in a related way, with life form: species from the Liliaceae (geophytes) took longer to begin germination than species from the Asteraceae (hemicryptophytes). The ecological implications of the observed germination biology on the potential formation of persistent soil seed banks and seedling recruitment dynamics are discussed.

Morgan JW (1998) 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

The effect of grassland gap size on the establishment of five non-clonal perennial forbs, comprising a range of seed masses, was investigated in two *Themeda triandra* Forsskal grasslands by sowing seed in the centre of artificially created 6 cm (36 cm^2) and 18 cm (324 cm^2) wide canopy gaps. Undisturbed vegetation (0 cm gap) was used as a control. Initial seedling establishment and growth in gaps was measured over 24 weeks, as was that of transplanted juvenile plants, and all were related to light availability at ground level. The rate at which natural canopy gaps in grasslands disappear with time since burning was also quantified in a chronosequence study to infer how long gaps persist after disturbance by fire. For four of the five species, relatively few seedlings emerged (< 30% of sown seed germinated), and emergence was largely independent of the effects of gap size, sward structure and seed mass. Only *Plantago gaudichaudii* Barneoud germination was inhibited under a closed sward (0 cm gap). Hence, the presence of vegetation *per se* largely did not affect germination for most species. Survival of seedlings, however, was negatively affected by vegetation, presumably because of low light levels in the small gaps. *Eryngium ovinum* Cunn., *P. gaudichaudii* and *Velleia paradoxa* R.Br. failed to establish in 0 cm gaps in the 3-year-old sward. Gaps in the vegetation, however, enabled all species to survive at low levels in at least one of the grasslands, with survival of seedlings in 18 cm gaps usually greater than that in 6 cm gaps. Survival of transplants was initially high (> 50%) for all species in the 2-year-old sward, but *E. ovinum* and *Senecio macrocarpus* Belcher mortality was substantial in 0 cm gaps in the 3-year-old sward where light levels were lowest (i.e. < 9% of available light). For these species, small gaps are likely to be hostile microsites for establishment at all times. Growth was also affected by gap size, most species positively responding to 18 cm gaps by growing substantially bigger than transplants in 0 cm gaps, particularly in the more shaded 3-year-old sward gaps. The large canopy gaps (i.e. > 300 cm^2) that enable the most effective recruitment in this grassland are rare in the years after fire and constitute only 8–19% of all gaps that are present at 1 and 2 years after burning. By 3 years after fire, canopy gaps are small (< 30 cm^2) and infrequent (< 3 gaps m^{-2}) as a result of rapid recovery of the dominant grass. These small gaps would appear to provide few opportunities for substantial seedling recruitment of many species by this time. If seedling recruitment events are to be optimised for the herbaceous dicotyledons that characterise this community, disturbance to the canopy is required at intervals of 1–3 years. This regime becomes particularly important when other features of the recruitment ecology of this grassland are considered.

Morgan JW and Lunt ID (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

Changes in tussock attributes and sward structure with time-since-fire were documented for the dominant tussock grass, *Themeda triandra*, at the Derrimut Grassland Reserve in southern Victoria, Australia. When the inter-fire interval exceeded 6 yr, the number of tillers per tussock and the total number of tussocks declined, and by 11 yr, few live tillers or tussocks remained in the sward. Below-ground biomass was also substantially lower at this time. With increasing time-since-fire, the canopy of live leaves was elevated high above the soil surface and dead leaves accumulated around and over the tussock bases. Productivity declined in long unburnt areas and by 11 yr without disturbance, the canopy “collapsed” upon itself, forming a thick layer of dead thatch over the soil surface. A single fire in an area previously unburnt for 12 yr did not immediately return the tussocks to a state more characteristic of a site with a 4 yr inter-fire interval burnt at the same time. Inter-fire intervals of =5 yr would appear necessary to maintain the health and competitiveness of *Themeda triandra*. These findings have important implications for the maintenance of faunal habitat and the potential for weed invasion into remnant grasslands.

Orr DM, Paton CJ, and Lisle AT (1997) Using fire to manage species composition in *Heteropogon contortus* (black speargrass) pastures 1. Burning regimes. Australian Journal of Agricultural Research 48:795-802

A reduction in the proportion of the desirable grass *Heteropogon contortus* (black speargrass) and an increase in the undesirable *Aristida* spp . (wiregrasses) are evident in commercially grazed pastures. This paper evaluates the effectiveness of spring burning regimes over a period of 4 years (1989-92) in reversing this form of pasture degradation.

Burning increased the proportion of *H. contortus* when pastures remained ungrazed but not when pastures were grazed, because cattle selectively grazed *H. contortus* after burning. Burning reduced the proportion of *Aristida* spp and other undesirable grasses such as *Bothriochloa decipiens* and *Chloris divaricata*. A strong 'year of burning' effect was evident.

Burning increased recruitment of *H. contortus* which, in turn, increased plant density and later basal area. Burning reduced the basal area of *Aristida* spp initially by reducing tussock size and later by reducing tussock numbers.

Results indicate that spring burning can restore pasture composition and that burning in at least 2 successive years appears to be necessary. Light stocking rates should be adopted so that the proportion of *H. contortus* can be maintained and so that pastures can be burnt when and if required.

Orr DM and Paton CJ (1997) Using fire to manage species composition in *Heteropogon contortus* (black speargrass) pastures 2. Enhancing the effects of fire with grazing management. Australian Journal of Agricultural Research 48:803-810

Burning in spring can increase the proportion of the desirable species *Heteropogon contortus* (black speargrass) when pastures remain ungrazed following burning and to a lesser extent when the pasture is grazed. Consequently, an experiment examined the effects on pasture composition of annual spring burning followed by grazing deferment for 0, 2, 4, or 6 months or for 0 months but at half the stocking rate of the other 4 treatments.

Either deferring grazing for 4 or 6 months or halving the stocking rate after burning in spring resulted in an increase in the proportion of *H. contortus*. Burning reduced the undesirable *Aristida* spp. as a pasture component and this effect occurred independently of grazing treatment.

The development of 2 cohorts of H. contortus seedlings was monitored for 18 months. Seedlings were selectively grazed but developed rapidly with few differences between treatments. Differences in seedling survival between years reflected differences in rainfall after establishment.

Results indicate that burning in spring to increase the proportion of *H. contortus* will be more effective if followed by 4–6 months rest or by reduced grazing pressure.

Pickett STA, Cadenasso ML, Grove JM, et al (2001) Urban ecological systems: Linking terrestrial ecological, physical, and socioeconomic components of metropolitan areas. In: Annual Review of Ecology and Systematics, 32, 1. Annual Reviews, pp 127-157

Ecological studies of terrestrial urban systems have been approached along several kinds of contrasts: ecology in as opposed to ecology of cities; biogeochemical compared to organismal perspectives, land use planning versus biological, and disciplinary versus interdisciplinary. In order to point out how urban ecological studies are poised for significant integration, we review key aspects of these disparate literatures. We emphasize an open definition of urban systems that accounts for the exchanges of material and influence between cities and surrounding landscapes. Research on ecology in urban systems highlights the nature of the physical environment, including urban climate, hydrology, and soils. Biotic research has studied flora, fauna, and vegetation, including trophic effects of wildlife and pets. Unexpected interactions among soil chemistry, leaf litter quality, and exotic invertebrates exemplify the novel kinds of interactions that can occur in urban systems. Vegetation and faunal responses suggest that the configuration of spatial heterogeneity is especially important in urban systems. This insight parallels the concern in the literature on the ecological dimensions of land use planning. The contrasting approach of ecology of cities has used a strategy of biogeochemical budgets, ecological footprints, and summaries of citywide species richness. Contemporary ecosystem approaches have begun to integrate organismal, nutrient, and energetic approaches, and to show the need for understanding the social dimensions of urban ecology. Social structure and the social allocation of natural and institutional resources are subjects that are well understood within social sciences, and that can be readily accommodated in ecosystem models of metropolitan areas. Likewise, the sophisticated understanding of spatial dimensions of social differentiation has parallels with concepts and data on patch dynamics in ecology and sets the stage for comprehensive understanding of urban ecosystems. The linkages are captured in the human ecosystem framework.

Prober SM, Lunt ID, and Thiele KR (2002) Determining reference conditions for management and restoration of temperate grassy woodlands: relationships among trees, topsoils and understorey flora in little-grazed remnants. Australian Journal of Botany 50:687-697

Temperate grassy woodlands were once widespread and dominant in many agricultural regions of south-eastern Australia. Most are now highly degraded and fragmented and exist within a context of broadscale landscape degradation. Greater understanding of natural processes in these woodlands is needed to benchmark management and restoration efforts that are now critical for their ongoing survival.

We studied physical and chemical properties of topsoils from rare, little-grazed remnants of grassy *Eucalyptus albens* Benth. and *E. melliodora* Cunn. ex Schauer woodlands in central New South Wales and examined natural patterns in topsoil properties and understorey flora in relation to trees and canopy gaps. Topsoils were generally low in available macronutrients (nitrogen, phosphorus and sulfur), but were favourable for plant growth in most other measured characteristics. Topsoils beneath trees were notably more fertile than in open areas, particularly in total carbon, total nitrogen, available phosphorus, available potassium and salinity. Higher nutrient concentrations, particularly of available phosphorus, may have contributed to patterns in understorey dominants, with *Themeda australis* (R.Br.) Stapf predominating in open areas and *Poa sieberiana* Spreng. beneath trees. Trees were also associated with a higher native-plant richness, possibly resulting from their influence on the competitive dynamics of the dominant grasses. We discuss the implications of these interactions for the use of burning, grazing and slashing in woodland management and re-establishment of native grasses and trees in restoration efforts.

Prober SM, Thiele KR, and Lunt ID (2002) Identifying ecological barriers to restoration in temperate grassy woodlands: soil changes associated with different degradation states. Australian Journal of Botany 50:699-712

Temperate grassy woodlands were once the dominant vegetation across many agricultural regions of south-eastern Australia, but most of these are now highly degraded and fragmented. Adequate conservation of these woodlands is dependent on successful ecological restoration; however, ecological barriers often limit ecosystem recovery once degrading processes are removed. To help identify these barriers, we used a state and transition framework to compare topsoils of little-disturbed (reference) and variously degraded remnants of grassy *Eucalyptus albens* Benth. and *E. melliodora* Cunn. ex Schauer woodlands. Topsoils of degraded remnants showed a repeated pattern, with the most compacted, most acidic and most depleted topsoils occurring in remnants dominated by *Aristida ramosa* R.Br. or *Austrodanthonia* H.P.Linder and *Austrostipa scabra* (Lindl.) S.W.L.Jacobs & J.Everett; the least compacted and most nutrient rich topsoils in remnants dominated by annual exotics; and generally intermediate topsoils in remnants dominated by *Bothriochloa macra* (Steud.) S.T.Blake or *Austrostipa bigeniculata* (Hughes) S.W.L.Jacobs & J.Everett. Surprisingly, topsoils beneath trees in reference sites (supporting *Poa sieberiana* Spreng.) were similar to topsoils supporting annual exotics for most soil properties. Chemical properties of topsoils from open areas of reference sites [supporting *Themeda australis* (R.Br.) Stapf] were usually intermediate and similar to *Bothriochloa macra* and *Austrostipa bigeniculata* topsoils. The most striking exception to these trends was for soil nitrate, which was extremely low in all reference topsoils and showed a high correlation with annual exotic abundance. We discuss the potential for positive feedbacks between soil nitrogen cycling and understorey composition and the need for intervention to assist possible nitrate-dependent transitions between annual and perennial understorey states. Dominant grasses, trees and annual weed abundance may be useful indicators of soil conditions and could inform selection of target sites, species and techniques for restoration projects.

Quinn JA and Hodgkinson KC (1984) Plasticity and population differences in reproductive characters and resource allocation in *Danthonia caespitosa* (Gramineae). Bulletin of the Torrey Botanical Club 111:19-27

Plasticity and population differences in reproductive characters and resource allocation in *Danthonia caespitosa* (Gramineae). How pronounced can variation in reproductive characters and resource allocation be among latitudinal populations of a widely distributed species? Do different characters show similar patterns of variability? Data to answer such questions were collected in field, transplant garden, glasshouse, and phytotron studies of Danthonia caespitosa Gaud., a perennial grass distributed throughout southern Australia. There were no significant latitudinal patterns in percentage biomass allocation (to leaves, stems, and panicles), and in number and weight of caryopses (seeds) per 10 grams of shoot biomass, in the field; or in number and weight of seeds per spikelet, number of spikelets per panicle, number of seeds per panicle, weight of individual panicles, and mean weight per seed in either field or garden, although there were often significant differences among populations. There were significant latitudinal patterns for number of panicles per 10 grams of shoot biomass in both field and garden and in the garden for percentage of shoot biomass allocated to panicles, and number and weight of seeds per 10 grams of shoot biomass. Measurements under field, garden, and phytron conditions indicated that mean weight per see is a population rather than species character, and that seed weight is as variable and plastic as the other reproductive characters. Phenotypic flexibility differed among populations, and the various characters showed strikingly different patterns of variability among populations. The predictability of character patterns from theory or prior studies was less than 50 per cent.

Read TR and Bellairs SM (1999) Smoke affects the germination of native grasses of New South Wales. Australian Journal of Botany 47:563-576

The germination responses to plant-derived smoke of seeds of 20 native grass species from New South Wales, Australia, were tested under laboratory conditions. The species belonged to 14 genera including *Bothriochloa*, *Chloris*, *Cymbopogon*, *Danthonia*, *Dichanthium*, *Digitaria*, *Eragrostis*, *Eriochloa*, *Microlaena*, *Panicum*, *Paspalidium*, *Poa*, *Stipa* and *Themeda*. The interaction between smoke and husk-imposed dormancy was examined by removing the floral structures surrounding the seeds, when sufficient seeds were available. Smoke was shown to be an important environmental stimulus for breaking the dormancy of native grasses; however, the response differed considerably between different genera and between species of the same genus. For almost half of the species, smoke significantly increased the germination percentage. *Panicum decompositum* showed the greatest response, with germination increasing from 7.7 to 63.1% when smoke was applied. *Panicum effusum* had no germination in the absence of smoke, but 16.7% germination when smoke was applied. *Stipa scabra* subsp. scabra had germination significantly reduced by smoke from 30.2 to 19.9%. Five species had their germination rate, but not the final germination percentage, affected by smoke, and a third of the species were unaffected by smoke. For five of the species, *Chloris ventricosa*, *Dichanthium sericeum*, *Panicum decompositum*, *Poa labillardieri* and *Stipa scabra* subsp. falcata, this is the first report of a smoke-stimulated germination response. For those species with germination promoted by smoke, retention of the covering structures did not prevent smoke stimulation of germination. Sowing smoke- treated husked seeds is likely to be preferable as it would still promote greater germination, whereas dehusking seeds can result in the seeds being more susceptible to desiccation and fungal attack in the field. It is suggested that other grassland communities that respond to pyric conditions may also contain species that respond to smoke.

Sharpe S (1997) Diversity, patterns and processes of vegetation and invertebrate orders in natural temperate grassland in the Australian Capital Territory. Diss. Applied Ecology Group, University of Canberra, p 135

The study aimed to gain understanding about diversity, patterns and processes in natural temperate grassland sites in the ACT. Thirty natural grasslands sites were surveyed for plant composition, soil invertebrate abundance and site attributes. Floristic associations were identified using multivariate analysis. These were compared to the other site attributes to determine related characteristics.

Total plant species richness was 191 species, of which 41 % were exotics. Forbes comprised 56 % of the total species, with 69 native formed species. There were 10 native grass species and 12 sub-shrubs record. The number of species found within 10 1 m 2 quadrates measured in each site ranged from a 23 to 56 species.

Three floristic associations were identified through classification analysis using frequency data. The *Danthonia* association occurred in well-drained sites on soils with a high clay content and low nutrient levels and a greater percentage of bare ground. The sites were assessed as having been subject to moderate to high disturbance in the past and 46% were grazed and 46% mown. Species richness of both natives and exotics was high (quadrat richness averaged 37 species, with a 32.8% exotic cover in spring). The Wet *Themeda* association occurred in poorly drained sites and had also been subject to moderate to high disturbance; 67% of sites were grazed and 25% mown. Phosphorus levels were higher in the sites and the acidity of the soil was also greater. Quadrat richness averaged 39 species, with 35.5% exotic cover in spring. The Dry *Themeda* association was well drained. These sites had a lower native and exotic diversity, with a mean quadrat richness of 30 species, and 11.1% exotic species cover in spring, but a high species richness in the sites (and mean 65.4 species) and a high litter cover of and 39.95. All have been subject to low disturbance and none were grazed. Phosphorus levels were low (7.9 ppm). Wet *Themeda* grassland sites were more similar to *Danthonia* grassland sites in terms of species occurrence and frequency than dry *Themeda* grasslands, despite both associations been dominated by *Themeda australis*. While trends emerged regarding management and disturbance levels in the three associations, these were not major differentiating attributes.

Invertebrates were collected from soil samples from the sites and identified to order level. Twenty two orders were found, but only three orders, Acarina, Collembola and Coleoptera, were sufficiently abundant to enable statistical tests to be undertaken. Invertebrate order richness and abundance showed strong relationships with vegetation attributes that measured or reflected vegetation structure, with higher abundance in sites dominated by *T. australis* and where wet soil colour was darker. Both order richness and total abundance of invertebrates were highest in mown sites and lowest in grazed site. The invertebrate ordered richness and abundance did not have significant relationships with that the floristic associations.

A field experiment was conducted in which above - and below-ground gaps were created using the herbicide, Glyphosate, to remove interspecific competition and comparing responses between the Dry *Themeda* and *Danthonia* associations. Litter load and store disturbance were also manipulated. The subsequent establishment of species was studied over two growing seasons, a period of 18 months. Both native and exotic forb richness and cover increased as a result of gap formation. Exotic grass cover and richness showed a strong increase in the first season, but after 18 months had decreased to a level similar to those prior to the application of treatments. Native grasses had not recovered to pre-treatment levels after 18 months. Native forb richness and cover were not inhibited by litter retention, but exotic forb richness and cover were higher in treatments with litter removal. Soil disturbance to a depth of 20 mm had no significant effect on the recruitment of the species.

Recommendations for protection and management of the sites were developed from the study. Conservation recommendations are based on the aim of maintaining or enhancing native species diversity and habitat, while protecting threatened species and their habitat. Management plans should recognise requirements based on the floristic associations, diversity of native species, drainage conditions and retention of the invertebrate habitat, including structural requirements. Grazing should be retained as a viable management regime, particularly in sites where small species occur. Future research should aim towards a greater understanding of the effects of management on species diversity, including invertebrates, and including a monitoring component with which to determine if the management actions should be modified.

Sindel BM, Davidson SJ, Kilby MJ, and Groves RH (1993) Germination and establishment of *Themeda triandra* (Kangaroo Grass) as affected by soil and seed characteristics. Australian Journal of Botany 41:105-117

The seed supply of *Themeda triandra*, syn. *T. australis* (kangaroo grass), for revegetation purposes may always be limited given the biological constraints on its production. It is important, therefore, that available seed be used efficiently by maximising germination and establishment. In two glasshouse experiments, we investigated the effects of various soil and seed factors and their interactions on germination and establishment of seeds sown on the soil surface and at depth. Maximum germination was achieved by either de-awning seeds and burying them manually at 1 cm depth or by sowing awned seeds on the soil surface in the vicinity of cracks or stones which allowed up to 96% of the seeds to bury themselves by natural means. Diurnal fluctuations in relative humidity of only 30% caused the 4-6 cm long geniculate awns to twist hygroscopically, thereby propelling the seeds along the soil surface and increasing their chances of becoming buried in favourable or 'safe' microsites for germination. A bitumen-coated straw mulch improved germination of de-awned seeds by maintaining high moisture content in the top 2 cm of soil, but inhibited the movement of awned seeds along the soil surface and their entry into safe microsites for germination. The data are discussed in terms of maximising germination and seedling establishment of *Themeda*, determining the most appropriate seed harvesting and cleaning methods, and selecting sowing methods which are most likely to be effective.

Singh DK, Bird PR, and Saul GR (2003) Maximising the use of soil water by herbaceous species in the high rainfall zone of southern Australia: a review. Australian Journal of Agricultural Research 54:677-691

The planting of deep-rooted pasture species, herbaceous shrubs, and trees has been widely recommended to reduce deep drainage and recharge to the groundwater in the high rainfall zone (HRZ). However, in more recent years, the value of perennial pastures to reduce recharge has been questioned in areas with >600 mm annual rainfall. Currently, pastures dominated by annual species with relatively low productivity occur across much of the HRZ where deep drainage is most likely contributing to recharge. This review outlines our current understanding of water use by various herbaceous species, and indicates ways in which their water use may be increased in the HRZ of southern Australia.

To reduce deep drainage in the HRZ, the soil water deficit must be increased prior to the opening autumn rains. This will allow a greater storage of water before any potential deep drainage occurs. There are two ways that this can be achieved with the use of herbaceous species. Firstly, change to or encourage species that use more water annually. Although plants with deeper root systems including lucerne have the ability to dry the soil to depth, a combination of winter- and summer-active species, rotational grazing, and pasture spelling would extend the active growing season and soil water use of annual and perennial species. A second option is to increase the productivity of the pasture, as there is a direct link between growth and water use. For example, improving pasture productivity by 50%, say from 8 to 12 t dry matter/ha, could use (transpire) approximately 160 mm more water annually by a C3 species, irrespective of evaporation from the soil surface or evaporative demand factors. This is supported by strong correlations between plant dry mass and water use among a wide range of C3 and C4 plants of diverse growth form and habitat. This relationship appears to have been overlooked in recent studies of various components of the soil water balance model, possibly due to limited and unreliable estimates of evapotranspiration (ET). An improved relationship between 'estimated' ET and measured dry matter production should improve the capability of the soil water balance model to predict deep drainage, which is primarily dependent on the ET. Ways to increase pasture productivity and soil water use include regular applications of fertiliser and lime, and better management of waterlogged and acidic soils in the HRZ. Summer-active native species may also be useful on soils where the persistence of other deep-rooted perennials is poor; however, little is known about their productivity and persistence when heavily grazed.

We believe that the relationship between water use and pasture production needs to be reassessed to improve the predictability of the soil water balance approach and recommend further research in both the field and under controlled conditions to determine the potential for increased water use in the HRZ of southern Australia by combinations of plant species and greater pasture productivity.

Stafford JL (1991) Techniques for the establishment of kangaroo grass in South Australian conservation reserves. Plant protection Quarterly 6(3):120-122

A successful direct seeding technique for kangaroo grass (*Themeda triandra* Forsskal) has been developed after field trials in South Australia. The technique involves cutting *Themeda* culms at the commencement of seed shedding in December and immediately broadcasting them over the seeding site. Germination is triggered nine months later by applying herbicides to weed growth and burning the vegetation as soon as it has cured. *Themeda* seedlings emerging in October usually thrive in the warm moist, undisturbed soil. The simple method is suitable for re-establishment of *Themeda* on both arable and non-arable land and requires only basic equipment.

Virgona JM, Avery AL, Graham JF, and Orchard BA (2000) Effects of grazing management on phalaris herbage mass and persistence in summer-dry environments. Australian Journal of Experimental Agriculture 40:174-184

Grazing management strategies that included resting or intensely utilising pasture on a seasonal basis were compared for their effects on phalaris production and plant frequency (persistence). Experiments were established at 4 on-farm sites (Cootamundra ‘old’, Cootamundra ‘new’, Springhurst and Cavendish) in southern New South Wales and Victoria that had previously been sown to phalaris and were grazed by sheep. At each site, 8 core treatments and extra locally determined treatments were initially imposed in 1993–94 on 2 spatial replicates. In order to determine and describe any year of start effects, treatments were applied again in 1994–95 to plots that had been maintained as controls. The phalaris component of the pastures varied from a minor component to the dominant component depending on site (11–54%). Measurements of botanical composition, available herbage and plant frequency were made between September 1993 and September 1996.

Of the core treatments, autumn closure (Cootamundra old and new), winter closure and grazing between defined levels of available herbage (mob stocking) during autumn–winter (Cootamundra old and new, Springhurst), were the most effective in either maintaining or increasing phalaris herbage mass compared to the continually grazed control treatment. In addition, the frequency of phalaris was higher than the control at each of these sites for the autumn–winter mob stocking treatment. These treatments had no effect at the Cavendish site where phalaris was a minor component of the pasture. Rotational grazing, imposed at 2 of the sites (Cavendish and Cootamundra new), led to an increase in phalaris herbage mass compared to continual grazing. A further treatment aimed at encouraging phalaris seedling recruitment by using an extended spring rest until seed fall in summer followed by a rest after the autumn break was imposed at the Cootamundra old site. This treatment increased phalaris herbage mass but did not result in seedling recruitment.

The results emphasise the need for periods of rest when buds are regenerating and tillers developing over the autumn–winter period for phalaris pastures in summer-dry environments.

Willis AJ and Groves RH (1991) Temperature and light effects on the germination of seven native forbs. Australian Journal of Botany 39:219-228

Seeds of seven native herbaceous species common in natural grasslands and woodlands of south-eastern Australia (including Canberra) were tested for germination over a range of alternating temperatures (15/5-35/25-degrees-C) with and without light. Seeds were also exposed to low (4-degrees-C) and high (50/40-degrees-C) temperatures and the addition of gibberellic acid. Tests were conducted on seeds stored for 0-15 months at room temperature.

The optimum temperature for germination differed among species, with only *Helipterum albicans* germinating maximally over all temperatures. Germination of *Bulbine bulbosa* seed was the most strongly temperature-dependent. Light and cold treatments promoted germination in *Helipterum albicans* and *Vittadinia muelleri* only. Short-term dormancy (3-4 months) was shown to occur in fresh seeds of *Stylidium graminifolium*, *Helichrysum apiculatum* and *Wahlenbergia stricia*, but not in seeds of the other species; addition of gibberellic acid to seeds of the two last-named species did not overcome that dormancy. Seeds of all species remained germinable after 15 months of storage. Seeds of most species germinated maximally at 20/10-degrees-C. Storage at high alternating temperatures for 1 month inhibited subsequent germination at 30/20-degrees in *Leptorhynchos squamatus* and *S. graminifolium* but increased it in *V. muelleri*, *H. albicans* and *H. apiculatum*. In the last species, exposure of 1-month-old seeds to high temperature broke dormancy. These results show that germination and dormancy of seeds of a range of native forbs vary with temperature and light regime.

Wilson AD and Hodgkinson KC (1991) The response of grasses to grazing and its implications for the management of native grasslands. In: Dowling P and Garden D (eds.), Native Grass Workshop Proceedings. Melbourne, Australian Wool Corporation, pp 47-57

In this review paper six principles of grazing management are proposed. They are not complete and best apply to semi arid environments.
1. Stocking rate (or grazing pressure) is the most important management variable.
2. The essence of grazing systems is the proper timing of resting to favour desirable

species, or grazing to inhibit undesirable species.
3. Grazing systems are applied for the benefit of the forage plants rather than the livestock. They reduce animal production unless there is a desirable changed in botanical composition.
4. Pastures containing mixtures of desirable and undesirable species provide the best opportunities for grazing.
5. Grazing management should be integrated with other management options, particularly with five.
6. Changes in botanical composition may take a number of years to show advantage, particularly arid areas where germination and establishment is irregular.