CHAPTER ONE

General introduction

Grassland characterised by slender rat's tail fescue (*Sporobolus creber*) east of Armidale

1.1 INTRODUCTION

Native grassy ecosystems and grassy woodlands are amongst the most threatened ecosystems in Australia (Benson 1996; Williams and Cary 2001) due to extensive and ongoing agricultural use since European settlement (Benson 1996). There is often an incompatible relationship between landholders' management goals and related biodiversity conservation, particularly in relation to grassy ecosystems or ground-storey vegetation. Usually landholders want to increase production by increasing stocking rates, application of fertiliser and planting of pastures, which often leads to a loss of biodiversity of native ground-storey vegetation (Moore 1970; Lodge and Whalley 1989; Garden and Dowling 1995; Garden *et al.* 1996). Improving the conservation of biodiversity in grassy vegetation in temperate Australia requires an understanding of the effects of past and current agricultural management and the balance between sustainable production and the protection of grassland biodiversity (Watkinson and Ormerod 2001). Raising the profile of grassy ecosystems in relation to ecological values (Williams and Cary 2001), issues related to the conservation of their diversity, and understanding of how management influences diversity are all imperative for its ongoing preservation (McIntyre *et al.* 2003).

Similarities exist between the grazing industries on the Northern Tablelands of NSW and those of south-eastern Australia, but native and natural pastures are more prominent than further south (Reseigh *et al.* 2003). Some native pastures in the region have been developed for agriculture (Morgan and Terry 1999), through the addition of fertiliser to native pastures or replacement by fertilised sown pastures (Reid *et al.* 1997; Morgan and Terry 1999; Reseigh *et al.* 2003). However, the benefits of operating a low input system utilising native pasture (Lodge 1994; Jones 1995), associated with greater awareness of responsibility for the environment (Curtis *et al.* 1995), has led to greater interest and research in combining diversity and agricultural production.

Research into the influence of grazing on ground-storey diversity in the region has generally that increasing intensity of grazing leads to a decline in native species richness and changes species composition (Lodge and Whalley 1989; McIntyre and Lavorel 1994a; Waters 2001; Clarke 2003; Reseigh *et al.* 2003). The influences of fertiliser application on native ground-storey species have not been as extensively researched and generally have been conducted in glasshouse or small plot trials (Robinson 1976; Robinson and Dowling

1976; Taylor *et al.* 1985). This has led to greater awareness of the responses of some native grass species to fertiliser. The implications of sowing a pasture on the diversity of native ground-storey vegetation in the region are unknown, although it is widely recognised that many sown pastures decline, lose productivity and are colonised by weeds or recolonised by native species (Hutchinson 1992; Hutchinson 1997; Reid *et al.* 1997; Scott 1997). Generally increasing intensity of agricultural management in the region has led to the loss or decline of some species (Lodge and Whalley 1989; McIntyre and Lavorel 1994b; Nadolny 1998; Clarke 2003; Reseigh *et al.* 2003), but moderate intensity has favoured other natives (such as *Bothriochloa macra, Sporobolus creber* and *Eragrostis* species) (Lodge and Whalley 1989).

1.2 LITERATURE REVIEW

The aim of the literature review is to define terminology associated with grassy ecosystems; review theory on species diversity, composition and disturbance; review temperate grassy ecosystems and their conservation; and the management and environmental variables that influence grassy ecosystems.

1.2.1 Terminology

With the increasing interest in native grassy ecosystems and pastures for agricultural purposes and conservation, there is a need to define terminology. The terms pasture and grassland are used interchangeably in this thesis, although pastures are generally used for livestock production while grassy ecosystems need not be. The *Native Vegetation Conservation Act 1997* (NSW) and the *Native Vegetation Act 2003* (NSW) which have defined native groundcover as that in which more than 50% of the cover is comprised of native species. Another term frequently used is that of 'naturalised' grassy ecosystems (Lodge and Whalley 1989) which refers to pastures in which have non-native species such as *Bromus*[1] species, *Vulpia* species and *Hordeum* species have colonised.

[1] Botanical nomenclature follows Harden (1993 a, b, 2000 and 2002) and Wheeler *et al.* (2002).

1.2.2 Species diversity and composition

Species diversity is made up of two concepts: species richness (McIntosh 1967) and evenness (Lloyd and Ghelardi 1964). These attributes of biological communities can be measured in many different ways. In order to measure species diversity of a community a number of assumptions are made (Krebs 1999). Assumptions summarised by Krebs (1999) include that there is a clear taxonomic classification of the subject matter (ground-storey species are well described for not only the study region but for Australia in general); an estimate of species importance in the community is made; that the collection environment is well described; and that species are all equally different. This last assumption, while not strictly true, tends to be generally disregarded in most studies (Krebs 1999).

Species diversity and composition play a critical role in the dynamics and functioning of ecosystems (Tilman 1990b; Tilman *et al.* 1997; Tilman 2000). Ecological process are driven by organisms, and their individual species traits can have large impacts on ecosystem processes (Tilman 1990b). Evidence suggests that greater diversity leads to greater productivity in plant communities that include grasslands (Tilman 1990a; Tilman *et al.* 1997). Tilman *et al.* (1997). Greater diversity may result in greater nutrient retention and greater ecosystem stability with some evidence suggesting communities become less susceptible to invasion from weeds (Tilman 1990b).

Patterns of diversity or plant composition are maintained by interactions of particular environmental constraints and species trade-offs (Tilman 1984; Sheil 1999), but communities can differ because of dispersal and mortality (Tilman 1994). Connell (1978) states that the species composition of communities is seldom in a state of equilibrium and that high diversity if maintained only when the species composition is continually changing.

1.2.3 Disturbance

Ecological communities are non-uniform, continually alter and are subject to random change, such that species composition of communities is seldom in a state of equilibrium and that high diversity if maintained only when the species composition is continually changing (Connell 1978).

Disturbance is defined by Begon *et al.* (1996) as "any relatively discrete event in time that removes organisms or otherwise disrupts the community by influencing the availability of space or food resources, or by changing the physical environment." Vegetation can be effected by several disturbances, and often these interact to effect vegetation (Collins and Barber 1985).

Theory predicts that maximum species diversity is achieved with intermediate levels of disturbance (Grime 1973; Connell 1978), as small scale disturbances do not effect the equilibrium sufficiently to allow establishment by colonising species and large scale disturbances perturb the environment so that all but the most tolerant species persist (Collins and Barber 1985).

Alternative theories to the intermediate disturbance hypothesis have been proposed including the spatial competition theory and the spatially heterogeneous habitat theory (see Tilman 1994). Spatial competition theory claims that diversity is maintained without large scale disturbance, rather through the plant by plant replacement of species which are limited and competing for a single resource in homogenous habitats (Tilman 1994).

In spatially heterogeneous habitats, heterogeneity allows coexistence. Tilman (1984) states that this mechanism has several other implications which are: plants are separated along edaphic gradients (Tilman 1994); the number of species coexisting in a habitat should be an increasing function of the amount of spatial heterogeneity in the habitat; and maximal biodiversity should be found in moderately productive habitats that have the greatest effective spatial heterogeneity (Tilman 1984).

Natural disturbances in grasslands have had an important role in the development of grassland vegetation, Collins and Barber (1985) grouped these disturbances into distinct three general categories: climatic, fire and biotic. These influences vary in scale, size, frequency and intensity (Collins and Barber 1985; Collins 1989). In grasslands these disturbances may in fact act together influencing both diversity and composition (Anderson 1982).

It is likely that the ground-storey vegetation of the Northern Tablelands is effected by several interacting disturbances as described by Collins and Barber (1985), following the increasing evidence that biotic and abiotic factors play important roles in maintaining not only diversity but also composition and structure in grasslands (Collins and Barber 1985).

1.2.4 Temperate grassy ecosystems

Natural grassy ecosystems occur extensively around the world and cover 27% of the earth's surface (UNEP 2002). Temperate grassy ecosystems include the steppes of Eurasia, the prairies of North America, the pampas of South America and the veld of South Africa, New Zealand and Australia (Watkinson and Ormerod 2001). Ecosystems with a grassy understorey range from forests to natural grassy ecosystems and once characterised most of inland south-eastern Australia. The vegetation west of the Great Dividing Range and NSW tablelands was dominated by woodlands (Sivertsen and Clarke 1999; Hamilton 2001), while areas of natural grassland existed on the tablelands, slopes and plains of New South Wales, the plains and Wimmera district of Victoria, south-eastern South Australia and the Tasmanian Midlands (Eddy *et al.* 1998; Hamilton 2001). In Australia, large areas of secondary grassland, which have been derived after the removal or dieback of the woody vegetation, contain elements of the original ground-storey vegetation. The nature and use of grassy ecosystems in Australia and elsewhere has changed considerably, but they continue to play an important role in flora and fauna conservation. Animals such as the Plains Wanderer (*Pedionomus torquatus*) in northern Victoria (Birds Australia 2000) or the mammals of the African savannas (Caro 1999).

Grassy ecosystems in Victoria, South Australia and southern NSW are highly fragmented and modified, and are among Australia's most threatened and poorly conserved ecosystems (Lunt 1991; Kemp 2002). In northern and western NSW where grazing is the predominant land use, the ground-storey vegetation remains dominated by native grasses (Lodge *et al.* 1984), except where pastures have been sown. This ground-storey vegetation has often been derived by the removal of trees (Benson 1996).

A variety of agricultural management practices threaten the integrity of the species composition of native grassy ecosystems. Cultivation and replacement by crops and pastures; the application of fertiliser to increase production; grazing of domestic livestock; thinning or removal of woody vegetation, and the establishment of introduced species have all contributed to widespread change in the species composition and abundance of grassy ecosystems (Lodge and Whalley 1989; Leigh 1990; Watkinson and Ormerod 2001).

The production value of grassy ecosystems has generally been taken for granted (Leigh 1990) and it is only recently that their inherent value in Australia has been recognised by landholders (e.g. Seis 2000; Wright and Wright 2000), agronomists (e.g. Simpson 2000) and conservationists (e.g. Duncan and Jarman 1993; Tscharke 2000; Windsor 2000) alike. This is reflected in the literature over the last two decades. Grassy ecosystems in Australia that have been studied include those occurring in small reserves and railway lines of south-eastern Australia (e.g. Lunt 1990; Prober and Thiele 1993, 1995; Lunt 1997; Prober *et al.* 2002a; Prober *et al.* 2002b), the Northern Tablelands of NSW (e.g. McIntyre *et al.* 1993; Trèmont 1993; McIntyre *et al.* 1995; Trèmont and Whalley 1995; Chilcott *et al.* 1997; Reseigh *et al.* 2003), central and south-eastern Queensland (e.g. Neldner *et al.* 1997; Fensham *et al.* 1999; McIntyre and Lavorel 2001) and the grassy ecosystems of tropical Northern Australia (e.g. Neldner *et al.* 1997; Woinarski *et al.* 2002; Woinarski and Ash 2002).

1.2.5 Grassland conservation

The suitability of grassy ecosystems for human settlement and use has often led to their modification for agriculture such that little remains in its natural state (Henwood 1998), and even smaller areas are preserved (ICUN 1994). Less than 1% of the world's temperate grassy ecosystems are protected in reserves (ICUN 1994). World wide recognition of the value of grassy ecosystems, and that the ecological community requires protection, is limited (Henwood 1998).

The prairie and plains grassy ecosystems of North America have undergone development (Henwood 1998) the improvement of pastures for sheep and cattle production and the planting of cereal crops. Less than 0.1% of the original grassy ecosystems remain in a natural state (Henwood 1998). This has led to the listing of North American prairie grassy ecosystems as the most endangered ecosystem in the continent (Henwood 1998). Elsewhere in the world (western North America, western Canada, Argentina, central and eastern Europe, and Australia), grassy ecosystems has undergone similar exploitation. Modification of grassy ecosystems in northern Eurasia, eastern Asia and South Africa has not been as significant, with estimates of 11% to 45% of lower elevation grassy ecosystems remaining in South Africa. In south-eastern Australia, the native grassy ecosystems have been replaced by cereal crops and introduced pastures for sheep and cattle (Henwood 1998). The grassy ecosystems and grassy woodlands of Victoria, South Australia and southern NSW are highly fragmented and modified, and are among Australia's most threatened and poorly conserved ecosystems (Edwards *et al.* 2000a; Kemp 2002).

1.2.6 Management impacts

Various management practices associated with agriculture influence the species richness and composition of ground-storey vegetation. Grazing by domestic livestock in Australia is usually by two classes of livestock: sheep and cattle or a combination of the two. The grazing pressure of these classes of domestic livestock can be equated by using the measure dry sheep equivalents (DSE). However, little is understood about management influences on the evenness of ground-storey vegetation.

Relationships associated with changes in continuous grazing and fertiliser management from the pre-European grassy vegetation are generally described for dominant grass species in the study region and the Northern Slopes of NSW (Lodge and Whalley 1989; Whalley 1994). Characteristic pre-European warm season perennial native grassy ecosystems of species such as *Themeda australis, Sorghum leiocladum* and *Cymbopogon refractus* have changed in composition to short warm-season perennial native grassy ecosystems which include the native species *Bothriochloa macra, Sporobolus creber* and native *Eragrostis* species with continuous grazing and fertiliser application. Heavy summer grazing and with or without fertiliser addition further changed composition to grassy ecosystems of *Microlaena stipoides*, *Austrodanthonia* and *Dichelachne* species (Lodge and Whalley 1989).

Grazing

The primary use of grassy ecosystems worldwide is for the grazing of domestic livestock. Grazing by domestic livestock is a major factor influencing the composition of natural communities and the relative abundance of species in pastures (Collins and Barber 1985; Collins 1987; Lodge and Whalley 1989; Noy-Meir *et al.* 1989; Puerto *et al.* 1990; Wilson and Hodgkinson 1990; Pettit *et al.* 1995). Grazing pressure in grassy ecosystems is often uneven (Collins 1987; Bakker 1998), as the selective nature of grazing by livestock, and the associated defoliation and trampling of vegetation differently affects discourages the survival and growth of some plants (Collins 1987; Bakker 1998). In general, composition changes from grazing result in some species (usually palatable grasses and herbs) declining, while other species increase, based on their ability to cope with grazing or that they are ungrazed (usually unpalatable grasses and forbs) (Collins 1987). Grazing particularly affects plants which have regenerative tissues or a large proportion of their foliage above ground level, plants with vertically oriented foliage (Milchunas and Lauenroth 1993; Trèmont 1994), and plants which store reserves for recovery from grazing in sections of the plant subject to defoliation (Garden and Dowling 1995).

Studies investigating changes in grassy ecosystems total species richness as a result of livestock grazing have recorded mixed results. Decreases in total species richness (Collins and Barber 1985; Collins 1987; Chaneton and Facelli 1991; Pettit *et al.* 1995) are generally a result of heavy grazing, as only few species are resistant to severe defoliation. Conversely increases in grassy ecosystems species richness have been recorded (Puerto *et al.* 1990; Noy-Meir 1995) generally only in light or moderately grazed grassy ecosystems, as herbivores alter the dominance structure of ground-storey vegetation, favouring less competitive species and enabling species invasion into gaps.

Comparisons of ungrazed and grazed grassy ecosystems often report lower species diversity in ungrazed areas compared to livestock grazed areas (e.g. Collins and Barber 1985; Puerto *et al.* 1990; Wilson and Hodgkinson 1990; Montalvo *et al.* 1993; McIntyre and Lavorel 1994a; Noy-Meir 1995; Pettit *et al.* 1995; Prober and Thiele 1995; Stohlgren *et al.* 1999; Clarke 2003; Reseigh *et al.* 2003). The reduced number of species in ungrazed areas is generally attributed to litter build up resulting in the suppression of species, especially small forbs, or due to competitive exclusion by dominant species. However, exceptions occur where very heavy grazing or disturbance from some other source such as small mammals results in higher species richness in the ungrazed areas (Jones 2003). Few details are known about the relationship between the species diversity of pastures and different types of grazing management as information in biodiversity experiments are seldom conducted in grazed pasture systems (Kemp *et al.* 2003a).

Grazing has many facets which influence grassland diversity, including grazing intensity, timing of grazing and the type of grazing animals. Grazing outcomes may be difficult to predict, as the grazing variables have differing, and sometimes opposing, influences on grassland diversity.

Continuous grazing

Continuous grazing is defined in this thesis as stocking at a consistent density[2] or 'rate[3]' throughout the year, whether or not by the same animals (adapted from FitzGerald 2000). Sometimes continuously grazed paddocks have to be spelled to allow the pastures to recover but this is not planned in advance. Subdivision by fencing is usually into paddocks for the one or more of the following reasons: allowing stock to be mustered; separating classes of livestock; enable pasture management activities; and prevent heavy grazing of different parts of the property (Andrews 1997). A continuous grazing regime allows livestock behaviour to form distinct patterns in the landscape, with merino sheep developing piospheres in rangelands (Lange 1969) and camps usually in the highest part of the paddock in higher rainfall areas (Taylor *et al.* 1984; Curtis and Wright 1993). Development of sheep camps can be undesirable because a small part of the paddock receives a large input of nutrients from dung and urine, resulting in increased fertility and an abundance of weedy species such as nettles, couch and thistles, while the rest of the paddock is depleted (Taylor *et al.* 1984; Taylor *et al.* 1987; Curtis and Wright 1993).

Lodge and Roberts (1979) and Lodge and Whalley (1983) found little evidence of change in the botanical composition of pastures on the North-west Slopes of NSW when grazed at low stocking densities. In contrast, Lunt (1991) concluded that continuous grazing at low densities may have a major impact on grassland flora. In southern Australia as grazing

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[2] Stocking density: the number of dry sheep equivalents (DSE) in a paddock at any one instant Savory (1999) and FitzGerald (2000).

[3] Stocking rate: the total number of dry sheep equivalents run per hectare (DSE/ha) on a farm or paddock averaged over a calendar year FitzGerald (2000).

pressure increases, tall, native perennial grasses such as kangaroo grass (*Themeda australis*) and blue grass (*Dichanthium* species) tend to be replaced by small tussock-grasses such as spear grass (*Austrostipa* species) and wallaby grass (*Austrodanthonia* species) at moderate grazing pressure, and by introduced annual grasses and herbs at high grazing pressure (Moore 1962, 1964; Lunt 1991). On the Northern Tablelands of NSW, specific changes associated with heavy continuous grazing are from tall, warm season perennial native grasses such as *T. australis,* native sorghum *(Sorghum leiocladum)* and barbed wire grass (*Cymbopogon refractus*) to short warm-season perennial native grasses including *Bothriochloa macra, Sporobolus creber* and native *Eragrostis* species (Lodge and Whalley 1989).

Planned rest grazing

Planned rest grazing is defined in this thesis as a grazing regime that involves planned periods of grazing followed by regular planned rest, and encompasses rotational[4] and cell[5] grazing. According to Parsons (1995), it is the holistic approach that sets planned rest grazing apart from other systems based on a single factor or reductionist approach, and that the principles used in planned rest grazing cannot be viewed in isolation from ecological, economic, human and livestock considerations. Many advantages are claimed for planned rest systems, including better weed control, improved pasture utilisation, increased root development and soil biological activity, disruption of sheep camping behaviour and improved nutrient redistribution, easier stock handling, a remedy for pasture deterioration due to patch grazing, and early recognition of stock health problems (Hutchinson 1993; Earl and Jones 1996; Andrews 1997; Teague and Dowhower 2003).

The effects of planned rest grazing on species richness and composition are not well understood in Australia or elsewhere. Generally studies have tended to have an agronomic or production focus on the composition of desirable and undesirable species and on defoliation rather than an ecological focus on species richness or species composition. Brougham (1960) stated that planned rest grazing of New Zealand pastures led to

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[4] Rotational grazing: "A paddock is not set stocked continuously but grazed and rested regularly either on a set calendar schedule or intermittently as needed." (Fitzgerald 2000).

[5] Cell grazing: "Grazing animals within a 'cell' consisting of a large number of paddocks of a size which permits a high stocking density to be applied to each paddock for a suitably short period. Grazing and rest periods are determined according to available herbage and estimated rate of recovery of desired pasture species." (Fitzgerald 2000).

undesirable changes in botanical composition. Similarly, in a study conducted in Mexico, the cover of desirable species declined under short-duration grazing, but was stable under continuous grazing after 4 years (Bryant *et al.* 1989). Comparisons between planned rest grazing and continuous grazing have emerged from West Texas (e.g. Bryant *et al.* 1989; Teague and Dowhower 2003). Bryant *et al.* (1989) concluded that differences in species composition were could be attributed to climatic variations rather than to differences between continuously grazed and short-duration grazing systems. Teague and Dowhower (2003) found that defoliation patterns were weak or absent in comparisons made between planned rest grazing and continuous grazing. In one of the first Australian studies on the Northern Tablelands of NSW (McCosker 2000), Earl and Jones (1996) found the basal diameter, relative frequency and dry weight contribution of desirable grass species increased while the least palatable grasses declined, under cell grazing. Similarly, in north Queensland, McCosker (2000) found that increases in ground cover and frequency of blue grass (*Dichanthium* species) were associated with cell grazed sites. Kemp *et al.* (2003a) reported that native species richness increased by up to two species per 1.5 ha under planned rest grazing in south-eastern Australia. No results have been thus far reported for composition in the study of Kemp *et al.* (2003a).

Cultivation

Cultivation has destroyed many grassy ecosystems, as it removes the natural cover of plants (Watkinson and Ormerod 2001), but little is known about the impact of herbicides, reseeding and fertilisation on grassy ecosystems or the invasion or return of volunteer species, which is the primary focus of this thesis. The length of time for ground-storey vegetation to return to its pre-cultivated composition (if ever) is unknown but is likely to depend on many factors such as the original species composition, number of cultivations, the species sown and accompanying changes including tree clearing, fertiliser application, and changes in stocking rates. Garden and Dowling (1995) reported that cultivation of a pasture can have long lasting effects, which may be irreversible in the short term, as many native species do not tolerate disturbance. Another school of thought is that native pastures can return to pre-existing condition from one or more cultivation events for pasture improvement[6], but recovery after recurrent cultivation is limited (Robinson *et al.* 1993; Garden and Bolger 2001; Garden *et al.* 2001).

Research on the impacts of cultivation has generally focussed on the responses of individual species or unwanted invasive species, rather than on ground-storey diversity. Lavorel *et al.* (1991) concluded that species richness of herbaceous vegetation increases with time since cultivation in abandoned Mediterranean grassy ecosystems in France. Native grassy species density (number of species/plot) declined in response to pasture sowing near Charters Towers, Queensland (McIvor 1998). A common weed of pastures, *Cirsium arvense* (spear thistle), increased in cover following a single cultivation in the United Kingdom (Edwards *et al.* 2000b). On the Northern Tablelands, NSW, *Austrodanthonia laevis* is sensitive to cultivation, whereas other species including *A. racemosa* and *A. bipartita* can tolerate this form of disturbance (Scott and Whalley 1982).

Fertiliser

Production in grassy ecosystems is often limited by soil nutrient levels, particularly nitrogen and phosphorus (Archibold 1995). Fertiliser is required to maintain (Archibold 1995) or increase production (Hutchinson 1997). Studies of the effects of fertiliser on ground-storey vegetation generally investigate species specific increases in plant growth (Owensby *et al.* 1970; Foster and Gross 1998), but also the effects on grassland species diversity and composition (Bakelaar and Odum 1978; Snaydon 1981; Henkin *et al.* 1996; Foster and Gross 1998; van der Werf and Petit 2002). Species differ in their response to nutrient addition, although plants generally respond to increased fertility with greater growth. This allows competitive species to dominate other plants and prevent seedling establishment of forbs (Garden and Dowling 1995; Foster and Gross 1998), often leading to a decline in grassland species richness. However, this may depend on the degree of nutrient enrichment (Bakelaar and Odum 1978).

Diversity responses of native ground-storey vegetation in Australia to fertiliser amendment are mixed. McIvor (1998) concluded that fertiliser application has little influence on native

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[6] Pasture improvement: the establishment of exotic species through cultivation, often associated with herbicide prior to sowing and increased fertiliser application.

grassy vegetation species frequencies in northeast Queensland. Garden *et al.* (2003) recorded that increasing fertiliser application of superphosphate led to decreased native perennial grass composition in south-eastern Australia. On the Northern Tablelands it has been assumed that fertiliser application causes a decline in native species richness (Whalley and Lodge 1987). Positive results in response to low fertiliser application have been observed for some native grasses such as certain *Austrodanthonia* species and *Microlaena stipoides.* These species are able to utilise the increased nutrients better than *Panicum* species, *Sporobolus creber* and other *Austrodanthonia* species which declined in response to superphosphate application (Robinson and Lazenby 1976; Garden and Dowling 1995).

Trees

Trees often influence the composition and diversity of herbaceous vegetation occurring beneath the canopy (Chilcott *et al.* 1997; Gibbs *et al.* 1999; Pitkanen 2000; Prober *et al.* 2002a). Prober *et al.* (2002a) concluded that trees are associated with heterogeneity in the floristic composition of herbaceous vegetation. On the slopes of the western Great Dividing Range in NSW, *Poa sieberiana* dominated beneath trees and *Themeda australis* dominated open areas (Prober *et al.* 2002a). Tree canopies also influence the dominant grass species on the Northern Tablelands, NSW. *Microlaena stipoides, Austrodanthonia* species and *P. sieberiana* dominate native grass pastures beneath trees in grazed situations (Chilcott *et al.* 1997). Similarly, Gibbs *et al.* (1999) concluded that *Aristida ramosa* is replaced by *M. stipoides* and *P. sieberiana* under trees. The effects of trees on ground-storey vegetation may not always translate into a modified assemblage. McIntyre and Martin (2001) found that trees have no effect on species composition in their study in south-eastern Queensland.

1.2.7 Environmental determinants

Seasonal and annual variation in radiation, temperature and precipitation occur at all scales. Extreme temperature ranges are generally relevant to plant adaptation, distribution and survival, as both heatwaves and frosts influence seasonal growth and species composition (Fitzpatrick and Nix 1975). Native warm-season perennials on the Northern Tablelands grow throughout the summer and become dormant in autumn when lower temperatures, frosts and a lack of rainfall limit growth (Whalley and Bellotti 1997). Cool-season perennials commence growth in autumn and are frost tolerant and may make some growth in winter. Perennial species grow throughout the year depending on soil moisture conditions. Exotic temperate pasture species in Australia are often dormant in summer when moisture is limited and temperature exceeds 20°C (FitzGerald and Lodge 1997).

Soil moisture frequently limits primary production in Australia (Fitzpatrick and Nix 1975) and elsewhere (Coupland 1979), either due to the small amount of rainfall or the seasonal nature of rainfall in wetter regions. Soil moisture also limits the area suitable for sowing of exotic pasture species, as the successful establishment and growth of grazed cultivated pastures requires constant moisture index with relatively little deficit (Fitzpatrick and Nix 1975). Production responses to precipitation have been studied in Australia (e.g. Harris and Lazenby 1974; Walker *et al.* 1996) and elsewhere (e.g. Peacock 1976; Buckland *et al.* 2001; O'Connor *et al.* 2001; Jobbagy *et al.* 2002). The variation in production of biomass is directly related to precipitation. However, studies of the responses of herbaceous species richness and composition to regional climate variation, including precipitation, are limited. Gilfedder and Kirkpatrick (1993) concluded that precipitation does not significantly influence native species richness in subhumid remnants in Tasmania, although it affects exotic plant cover which declined with increasing rainfall in the driest month and driest quarter.

Solar radiation is a crude index of the light environment, but is useful in discussing the light requirements of plants (Fitzpatrick and Nix 1975) which also relate to the production responses of herbaceous vegetation. There is a lack of literature on the response of pasture diversity to solar radiation.

Lithology has been established as an important determinant of ground-storey species richness on the Northern Tablelands by various authors (McIntyre *et al.* 1993; Waters 2001; Clarke 2003). The lithology with the most inherent fertility is basalt, followed by granite and metasediment lithology with the lowest fertility. As with fertile soils, the most fertile lithology has been extensively cleared and developed through the sowing of pasture species, with associated increases in productivity and dominance of exotic sown pasture species.

Soil nutrient levels are related to parent materials and climate (Cumming and Elliott 1992). Soil nutrient status is an important determinant of ground-storey species richness and composition. Fertile soils lead to greater productivity and dominance of competitive species, resulting in fewer species (Begon *et al.* 1996). Phosphorus generally has a positive influence on exotic species in Tasmania (Gilfedder and Kirkpatrick 1993), and along with total nitrogen, strongly influences species composition (Prober *et al.* 2002a). Other nutrients such as potassium as well as the nitrogen/phosphorus ratio, carbon/nitrogen ratio and pH have been found to influence ground-storey vegetation richness (Gilfedder and Kirkpatrick 1993; Waters 2001; Prober *et al.* 2002a).

Site characteristics such as aspect, slope and altitude may determinate the diversity of ground storey vegetation, although often these cannot be isolated as their influences are confounded with other variables, such as parent material, rainfall and temperature (McIntyre and Lavorel 1994a; King 2002).

The slope of a site influences ground-storey vegetation through a number of ecological processes. Slope indicated whether ground-storey vegetation is likely to have been disturbed for intensive development of pastures in terms of tree clearing, sowing of introduced pasture species or ground spreading of fertiliser with steep slopes less likely to have been developed. Patterns of herbivore grazing are also influenced by slope, as animals are generally unwilling to graze steep slopes (Hester *et al.* 1999), resulting in increases in exotic species richness on moderately sloping (3-10°) in Tasmania (Gilfedder and Kirkpatrick 1993), and fewer grazing-induced losses of native species. Southern facing slopes receive more solar radiation than north facing slopes in the northern hemisphere (Auslander *et al.* 2003), while in Australia north facing slopes are warmer than south facing slopes (Bale 1974; King 2002), affecting evaporation, soil moisture, plant growth, and species diversity (Hutchings 1983; Bean and Whalley 2001; King 2002). Steep slopes are often associated with shallow erodible soil (King 2002), and lower slopes are richer in resources, particularly water (Puerto *et al.* 1990) but also nutrients due to the downslope movement of water, solutes and matter.

Altitudinal influences on ground-storey diversity may be confounded in some instances by slope, precipitation and lithology, but Gilfedder and Kirkpatrick (1993) found that altitude does not influence native species richness and negatively affects exotic species richness .

1.2.8 Seasonality of ground-storey vegetation

Species incidence, abundance, cover and phenology, such as the timing of flowering, vary according to seasonal conditions (Snaydon 1981; Kent and Coker 1992; Bullock 2003). Studies of seasonal changes in herbaceous vegetation refer predominantly to only dominant species, frequently exotic legumes or grasses that have a agronomic value for increasing production (Brougham 1960; Rossiter 1966; Garden *et al.* 2000; Bullock 2003; Chapman *et al.* 2003; Garden *et al.* 2003; Leggett *et al.* 2003), rather than an ecological focus. Warm season perennial grasses on the Northern Tablelands usually seed during late summer and early autumn, cool season perennial vegetation usually reproduces during late spring to early summer, whereas year long green perennials reproduce during late spring and early summer and also in early autumn.

Studies of ground-storey vegetation rarely report explanations as to why sampling occurred at the chosen time. On the Northern Tablelands sampling of herbaceous vegetation generally occurs from spring to autumn (November to March) (Robinson and Dowling 1976; McIntyre *et al.* 1993; McIntyre and Lavorel 1994a, 1994b; Tremont 1994; McIntyre 1995; McIntyre *et al.* 1995; Chilcott *et al.* 1997). Reasons for the selection of these sampling times are limited. However, McIntyre *et al.* (1993) stated that sampling time was selected 'to facilitate collection of reproductive material for identification'.

The ability to identify ground-storey vegetation, in grazed landscapes has not often been reported as an issue in Australia (e.g. Gilfedder and Kirkpatrick 1993; McIntyre *et al.* 1993; Garden *et al.* 2000; Clarke 2003; Garden *et al.* 2003) and elsewhere (e.g. Collins and Barber 1985; Puerto *et al.* 1990; Belsky 1992; Montalvo *et al.* 1993; Noy-Meir 1995; Grace and Jutila 1999; Stohlgren *et al.* 1999). However, Kemp *et al.* (2003a) stated 'grazed pastures present a particular taxonomic challenge since livestock more or less continuously destroy plant structures which are the key diagnostic features'.

1.3 RESEARCH AIMS AND OBJECTIVES

1.3.1 Study objectives

This study aimed to determine the influence of agricultural management on native ground-storey vegetation on the Northern Tablelands of NSW, on a variety of land tenures where management information was available and quantifiable. This study was reliant on the natural experimental approach (Diamond 1986). Natural experiments are defined as experiments where the perturbation is not established for the purposes of the research, but is already running or has occurred (Diamond 1986). Perturbations in this experiment were initiated and managed by landholders as part of their ongoing commercial management and public land managers. The advantages of using natural experiments rather than small-scale field experiments are many, with the most important being the realism and generality associated with such an approach. They also reflect the natural variation that exists in the environment. Limitations of natural experiments such as this 'experiment' include regulation of independent variables and difficulty in matching sites. These limitations were avoided through collection of large numbers of management and environmental variables, the stratification and 'replication' of sites (Diamond 1986).

Before the sampling of commercial properties could commence, information was required as to the phenology of the native and exotic ground-storey vegetation community so that the best time to sample could be established. The objective of this study, was to determine the time to sample ground-storey vegetation. The second objective was to determine the influence of management and the environment on the evenness and species richness of ground-storey vegetation. The final objective related to the management and environmental determinants of the composition of ground-storey vegetation. The specific objectives of this study were to:

1. determine the best time of year to sample ground-storey vegetation;
2. determine the influence of agricultural management and environmental variables on the evenness and species richness of ground-storey vegetation; and
3. determine the influence of agricultural management and environment on the composition of ground-storey vegetation.

1.3.2 Thesis outline

The sequence of chapters flows from the specific objectives outlined in the previous section (Section 1.2.1). The following approach has been undertaken to fulfil the aim and objectives of this study. A review of key literature is provided in this chapter. The study region is described in Chapter 2. Chapter 3 explores the seasonal nature of ground-storey vegetation and the optimal time to sample. Chapter 4 introduces the regional study and the agricultural management regimes and main environmental influences. The relationships between agricultural management and environment variables, and evenness and species richness are reported in Chapter 5. The relationships between ground-storey composition and agricultural and environment management are described in Chapters 6 and 7, respectively. Chapter 8 concludes with a synthesis of the results, and a discussion of future management and research needed to confirm or expand our knowledge of the influences of agricultural management on ground-storey vegetation on the Northern Tablelands of NSW.

CHAPTER TWO

Northern Tablelands study area

Mt Duval, north of Armidale, NSW

2.1 INTRODUCTION

This chapter describes the Northern Tablelands study region, the lithologies, soils, climate, land use and vegetation that characterise the area.

The study was conducted within 60 km of Armidale on the Northern Tablelands of NSW (Figure 2.1). The Northern Tablelands covers about 38 000 km² of temperate highlands with altitudes generally above 800 m and isolated peaks above 1400 m. The region stretches from the escarpment of the Great Dividing Range and the Macleay River in the east to west of Guyra and Uralla. The region had a long Aboriginal history with Europeans arriving in the 1820s (Lodge and Whalley 1989). The region's vegetation reflects over 150 years of European settlement, with agricultural production being the dominant land use, and livestock grazed on crops, native and sown pastures.

Figure 2.1 Location of Armidale, northern NSW.

2.2 LITHOLOGY AND SOILS

Three main parent materials occur in the region: sediments and metasediments; basic volcanic rocks (basalt); and acid volcanic and igneous rocks (granite) (Figure 2.2). Granite, meta-sedimentary and basalt-derived soils are distributed over 44%, 34% and 22% of the region respectively (Spencer and Barrow 1963).

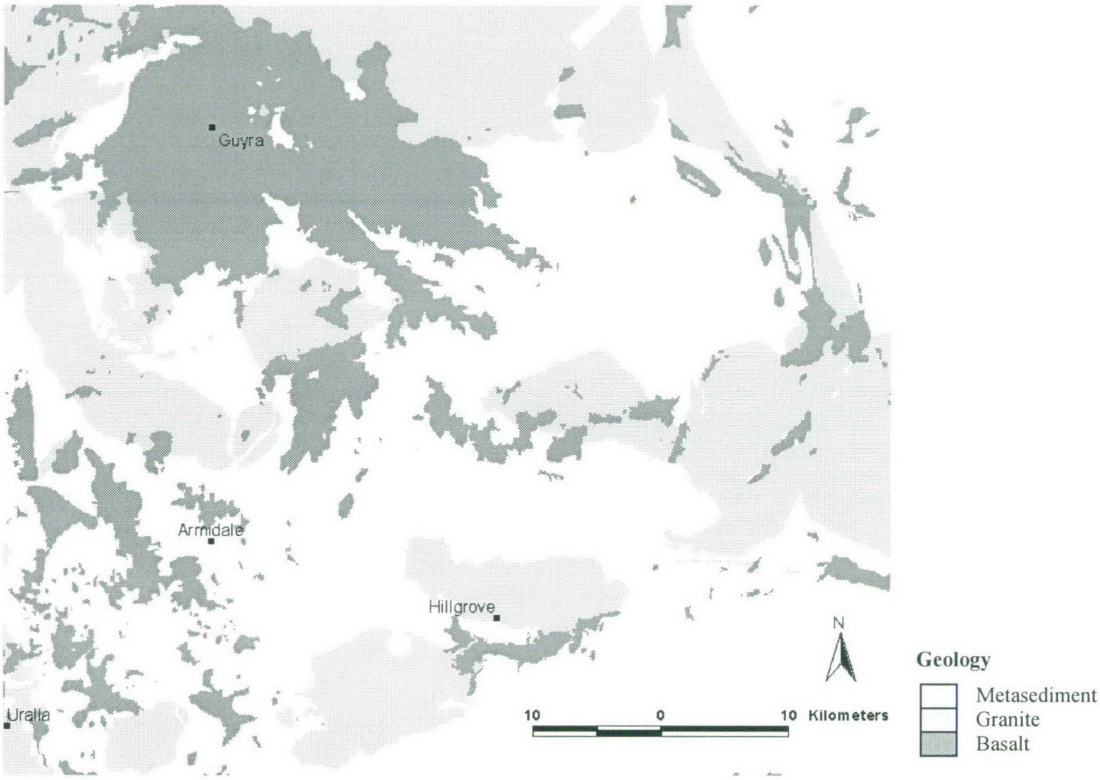

Figure 2.2 Parent materials of central and eastern Northern Tablelands (adapted from Department of Mines 1969).

The sediments and metasediments of the region were deposited during the Palaeozoic era. The weathering of these rocks has formed duplex fine-grained siliceous soils of moderate fertility (Morgan and Terry 1999). Areas near Armidale are mainly chromosols, which at lower altitudes are dominated by yellow box (*Eucalyptus melliodora*) and Blakely's red gum (*E. blakelyi*) grassy woodlands and open-forests. New England peppermint (*E. nova-anglica*) occurs on flats, and New England stringybark (*E. caliginosa*) in hillier areas (Morgan and Terry 1999).

Granite soils are characterised by low-fertility siliceous sands and duplex profiles that have weathered from siliceous rocks. Granite soils support similar grassy woodland vegetation to the metasediments with the additions of apple box (*E. bridgesiana*) and silver-top stringybark (*E. laevopinea*) (Gibbs *et al.* 1999; Morgan and Terry 1999).

The soils formed from the dark, fine-grained basaltic rocks include the siliceous diorites and the calcium rich basalts, and are of moderate to high fertility (Harrington 1977; Morgan and Terry 1999). The grassy woodlands and open-forests are dominated by snow gum (*Eucalyptus pauciflora*), black sally (*E. stellulata*), white gum (*E. viminalis)* and white box (*E. albens*) (Morgan and Terry 1999).

2.3 CLIMATE

Early settlers in the early 1830s noticed the similarity between the climate of the Northern Tablelands and England, with warm summers and cold winters with severe frosts and occasional snow falls. Hence the region gained the name 'New England'. The region's climate is subhumid with summer dominant rainfall (Tweedie and Robinson 1963; Lodge and Whalley 1989). The wettest months are December and January and the driest are April, May and August (Table 2.1). The region experiences frosts from April to September with mean minimum temperatures below 2°C in June, July and August in most centres (Table 2.2). Summer (December to February) is characterised by warm to very warm days, with mean daily maxima ranging from 23°C to 28°C (Table 2.3). Summer temperatures do not often exceed 30°C, and rarely reach higher than 35°C.

2.4 LAND USE AND VEGETATION

2.4.1 Pre-European settlement

Oxley and his party were the first European explorers to reach the region in 1818. Oxley reported that the top country was 'well clothed with grass' and displayed 'a great number of fallen trees' (Norton 1971), with rolling hills and plains with open grassy woodland in the valleys and denser open forests on the ridges (Oxley 1820). There are few records of the vegetation and its disturbance history on the Northern Tablelands prior to European settlement.

There were also smaller areas of natural grassland and wetlands. The ground-storey vegetation was dominated by tussock grasses such as kangaroo grass (*Themeda australis*), native sorghum (*Sorghum leiocladum*) and tussocky poa (*Poa sieberiana*), with redgrass (*Bothriochloa macra*), wire grass (*Aristida* species), bluegrass (*Dichanthium sericeum*) and wallaby grass (*Austrodanthonia* species) also widespread (Lodge and Whalley 1989). Frequent burning of the vegetation by Aborigines may have maintained tree density at a low level (McIntyre 1994). Aboriginal dislocation was rapid following the commencement of European invasion (Atchison 1977).

Table 2.1 Rainfall (mm) averages for selected stations on the Northern Tablelands of NSW (Commonwealth Bureau of Meteorology 2002, 2003a, b, c)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Annual
Uralla	105.5	83.7	61.1	40.9	46.8	54.3	57.5	56.3	54.8	73.6	83.7	85.7	803.7
Walcha	103.9	86.3	63.2	44.8	46.0	58.6	54.4	53.4	56.1	70.7	80.8	90.0	808.0
Guyra	114.1	92.3	72.3	47.8	52.2	61.2	60.2	55.0	57.9	82.3	87.5	99.8	882.6
Armidale	104.5	87.1	65.0	45.9	44.4	56.9	49.2	48.4	51.6	67.8	80.4	89.2	790.1

Table 2.2 Mean minimum temperature (°C) for selected stations on the Northern Tablelands of NSW (Commonwealth Bureau of Meteorology 2002, 2003a, b, c).

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Uralla	12.6	12.7	11.1	6.8	3.0	0.9	-0.4	0.4	2.8	6.2	8.7	11.1
Walcha	11.8	12.2	9.7	5.2	1.3	-0.2	-2.0	-0.2	1.8	5.5	7.9	10.6
Guyra	10.8	10.8	9.2	5.5	2.4	0.3	-0.6	0.1	2.4	5.3	7.6	9.8
Armidale	13.4	13.3	11.3	7.5	3.9	1.6	0.3	1.1	3.7	7.0	9.8	12.2

Table 2.3 Mean maximum temperatures (°C) for selected stations on the Northern Tablelands of NSW (Commonwealth Bureau of Meteorology 2002, 2003a, b, c).

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Uralla	26.5	25.5	23.9	20.0	15.7	12.8	11.8	13.3	16.9	20.0	23.6	26.0
Walcha	25.3	25.2	23.1	20.2	15.5	12.8	11.9	12.7	16.1	19.9	22.6	24.6
Guyra	24.6	23.4	21.8	18.3	14.1	11.2	10.3	12.0	15.5	18.8	21.5	24.0
Armidale	27.1	26.1	24.1	20.6	16.4	13.1	12.2	14.2	17.6	21.2	24.3	26.5

2.4.2 Post-European settlement

The grazing industry developed rapidly with the arrival of the first settlers on the Northern Tablelands (Nadolny 1998). The movement of people and stock resulted in heavy grazing, associated impacts such as trampling of vegetation by stock, and changes in species composition were inevitable. In addition, extensive vegetation clearing, draining of swamps and other developments were carried out to facilitate grazing enterprises and crops such as wheat for flour production, up until the early 1880s (Hutchinson 1993). Eucalypt regrowth was usually dense and had to be repeatedly cleared, and many pastures were regularly burnt. Livestock numbers reached a peak around the 1950s, with stock being heavily grazed on decreasing areas of land due to the increasing areas of cultivation and the increasing incidence of rabbits competing with livestock for fodder (Lodge and Whalley 1989).

The increasing stock numbers and pressure on pastures led to pasture quality deterioration, with the relative abundance of desirable species, such as *Austrodanthonia* species, diminishing and undesirable species, such as *Aristida* species, increasing by the 1940s (Lodge and Whalley 1989). The original native legumes, which were usually either twiners or shrubs, also declined as a result of continuous grazing (Nadolny 1998).

Top-dressing of pastures with artificial fertilisers began in the 1930s, and in the 1950s it became an established practice to spread superphosphate and clover seed using aircraft. The first sown pastures were established in 1947 (Hutchinson 1997), and with associated high wool prices, a considerable area (23%) of the region was sown to improved pastures to support the increasing number of sheep (Reid *et al.* 1997). Agriculture intensification was concentrated on basalt-derived soils, although pasture intensification also occurred on soils derived from granites and metasediments. These soils are of lower fertility and hence development was less intense and extensive due to the higher inputs required. The increase in soil nutrients and sowing of exotic pasture grasses, such as phalaris (*Phalaris aquatica*), fescue (*Festuca* species) and cocksfoot (*Dactylis glomerata*) led to a dramatic increase in stocking rates from 2-3 sheep/ha to 8-12 sheep/ha (Cook and Malecky 1974).

New England dieback, associated with severe defoliation of *Eucalyptus* species by various leaf eating insects, began in the 1950s and became severe in the 1970s (Heatwole and Lowman 1986; Reid *et al.* 1997). It provided a warning that the new agricultural regime was unsustainable (Reid *et al.* 1997). The enhanced nutrient status of soils, partly resulting from the camping habits of livestock (Taylor *et al.* 1984), and high rainfall from the 1950s to 1970s were some of the factors that appeared to contribute to the build-up of insect populations (Landsberg *et al.* 1990; Reid *et al.* 1997; Nadolny 1998). Other problems with improved pastures began to emerge. These included sensitivity to drought, lack of regeneration of trees and shrubs, loss of natural controls for pasture pests, an increase in exotic weeds and an increased risk of land degradation, especially where intensification was attempted on marginal country (Nadolny 1998). By the late 1980s, some graziers were questioning the sown pasture philosophy because expected increases in production or profit were not sustained and they began to seek information on native species (Reid *et al.* 1997).

A decrease in rainfall, the 1979-1982 drought, an increase in the cost of inputs and declines in the sale of wool and livestock resulted in many farmers lowering their inputs in terms of sown pastures and fertiliser (Connell *et al.* 1996; Reid *et al.* 1997; Reseigh *et al.* 2003). The benefits of lower input systems utilising native pastures became apparent (Lodge 1994; Jones 1995). Landholders experimented with 'new' approaches to management, and interest in an approach to grazing management that involved planned rests, generally called rotational or cell grazing, increased (Reid *et al.* 1997; Reseigh *et al.* 2003).

Private remnants

Private remnants[1] in the region are often fragmented and in some cases severely degraded. Some private remnants have been purposely preserved, particularly in the past decade, while others have been preserved by chance they are not suitable for grazing due to the terrain or location of the area. Prober *et al.* (2002a) advocated that these areas be kept intact for a variety of reasons with one being that they are reference sites for the conservation of intact (relatively unaltered) vegetation in the region. Morsley and Trèmont (2000) suggested that private remnants be actively managed for conservation, by a range of management practices including fencing, ceasing continuous grazing and burning.

[1] Private remnants: vegetation on private land dedicated to conservation, typically open woodland, woodland or open forest.

Travelling Stock Reserves (TSRs)

Travelling Stock Reserves were created more than 150 years ago as tracks leading to grazing lands from early settlements and are preserved under legislation for the movement of travelling stock (Morcombe and Worsley 2001). Tracks were opened up from Sydney to country NSW by the 1860s when pastoralists began moving livestock to open new lands for settlement, and additional stock routes were soon established to provide access to markets.

Travelling stock reserves in the region generally form a chain linked routes, with watering points occurring at intervals. Travelling stock reserves in the region are increasingly being used for agisting stock, and to a lesser extent, conservation and recreation. Due to the ongoing movement of stock along travelling stock routes since their establishment, the vegetation reflects the impact of periodic grazing (Austen 2002) but not cultivation or fertilisation.

Some travelling stock reserves in the region have been leased to landholders for their own commercial grazing enterprises. Many of the reserves, however, are unsuitable for commercial grazing due to inadequate fencing or water supplies and are only used for the droving of stock. These areas consequently experience low stock numbers averaged over time and are only grazed for short periods in accordance with regulations set down by Rural Lands Protection Boards. Regular grazing of travelling stock reserves by neighbouring licensees in north-west NSW has led to a reduction in, and in some cases, an absence of, palatable native shrubs and groundcovers (Austen 2002). However, travelling stock reserves are widely acknowledged as containing significant sites of valuable native vegetation for conservation that may include threatened and endangered species (Morcombe and Worsley 2001). Many TSRs may be suitable for the conservation purposes (Williams and Metcalfe 1991).