Section 1

CHAPTER 1

INTRODUCTION

Topography, Geology, Soils and Climate of the Study Area

Approximately 70 percent of the 2,893,837 hectares of rural land in the Northern Slopes Statistical Subdivision of New South Wales have not been sown to improved pasture species and can be classified as native or natural pasture[1]. The region supports 2.08 million sheep and 508,000 cattle mostly on native and natural pasture (Australian Bureau of Statistics 1982), which when unimproved carries less than two sheep per hectare. It is bounded in the south by the Liverpool Range, and in the north by the Queensland border. The eastern limit approximates the 750 metre contour of the western edge of the Great Dividing Range and the western limit follows a line through Boggabri and Pallamallawa.

In the present project the area of study has been contained mainly within the Shires of Barraba, Manilla and Parry. In these three Shires rural holdings cover an area of 841,000 hectares, and although 75 percent of the area of these rural holdings is native or natural pasture, they support 861,000 sheep and 186,000 cattle (Bryant 1981).

The topography of the study area (Fig. 1.1a) varies from mountainous along the escarpment of the Moonbi range, with altitudes up to 800 m in the east, through rolling hills to the gently sloping areas of the Liverpool Plains with altitudes less than 250 m on the western edge. The general variations in slope are shown in Fig. 1.1b. According to the New South Wales Soil Conservation Service criteria for land capability classification, the slope angle on arable land should not exceed eight percent. Using this slope angle as the limit of cultivation the only potential means of improving approximately 508,000 hectares or over half of the land in the study area is by aerial agriculture and/or grazing management.

The major drainage system of the study area consists of the westward flowing Namoi River which rises in the Great Dividing Range above

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1. As defined by Whittet (1966) and Southwood (1972).

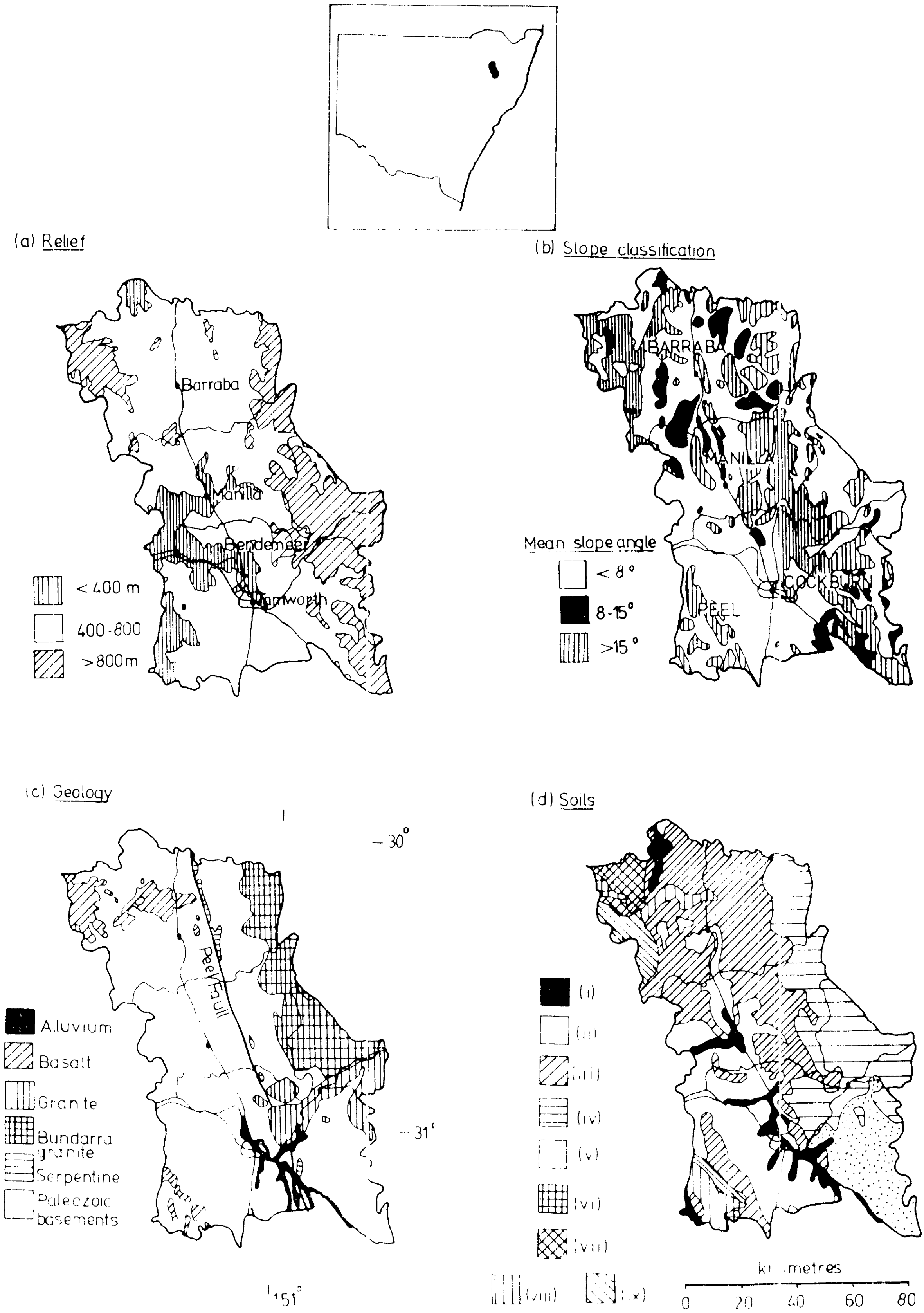

Figure 1.1 Physical features of the study area on the Northern Slopes of New South Wales (a) Relief, (b) Slope Classification, (c) Geology and (d) Soils.
(i) Black-earth prairie, (ii) red podzolic, (iii) non-calcic brown, (iv) yellow podzolic, (v) red brown earth, (vi) chocolate prairie, (vii) yellow solodic skeletal soils, (viii) black earth prairie, (ix) solonetzic red brown earth.

From: Lea et al. (1977).

Bendemeer, and its tributaries the Manilla River and the Peel River draining the north and south-east of the region respectively.

The study area is dissected by a series of thrust faults that traverse the area from north-north west to south-south east. In the east granitic igneous formations occur on the western escarpment of the northern Tablelands (Fig. 1.1c). Between this region and the Peel fault are sediments of shales, sandstones and conglomerates deposited in the Silurian to Middle Carboniferous age. West of the Peel fault is a wide band of hard grey muddy sandstone (greywacke), cherts, conglomerates and dolerite intrusions of the Devonian period. Further west is a parallel band of sandstones, conglomerates and mudstones of Carboniferous origin. Quaternary alluvial floodplains extend along the Peel and Cockburn Rivers and their tributaries near Tamworth.

Soils in the area have been influenced in their development and distribution by both topography and parent material (Fig. 1.1d). In the study area the principal soil types are the red-brown earths formed on Devonian and Carboniferous sediments (Northcote (1971) classification (Dr. 2.23)) and the non-calcic brown soils formed on Silurian sediments (Db 1.22, Dr 2.12, 2.22). On river flats prairie soils (Um 6.11) formed on alluvium occur and yellow podzolic (Dy 2.21) and grey podzolic soils are present on the eastern granites.

Spencer and Barrow (1963) reported phosphorus (P), sulphur (S) and nitrogen (N) nutrient deficiencies on the podzolic soils formed on granites in the east of the area. An analysis of 200 soil tests taken by Australian Fertilizer Limited indicated an average soil phosphorus level of 48 ppm (bicarbonate test) in unfertilized native and natural pastures in the study area. Throughout the area yield responses have been obtained with applied S at Goonoo Goonoo (Lodge and Roberts 1979), and Barraba and Duri (Sheridan unpublished data) and with P and S on soils from Tamworth (McLachlan 1955; Lodge 1980). Unpublished data indicates that on most soils N is deficient for grass growth. Further physical and chemical properties of the red-brown earths are presented in Appendix 1.

Climatically, the area is classified as sub-humid with a summer rainfall maximum (Tweedie and Robinson 1963). The study area is approximately bisected by the 650 mm average annual rainfall isohyet. Rainfall data for selected centres in the area are shown in Tables 1.1(a) and (b). April and May, and August and September tend to be the driest months with the summer months the wettest. In addition there is a seasonal contrast in that heavier falls of rain are expected from January to March and smaller falls from April to September. The frequency of rainfall occurrence (Table 1.1(b)) generally follows the pattern of monthly rainfall totals, highlighting the relatively dry periods in spring and autumn.

Annual average pan evaporation at Manilla is 123 cm ranging from a maximum of 216 mm in January to a minimum of 48 mm in July. Seasonal moisture index maps (Fitzpatrick and Nix 1970) relating plant growth to moisture availability based on a water balance model show that in the study area higher summer evaporation more than offsets the rainfall maximum at that time, compared to the winter situation. Thus, soil moisture is generally not limiting plant growth in winter, but may be limiting in summer.

Temperature data for Barraba and Tamworth are presented in Table 1.2, but there are no official temperature recording stations in the Manilla district. In the study area January is the hottest month and July is the coldest.

All of the study area experiences frost during the cooler part of the year. At Tamworth the average frost free period is 217 days (Foley 1945) with the frost period generally extending from late April until the end of September.

Although soil moisture may be limiting in summer in some years, high summer temperatures and rainfall generally provide good conditions for the growth of the warm season[2] native perennial grasses, the principal species of the native and natural pastures of the study area (Williams 1979). The growth of these grasses continues until autumn when decreasing temperatures, frost and lower rainfall lead to a cessation of growth and, although soil moisture is adequate in winter and early spring, many species remain totally dormant until late spring.

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2. Terminology according to Taylor (1980).

Table 1.1(a) Monthly and annual rainfall data (mm) for selected stations in the study area.

Station	No. years recorded	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Total
Barraba	83	79.5	75.1	58.6	41.4	40.1	50.5	43.6	40.1	42.6	62.7	71.3	73.6	680
Manilla	81	82.5	67.0	56.3	41.4	39.1	48.2	42.6	39.8	39.8	58.4	65.0	70.8	650
Tamworth	83	75.4	70.3	50.8	44.4	42.1	53.0	45.4	46.7	48.5	59.4	66.2	73.1	675

(b) Average number of rain days for selected stations in the study area. A rain day is defined as one having 0.24 mm or more of rain or snow.

Station	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Total
Barraba	8	7	5	5	5	7	7	7	6	7	7	7	78
Manilla	7	7	5	5	5	7	7	7	6	8	7	7	78
Tamworth	8	8	5	5	6	8	8	8	7	8	7	8	86

Table 1.2 Temperatures for two stations in the study area (°C) showing (a) mean maximum, (b) mean minimum, and (c) average mean daily.

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Barraba													
a	30.7	30.7	28.2	25.8	19.4	17.0	16.1	17.3	19.8	24.8	27.4	29.3	23.9
b	15.8	15.8	12.5	7.4	3.4	1.4	-1.2	1.7	3.6	8.0	10.4	13.9	7.7
c	23.3	23.3	20.4	16.6	11.4	9.2	7.5	9.5	11.7	16.4	18.9	21.6	15.8
Tamworth													
a	32.8	31.9	29.2	24.9	20.6	16.7	15.8	17.9	22.0	25.8	29.5	31.4	24.9
b	17.4	17.2	14.6	10.2	6.2	3.7	2.7	3.2	5.7	9.8	13.4	16.1	10.0
c	25.1	24.6	21.9	17.6	13.4	10.2	9.3	10.6	13.9	17.8	21.5	23.4	17.5

Stage 1

TALL, WARM SEASON NATIVE PERENNIALS

Themeda australis, *Sorghum leiocladum*, *Aristida ramosa*
(coarse textured soils)

↓ GRAZING, LOWER FIRE FREQUENCY ↓

Stage 2

SHORT, WARM SEASON NATIVE PERENNIALS + SHORT, YEARLONG GREEN NATIVE PERENNIALS + NATURALIZED COOL SEASON ANNUALS

Aristida ramosa, *Bothriochloa macra*, *Chloris truncata*, *Dichanthium sericeum*, *Eragrostis* spp., *Eulalia fulva*, *Panicum effusum*, *Sporobolus elongatus*

Danthonia spp., *Stipa scabra*, *Enneapogon nigricans*, *Dichelachne micrantha*

Trifolium glomeratum, *Medicago minima*, *Medicago polymorpha*, *Bromus molliformis*, *Hordeum leporinum*, *Vulpia myuros*

↓ GRAZING AND REGULAR BURNING ↓

Stage 3

SHORT, WARM SEASON NATIVE PERENNIALS + NATURALIZED COOL SEASON ANNUALS

↙ HEAVY GRAZING + SUPERPHOSPHATE ↓

Stage 4A

SHORT, COOL SEASON NATIVE PERENNIALS + NATURALIZED COOL SEASON ANNUALS

↘ VERY HEAVY GRAZING + HIGH NUTRIENT ACCUMULATION OR FERTILIZER ↓

Stage 4B

NATURALIZED COOL SEASON ANNUALS

Figure 1.2 Relationship among the postulated original and present day native and natural pastures on the Northern Slopes of New South Wales as related to grazing intensity, fire and fertilizer application.

The native and natural pastures of the study area

Development and History

Before European settlement in Australia, the native pasture communities were in equilibrium with the existing climate and soil and were adapted to light intermittent grazing by soft-footed indigenous marsupials as well as recurrent burning (Moore 1959). This grazing intensity resulted in a heavy cover of grass at the end of summer which dried off with the first frost leaving a dense canopy of dry herbage with little opportunity for the establishment of cool or warm season annuals.

Detailed descriptions of the pastures as they appeared to the first settlers do not exist, although they were probably dominated by tall caespitose warm season (summer-growing) perennial grasses. Dominant species in the original grasslands of the study area were probably Themeda australis[3] (Kangaroo grass)[4] and Sorghum leiocladum (Fig. 1.2, Stage 1) (wild sorghum)[5] with grasses such as Bothriochloa macra (redgrass)[6], Aristida ramosa (wiregrass), Dichanthium sericeum (bluegrass)[7] and Danthonia spp. as subsidiary species. Kangaroo grass was originally a widespread dominant over much of south-eastern Australia (Moore 1970). Together with Poa spp. (snow grasses), S. leiocladum, and Stipa spp. it has been proposed as the original dominant species of pastures in several regions; with the former two on the northern Tablelands (Whalley et al. 1978) and with Poa spp. and Stipa spp. on the southern Tablelands (Moore 1966) and south-western Slopes of New South Wales (Moore 1953a). However, it is unlikely that either P. sieberana or S. aristiglumis were widespread co-dominants on the Northern Slopes

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3. Nomenclature used for species names throughout this thesis follow that of Jacobs and Pickard (1981) where possible. References for species not listed in Jacobs and Pickard (1981) are given in the text.

4. Also referred to as Anthistiria ciliata Linn by Turner (1905).

5. Also referred to as Sorghum plumosum Beauv by Turner (1905).

6. Also referred to as Andropogon pretusus Willd by Turner (1905); Amphilophis decipiens by Moodie (1934a); erroneously as Bothriochloa decipiens (Hack C.E. Hubbard by Durham (1953); Bothriochloa ambigua S.T. Blake by Moore (1958) and Bothriochloa macera (Steud) S.T. Blake by Moore (1970).

7. Also referred to as Andropogon sericeus R.Br. by Turner (1905).

because the distributions of these two species are restricted by environmental and edaphic factors. The distribution of P. sieberana is limited to higher elevations, while S. aristiglumis is only commonly found on heavy textured soils.

Large scale stock movements into the area occurred in the late 1820's (Jervis 1962) and with heavier grazing pressure, trampling, nutrient cycling changes and a lower frequency of fire, changes in the original species composition of the pastures were inevitable. Hence, the present state of the grass communities in the study area reflects about 150 years of grazing by domestic livestock (Jervis 1962). The first botanical records of the region were made by Bentham and Mueller (1878) and these together with species lists by Turner (1905) suggest that the most probable grass species in the early days of European settlement were the original dominants previously listed, together with Chloris spp., Sporobolus spp., Eragrostis brownii (Brown's lovegrass), Eulalia fulva (silky browntop). Enneapogon nigricans (nigger-heads) and Panicum effusum (hairy panic) (Fig. 1.2, Stage 2). Bentham and Mueller (1878) and Turner (1905) also listed several naturalized cool season annual species of the genera Briza, Bromus and Hordeum which invaded the native pastures following disturbance by grazing. Seeds of these grasses and the cool season annual Medicago spp. and Trifolium spp. were probably introduced when stock numbers rapidly increased during the gold rushes of the 1850's (Peel 1973) and by the early 1900's Turner (1905) reported that "many exotic species had acclimatised in the North-West of New South Wales". This increase in the abundance of exotic species altered the species composition of these grasslands which necessitated a change in terminology. Native pastures consisted solely of indigenous species; natural pastures contained a mixture of both indigenous and introduced species.

During the 1880's and early 1890's several factors led to increased pasture exploitation in the region. Higher stock numbers (Williams 1979), increased areas of cultivation, the occurrence of rabbits, and a reduction in the size of leaseholds (Peel 1973) led to increased numbers of stock being grazed on decreasing areas of land. Furthermore, the granting of freeholds in the 1880's led to the erection of buildings and fences and the establishment of permanent watering points which gave rise to more intensive systems of grazing. Further developments in the pastoral industries of the Northern Slopes have been few. The use of artificial fertilizers to topdress native and natural pastures began in the 1920's (Moodie 1934a), but even today it is not a widespread practice, with less than 5% of the natural pastures receiving fertilizer (Australian Bureau of Statistics, 1982). Further increases in the area of cultivation, particularly since the mid 1940's (Macindoe 1975) and an upward trend in stock numbers since that time, greatly increased the grazing pressure on native and natural pastures.

Breakwell (1923) listed the "best native grasses" for the Northern Slopes as kangaroo grass, bluegrass and *Chloris truncata* (umbrella or windmill grass). McTaggart (1936) described a kangaroo-wire-spear grass (*Stipa* spp.) association as typifying the region with different species being dominant in different areas. The sub-dominants of the region were listed as *Dichelachne micrantha* (plume grass), *B. macra*, *Chloris* spp. and *Danthonia* spp.. Kaleski (1940) indicated that bluegrass, *Danthonia* spp. and *Stipa* spp. were found on the Slopes area from Tamworth to Inverell; no mention was made of either wiregrass or redgrass. The most frequent species encountered in the survey of Williams (1979) were *B. macra*, *A. ramosa* and *D. sericeum* and this is in reasonable agreement with the survey of Durham (1953) who found that *Bothriochloa*, *Aristida* and *C. truncata* were widespread in the Keepit dam catchment area.

Despite changes in stock numbers and land use since the 1900's there appears to have been little widespread change in the species present in the natural and native pastures since that time. Such changes as may have occurred in recent times are mainly in the relative abundance of the individual native perennial grasses and an increase in the abundance of the naturalized cool season legumes and grasses. The native grass component of the present day native and natural pastures is probably just as complex as that of these pastures at the turn of the century. Supportive evidence comes from an examination of the species listed by Turner (1905) and Williams (1979). Turner (1905) listed 139 species of grasses of some 60 genera which occurred in the area of the Northern Slopes and Williams (1979) listed 142 grasses of 56 different genera. Of these only 37 can be classified as common or very common in the area today and all of these are native perennial grasses.

In the present day pastures with low fertilizer input and rates of stocking of about 3 dry sheep equivalents (DSE's) per hectare the native perennial grasses appear to have reached a state of equilibrium. It is only in heavily grazed and fertilized pastures (Harradine 1976) or in sheep-camp locations that pasture degeneration to the cool season annual phase described by Moore (1966) is evident (Fig. 1.2, Stage 4B). In such situations cool season annual Trifolium spp., Medicago spp., Erodium spp. and grasses of the genera Hordeum, Bromus, Vulpia and Koeleria occur. Williams (1979) proposed that B. macra was an original dominant of the study area, but this is unlikely. In early species lists and up until about 1940 Danthonia spp. were commonly mentioned. Anecdotal evidence from graziers would also indicate that Danthonia spp. were more common in the early 1900's than they are today, and that A. ramosa and B. macra occurred less frequently than they do today.

It is generally agreed that regular early spring burning, a common practice in the study area, favours Aristida spp. (Harradine 1976) and this may have led to an increase in its abundance in native and natural pasture (Fig. 1.2, Stage 3). McFarlane and Gallagher (1963) reported that Aristida spp. had rapidly spread in the previous 10-15 years in the pastures of north-western New South Wales. They attributed this increase to above average summer rainfall since 1947, sulphur deficiency and inadequate grazing following severe defoliation by rabbits, horses and sheep. Durham (1953) in describing the vegetation of the Keepit Dam catchment area noted that in country that had been overstocked for some years, heavily infested with rabbits and regularly burnt, Danthonia spp. and Eragrostis spp. had been replaced by Aristida spp and B. macra (Fig. 1.2, Stage 3). Danthonia spp. were common only in areas that had been lightly grazed, and T. australis was favoured by light grazing by cattle and regular burning (Durham 1953). Similar conditions have been shown to favour the persistence of T. australis in other regions (Barnard 1964; Moore 1970). An increase in the abundance of B. macra and an apparent decrease in the frequency of Danthonia spp. in recent times may be similar to the invasion of Danthonia pastures by B. macra following overgrazing (Moore 1958) in the southern Tablelands of New South Wales. With top-dressing and stock management in the New England district Moodie (1934a) stated that redgrass had largely been controlled and Danthonia spp. had become established (Fig. 1.2, Stage 4A). Similar changes occurred with top-dressing and heavy stocking, in pastures dominated by Aristida spp., indicating that the abundance of both these species could be controlled by management.

In other areas descriptions of successional trends that have occurred since grazing have followed a similar pattern; Biddiscombe (1963) in the Macquarie region; Moore (1966) in the south-western Slopes; Beadle (1948) in the western districts; Biddiscombe (1953) in the Trangie district; Moore (1953a and b) in the Riverine Plain, and, Whalley et al. (1978) in the northern Tablelands. These trends will be more fully discussed in the following literature review.

Structure and characteristics of the native and natural pastures

The native and natural pastures of the study area are usually dominated by warm season frost susceptible grasses, which determine the general structure of the pasture community (Williams 1979). Also found in these pastures, however, are a diverse range of other perennial and annual grasses and forbs (weeds and legumes) (Jacobs and Pickard 1981). A natural pasture is therefore a very complex plant community with up to 100 herbaceous species being present in a single paddock. Sometimes only one or two species may be very abundant with only a few species common, or up to 20 species may be dominant. There is also much inter- and intra-paddock heterogeneity in species composition (Williams 1979; Taylor 1980) which is often related to past management and the grazing behaviour of livestock, particularly Merino sheep (Whalley et al. 1978; Taylor 1980).

There are about 230 species of grasses that occur in the study area (Jacobs and Pickard 1981). This large number of grass species can be conveniently grouped into two major categories, native (indigenous) and naturalized (introduced). Each of these groups can be further subdivided into annuals and perennials. The annual group contains both cool season and warm season species, while the perennials contain species that make most of their growth in the cool season, the warm season, or all year round. The characteristics of species in each of these groups and examples of common species in each group are shown in Table 1.3. Other than the warm season grasses the only grasses that are commonly found in the study area are the yearlong green perennials and the cool season annuals. The

Table 1.3 Characteristics of annual and perennial grasses in each of the major species groups and common native and introduced species found in each group.

Species group	Growth Characteristics	Common species in native and natural pastures
PERENNIALS Warm season	Summer-growing frost-sensitive grasses. Some species flower throughout summer (indeterminant flowering) while others have only one flowering period (determinant)	Native: A.ramosa; B.macra; D.sericeum; S.elongatus; E.leptostachya (indeterminant flowering); and, T.australis (determinant flowering) Introduced: Paspalum dilatatum
Cool season	Commence growth in autumn and flower and set seed in spring. They are usually dormant in summer.	Native: Agropyron scabrum Introduced: Not common.
Yearlong green	These species are frost tolerant and grow in both winter and summer. They usually have two flowering periods one in late-spring, early-summer and a second in autumn.	Native: Danthonia spp. such as D.linkii and D.racemosa; S.scabra
ANNUALS Warm season	Seeds germinate in spring. Plants of these species are usually frost-sensitive, they grow rapidly and flower and set seed and die in autumn.	Native: Generally rare Dactyloctenium radulans; Sporobolus caroli Introduced: Not common. Species that are weeds of cultivation include Digitaria sanguinalis and Echinochloa crus-galli
Cool season	Seeds of these grasses germinate in autumn, grow during winter and flower, set seed and die in late-spring or early-summer	Native: Not common Introduced: Hordeum leporinum; Bromus molliformis; Vulpia myuros

most commonly occurring yearlong green perennials are Stipa scabra and Danthonia spp.. Jacobs and Pickard (1981) list 10 species of Danthonia for the North Western Slopes, but of these only two D. linkii and D. racemosa occur very frequently. The yearlong green perennials have often been referred to by earlier authors (e.g., Moore 1966; 1970) as cool season perennials. However, the terminology adopted by Taylor (1980) is more correct in that it describes the potential that these species have for year round production of green leaf.

Other herbaceous species that occur in the natural pastures of the study area have been listed by Williams (1979) and Jacobs and Pickard (1981), of which the most predominant group is the cool season exotic annual legumes. These legumes have a growth pattern similar to that of the cool season annual grasses. Hence, a natural pasture is a collection of species of different growth habits and seasons of growth and so the botanical composition of individual pastures within the study area and within a property can vary substantially. The botanical diversity and complexity of these natural pastures is exemplified by a complete species list (Table 1.4) for a 20 hectare fertilized, grazed natural pasture described by Lodge and Roberts (1979). These data were collected in late spring, early summer 1973 using the point frame method of Levy and Madden (1933). The frequency of 20 species (8 native and 12 naturalized) were scored and a further 26 species were recorded as being present in the pasture, but in low abundance. Prolific legume growth occurred in spring 1973 (Lodge and Roberts 1979) and so these species had an abnormally high occurrence. The only other species that were abundant in these pastures were the warm season and the yearlong green native perennial grasses.

For animal production, the natural pastures of the study area have the major limitation of a low availability of green forage in late autumn, winter and spring. In a long-term study of a grazed natural pasture in the Tamworth district, dominated by warm season native perennial grasses, Lodge and Roberts (1979) found that although green grass herbage mass[8] was as high as 1500 kg ha^{-1} in the summer it never exceeded 500 kg ha^{-1} in the winter of each year. This seasonality of the green

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8. Terminology according to Hodgson (1979).

Table 1.4 The frequency (%) and presence of species for a grazed, fertilized 20 hectare natural pasture site.

Species and Group	Frequency	Other species present
Grasses	%	
WARM SEASON PERENNIALS		
(N)[+] B.macra	6.9	(I) Paspalum dilatatum; (I) Cynodon dactylon
(N) A.ramosa	6.9	(I) Eleusine tristachya
(N) C.truncata	9.7	
(N) S.elongatus	1.4	
YEAR LONG GREEN PERENNIALS		
(N) S.scabra	5.5	(N) Enneapogon nigricans
COOL SEASON ANNUALS		
(I) Hordeum leporinum	<1	(I) Koeleria cristata
(I) Briza minor	<1	
(I) Vulpia myuros	<1	
(I) Bromus molliformis	<1	

Species and Group	Frequency	Other species present
Forbs	%	
WARM SEASON PERENNIALS		
(N) Glycine tabacina	2.8	
(N) Rumex brownii	<1	
YEAR LONG GREEN PERENNIALS		
(I) Boerhavia diffusa	1.4	(N) Vittadinia caneata; (N) Hydrocottle laxiflora; (N) Plantago debilis; (I) Cirsium vulgare (biennial); (N) Urtica incisa; (N) Mentha satureoides; (I) Hypochoeris radicata; (I) Phyllanthus filicaulis; (I) Capsella bursa-pastoris
(N) Dichondra repens	<1	
(N) Oxalis corniculata	<1	
COOL SEASON ANNUALS		
(I) Trifolium repens	1.4	(N) Ranunculus sessiliflorus; (I) Cerastium glomeratum; (I) Trifolium tomentosum.
(I) T.campestre	11.1	
(I) T.glomeratum	26.4	
(I) T.arvense	12.2	
(I) Medicago polymorpha	1.4	
(I) Erodium cicutarium	<1	
(I) Daucus glochidiatus	<1	
WARM SEASON ANNUALS		
[illegible]	[illegible]	[illegible] communis; (N) Chenopodium polygonoides; (I) Catula australis; (I) Malva parviflora; (N) Cymbonotus lawsonianus; (I) Hedypnois rhagodioloides.
(I) Geranium solanderi	<1	

+ (N) Native; (I) Introduced.

herbage accumulation within these pastures is reflected in the general low rate of stocking (3.3 DSE ha^{-1}) in the study area. The low levels of winter green forage and low N content (Lodge and Roberts 1979), restrict carrying capacity by limiting intake in cattle (Johnstone-Wallace and Kennedy 1944) and sheep (Willoughby 1959).

Hilder and Spencer (1954), Begg (1963) and Sheridan (1973) suggested that the shortage of green forage in winter and spring could be overcome by applying P and S to pastures containing naturalized cool season annual legumes. The herbage accumulation of these species, however, is highly seasonal and unreliable (Lodge and Roberts 1979) and their herbage masses are more closely related to seasonal conditions, rather than fertilizer application. With a low abundance and productivity of cool season annual species in lightly-grazed natural pastures, an increase in the abundance of either the cool season perennial or the yearlong green perennial grasses to provide green winter forage may be more desirable. However, in the study area cool season native perennial grasses are rare and although the yearlong green native perennial grasses occur at a low frequency this group has the best potential for increasing the amount of winter green forage in these pastures, if their abundance could be increased. Yearlong green native grasses, such as the Danthonia species (Table 1.5), are among the most highly regarded grasses of native and natural pasture (Breakwell 1923; Christian and Donald 1960) that are capable of responding to N fertilization (Robinson 1976; Harradine and Whalley 1978) and superphosphate (Davies et al. 1934) and persist under heavy grazing (Robinson and Dowling 1976).

Associated with the lack of winter green forage and low carry capacity of the native and natural pastures of the study area is the widespread dominance of A. ramosa (Table 1.6). This species is an undesirable component of these pastures as it is a coarse, tussocky grass of low palatability and nutritional value (Breakwell 1923; Harradine 1976) whose three-awned seeds are a major source of contamination of wool (Cornish and Beale 1974) and meat (Hamilton 1978; Lodge and Hamilton 1981).

The grazing value of many of the other native perennial grasses found in the study area is not well documented and there are few objective data (e.g., Tables 1.5 and 1.6) on which to assess their desirability or

Table 1.5 The abundance (%), crude protein content and some characteristics of some yearlong green perennial native grasses in the study area.

Species	Abundance (%)[+]	Crude protein[++]	Characteristics
Stipa scabra	6	9.4-11.1	.Drought resistant. Provides good feed in late winter and early spring. Palatable and nutritious (Breakwell 1923). .Seeds cause vegetable fault in wool (Cornish and Beale 1974).
Danthonia spp.	5	-	.Generally increase with grazing (Whittet 1936) .Well known for their persistence, palatability and production particularly in winter (Breakwell 1923)
Danthonia linkii	3	-	.Considerable economic importance in natural pastures (Breakwell 1923)
Danthonia racemosa	0.5	8.3-15.0	.Responsive to increased fertility (Robinson 1976)

[+] After Williams (1979)

[++] After Begg and Freney (1960). Highest summer and winter values are shown.

Table 1.6 The abundance (%) crude protein content and some characteristics of some warm season perennial native grasses in the study area.

Species	Abundance (%)[+]	Crude protein (%)[++]	Characteristics
Aristida ramosa	26	-	.Drought resistant, providing valuable roughage and soil cover in severe droughts. .Relatively unpalatable. .Unresponsive to added nutrients (Harradine and Whalley 1978). .Seeds cause wool and meat contamination (Cornish and Beale 1974; Lodge and Hamilton 1981).
Bothriochla macra	34	10.3-10.4	.Drought resistant, produces good summer growth in drought (Moodie 1934b) .Responsive to increased fertility (Cook *et al* 1976) .Invades poorly managed pastures (Cook 1974) .Low feed value (Breakwell 1923)
Dichanthium sericeum	15	-	.Seedlings readily germinate and establish on good rainfall. Palatable and highly valued (Breakwell 1923)
Sporobolus elongatus	6	12.4-7.4	.Increases with grazing, unresponsive to improved fertility (Robinson and Lazenby 1976) .Generally unpalatable (Breakwell 1923)
Eragrostis spp. *Eragrostis leptostachya*	5	6.4-7.1	.One of the first species to colonize after clearing, good grazing value when young (Breakwell 1923) .Increases with grazing (Robinson and Lazenby 1976; Whalley *et al* 1978)
Chloris truncata	4	10.9-9.4	.Good summer carrying capacity (Breakwell 1923) .Colonizes bare areas (Moore 1966; Cameron 1961) .Increases with heavy grazing (Biddiscombe 1953; Moore 1953b)
Panicum effusum	4	12.4-20.0	.Drought resistant but of less value than *P.decompositum* (Breakwell 1923) .Increases with grazing (Moore 1953b) .Unresponsive to increased fertility (Robinson and Lazenby 1976) .May cause photosensitisation
Themeda australis	2	9.1-5.5	.Relatively unpalatable to sheep (Breakwell 1923) .Decreases with continuous grazing (Moore 1966; Robinson and Dowling 1976; Whalley *et al* 1978)

+ After Williams (1979) ++ After Begg and Frency (1960). Highest summer and winter values are shown.

undesirability as pasture species. A subsequent literature search showed a lack of existing knowledge on the effects that pasture management practices may have on the species composition and herbage accumulation of the native and natural pastures of the study area.

CHAPTER 2

LITERATURE REVIEW

Literature Review: The effects of grazing, fertilizer application and fire on the herbage mass and composition of native and natural pastures and individual species of native perennial grasses.

Terminology

Throughout the text I have adopted the nomenclature and definitions of Hodgson (1979) for the grazing and evaluation studies and those of Heady (1975) for grazing management systems. The major terms are defined below.

Herbage The above-ground parts of a population of herbaceous plants viewed as an accumulation of plant material with characteristics of mass and nutritive value, but no connotations of organisation or structure.

Pasture An area of sward, usually bounded by a fence, considered as a functional unit for grazing.

Herbage mass The instantaneous measure of the total weight of herbage per unit of ground, preferably measured to ground level.

Herbage accumulation The change in herbage mass between successive instantaneous measurements, summed over time where appropriate.

Herbage harvested The mass of herbage per unit area removed by mechanical means at a single harvest or series of harvests.

Grazing plan A schedule for moving grazing animals from one pasture to another.

Grazing management system A concept which encompasses the day-to-day operations of the seasonal grazing plan as well as feeding, health precautions and other practices such as fertilizer application, burning, etc.

Grazing period That portion of the grazing season in which grazing actually occurs.

Rest period The length of time between the end of one grazing and the start of the next on a particular area.

Deferred grazing A pasture is not grazed until seed maturity is assured or a comparable growth stage has been reached and that it is grazed after seed maturity.

Continuous grazing The practice of allowing animals unrestricted access to an area of land for the whole or substantial part of a grazing season.

Rotational grazing The practice of moving animals from one pasture to another on a scheduled basis.

Grazing

Grazing management has been defined by Morley (1966) as "the control of pastures, and livestock and their movements in a pasture ecosystem". This broad definition embraces control of the pattern of stock movements or grazing strategy, pasture management or the control of species, fertilizers, agronomic practice, animal management, or the control of type of stock and operations such as lambing or calving. The objectives of grazing management may differ and different methods of grazing management may vary greatly in their objectives. These may vary from pasture improvement with little regard for the animal to a total preoccupation with the latter in which case the aim is to produce a maximum quantity of livestock products per hectare or per animal. The major objectives of grazing management were considered by Morley (1966) to be:

(1) maximum profits;

(2) a stable biological system; and

(3) minimum animal stress.

Traditionally, the main objectives of pasture management in Australia have been maximum animal production consistent with long-term stability (Whalley 1980).

Often pasture management may have the aim of altering the species composition of the pasture so that more stock can be carried on the same area. Other objectives are associated with the use of pasture for parklands and recreation, reclamation after mining and for landscaping purposes. It is generally easier to pursue one object to the exclusion of others (Spedding 1970), but this is rarely desired. Management of agricultural pastures usually aims at achieving high output of animal products in relation to a variety of inputs.

Factors such as the grazing method, the number of animal units employed in harvesting and the kinds of animals in terms of their physiological state and their inherent productive merit affect grazing management (McMeekan 1956). These factors interact not only with each other, but with the quality and quantity of pasture grown, its seasonality of output, the amount harvested by livestock, the efficiency of conversion to animal products and the efficiency of animal husbandry. Within this concept of grazing management McMeekan (1956) argued that the impact of grazing management depends on three components controllable by man; the grazing method, the stocking rate and the type of stock used. Willoughby (1970) considered that grazing management involved the adjusting of grazing periods on different parts of a holding to reduce the disadvantages of not being able to make adjustments from time to time between grassland production and animal demand. Feed supply is a balance between plant growth and its depletion by breakdown and intake. To increase the supply, either growth must be increased or breakdown and intake must be decreased. For a given grassland community, the only one of these aspects that can be directly manipulated by management (Willoughby 1970) is to decrease intake and this can be achieved by increasing stocking rate on, or restricting grazing to only part of the grassland. Hence, a reduced intake which may be associated with lower current animal production is a necessary preliminary to increasing feed supply by management. However, this is only correct when all of the plant biomass is equally palatable. If, by selective grazing, grazing management can alter species composition from species with a low ratio of green leaf to stem to species with a higher ratio then feed supply can be increased without affecting the factors mentioned by Willoughby (1970). The simplest form of management involves only the control of stock numbers, however, in more complex systems the timing and duration of grazing periods are controlled. Management systems may vary from continuous, year long, and various forms of alternate resting and grazing, to no grazing at all.

According to Heady (1975) grazing management aims to "combine the cycles of forage supply, quality and demand to obtain the highest profit from the operation consistent with maintaining excellent condition range". This definition differs slightly from the use of the term management in the range context where it implies selecting from among alternative techniques for optimum production (Heady 1975), rather than maximum production. Range management, a term which more particularly applies to the native and natural pastures of Australia was defined by Heady (1975) as "a land management discipline that skilfully applies an organized body of knowledge known as range science to renewable natural resources for two purposes

(1) protection, improvement and continued welfare of the basic range resource, which may include soils, vegetation and animals, and
(2) optimum production of goods and services in combinations needed by mankind".

Clearly, the objectives of grazing, pasture and range management are interrelated and should not be considered in isolation. The utilization of management systems should be considered within the framework of our existing pasture knowledge, the pasture type in which they are to be used and the purpose for which they are to be used. Management procedures on sown, fertilized pastures should aim to improve the quantity, quality and seasonal distribution of the forage available to domestic livestock; there should be little need to alter the floristic composition of the pasture although it does need to be maintained with associated energy and labour costs. In annual grasslands of the Mediterranean type the maintenance of a desirable botanical composition is almost entirely dependent upon the intensity of utilization (Heady 1975) and very little on the season of grazing. In contrast the management of native and natural pastures should aim to encourage the production of species already present in the pasture (Moore 1966), and to enhance the value of the vegetation as feed for stock. However, such aims have generally not been adopted for Australian native and natural pastures and there is little published information (Biddiscombe et al. 1956; Roe et al. 1959; Suijendorp 1969) on the management of these grasslands.

Ideally pasture management should be concerned with producing a particular species assemblage in a particular pasture and maintaining it (Whalley 1980). If pasture management objectives are defined in terms of the most desirable species assemblage for a particular situation, consistent with the overall management objectives, then a knowledge of the population dynamics and the factors regulating populations of individual species is of great importance. In the U.S.A. most range management systems are based on the reduction or elimination of the grazing pressure on the pasture by domestic livestock for strategically timed periods to allow chosen species to set seed, or having seeded, to become established. Sampson (1913, 1914) after considerable ecological research in the Wallowa Mountains of Oregon recommended deferred-rotation grazing as a general practice in order to improve range by correlating grazing use with vegetational phenology. Since seasonal differences in plant development vary from one region to another, seasonal grazing schedules should be correlated with the growth characteristics of the particular species in a particular location. Hence, the decisions made by the range managers in the U.S.A. are based on ecological details that apply to a given locality.

Unfortunately in Australia very little information is available on the ecology of the native species and unlike the American situation few management systems have been developed for native and natural pastures. While a great deal of knowledge on the best methods of handling and managing the indigenous grasslands of America has been gained since the 1930's, there has been little such work in Australia. Indeed the large rise in pastoral production in Australia since that time has been based on the development of more productive pastures of introduced species and not as a result of the improvement of the indigenous grasses (Barnard 1964). This concentration of pasture research on the development of sown pastures rather than native and natural pastures was also noted by Whalley (1970).

If pasture management is defined in terms of the most desirable species assemblages for particular situations then the rational management of any pasture system is impossible without clearly defined objectives based on a thorough knowledge of the ecology of each grassland area. This approach has been used to stabilize areas of native pasture on an ecological basis in arid and semi-arid areas in Australia (e.g. Nunn and Suijendorp 1954), but has not been adopted in the higher rainfall areas. Four relevant experiments give some insight into why grazing management systems have not been more widely studied and implemented in the high rainfall zones. Roe and Allen (1945) reported the animal data from a three-year grazing experiment on a Mitchell grass (Astrebla spp.) dominant grassland in south-western Queensland where the mean rainfall is 350 mm, mainly of summer incidence. Continuous year round grazing was compared with a six-month rotation; stock being confined to one-half of the grazing area during winter, and the other half in the summer. Although each management treatment was compared at stocking rates of 0.33, 0.50 and 1.00 Merino wethers ha^{-1} no significant differences were recorded in liveweight or wool production for the continuous or rotational-grazing systems. Effects of these grazing systems on pasture composition were not reported. The effects of deferred grazing on sheep and wool production and pasture composition of a Stipa-Chloris grassland were studied over a five-year period (Biddiscombe et al. 1956) at Trangie, New South Wales, where the average annual rainfall is 432 mm per annum. Three rates of stocking, 1 Merino wether to 0.4 ha, 0.6 ha and 0.8 ha were combined with three grazing management systems, continuous grazing, and autumn deferment and spring deferment, in which grazing was deferred for six weeks after the first effective rainfall in autumn and spring. Throughout the experiment the seasons were unusually favourable and so at all stocking rates deferment gave no advantage over continuous grazing either in terms of the bodyweight and wool production of the sheep, the amount of pasture available or the density and basal area of the perennial grasses.

In the north-west of Western Australia a deferred grazing system has been described for spinifex (Trioda spp.) dominant pastures in which continuous grazing and winter burning have decreased the cover of palatable perennial grasses such as Chrysopogon latifolius (weeping grass) and Eragrostis eriopoda (Woolly butt) (Nunn and Suijendorp 1954). Part of the area was burnt in November before the opening of the summer rains to check spinifex growth and sheep were excluded from burnt paddocks until the seedling establishment of grasses after the summer rains (Suijendorp 1969). Deferred grazing decreased the ground cover of soft spinifex and increased the ground cover of Eragrostis spp. and Aristida spp. which produced large quantities of nutritious forage during the wet season.

Rotational grazing has been compared with continuous grazing in a four-year experiment on a B. macra pasture in a 762 mm rainfall environment on the northern Tablelands of New South Wales (Roe et al. 1959). No differences were found between rotational and continuous grazing in their effects on the botanical composition and productivity of the pastures or on the liveweight, wool quality and quantity and parasitic infection of the sheep.

There is a marked disagreement about the relative merits of various management systems both for animal and vegetational responses to continuous grazing and specialized grazing systems such as rotation, deferred, rest-rotation and deferred-rotation grazing. The advantages and disadvantages of these different systems have been considered by Heady (1961), Wheeler (1962) and Myers (1972). The advantages of a specialized grazing programme are generally stated in terms that a rest from grazing allows the established plants to gain vigour and to produce seed and encourages seedling establishment. However, with specialized grazing systems there is also a higher cost associated with fencing and water and in rested pastures there is a loss of feed value after plant maturity. Continuous grazing on the other hand would appear to provide, more consistently then intermittent grazing, a bulk of feed in excess of the critical level required for animal production. A reasonably uniform daily intake of herbage is also assured in a continuously grazed pasture and theoretically, such pastures may be more efficient in their utilization of light than one that fluctuates in height. The contradictory results of animal responses in grazing experiments can often be explained by variation in stocking rate (Morley 1966). Only where the grazing pressure is severe enough to limit pasture growth substantially for an important proportion of the year is a management system likely to be beneficial.

The response of animals in experiments conducted with equal stocking rates which compared continuous and specialized grazing systems have shown negligible differences in annual production of meat or milk per acre (Carrier and Oakley 1914; Salter et al. 1929; Moore et al. 1946). Some experiments particularly with sheep and lambs have shown higher livestock yields from continuous grazing than from rotational grazing (Wheeler 1962). However, the animal data from such experiments should be interpreted in terms of the vegetational changes that occur as a result of the grazing system imposed. Experiments which indicate either no advantage in livestock gains with specialised grazing systems or more gains with continuous grazing also report no significant differences in the vegetation under the various systems (e.g. Moore et al. 1946). Improvement in range condition using specialized grazing systems has been emphasised by Clarke and Tisdale (1936) for short grass ranges in southern Canada, and demonstrated by Hormay (1955) in north-eastern California. A review of available literature led Heady (1975) to conclude that "no matter how stated and practiced, a period of time without grazing during the growing season allows the palatable species to gain in vigor and produce seed if climate permits, and lets the seedlings become established".

The reasons why many continuously grazed versus rotationally grazed experiments have produced conflicting results in terms of their benefit to pastures is that they have often been conducted on a schematic calendar basis (McMeekan 1956). Such designs ignore basic facts involved in the biology of pasture growth and animal needs and are not related to species phenology. Hence, it is not surprising that where rotational grazing has been advocated on a fixed calendar basis it has shown little or no advantage over continuous grazing in terms of both livestock and pasture production. The small effect of partial grazing deferment on Stipa spp.-Chloris spp. grasslands at Trangie, New South Wales (Biddiscombe et al. 1956) is markedly different from the substantial changes reported for short deferments of eight weeks in the north west of Western Australia (Nunn and Suijendorp 1954; Suijendorp 1969). In the Western Australian studies changes in species dominance were brought about by matching the deferment period to the reproductive biology and phenology of the desirable grasses and to the incidence of summer rainfall. This marked improvement in the species assemblages occurred with favourable seasonal conditions and strongly indicates that strategic grazing management could have a large effect on the species composition of at least some Australian native and natural pastures.

The purposes of resting pasture after a season of grazing or deferring grazing at certain times of the year are four-fold (Hormay 1970);

(1) to allow plants the opportunity to build up plant reserves. McMeekan (1956) indicated that the destruction of the apical meristems during the reproductive phase of grass growth can seriously reduce pasture herbage mass;
(2) to allow seeds to ripen;
(3) to allow seedlings to become established; and
(4) to allow litter to accumulate between plants.

Pechanec (1956) described a grazing plan for arid and semi-arid sagebrush range in the western United States which reduces the grazing frequency in spring, when desirable plants are most easily injured by grazing, and allows plants to periodically produce and scatter seed. In the semi-desert regions of the U.S.S.R. Larin (1956) reported a grazing rotation in which grasses were allowed to seed and build up plant reserves in the second and fourth years of operation. Naveh (1970) outlined a rotational-deferred grazing plan in which the timing and intensity of grazing were based on the growth and seed production requirements of Avena sterilis (Naveh 1970) a productive and palatable grass in the Lower Galilee foothills of Israel. Deferred grazing until plants had seeded in autumn resulted in a steady increase in A. sterilis and the perennial grass Hordeum bulbosum (Naveh 1970).

A few studies have attempted to manipulate the composition of both the desirable and undesirable pasture species in the same pasture. In parts of South Africa where highly palatable and unpalatable species are mixed (Hugo 1968) spring grazing tends to reduce, and deferment to increase the unpalatable species. The absence of grazing in early summer provides for the seedling establishment of the desirable species and deferment of grazing in late summer and autumn promotes the seed production and vigour of these grasses. Heavy grazing of Aristida stricta (pineland three-awn grass) (Hughes 1970) either after burning or in the early spring reduced the abundance of this undesirable species in the ranges of the south-eastern United States. In the same pastures deferred grazing during the growth period from early spring until after seed maturity, re-established the plant vigour of the desirable grass Andropogon stolonifer (creeping bluestem) (Hughes 1970), encouraged rhizome growth, and stimulated new shoot development.

The effects of grazing in changing the species composition of native pasture in southern Australia from tall, perennial species to shorter, more prostrate perennials and eventually pastures dominated by annual species have been described for a large number of regions (e.g. Moore 1953b; Moore 1966; Beadle 1948; Biddiscombe 1963; Whalley et al. 1978). Generally such changes have been proposed on the basis of surveying heavily grazed and ungrazed areas and so the reasons for these changes and the stocking rates, management systems and time intervals needed to achieve them have not been specified. Grazing is an ecological factor that has been assumed to be of great importance in the development of the present pattern of plant communities in Australia. However, the statement by Leigh (1972) that "very few grazing trials have been conducted with a degree of scientific rigour equivalent to that often practised on laboratory and animal house experiments" highlights serious deficiencies in our knowledge of the processes of change in species composition with grazing management.

Generally, studies of native and natural pastures in Australia have been either:

(1) survey studies designed to describe the existing vegetation and, by examining heavily grazed and ungrazed areas, determine the influence of rate of stocking on species composition; or,

(2) experimental studies designed to investigate the effects of continuous stocking, at various rates, on livestock production, the herbage mass of the pasture and its botanical composition.

The first of these types of studies have been undertaken, in comprehensive surveys, for the New England District of New South Wales (Roe 1947); the Western District (Beadle 1948); the south-eastern Riverina (Moore 1953a, 1953b); the Trangie district (Biddiscombe 1953); the Macquarie region (Biddiscombe 1963); the southern Tablelands and south-western Slopes (Moore 1970); and, the north-west Slopes (Williams 1979). Many of these surveys used different methods and were undertaken at different times of the year and so their observations are strictly not comparable. However, where lightly grazed or ungrazed areas (cemeteries and railway embankments) were compared with heavily grazed (stock route) situations changes in species composition with grazing have been deduced. The dominant species of the climax communities of many regions have been outlined in Chapter 1. In the south-eastern Riverina (Moore 1953b) proposed that with grazing Stipa falcata, S. scabra and Danthonia spp. became dominant, but these species then responded differently to any further increase in grazing pressure. For example, in an Eucalyptus microcarpa alliance heavy grazing on a light textured soil completely removes Danthonia spp. and increases the proportion of S. falcata, Panicum effusum and annual species; on heavier textured soils S. falcata becomes a minor constituent of the pasture and the proportion of Danthonia spp. increases (Moore 1953b). Similar differences in the response of Stipa spp. and Danthonia spp. to grazing have also been demonstrated in a E. microcarpa woodland and a E. melliodora-E. blakelyi woodland (Moore 1966). Biddiscombe (1953) found that light grazing (1 sheep per 0.82 ha) gave increased dominance of S. falcata (light soils) and Stipa setacea (heavy soils), these ultimately being replaced by C. truncata as grazing pressure became more severe. Moore (1953b) also observed that C. truncata was dominant in heavily grazed areas. Danthonia pilosa on light textured soils and D. simulans (Biddiscombe 1953) were observed to persist under heavy and severe grazing contrasting with the statement of Beadle (1948) that Danthonia semi-annualaris disappears with heavy grazing. However, in agreement with observations by others, Beadle (1948) noted that C. truncata dominated in heavily grazed areas. Moore (1953b) suggested that heavy grazing of Stipa spp. and Danthonia spp. grasslands led to an increase in the development of Aristida spp. which being unpalatable are not affected by grazing. On the deep sands in the E. dealbata-E. sideroxylon alliance A. jerichoensis var. subspinulifera (low rainfall areas) and A. ramosa (higher rainfall areas) became dominant with heavy grazing (Moore 1953b).

In the higher rainfall E. albens alliance Bothriochloa macra may become a dominant species of heavily grazed pastures. Both Beadle (1948) and Moore (1970) reported that with heavy grazing Stipa spp. and Aristida spp. grasslands ultimately changed to cool season annual pastures. Biddiscombe (1963) suggested that heavy grazing (more than 1 sheep per 0.4 ha) reduced the proportion of; S. falcata in contrast to the observation of Moore (1953b); S. aristiglumis in agreement with the observations of Moore (1953b), Biddiscombe (1953) and Moore (1966); Enneapogon spp.; D. sericeum, in agreement with the reports of Beadle (1948); E. fulva, and, T. australis in agreement with the observations of Roe (1947), Moore (1953b) and Moore (1970). The contrasting observations on the reaction of Stipa spp. and Danthonia spp. to grazing appears to be related to a number of factors including; the species and may be even the ecotype involved, soil texture, incidence of rainfall, the type of stock, and the intensity of grazing. These detailed observations over such a wide area tend to support the proposal that with grazing the native pastures in the southern (Moore 1970) and northern (Whalley et al. 1978) areas of New South Wales have progressively changed from pastures dominated by tall warm season perennials to those dominated by cool season perennials, short warm season perennials and cool and warm season annuals.

These proposed changes in the species composition of native pastures since European settlement have not been duplicated in experimental studies. Generally there is little experimental evidence to indicate that continuous grazing of native pastures over a wide range of environments and stocking rates has produced any large scale changes in the species composition and structure of native pastures. However, it should be noted that no results of native pasture grazing experiments have been published for pastures dominated by the proposed climax species for any grassland. After five years of grazing at stocking rates as high as 15.6 Merino wethers ha^{-1} a Danthonia spp.-Panicum spp. grassland on the northern Tablelands of New South Wales was still strongly dominated by these two species (Robinson and Lazenby 1976). Similarly, six years of grazing at stocking rates up to 7.3 sheep ha^{-1} on a B. macra-A. ramosa-S. scabra pasture on the north-west Slopes did not cause any large scale changes in the basal cover of the native perennial grasses (Lodge and Roberts 1979). In other experiments, in a nine year study, Williams (1968) reported that a stocking rate of 1 sheep to 0.5 ha had little effect on the basal area and density of Danthonia caespitosa; four years of grazing at 3.1 sheep ha^{-1} (Roe et al. 1959) did not affect the botanical composition of a Bothriochloa macra pasture; four years of grazing (0.81 ha per sheep) did not affect the density of an Aristida spp.-Astrebla spp. pasture (Purcell and Lee 1970), and, after four years of grazing a Stipa spp.-Aristida spp.-Chloris spp. pasture grazed at stocking rates of 2.04 wethers ha^{-1} (Brownlee 1973) was still dominated by native perennial grasses.

Although the overall structure of these pastures was not greatly changed, stocking rate did affect the abundance of some of the individual species. The frequency of Panicum spp., Eragrostis spp. and S. elongatus increased at a stocking rate of 15.6 Merino wethers ha^{-1} while grazing at 7.8 sheep ha^{-1} reduced the frequency of T. australis, B. macra and A. ramosa (Robinson and Lazenby 1976). Increasing stocking rate from 2.2 to 7.3 sheep ha^{-1} decreased the percentage basal cover of A. ramosa (Lodge and Roberts 1979) and in some years decreased the percentage of A. ramosa and S. scabra, and increased that of C. truncata and D. linkii; B. macra and S. elongatus were unaffected by grazing. Brownlee (1973) also reported that grazing, at 2.04 sheep ha^{-1}, reduced the density of A. jerichoensis and S. scabra, but it did not affect the density of Danthonia auriculata and Chloris acicularis. However, over a 16 year period Williams (1969) found that grazing at rates of 0.25 to 0.5 sheep ha^{-1} encouraged both seedling and mature populations of D. caespitosa.

The lack of any large scale changes in pasture composition in these experiments and the lack of any change in the basal area and plant density of perennial species in a number of other experiments (e.g. Biddiscombe et al. 1956; Roe et al. 1959; Williams 1968) would appear to negate the argument that manipulation of the grazing animal can alter botanical composition. However, changes in pasture species composition and pasture structure may be of a more long-term nature than many of experiments reported. Such changes would also depend on favourable seasons, the influence of rainfall and the condition of the pasture.

The long-term nature of changes in species composition is exemplified by the studies of Biddiscombe (1953) and Campbell et al. (1973) in the Trangie district of New South Wales. The trend for heavier grazing of Stipa spp.-Chloris spp. pastures, which were the dominant grasslands of the area was noted by Biddiscombe (1953) and apparently continued; Campbell et al. (1973) reported that only a small percentage of natural pasture in the area was dominated by perennial grasses. The majority of pastures in the Trangie district now consist of swards dominated by cool season annuals such as H. leporinum, Erodium spp. (crowfoot) and Medicago spp. (Campbell et al. 1973). With protracted drought conditions Purcell and Lee (1970) found that grazing did not significantly affect the density of Aristida latifolia in a Mitchell grass grassland. However, with more favourable seasons, Hall and Lee (1980) reported large changes in the frequency of A. latifolia in a similar pasture. Light grazing by sheep increased A. latifolia frequency from 6 to 88% and heavy grazing by cattle prevented the build up of Aristida. The interaction of grazing effects and seasons was also noted by Biddiscombe et al. (1956) who indicated that rainfall rather than grazing may be a more important factor affecting changes in species assemblages. All of the studies reported in this review were conducted on disclimax communities. These degraded pastures had reached an equilibrium with current management practices, stocking rates and the occurrence of drought. In order for grazing to induce changes in these plant populations the treatments would have to have been much more severe or of a different nature to those that had previously given rise to the existing plant communities.

Fertilizer application

The productivity of native and natural pastures can be greatly improved by fertilizer application associated with higher stocking rates, provided that there are efficient legumes present in the pasture (Moodie 1934a; Davies et al. 1934; Simpson and Robinson 1967; Robinson and Lazenby

1976). However, the success of such methods of improving pasture production depends on favourable seasonal conditions for legume growth (Lodge and Roberts 1979). In the Mediterranean-type climate of southern Australia, Trifolium subterraneum (subterranean clover) sown with superphosphate has increased pasture production (e.g. Davies et al. 1934; Carter and Day 1970; Reed 1972). The success of this technology and the replacement of native grasses by introduced grasses, which are assumed to be better able to respond to increased fertility than the indigenous grasses, has resulted in the concentration of pasture research on the exotic species (Whalley 1970). In the higher rainfall areas of eastern Australia it is now a generally accepted philosophy to replace the indigenous species with fertilized legume-based pastures (Donald 1970; Wolfe 1972).

Fertilizer applications increase soil fertility levels and as the pastures pass through the development phase and approach the maintenance phase, the proportion of sown species increases, while that of the native species declines (Donald and Williams 1954; Wolfe and Lazenby 1973). Such changes in pasture species composition were also noted by Moore (1966), who found that T. subterraneum increased, and by Davies et al. (1934) who showed that T. arvense, T. procumbens (Davies et al. 1934) and T. glomeratum increased as Danthonia spp. and other native perennials were replaced by Mediterranean annual grasses and forbs. However, in many environments many sown pastures fail to reach a stable maintenance phase which depends on factors such as the pasture type, the environment and the grazing animal interacting with factors such as rates of fertilizer application, number of applications, stocking rates and competition between grasses and legumes (Wolfe 1972). Unfortunately pasture degeneration tends to be the rule rather than the exception (Stern 1969) and production declines as native species re-invade, or weed species ingress into the pasture (Cook 1974).

Where there are fewer volunteer legumes in natural pastures, such as in northern New South Wales and southern Queensland the improvement of grazing lands by fertilizer application has been slower (Moore 1970). The poor response of natural pastures to low levels of superphosphate initially applied to basaltic soils also delayed the widespread use of fertilizers to improve these pastures. These soils were subsequently shown to be S rather than P deficient (McLachlan 1952; Hilder and Spencer 1954). On the northern Tablelands of New South Wales the native perennial grasses do not disappear as readily following fertilizer application (Robinson and Lazenby 1976; Whalley et al. 1978) as that described for the southern Tablelands (Donald and Williams 1954), or for Mediterranean-type areas (Davies et al. 1934). In field experiments (Hilder and Spencer 1954; Lodge and Roberts 1979) and glasshouse experiments (Begg 1963; Lodge 1980) the winter growing naturalized annual legumes of the northern Tablelands and Northern Slopes have been shown to be capable of responding to applied P and S. In these regions fertilizers such as single superphosphate, sulphur-fortified superphosphate and gypsum are often applied (McLaughlin 1980) without the addition of a high producing pasture legume. Little is known of the subsequent changes in species composition or the increase in animal production that can be obtained by this practice. The application of superphosphate to these pastures can, however, increase productivity depending on the response from annual naturalized legumes (Lodge and Roberts 1979) or white clover (Robinson and Lazenby 1976). The responses of the native grasses to increased P and S levels and to increased N availability that may result from legume growth are not so well documented.

One of the first positive responses to topdressing natural pastures in northern New South Wales was recorded by Moodie (1934a). Annual applications of 125 kg ha^{-1} of superphosphate over a six-year period decreased B. macra dominance in pastures, increased the proportion of Danthonia spp., Trifolium spp. and Medicago spp. and increased carrying capacity from 3.7 to 9.1 sheep ha^{-1}. Similarly, at the Waite Institute, Davies et al. (1934) found that applications of 225 kg ha^{-1} of superphosphate per year for three years increased the content of clover and Danthonia spp. in pasture, resulting in an increase in carrying capacity from 2.5 to 3.9 sheep ha^{-1}.

In the New England district annual applications of between 110 and 225 kg ha^{-1} of superphosphate for four years were reported by Berman (1954) to change the botanical composition of a Aristida spp.-Bothriochloa spp.-Sporobolus spp. pasture to a clover-grass mixture with the virtual elimination of the former species. Simpson and Robinson (1967) demonstrated that in a Themeda spp.-Danthonia spp.-Bothriochloa spp. grassland containing white clover the response to applied fertilizer depended on the stocking rate. This result was confirmed in an experiment by Robinson and Lazenby (1976) in which the application of 500 kg ha^{-1} of superphosphate per year over a five year period increased the frequency of T. repens and decreased the frequency of Panicum spp.-Eragrostis spp. and S. elongatus, particularly at low stocking rates. Over the period of the experiment animals on pastures that received superphosphate also averaged 15% heavier bodyweights and gave 18% more wool than those that were unfertilized. Whalley et al. (1978) also found that stocking rate, fertilizer application and seasonal effects may markedly influence the response to fertility. Superphosphate applications of 65, 190 and 375 kg ha^{-1} applied annually over an eight year period resulted in an initial increase in the frequency of Danthonia spp. (Whalley et al. 1978), but following a period of clover dominance the frequency of Danthonia spp. decreased, probably as a result of competition from the clover (Donald and Williams 1954).

A large interaction between stocking rates and fertilizer application over time on the herbage mass of a Bothriochloa spp.-Aristida spp.-Stipa spp. pasture was also shown by Lodge and Roberts (1979). At 4.8 and 6.3 sheep ha^{-1} the optimum rate of P for herbage mass production was 15 kg ha^{-1}, but at 3.2 sheep ha^{-1} it increased from 15 to 23 kg P ha^{-1} over a five year period. S had little effect on the herbage mass at the start and end of the experiment, but in between its effect depended on stocking rate; at 3.2 sheep ha^{-1} low levels (less than 14 kg ha^{-1}) were optimal, but at 4.8 and 6.3 sheep ha^{-1} very high levels (greater than 54 kg ha^{-1}) were needed. However, Lodge and Roberts (1979) were unable to demonstrate any consistent effect of annual applications of up to 29 kg P ha^{-1} and 67 kg S ha^{-1} on the frequency of annual legumes and grasses, and the basal cover of the native perennial grasses.

Despite the results of the above experiments native perennial grasses are still generally considered to lack potential to respond to improved fertility (Cook et al. 1976). However, few if any long-term studies have been undertaken to compare the animal productivity and persistence of fertilized native and natural pastures and sown pastures in the same environment. The studies of Moodie (1934a), Davies et al. (1934), Robinson and Lazenby (1976) and Whalley et al. (1978) clearly indicate that the application of superphosphate to natural pastures that contain Danthonia spp. and legumes, or that have been oversown with Trifolium spp. has led to increased carrying capacity. The results of the above experiments also indicate that any further experiments designed to investigate the effects of fertilizer application must necessarily be long-term, to cover a number of seasons, and must involve a range of both fertilizer and stocking rates.

Over a three year period ungrazed field plots of D. racemosa were as productive as those of Lolium perenne and some lines of Dactylis glomeratum (Robinson 1976) and produced more dry matter than those of Phalaris acquatica and Festuca arundinaceae. These plots had received 125 kg ha^{-1} of superphosphate and two applications of 250 kg ha^{-1} of sulphate of ammonia per year. Under these conditions the native perennial grass D. racemosa proved capable of producing as much dry matter as any of the exotic sown species and maintained a high total herbage mass in spite of annual variations. Robinson (1976) also found that over a three-year period annual applications of up to 90 kg N ha^{-1} produced similar increases in the herbage mass of P. aquatica and D. racemosa plants grown in pots, although P. aquatica produced the most growth in the autumn and winter.

Recent pot culture experiments in which the effects of fertility on the herbage mass of native perennial grasses have been investigated have shown a differential response between species; D. racemosa responded better to applied N than either T. australis or B. macra (Robinson 1976), and, in the seedling stage A. ramosa, Danthonia linkii and D. richardsonii differed markedly in their response to applied N (Harradine and Whalley 1978). When T. australis and Poa labillardieri were grown alone in pots both species were shown to be capable of responding to P levels equivalent to 125 and 500 kg ha^{-1} of superphosphate and N levels of 125 and 250 kg ha^{-1} (Groves et al. 1973). All of these results indicate that the application in the field of either N, or more commonly the application of superphosphate to stimulate legume growth, or P and S may be used to manipulate species composition. Furthermore, in any management strategies involving fertilizer application it is apparent that any changes in the total herbage mass of the whole pasture will depend on the response of the individual species.

Fire

The effects of fire on grazing lands have been reviewed for Africa (West 1965); North America (Daubenmire 1968); for north-eastern Australia (Tothill 1971), and for many areas of Australia (Leigh and Noble 1981). These reviews highlighted the many contradictory reports that have been published in the literature on the effects of fire on vegetation. Some of the interacting factors that may affect the results of burning experiments are: the season of the year; the amount of herbage; frequency of burning; the intensity of the burn; weather conditions at the time of, and following the burn; the time allowed after the burn before stock are permitted to graze; the effects of grazing on the regenerating plants, and the resistance of the individual plants to fire. Unless the conditions and treatments are the same or similar the results of different burning experiments are not comparable.

Burning has long been practised by man both before and since European settlement in Australia. Aborigines used fire as an aid in hunting and fighting and made little attempt to control wild fires. The prevention of wild fires has commonly been an essential corollary of settlement. Reduction in fire frequency, combined with increased grazing pressure since settlement, has had a profound effect on the botanical composition of grazing lands (Moore 1962). Hence, changes in vegetation since settlement are a result of the response of individual species to changes in fire frequency and grazing pressure. The interaction of these two factors was demonstrated by Shaw (1957) who found that regular burning in spring encouraged *Heteropogon contortus* (spear grass) in ungrazed pastures in coastal and sub-coastal Queensland. However, regular burning does not always result in the dominance of *H. contortus*; railway enclosures and country cemeteries, both of which are regularly burnt but not grazed, are commonly dominated by *T. australis*. Moore (1970) also reported that the practice of burning grazing lands to remove dry debris in spring before growth commences and light grazing by cattle favours *T. australis*. It would appear that regular burning and light grazing has increased *H. contortus* dominance over wide areas of western Queensland because established plants are resistant to fire (Shaw and Bisset 1955), fire favours the germination of seed (Shaw and Bisset 1955; Tothill 1971) and fire reduces the ground cover of other species.

Increasingly land managers are making use of fire as a management tool (Heady 1975). The objectives of such management may be to:

(1) remove top herbage in order to increase the availability of new seasons growth, remove patchiness in unevenly grazed pastures or to reduce competition;
(2) stimulate growth at a time when it might not otherwise occur;
(3) reduce undesirable plants;
(4) favour certain plant species;

(5) produce more forage for livestock and increase the quality of livestock feed;
(6) attract animals to areas that might otherwise be left ungrazed;
(7) remove the hazards of wild fires and establish fire breaks;
(8) control diseases, pests and undesirable animals;
(9) produce ash for fertilization.

The most common use of fire as a management tool is the removal of undesirable plants (Heady 1975). Purcell and Lee (1970) and Halls et al. (1952) reported the use of fire to control undesirable Aristida species in grassland and Reynolds and Bohning (1956) observed that fire controlled the abundance of mesquite, cactus and burro-weed in southern Arizona. The use of fire and grazing to reduce the abundance of the undesirable Trioda spp. and increase the abundance of grasses in north-western Australia (Suijendorp 1969, 1981) has already been described. Winter burning increases the availability and usefulness of the early growing species Aristida stricta (Hilmon and Hughes 1965) and in the first two to three months after burning cattle readily grazed the wiregrasses. Burning has also been shown to assist in the establishment of grasses and clovers oversown into wiregrass pasture (Killinger and Stokes 1947) and of Stylosanthes humilis (Townsville stylo) in tropical tallgrass woodlands (Stocker and Sturtz 1966). Shaw and Norman (1970) reported that a general management practice in much of northern Australia, where the dry season is long and severe, is to burn the grazing land in the dry season to encourage the dormant perennial grasses to utilize residual soil moisture and produce new shoots.

Although the time of burning may have a marked effect on botanical composition, to some extent time of burning is dictated by the phenology of the species it is designed to control. West (1965) has reviewed the African work which generally showed that burning at any time the vegetation was dormant encouraged Themeda trianda (West 1965), while burning in the summer growing season reduced it. In reviewing the North American literature, Daubenmire (1968) pointed out that grasses were little affected by burning if they were in the dormant state. Invariably a grassland fire occurring when some species are green and others are dry will damage the green species more than the dry ones (Heady 1975). Similarly, a fire that occurs after the cool season species begin to grow in the true prairie region will damage them (Curtis and Partch 1948), but not harm the warm season species. Decreased size of perennial grass plants following a fire (West 1965) may be accompanied by increased flowering and seed production for one to two years after burning. The species that respond in this manner are mainly warm season species of the true prairie and of the tropical and sub-tropical grasslands (Heady 1975). Short grasses and bunch grasses of the dry and cool grasslands tend to have fewer inflorescences after burning than do the warm season grasses (Daubenmire 1968).

Obviously the three factors of grazing, fertility and fire, either separately or in combination have been of major importance in the development of our present day grasslands. Why changes from the original composition have occurred, and how these factors may be used to produce changes in botanical composition in a desired direction are not so clearly understood. Where management practices such as grazing, fertilizer application and fire have been applied to improve degraded grasslands they have had the most success when their use has been matched to the phenology of the desirable and undesirable species in the pasture. The matching of burning and grazing management to the biology of the undesirable species, together with suitable seasons led to successful pasture improvement in Western Australia (Suijendorp 1981). However, this approach has not been adequately tested in other areas, particularly in the humid rangelands of Australia where the potential benefit from an improvement in carrying capacity of native and natural pastures is high.

CHAPTER 3

OUTLINE OF INVESTIGATIONS

It was shown in Chapter 1 that the native and naturalized grasses which occur in the pastures of the study area can be classified into five groups on the basis of their growth pattern and phenology. In addition, it would be surprising indeed if there was not further variation among their green leaf production, acceptability, digestibility, protein content and other features which contribute to their value as pasture components. In the absence of the replacement of native grasses by improved exotic species a valid approach for improving these pastures seems to lie in manipulating the species composition of the native grass component in the direction of the more valuable species, using low cost management techniques. In order to do this detailed knowledge of the value for grazing and autecology of the constituent species is necessary.

Value for grazing

Estimation of mass: The procedures outlined by Brown (1954) have generally been used to study the total herbage mass and the botanical composition of pastures. These techniques are limited either by the need for hand-separation of samples, which is time consuming, or by a loss of accuracy when the relative proportions of each species are estimated by eye (Davies and Trumble 1934). Only one of these procedures, which involves the harvesting of herbage in quadrats, its separation into component species and the weighing of each component, was considered by Brown (1954) to be sufficiently accurate for studying the effects of management on pasture species composition.

Total herbage mass in a pasture can be estimated by either harvesting herbage within quadrats (e.g. McLachlan 1968; Fisher 1974; Lodge and Roberts 1979), mowing (Robinson 1976), capacitance probe measurements (Lazenby and Lovett 1975), coring techniques (Hamilton *et al*. 1973) or by estimation techniques (Morley *et al*. 1964; Campbell and Arnold 1973; Haydock and Shaw 1975). Such estimates of total pasture mass can be partitioned into component species by using the dry-weight rank method ('t Mannetje and Haydock 1963; Tothill *et al*. 1978). However, the dry-weight rank method of estimating species composition does not include the minor species in the pasture and so the herbage mass of species which do not attain a rank cannot be estimated. However, management may be aimed at increasing the abundance of one or more of the minor species. Many native grasses have similar vegetative characteristics and so the accurate identification of species from harvested herbage is usually extremely difficult. Hence, in these pastures there is an obvious need for improved methods of estimating the individual herbage mass of both the major and minor perennial grasses and assessing their responses to management.

Few pasture studies of exotic or native grasses have separated the green and dead portions of the herbage, although the green portion is directly related to animal production (Roe et al. 1959). In a P. aquatica-T. subterraneum pasture, Willoughby (1959) found that 1560 kg ha^{-1} of available green pasture was required to maintain liveweight gain in sheep, but no attempt was made to separate the grass and clover components. In pure grazed swards of four exotic grasses, however, Hamilton et al. (1973) has shown that when the amount of green herbage exceeded 550 kg ha^{-1} sheep selected a diet more digestible than the mean of the green herbage on offer. The relative importance of the leaf and stem, and green and dead fractions of the total herbage mass of individual species should not, therefore, be overlooked when evaluating the desirability of a species for grazing.

Because of problems associated with the collection of data little information is available on the herbage mass of individual native perennial grass species, and few studies have been conducted to compare the masses of native perennial grasses growing in the same environment. Groves (1965) found that the herbage mass of the warm season grass T. australis ranged from 700 to 3000 kg ha^{-1}, but green and dead portions were not separated. Growth rates of T. australis varied from 39 kg/ha/day in spring to 2 kg/ha/day in winter compared with 45 kg/ha/day and 2 kg/ha/day for a L. perenne-T. subterraneum pasture for the same periods. In a Themeda grassland without N applied dry matter herbage masses ranged from 20 kg ha^{-1} in August to 1520 kg ha^{-1} in December (Fisher 1974) and depending on the frequency of cutting estimates of the annual herbage mass of T. australis varied from 200-1800 kg ha^{-1}. At Trangie, New South Wales the average quantity of green forage of C. truncata varied from 560 kg ha^{-1} in summer (Biddiscombe et al. 1956) to 224 kg ha^{-1} in winter, and S. falcata herbage masses ranged from 124 kg ha^{-1} in summer to 21 kg ha^{-1} in winter.

Evaluation of grazing potential: Because of the difficulties involved in producing pure stands of individual species of native grasses to obtain animal production data the best practical means of obtaining a preliminary estimate of the relative grazing value of the different species appears to be to study, in situ, the seasonal growth patterns of the different species together with analyses of the total nitrogen (crude protein) and in-vitro digestibility of the forage produced. Diet selection and animal production studies would be required to further validate these initial estimates.

Autecological information required

Several outlines for autecological studies have been proposed (e.g. Stevens and Rock 1952; Pelton 1953; Clapham 1956; West 1968). The latter author stressed the importance of such studies for the formulation of pasture management practices.

In the design of grazing plans and grazing management systems to manipulate species composition, the time of seedling emergence and the flowering of species are of major importance (Hormay 1970; Heady 1975). In other environments it has been shown that temperature, moisture and seed dormancy may affect the establishment of several native grasses e.g. Danthonia spp. (Cashmore 1932; Moore 1946; Hagon 1976); Stipa nitida (Osborne et al. 1931); Aristida contorta (Mott 1972), and, B. macra (Moore 1958; Hagon 1976). However, little such work has been done on the dominant native grasses on the Northern Slopes and little is known of the factors that may affect seedling establishment and flowering.

Study outline

A series of studies were undertaken at five major Study areas throughout the Northern Slopes of New South Wales (Fig. 3.1) to:-

(1) develop and test techniques for estimating the herbage mass of native perennial grasses from measurements of plant density, basal area and mass per unit basal area;
(2) determine in field and glasshouse studies the effect of fertility on the herbage mass of the dominant native perennial grasses;

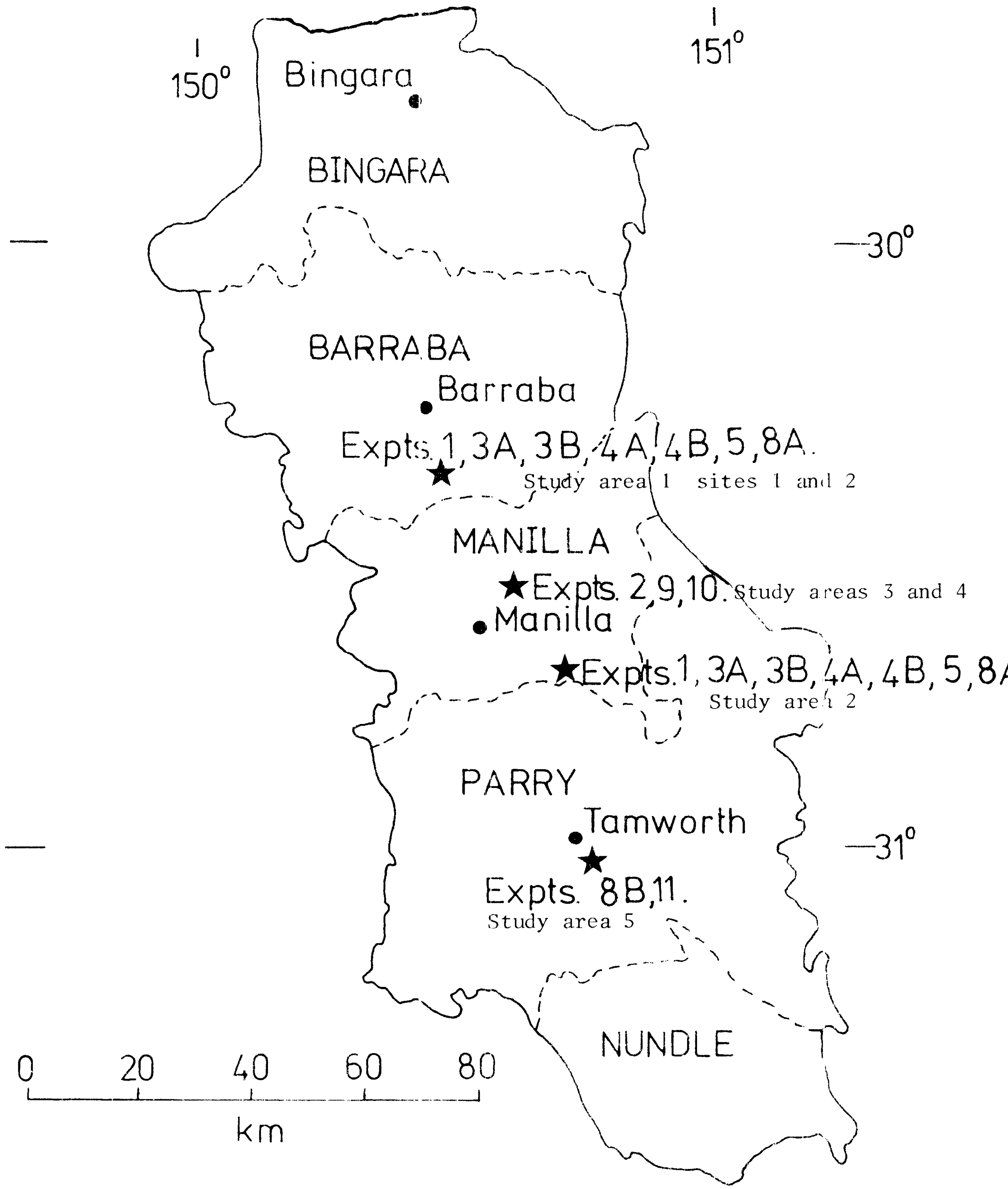

Figure 3.1 The location of the field experimental sites within the study area.

(3) classify the dominant native perennial grasses as desirable or undesirable pasture species for grazing. In the reported research preliminary estimates of the relative grazing value of the warm season native perennial grasses _Aristida ramosa_, _Bothriochloa macra_, _Dichanthium sericeum_, _Sporobolus elongatus_, _Eragrostis leptostachya_ and _Chloris truncata_, and the yearlong green native perennial grasses _Stipa scabra_ and _Danthonia linkii_ were based on studies of seasonal changes in green herbage mass, crude protein and _in-vitro_ digestibility;
(4) investigate the effects of seed dormancy and temperature on the germination of the above eight native perennial grasses, together with field studies of seedling emergence, survival and the flowering periods of mature plants;
(5) design grazing management systems based on species phenology to increase the abundance of native perennial grasses found to be desirable and to reduce the abundance of those shown to be undesirable;
(6) test the proposed grazing management systems in field experiments.

The field sites at the five Study areas were all natural pastures dominated by warm season native perennial grasses (either _B. macra_ or _A. ramosa_). These pastures also contained varying proportions of yearlong green native perennial grasses, naturalized cool season annual grasses and forbs, warm season annual and perennial forbs and yearlong green perennial forbs.

Section 2

CHAPTER 4

TECHNIQUES FOR ESTIMATING THE HERBAGE MASS OF NATIVE PERENNIAL GRASSES

This Chapter investigates methods of estimating the herbage mass of individual species of both major and minor native perennial grasses in a pasture and assessing their responses to management. A change in the herbage mass of a particular species in response to management strategies such as fertilizer application or grazing, results from changes in a combination of either the number of plants per unit area (plant density) or the basal area of individual plants, or the plant mass per unit of plant basal area of individual plants. Data on each of the above three plant parameters is essential to an understanding of the process of change in species composition.

Experiment 1. Estimating plant basal area, mass and mass per unit basal area and assessing plant mass per unit of plant basal area as a method of measuring response to management.

Estimates of plant basal area obtained by the methods proposed by Pearse (1935) and Vose (1956) tend to be overestimates because these methods assume that plant bases have regular outlines and that all within the outline is living plant material. Plant bases actually consist of a cross-sectional area of both live and dead stems as well as air-space, and the relative proportions of these components of basal area vary markedly from plant to plant within a species and from species to species. Hence, there is a need for improved techniques for estimating plant basal area and also for accurately defining the components of the plant base that need to be measured.

In this study plant basal area was taken to be the total cross-sectional area of the individual stems at the plane of harvest. Estimates of basal area could be obtained by observing plant bases through a transparent overlay. This permits the irregular basal outline and the stem cross-sectional area of the base to be considered when estimating its area. The plant mass and basal area of six native perennial grasses were estimated at two sites to assess plant mass per unit of plant basal area as a method of measuring the response to management of some major and minor grasses. For each individual species herbage mass estimates were calculated from plant density data and plant herbage mass and basal area data.

A. Materials and Methods

Estimation of plant basal area

Field studies

This study was undertaken on two separate natural pastures (Fig. 3.1) that occurred on a red-brown earth (Northcote (1971) classification (Dr 2.23)) and were situated on a north-west aspect. The first was a fertilized site at Barraba, New South Wales (Study area 1 site 1) that had received 150 kg superphosphate ha^{-1} annually over a period of 10 years, and the second was a natural pasture near Manilla, New South Wales (Study area 2) that had never been fertilized. Despite their differences in past fertilizer application and fertility (Appendix 1) both sites had similar past grazing histories; about 2 sheep ha^{-1} over the previous 15 years. Further site descriptions and environmental data are given in Chapter 6 and Appendices 1, 5A and 5B.

At each site 20 individual plants of the native perennial tufted grass species A. ramosa, B. macra, S. elongatus, E. leptostachya, D. linkii and S. scabra were clipped at ground level in April 1978. At each of the sites individual plants were randomly selected, although they generally covered the range in plant size encountered in the field. The basal area of individual plants was then estimated by the following methods:

(i) A transparent unmarked perspex sheet (15 x 15 cm) was placed on the ground on each clipped plant base. The periphery of each plant base was outlined, transferred to a sheet of white paper, labelled, cut out with scissors and the area measured with an automatic leaf area meter (UOG).

(ii) The tuft of stems and leaves from each plant was inverted and the base trimmed with shears. The area of green stems (GOG) and dead stems (GOD) was then estimated with a 5 mm grid overlay to the nearest one-tenth of a filled grid cell and expressed as a count of filled cells. Basal area data were generated by multiplying the counts by the area of an individual grid cell. The area of green stems was added to that of dead stems to provide an estimate of the total area of the base of each tuft (GOT). Grid overlays were made by etching fine lines onto a 10 x 10 cm sheet of 2 mm thick perspex. Black chirograph pencil was used to enhance the visibility of the lines.

(iii) The unmarked perspex overlay was placed on the base of each of the above hand-held tufts. The periphery of the total plant base was outlined, transferred to a sheet of paper and the area measured with an automatic leaf area meter (UOH).

For each of the six species significant differences between the mean estimates of basal area were measured by 't' tests.

Laboratory studies

Thirty artificial plant bases of different size were constructed by clustering, but not overlapping, adhesive black paper discs (representing transverse sections of stems) of 3.5, 2.0 and 1.0 mm diameter on paper to create ten 'bases' with each size of disc, each with a different area. These clusters were intended to represent transverse sections of tufts of clipped grass plants of different species, using discs of different diameters; and of different basal areas, using different numbers of a particular size of disc. Field observations suggested the disc sizes employed and the actual basal areas used in the validation procedures ranged from 0.02 to 10.39 cm^2.

Two separate methods of estimating area were examined:

(i) grid overlays of dimensions 10, 5, 3 and 2 mm were placed over each of the artificial bases and a count made of the number of grid cells estimated by eye to be filled by the area of discs;

(ii) the peripheral outlines of the artificial plant bases were traced onto an unmarked overlay. These outlines were then transferred to a sheet of white paper, labelled, cut out with scissors and their area estimated using an automatic leaf area meter.

For all data the linear model $y = bx + a$ was fitted where, y is the estimated area of the artificial plant bases and x is the actual area of the artificial bases. Differences between the regression coefficients and the intercept values for the two regression equations, and between the regression coefficients and $y = x$, were compared by 't' tests.

Estimation of plant mass per unit of plant basal area

The plant material harvested in the field studies was hand-sorted into green leaves (excluding leaf sheaths), green stems plus leaf sheaths, dead leaves, dead stems and flowering culms. These portions were dried in a forced draught dehydrator for 48 hours at $80^{o}C$ and then weighed.

The mass of each of the above plant portions and the total green, total dead, total vegetative and total plant mass values were calculated per unit of plant basal area for each plant harvested. For all data the linear model $y = bx + a$ was fitted, where y is herbage mass (g) and x the plant basal area (cm^2).

Estimation of the herbage mass of individual species per unit area

Data were collected at the two field sites to estimate herbage mass per unit of land area, plant density, plant basal area and plant mass per unit of plant basal area. Numbers of plants of each of the six species were counted in 20 quadrats, each of 1 m^2, at the fertilized (Study area 1 site 1) and unfertilized (Study area 2) pasture sites in November 1977. Plant basal area of each species was estimated from the 20 unmarked overlay (UOG) determinations taken at each site and plant mass per unit of plant basal area was calculated as previously described.

The mean herbage mass (kg ha^{-1}) of the six species growing at the two field sites was calculated using the following equations:

$$\text{Herbage mass} = (p \times q)\, r \times 10 \quad \text{kg ha}^{-1} \qquad (1)$$

$$\text{Herbage mass} = p \times s \times 10 \quad \text{kg ha}^{-1} \qquad (2)$$

where, p = mean number of plants m^{-2}, q = mean plant basal area (cm^2), r = mean mass of plant portion per unit of plant basal area (g m^{-2}), and, s = mean total mass of plant (g).

To validate the herbage mass estimates calculated from equations (1) and (2), ten 0.16 m^2 quadrats were sampled in November 1979 from a 0.2 ha area of unfertilized natural pasture near Manilla, New South Wales (Study area 3). Each of the native perennial grass plants growing in each quadrat were identified to species, counted, harvested to ground level and placed in individual bags. The remainder of the material in the quadrat (herbaceous weeds, annual legume and grass and litter) was harvested separately and bulked together. The harvested material of each individual native grass was hand-sorted into green leaves, green stem plus leaf sheaths, and dead material. These portions were dried in a forced draught dehydrator for 48 hours at 80°C and then weighed. The basal area of each of the harvested plants was estimated using the unmarked overlay method (UOG) previously described. Herbage mass estimates from the clipped quadrats and those from equations (1) and (2) were calculated for each of the native perennial grasses harvested.

B. Results and Discussion

Overlay estimates of basal area

For each of the six species in the field the estimates of basal area obtained by either the UOG, the GOT, or the UOH method were not significantly different (Table 4.1). However, because of the amount of airspace between the stems that is included in the basal area estimate when the periphery is traced at ground level, the UOG estimates tended to be higher than both the GOT and UOH estimates. Using the UOH method the compression of the hand-held tufts reduced the airspace, decreasing the UOG estimates from 18% tc 46% depending on the 'openess' of the plant base.

In the laboratory studies the regression equations for the 10, 5, 3 and 2 mm grid overlays were not significantly different and all data were pooled. The regression coefficients relating the UOG and GOT estimates of area and the actual area were both significantly different ($P < 0.05$) from each other and the UOG coefficient was significantly higher ($P < 0.05$) than $b = 1$ (Table 4.2). The intercept value of -0.23 for the UOG method was also significantly different ($P < 0.05$) than that for the GOT method, and for $a = 0$. Although overestimation is an inherent characteristic of the UOG method it should be noted that short, semi-prostrate species, such as C. truncata, are not easy to harvest as discrete tufts. Therefore this method provides the only feasible means of estimating basal area using transparent overlays for these species. In the laboratory, basal area estimates obtained by the GOT method were close to the actual area of the black paper discs, and so for plants of medium to tall tufted species this method of estimating plant basal area may be preferable. However, compared to the UOG and UOH methcds the GOT method requires considerable operator training and the estimates by eye should be regularly checked against a set of standards of known area. In using the grid overlay technique a small grid

Table 4.1 Mean estimates of basal area for the UOG, GOT and UOH transparent overlay methods for six native perennial grasses growing in fertilized and unfertilized natural pasture. Standard errors are given in parentheses. Differences between mean estimates of basal area obtained by the three methods were not significantly different ($P < 0.05$).

	Fertilized			Unfertilized		
	UOG	GOT	UOH	UOG	GOT	UOH
S. elongatus	5.03(0.92)*	4.51(0.81)	4.08(0.56)	3.33(0.51)	2.71(0.46)	2.78(0.30)
E. leptostachya	3.20(0.62)	2.43(0.32)	2.12(0.26)	3.86(1.09)	3.35(0.66)	1.81(0.41)
S. scabra	4.47(1.31)	3.62(0.65)	2.78(0.49)	4.49(0.64)	3.33(0.33)	2.34(0.58)
B. macra	6.42(1.21)	5.26(1.37)	4.72(1.05)	7.82(1.61)	5.26(0.90)	4.29(0.79)
A. ramosa	7.48(1.62)	5.03(0.75)	5.19(1.28)	3.56(0.68)	3.51(0.66)	2.30(0.53)
D. linkii	1.74(0.45)	1.46(0.26)	0.96(0.18)	0.47(0.07)	0.42(0.07)	0.33(0.06)

*Mean and standard error of 20 estimates.

size should be used for species with small stems (< 1 mm diameter) and that for larger plant bases appropriate grid sizes should be selected to reduce the over-or-underestimation of the area of the incompletely filled cells. All three techniques used to estimate basal area were rapid, taking one to two minutes per sample in the field.

Table 4.2. The relationship between the actual area (cm^2) of artificial plant bases constructed from black paper discs and the area (cm^2) estimated by the grid overlay and unmarked overlay methods. Standard errors are given in parentheses.

Grid overlay (GOT)	
Estimated area = 0.952 (0.008) x Actual + 0.038 (0.021)	R^2 = 0.99
Unmarked overlay (UOG)	
Estimated area = 1.72 (0.03) x Actual - 0.23 (0.09)	R^2 = 0.99

Plant mass per unit of plant basal area as a method of evaluating seasonal changes in the herbage mass of individual species

The expression of the different components of plant mass per unit of plant basal area provided a rapid method of comparing different species throughout the year (Fig. 6.1) using data from individual plants (Lodge et al. 1981).

Seasonal variations in the green leaf mass per unit area of plant basal area for the species studied in this experiment are detailed in Figure 6.1, and the seasonal estimates of the green leaf, and stem, and total dead and vegetative components are given in Table 6.2. The green leaf masses (Fig. 6.1) of the warm season native perennial grasses S. elongatus, E. leptostachya, B. macra and A. ramosa were higher in summer and early autumn than in winter and spring, while those of the yearlong green species D. linkii and S. scabra were higher in winter and spring and varied less throughout the year. Differences in the seasonal variations in green leaf and stem and dead and total vegetative herbage mass are further discussed in Chapter 6. The results of these studies clearly indicated that the relationship between plant mass and basal area reflected changes in the leafing (e.g. Fig. 6.1) and flowering phenology (Lodge et al. 1981) of the species studied. Accordingly the response to any management strategy that has an effect on the growth and phenology of individual plants, such as fertilizer application, grazing or defoliation, could be monitored by measuring plant mass per unit of plant basal area. Compared with the clipping of individual plants of different species in quadrats the measurement of plant basal area increased sampling time by up to three minutes per plant. However, by estimating both plant mass per unit of plant basal area and plant basal area, the mechanisms that individual plants of different species use to alter their herbage mass can be investigated.

Past fertilizer history also appeared to have some effect on the mean plant density and mean basal area of the six native grasses studied (Table 4.3). Plant densities of E. leptostachya were much higher at the fertilized site (Study area 1 site 1) that at the unfertilized site (Study area 2), while those of A. ramosa were higher at the unfertilized site. The mean basal areas of all species except E. leptostachya, growing at the fertilized site were higher than those of the unfertilized site. Therefore all of these data should be considered when estimating the herbage mass response of individual species of native perennial grasses to management. The effect of fertility on the relationship between plant mass, basal area and plant density and how a change in any one of these components may effect herbage mass estimates have been further examined in Experiment 3B.

Herbage mass estimates of individual species per unit area

The mean plant density, mean basal area and mean herbage mass data from Table 4.3 were substituted into equations (1) and (2) to estimate the mean total herbage mass of the six most abundant native grass species in both of the pastures studied (Table 4.3). Herbage mass estimates calculated from equations (1) and (2) were compared with those from clipped quadrats for the same pasture (Table 4.4), and were in good agreement. Therefore both of the proposed equations can be used to estimate herbage mass. However, because of the sampling errors associated with the estimation of the three mass components, the herbage mass estimates obtained from these equations may not be the best statistical estimates. A method of data collection for more accurately estimating herbage mass and assessing the relative importance of plant density, plant basal area and plant mass per unit basal area is presented in Experiment 2.

Table 4.3. The mean number of plants, mean basal area, mean herbage mass per cm^2 of plant basal area and the estimated herbage mass (kg ha^{-1}), calculated from equations (1) and (2) for six native perennial grasses growing in fertilized (Study area 1 site 1) and unfertilized natural pastures (Study area 2).

	Fertilized					Unfertilized				
	Mean No. plants	Mean basal area	Herbage mass per unit basal area	Estimated herbage mass Equation 1	Estimated herbage mass Equation 2	Mean No. plants	Mean basal area	Herbage mass per unit basal area	Estimated herbage mass Equation 1	Estimated herbage mass Equation 2
	m^{-2}	cm^2	g cm^{-2}	kg ha^{-1}		m^{-2}	cm^2	g cm^{-2}	kg ha^{-1}	
S. elongatus	1.80	4.52	0.83	68	76	1.30	2.71	1.16	41	39
E. leptostachya	9.25	2.38	0.42	93	98	2.35	3.36	0.56	44	38
S. scabra	9.30	3.61	0.60	201	213	6.35	2.98	1.51	286	247
B. macra	4.10	5.26	1.50	324	366	6.45	4.95	0.68	216	236
A. ramosa	1.60	5.76	4.06	253	244	8.90	3.51	2.33	728	693
D. linkii	5.40	1.46	0.38	30	38	4.95	0.42	0.45	9	13

Table 4.4. The herbage mass of individual native perennial grasses estimated from (a) clipped quadrats, (b) equation (1) and (c) equation (2) for a grazed natural pasture near Manilla, N.S.W. (Study area 3) in November 1979.

Species	Estimates of herbage mass (kg ha^{-1}) Clipped quadrat	Calculated from equation (1)	Calculated from equation (2)
S. elongatus	247 ± 80*	298	221
S. scabra	118 ± 86	138	118
B. macra	473 ± 206	396	408
A. ramosa	1269 ± 187	1351	1269
D. sericeum	15 ± 5	19	15
Total	2122 ± 154	2202	2031

*Mean and standard error.

D. linkii, S. scabra and E. leptostachya plants had the highest proportion of green leaf, particularly during the late winter-early spring period (Fig. 6.1). Their contribution to the total herbage mass, however, is relatively low (Table 4.3) and management could well be directed to increase the relative abundance of these three species. The proposed method of measuring herbage mass would indicate changes in the contribution of these three, at present, minor species and so would be a sensitive indicator of the progress attained.

Compared with other methods of estimating herbage mass the advantages of the proposed method of collecting herbage mass data are twofold. Firstly, the sorting into individual species is done in the field, in situ, prior to harvesting; the number of samples harvested depending on the number of species being studied and the availability of resources. This overcomes the problem of species identification noted by Robinson and Lazenby (1976). Secondly, it is the only method that provides information on plant mass, basal area and plant density which are essential data for assessing the responses of individual species to management.

For surveys, evaluation studies and preliminary experiments it is suggested that plant mass and plant density data could be used to estimate the herbage mass of individual species and their contribution to the total herbage mass. Information on plant mass, basal area and density collected in more detailed studies of the response of species to management may lead to a better understanding of the process of change in composition within the pasture system.

Experiment 2. Assessing the relative importance of plant density, plant basal area and plant mass per unit basal area in estimating herbage mass.

Results from Experiment 1 indicated that the sampling of individual plants in the field overcame many of the problems associated with laboratory hand-sorting of herbage from whole-quadrat harvesting. However, while the estimates of herbage mass obtained from individual selected plants are in reasonably good agreement with those from clipped quadrats, they are clearly not the best estimates. The best estimate of the herbage mass of an individual species is obtained by harvesting all plants of that species from within a quadrat. Quadrat sampling also has the added advantage of allowing the relative importance of the different mass components, viz. plant density, basal area and mass per unit basal area to be assessed using the procedure of Henderson and Hayman (1960).

This section presents the results of field studies in a grazed natural pasture to estimate the herbage mass of four native perennial grasses, and investigates the extra sampling time needed to measure the components of herbage mass.

Materials and Methods

A 0.84 ha area of unfertilized, grazed natural pasture (Study area 3) located near Manilla on the Northern Slopes of New South Wales dominated by the warm season native perennial grasses *A. ramosa* and *B. macra* was selected (Fig. 3.1). The percentage basal cover of the native perennial grasses and of bare ground, estimated from 21,000 wheel-point determinations (von Broemsben 1966), were:

Species	Basal Cover %
A. ramosa	12.1
B. macra	2.3
S. elongatus	1.2
S. scabra	0.2
C. truncata	0.2
D. sericeum	0.1
Bare ground	83.9

Other major species present included: Medicago minima; T. glomeratum; D. repens, and Cyperus spp.

Data were obtained in November 1979 from 60 quadrats (0.16 m^2) randomly located in the experimental area. In each of the quadrats all individual plants of A. ramosa, B. macra, S. elongatus and S. scabra were counted, harvested to ground level with hand shears and placed in separate bags. The remainder of the herbage in each of the quadrats (other native perennial grasses, herbaceous weeds, annual legumes and grasses, and litter) was harvested and bulked. The basal area of each of the individually harvested plants was estimated using the unmarked overlay (UOG) method described in Experiment 1. The harvested material of each of the native perennial grass plants was hand-sorted into green leaf, green stem including leaf sheaths and dead material and dried in a forced draught dehydrator for 48 hours at 80°C.

The time taken for an experienced person to harvest, count and estimate the basal area of individual plants of A. ramosa was recorded for each of 10 randomly selected quadrats. In another 10 quadrats the time taken to harvest, count and estimate the basal area of individual plants of A. ramosa, B. macra, S. elongatus and S. scabra plants was also recorded.

Masses of green leaf, green stem and dead material were estimated separately for each of the four native perennial grasses in each of the 60 quadrats containing plants of the particular species; these were summed to estimate the mass of total vegetative material. The herbage mass of each of the four major species was estimated by summing the masses of the individual plants for each species in each of the 60 quadrats. The best estimate of herbage mass is then obtained by taking the mean over quadrats. These estimates are in g/0.16 m^2, so multiplication by 62.5 converts the units to kg ha^{-1}.

To determine the importance of components of herbage mass only those quadrats containing plants of the particular species being examined can be used. To illustrate the method the following notation is introduced.

Let y_{ij} = mass (g) of plant j in quadrat i ,

x_{ij} = basal area (cm^2) of plant j in quadrat i ,

where i = 1, 2, ..., q, the number of quadrats containing at least one plant of the particular species ($q \leqslant 60$), and

j = 1, 2, ..., n_i the number of plants of the particular species in quadrat i.

Then, for quadrat i,

the mean mass of plants, $\bar{y}_{i.} = \sum_{j=1}^{n_i} y_{ij}/n_i$,

the mean basal area of plants, $\bar{x}_{i.} = \sum_{j=1}^{n_i} x_{ij}/n_i$, and

the mean mass per unit basal area is defined as, $\bar{z}_{i.} = \bar{y}_{i.}/\bar{x}_{i.}$.

The estimated herbage mass of a species in quadrat i, M_i, can then be expressed as,

$$M_i = n_i \times \bar{z}_{i.} \times \bar{x}_{i.}$$

and this can be converted to an additive equation by taking natural logarithms:

$$\ln M_i = \ln n_i + \ln \bar{z}_{i.} + \ln \bar{x}_{i.}$$

The percentage variation in $\ln M_i$ attributable to variation in $\ln n_i$, say, is 100 b_n where b_n is the regression coefficient of $\ln n_i$ on $\ln M_{i.}$ similarly for the percentage of variation in $\ln M_i$ attributable to $\ln \bar{z}_{i.}$ and $\ln \bar{x}_{i.}$. The significance of the contribution of $\ln n_i$, say, to variation in $\ln M_i$ can then be tested simply as the significance of b_n, and similarly a test of the difference in relative importance of two components, $\ln n_i$ and $\ln \bar{z}_{i.}$, say, is simply a test of the difference between b_n and b_z, their respective regression coefficients. Also, since the mean mass of a plant in quadrat i, is, $\bar{y}_{i.} = \bar{z}_{i.} \times \bar{x}_{i.}$, which after a logarithmic transformation gives $\ln \bar{y}_{i.} = \ln \bar{z}_{i.} + \ln \bar{x}_{i.}$, then the percentage variation in $\ln M_i$ attributable to the mean plant mass is simply 100 x the sum of the regression coefficients corresponding to $\ln \bar{z}_{i.}$ and $\ln \bar{x}_{i.}$. A more detailed description of this analysis is given by Henderson and Hayman (1960).

Results and Discussion

Estimates of the mass of the four perennial grasses (Table 4.5) reflect important differences in each of the species examined in their proportion of green leaf and stem as well as the ratio of green to dead material in the total herbage mass.

Table 4.5. The mean estimates of the green leaf, green stem, dead and total vegetative herbage mass (kg ha^{-1}) of four native perennial grasses. Standard errors of the means are given in parentheses.

	Green leaf	Green stem	Dead	Total Vegetative
		kg ha^{-1}		
A. ramosa	60 (6.3)	651 (61.9)	1154 (141.1)	1865 (201.7)
B. macra	22 (3.6)	20 (4.9)	221 (52.2)	263 (55.7)
S. elongatus	33 (6.9)	15 (2.9)	95 (19.6)	143 (27.6)
S. scabra	21 (6.8)	9 (3.8)	70 (25.9)	93 (33.8)

Plant density contributed significantly ($P < 0.05$) to the green leaf, green stem, dead and total vegetative herbage masses of *A. ramosa*, *B. macra* and *S. elongatus* (Table 4.6), except for *B. macra* green stem. Density, however, was not a major factor in the herbage mass estimate of *S. scabra*, but with only 23 individual *S. scabra* plants collected in 15 of the 60 quadrats sampled, this result probably reflects the low occurrence of this species in the pasture. For *S. elongatus* and *S. scabra* the plant basal area was a more significant ($P < 0.05$) component of plant mass than the mass per unit basal area, with the same trend occurring in *A. ramosa* but not always significantly. However, for *B. macra* the mass per unit basal area was a significantly ($P < 0.05$) greater component of plant mass than basal area.

Table 4.6. Proportion of variation in herbage mass per quadrat due to variation in (a) ln plant density per quadrat, (b) ln plant basal area per quadrat, and (c) ln mean mass per plant basal area per quadrat, for four native perennial grasses. Standard errors are given in parentheses.

Species and Plant component	ln plant density	ln plant basal area	ln mean mass/basal area
		Proportion (%)	
A. ramosa (58)[+]			
Green leaf/quadrat	40.3* (6.2)	35.3* (7.9)	24.3* (8.2)
Green stem/quadrat	40.7* (6.0)	46.6* (6.6)	12.6* (5.2)
Dead matter/quadrat	29.2* (5.6)	41.1* (5.3)	29.6* (5.2)
Total dry matter/quadrat	36.7* (6.1)	47.6* (6.0)	16.0* (5.1)
B. macra (40)			
Green leaf/quadrat	31.6* (7.5)	17.7 (9.3)	50.7* (9.9)
Green stem/quadrat	12.9 (6.8)	6.2 (7.6)	80.8* (9.7)
Dead matter/quadrat	25.7* (6.7)	16.6* (8.0)	57.7* (8.6)
Total dry matter/quadrat	29.7* (7.4)	20.1* (8.9)	49.8* (9.5)
S. elongatus (30)			
Green leaf/quadrat	21.2* (7.6)	65.3* (9.5)	13.5 (7.8)
Green stem/quadrat	32.3* (8.7)	61.7* (15.3)	5.9 (13.7)
Dead matter/quadrat	20.8* (6.7)	50.2* (10.4)	29.0* (9.6)
Total dry matter/quadrat	26.8* (7.9)	66.4* (11.5)	6.8 (9.2)
S. scabra (15)			
Green leaf/quadrat	12.4 (8.8)	71.2* (14.8)	16.4 (10.9)
Green stem/quadrat	8.8 (9.1)	62.0* (17.5)	29.1 (16.2)
Dead matter/quadrat	9.4 (6.6)	54.6* (10.4)	36.0* (7.0)
Total dry matter/quadrat	11.5 (8.0)	65.1* (12.3)	24.3* (10.2)

[+]Number of quadrats which contained plants of each species.

*Significantly different from zero (P <0.05).

These data confirm not only the importance of plant density, but also basal area and mass per unit basal area data in estimating the herbage mass of an individual species in a pasture. In different species different components of herbage mass, viz. plant density, plant basal area and mass per unit of basal area, assume importance. Hence, all three components of herbage mass should be measured and their relative importance assessed.

In this study all plants of a particular species within a quadrat were harvested and these data were used to estimate herbage mass. This method provides the best estimate of herbage mass for each species because it uses all of the available information. In Experiment 1 individual selected plants were used to estimate herbage mass. While these estimates are clearly not the best estimates of herbage mass, they are the only estimates that can be calculated from single plant data. These estimates were also in reasonably good agreement with those from clipped quadrats and hence would be sufficient for survey data or comparative evaluation studies. For more detailed studies the effects of management on the herbage mass of an individual species should be estimated by harvesting all of the plants of that species that occur within the sampled quadrats. The relative importance of the different components of mass; plant density, basal area and mass per unit basal area, can then be assessed using the procedure of Henderson and Hayman (1960) at either a single sampling or several samplings over time to determine the response to management of different species. For the data presented, for example, the most important factors influencing plant herbage mass were plant density and basal area for A. ramosa and S. elongatus; density and mass per unit basal area for B. macra; and plant basal area for S. scabra. However, the plant populations in the natural pasture at Study area 3, developed under a management system of low, intermittent grazing (< 2 sheep ha^{-1}) and no fertilizer input. Under different management, with higher stocking rates and fertilizer use, the importance of each of the three components of plant mass of an individual species will change.

Harvesting individual A. ramosa plants, counting their density and estimating their basal area with an unmarked perspex overlay took 3 minutes per quadrat longer than harvesting individual plants in quadrats (Table 4.7).

Table 4.7. The mean time taken for an experienced operator to clip individual plants to ground level, place the harvested material in a bag, and collect plant density and basal area data for one and four native perennial grasses growing in an 0.16 m^2 quadrat. The estimated times for each group are the mean of 10 randomly selected quadrats.

		Four native perennial grasses				
	Aristida plants only	Aristida	Bothriochloa	Sporobolus	Stipa	Total
		Time (minutes)				
(1) Harvest each plant to ground level, place in bag	7.5	10.5	2.6	1.5	1.3	15.9
(2) (1) + count harvested plants	8.0	11.0	2.8	1.6	1.4	16.8
(3) (2) + estimate the basal area of the harvested plants	10.5	13.5	3.3	2.1	1.9	20.8
Mean No. plants per quadrat	4.0	8.2	1.2	0.6	0.4	

When two major and two minor species were sampled (Table 4.7) the collection of plant density and basal area data increased sampling time from 15.9 to 20.8 minutes per quadrat. Results of this study show that an experienced person would be able to harvest individual plants of four species within 29 quadrats per day, and harvest and count each species and estimate the basal area of individual plants in 23 quadrats per day.