The Ecograze Project:

developing guidelines to better manage grazing country

Andrew Ash   Jeff Corfield   Taoufik Ksiksi

ACKNOWLEDGEMENTS

CSIRO

SUSTAINABLE ECOSYSTEMS

MEAT & LIVESTOCK AUSTRALIA

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SECTION A BACKGROUND

Introduction

Most of the pasture grazed by cattle in northern Queensland is found in the understorey of various types of Eucalypt woodlands (forest country). This understorey is made up mainly of native pastures. While some exotic legumes and grasses have been introduced to increase livestock production they account for less than 10% of the grazed lands. In general, the main improvements, other than pasture development, are water points and fencing.

Eucalypt woodlands dominate the catchments of the Burdekin, Gilbert, Mitchell and upper Herbert Rivers. They cover approximately 15 million ha and support about a million head of cattle. They are, therefore, an important natural and economic asset. Keeping these pasture lands productive and healthy demands good management. However, getting the right balance between stock numbers and the forage resource is a considerable challenge for management. Short-term economic pressures can force an increase in stock numbers that leads to an imbalance between forage supply and demand. The complexity of the management task is increased by the fact that highly variable rainfall results in a pasture supply that fluctuates greatly from year to year.

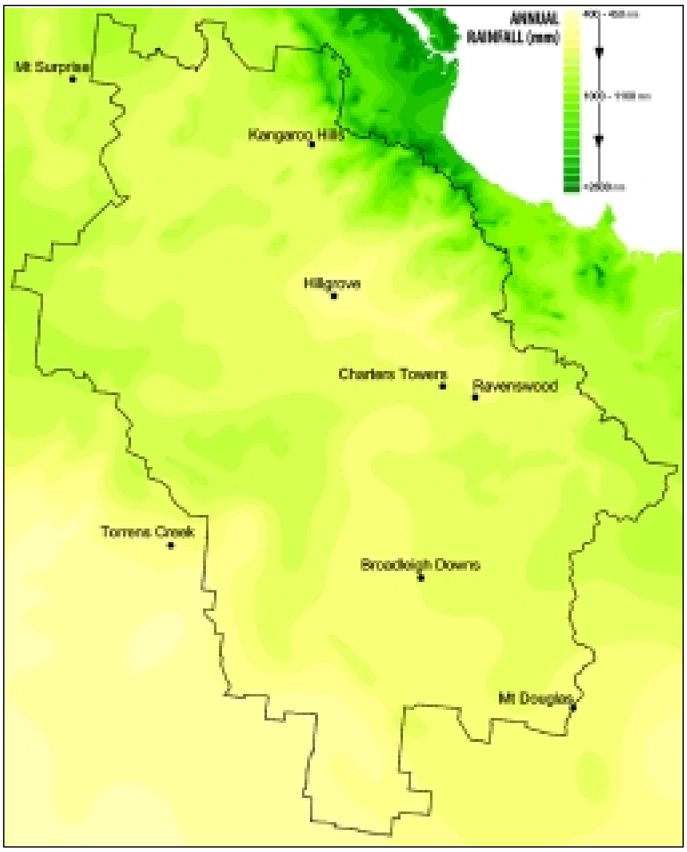
As a consequence of short-term economic pressures and generally over-optimistic expectations of good rains in the future, stocking rates often err on the high side. Over the last twenty years this has led to a decline in the condition of grazing lands in northern Queensland. Fortunately, improved grazing management and a better understanding of climate variability can reverse much of this deterioration in condition.

With this in mind, in 1992, Meat and Livestock Australia initiated the ECOGRAZE project. The project was designed to improve our understanding of the effects of grazing, spelling, fire and climate on the condition and productivity of open eucalypt woodlands in north-eastern Queensland. From this improved understanding, guidelines to better manage grazing country are being developed.

This publication summarises the results of the ECOGRAZE project in a way that we hope is useful to agency staff and producers. It covers the main findings of the study and their implications for grazing management. Separate scientific publications will provide more details on individual aspects of the project.

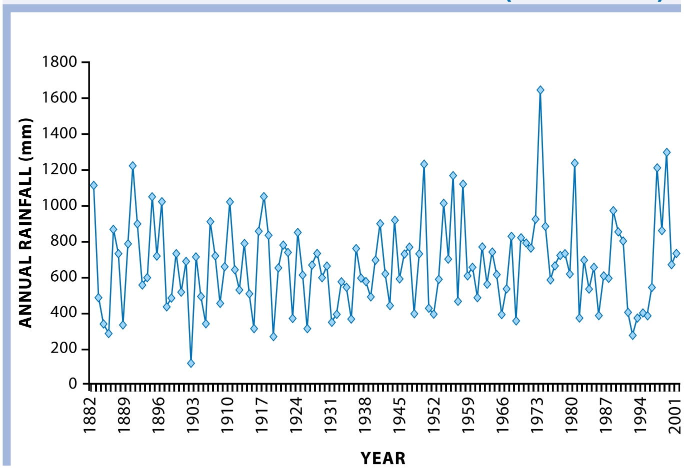
Courtesy P. Stevenson

Open eucalypt woodland in north-east Queensland



Rainfall variation across north-eastern Queensland grazing lands

"Of drought and flooding rains"
Rainfall variation at Charters Towers (1882-2000)



Land types in the region

The large number of geological landscapes in the region gives rise to a complex mixture of land types. The landscapes include goldfields country; red and yellow earths of the desert uplands; creek and river frontages; fertile red and black basalt soils; and sedimentary and igneous country in the more mountainous north-east part of the region. With the exception of the basalt black soils, which are treeless, and the relatively small areas of brigalow, blackwood and lancewood scrub, the region is very largely open forest country. Various eucalypt species dominate the woody layer of this open forest country and there is an almost continuous grassy layer underneath. This grassy layer is the main pasture resource supporting the beef industry in the region.

Climate

The region lies within the seasonally wet-dry tropics, characterised by a distinct hot, wet summer and a mild, dry winter. Annual average rainfall varies from 500 mm in the south-west to over 1,500 mm near the high coastal ranges. The majority of the region receives, on average, around 600 mm annually, with over 80% of the total rainfall occurring between November and April.

A feature of the climate is the extreme year to year variation in rainfall

A feature of the climate is the extreme year to year variation in rainfall. There are relatively few "average" years. El Niño - Southern Oscillation (ENSO) is a major influence on this high rainfall variability.

Waiting for the rain - first storms after drought

The grazing resource

The grassy layer in the open forest country underpins the beef industry. While this layer may appear fairly uniform, it contains a wide range of plant species and plant types that are important to cattle and to the health of the landscape.

Decreaser native perennial grasses - the 3Ps

These are native tussock perennial grasses that are preferred by cattle and that tend to decrease in abundance with persistent grazing. These grasses are commonly referred to as the '3P' grasses – **perennial, productive** and **palatable**. They are relatively long-lived and, in an undisturbed environment, tend to dominate the herbaceous layer, accounting for 70-90% of available forage. However, under moderate to heavy grazing their contribution to pasture bulk can be reduced to between 10 and 40%. The 3P grasses have good nutritive value in the wet season but are deficient in protein and energy during the dry season. Typical 3P grasses are black speargrass *(Heteropogon contortus)*, desert mitchell grass *(Bothriochloa ewartiana)*, Queensland blue grass *(Dichanthium sericeum)* and kangaroo grass *(Themeda triandra)*.

Example of pasture dominated by 3P grasses, including desert mitchell grass, black speargrass and Qld. bluegrass

Increaser native perennial grasses

These native tussock perennial grasses are generally not preferred by cattle, although they will be eaten when more preferred species have been grazed out. In environments that do not have a history of grazing, they usually only account for 10-30% of the pasture biomass. They tend to be less leafy than the 3P grasses, which may explain why they are less preferred by cattle. Species common to this group are wire grass *(Aristida* spp.*)*, northern wanderrie grass *(Eriachne obtusa)* and bottle-washer grass *(Enneapogon polyphyllus)*.

Jericho wire grass - A common increaser perennial species

Introduced (exotic) perennial grasses

Introduced, or exotic perennial grasses have either naturalised in the region or have been intentionally planted to improve pasture productivity and animal production. Once established, these species tend to increase over time and, usually, the higher the grazing pressure the more the species increase. Indian couch *(Bothriochloa pertusa)* is a stoloniferous (lawn-like) perennial grass that was introduced accidentally and has naturalised in the region, particularly on the Goldfields country. The main sown species are buffel grass *(Cenchrus ciliaris)* and sabi grass *(Urochloa mosambicensis)*. Buffel grass and sabi grass tend to respond to smaller falls of rain than do the native perennial grasses but have about the same nutritive value.

A vigorous buffel grass pasture

Annual grasses

These short-lived grasses are shallow-rooted and usually persist for about six to nine months. They regenerate by producing large amounts of seed before they die off. They are usually only a minor part of the pasture (<10%), although where perennial grasses have been grazed out they can contribute 70-90% of pasture biomass. They are of reasonable forage quality when young and leafy but tend to hay off quickly and lose their protein before the perennial grasses. Species commonly found in north-east Queensland include fairy grass *(Sporobolus australasicus)*, button grass *(Dactyloctenium radulans)*, small burr grass *(Tragus australianus)* and liverseed grass *(Urochloa panicoides)*.

Button grass is a common annual grass in the region

Native legumes and forbs

Annual and perennial native legumes and forbs *(small, herb-like plants)* are common throughout the region. They include a large number of species that are relatively abundant. However, due to their generally small size they rarely contribute much bulk to the pasture. They remain high in protein throughout the year and can be selectively grazed early in the dry season as the grasses hay off. At this time, they can substantially improve diet quality. Common native legume species include rattlepods *(Crotolaria* spp.*)*, indigos *(Indigofera* spp.*)*, woolly glycine *(Glycine tomentosa)*, rhyncosia *(Rhyncosia minima)* and necklace pea *(Desmodium* spp.*)*, while some common forbs are tarvine *(Boerhavia schomburgkiana)*, pinktongues *(Rostellularia adscendens)*, pigweed *(Portulaca* spp.*)*, cobbler's pegs *(Brunoniella acualis)*, tropical speedwell *(Evolvulus alsinoides)* and spurge *(Phyllanthus* spp.*)*.

Birdsville Indigo – a commonly found native legume

Introduced legumes

Introduced legumes have been planted fairly widely through the region to improve the quality of the diet. These introduced legumes are far more productive than native legumes and are generally more palatable. Species from the genus *Stylosanthes* (seca and verano) are the most widely planted legumes.

Seca stylo – an important introduced pasture legume

Introduced forbs

These are common throughout the region and are particularly abundant in frontage (alluvial) country. Few of them have been intentionally introduced, with most arriving as contaminants in commercial seed. Most are unpalatable to cattle and most tend to increase with higher grazing pressures. Common species include spiny-head sida *(Sida acuta)*, hyptis *(Hyptis suaveolons)*, caltrop *(Tribulus terestris)* and goat's head *(Acanthospermum hispidum)*

Sida species can be important pasture weeds

Shrubs

A wide range of shrubs can be found in the region. Many of them (eg. currant bush) have increased in the last 20 years or so in response to reduced fire frequency. Most are relatively unpalatable but during the dry season they are higher in protein than the grasses, and some can make a valuable contribution to the diet of cattle at this time. Shrubs can also provide useful 'top feed' during droughts. Common species include currant bush *(Carissa ovata)*, whitewood *(Atalaya hemiglauca)*, false sandalwood *(Eremophila mitchellii)*, yellow wood *(Terminalia oblongata)* and wattles *(Acacia* spp.*)*.

Currant bush is a common native shrub in the grazing lands of northern Queensland

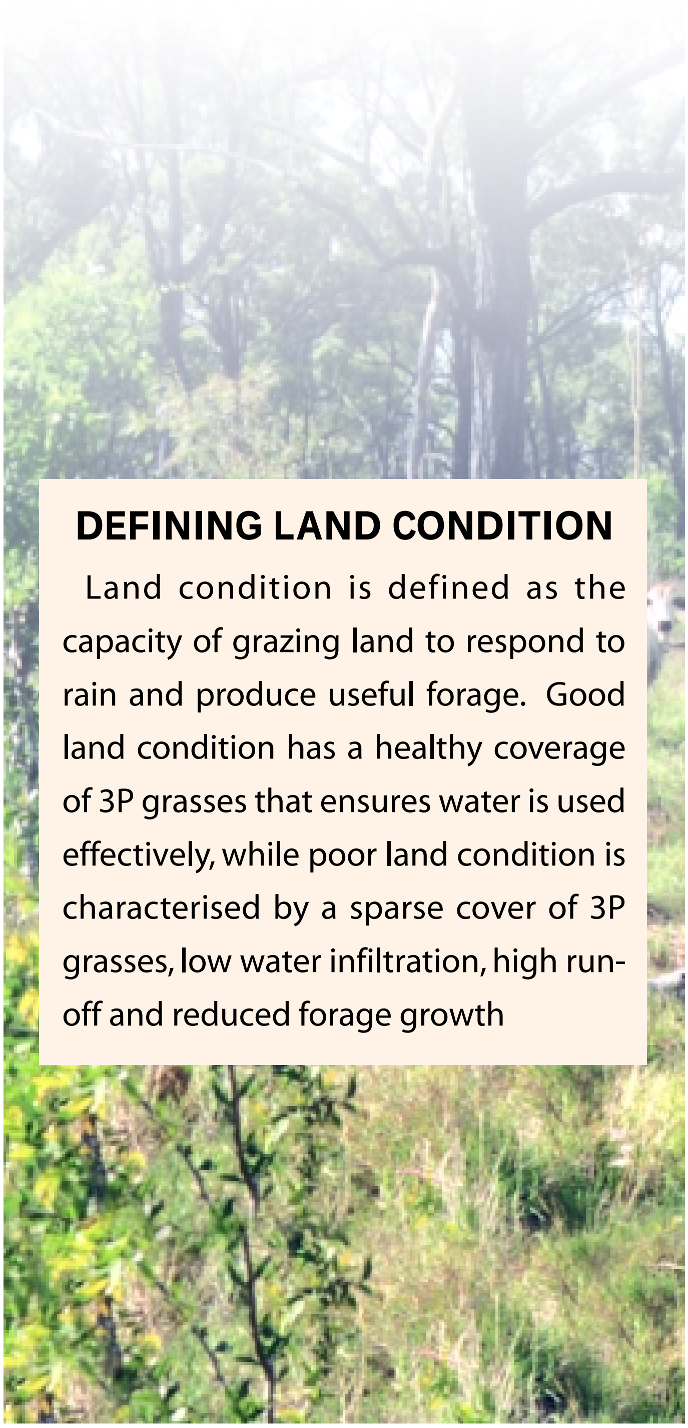
The importance of perennial grasses in maintaining land condition

In a grazing management context, land condition is assessed in terms of soil condition and pasture condition. Soil condition is the capacity of the soil to absorb and store rainfall, to store and cycle nutrients, to provide appropriate habitat for seed germination and plant growth, and to resist erosion. Pasture condition is the botanical composition and density of pasture plants and other vegetation.

Perennial grasses play an important role in maintaining land condition in the open woodlands of north-eastern Queensland

Perennial grasses play an important role in maintaining land condition in the open woodlands of north-eastern Queensland. For grazing land management, land condition is defined as the capacity of grazing land to respond to rain and produce useful forage. This definition is intentionally restricted to the primary use of the land - that is, livestock grazing. It excludes some aspects of sustainable use, such as conservation of biodiversity.

Land in good condition can sustain a reliable forage supply and contribute to the long-term health of the grazing enterprise. In contrast, degraded grazing land temporarily or permanently loses its capacity to grow and sustain cattle. In the extreme, the rehabilitation and the restoration of the productive values of severely degraded land, *where it is possible*, involves significant expense.



DEFINING LAND CONDITION

Land condition is defined as the capacity of grazing land to respond to rain and produce useful forage. Good land condition has a healthy coverage of 3P grasses that ensures water is used effectively, while poor land condition is characterised by a sparse cover of 3P grasses, low water infiltration, high run-off and reduced forage growth

Land condition and vegetation change – a simple framework

Changes in land condition can occur gradually, like the steady loss of perennial grasses, or rapidly in response to a major disturbance, like a flood event introducing a weed species and providing good conditions for its establishment. Sometimes changes in vegetation occur gradually until some threshold is crossed, at which point change becomes rapid. An example of this would be the gradual loss of perennial tussock grasses in response to overgrazing, followed by a rapid invasion of Indian couch.

'State-and-transition' models provide a framework for describing these gradual and rapid changes. The models use a series of vegetation 'states', with transitions between the states being driven by grazing, climate, fire and weeds.

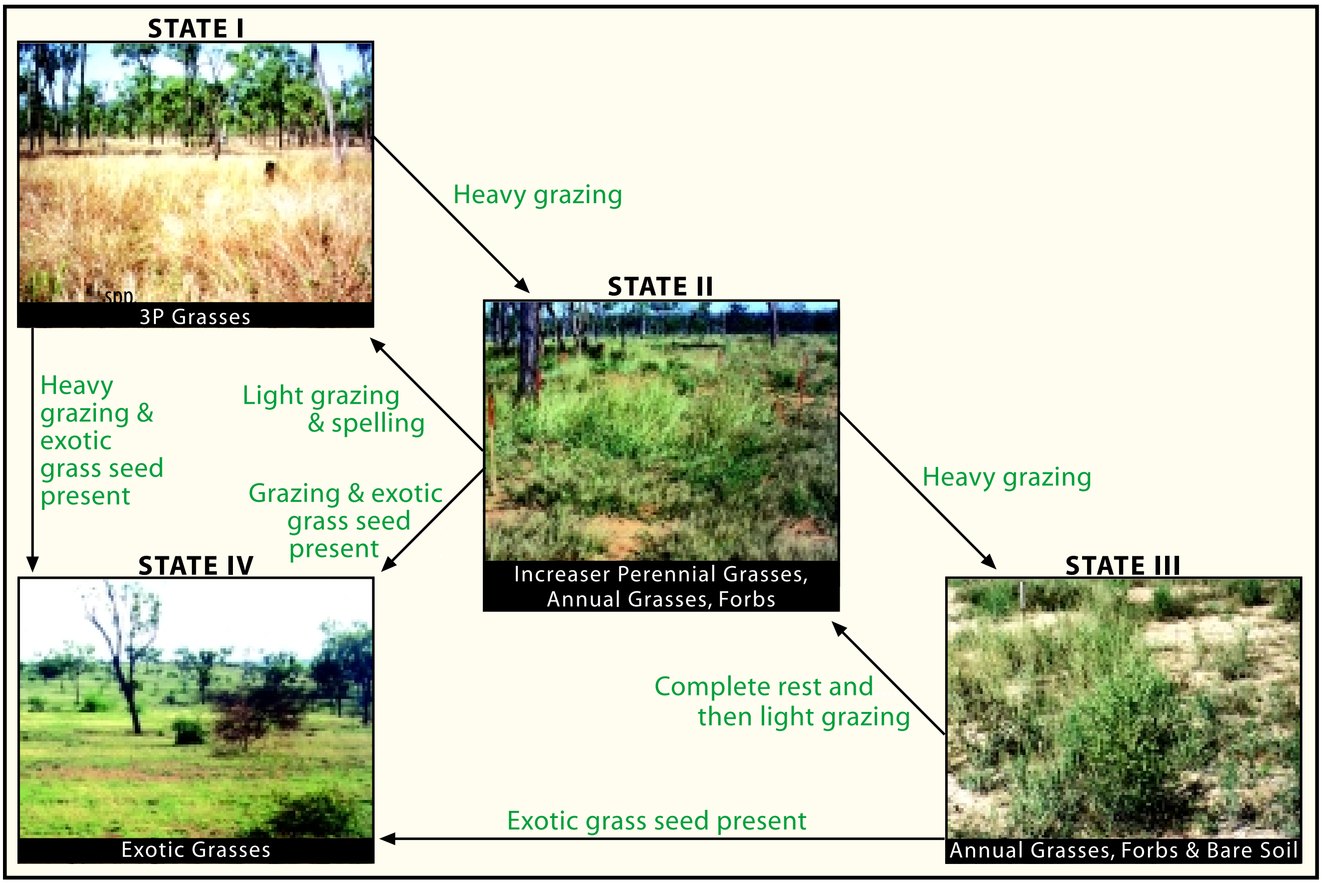
Factors that cause a change in land condition

Grazing, fire, tree clearing, weeds and pasture improvement can all influence land condition. Often these influences interact with each other and with the climate to alter land condition.

Grazing is the major influence on land condition; its impact can be both subtle and obvious. Often the effects of grazing on land condition are made worse by poor seasons. Consequently, climate is frequently blamed for a decline in land condition when, in fact, all or a large part of the cause has been poor grazing management.

This interaction between grazing and climate and how it affects land condition has been the focus of much of the grazing management research in the region; indeed, it is at the centre of the research described in this book. The aim of that research has been to develop grazing management guidelines that will lead to the sustainable management of open eucalypt woodlands in north-east Queensland.

However, before we describe the research and its results it is useful to discuss some basic concepts in pasture and grazing management that will help grazing managers interpret and apply the research findings.



Factors that cause a change in land condition

1. How pastures grow and their role in the landscape

Grazing lands are ecosystems – complex communities of organisms, interacting within their environment. Sustainable management of grazing lands requires an understanding of what ecosystems are and how they work. The components of a grazing land ecosystem (soils, climate, plants, animals, microbes) are linked by various biological, chemical and physical processes. Energy is transferred and water and nutrients are cycled through the system. These ecological processes are essential for the healthy functioning of ecosystems.

Grazing lands are ecosystems - complex communities of organisms, interacting within their environment

A. Energy Flow

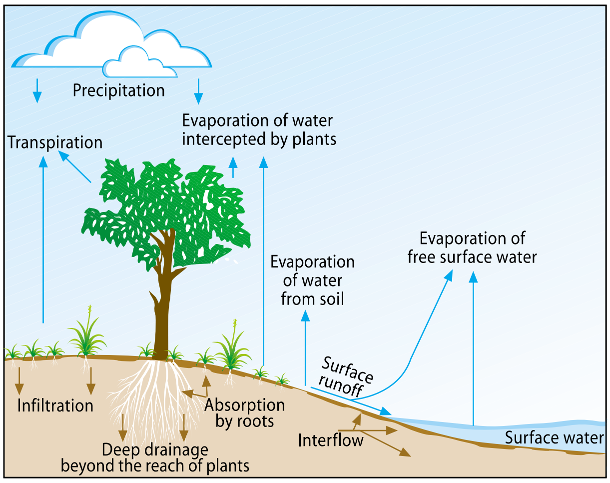
All living things require energy to function. The energy of life ultimately comes from the sun; green plants are able to directly convert the sun's energy into 'food' via photosynthesis. Because of this ability to produce their own food from the sun, plants are referred to as primary producers. Primary production refers to the biomass they produce. In a grazing system the energy captured and stored by plants subsequently flows to two broad categories of organisms:

- herbivores (e.g. cattle, sheep, kangaroos) gain the energy and nutrients in plant tissue by consuming and digesting their leaves and stems; and

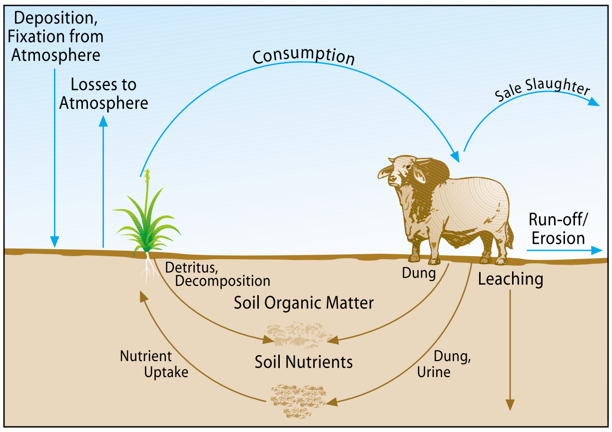
- decomposers (e.g. soil microbes, termites) gain energy by consuming dead organic material. This material may be from dead plant or animal tissue or from animal waste (dung and urine).

B. Water

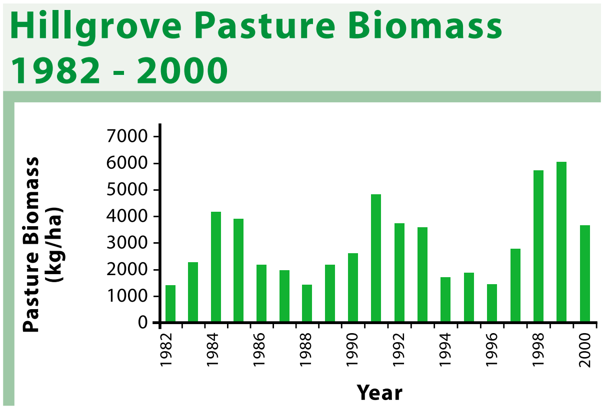
Every life-sustaining process is directly or indirectly affected by water. It is an essential component of plant and animal cells. Water also strongly influences the landscape through soil erosion and nutrient transport.

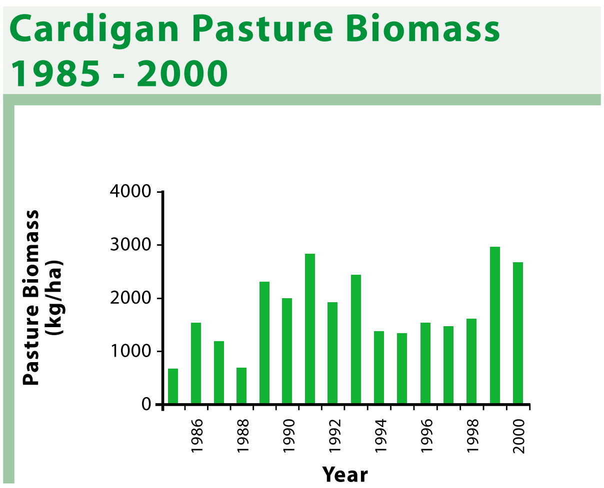


The water cycle in an open eucalypt woodland



Nutrient cycling in grazed ecosystems





Annual variation in pasture biomass in conservatively grazed experimental paddocks at Hillgrove & Cardigan stations, which highlights the strong influence of climate variability on forage supply

Apart from small amounts of rain trapped by leaves, the rain reaches the soil surface where it either infiltrates (ie. soaks into the soil) or runs off to become stream flow. The degree of infiltration depends on the storm duration and intensity, soil characteristics, slope and groundcover. Of the water that infiltrates, some is lost by direct evaporation from the soil surface, some is used by plants (transpiration) and some drains through the soil to the ground water or into streams.

C. Nutrients

Nutrients cycle from the soil or atmosphere into plants, where they are used for growth, and are then, often, consumed by herbivores or microbes. Waste from animals and the death of microbes and plants returns nutrients to the soil or atmosphere. To maintain a stable system the flow of nutrients in must balance the flow of nutrients out. Nutrients are lost when animals leave the system (sold or slaughtered). In extensive beef cattle systems these losses are small relative to that in intensive grazing systems. Most nutrients are lost when sediments and water leave the landscape in run-off. Some nutrients are also lost as they leach through the soil profile into groundwater.

2. Role of climate variability

Because rainfall from year to year varies, the amount of pasture that grows from year to year is also highly variable

Because rainfall from year to year is variable, the amount of pasture that grows from year to year is also highly variable. It is not unusual to have runs of years that are extremely dry or wet. For example, the period 1992-1997 in north-east Queensland was unusually dry – pasture growth was very poor and large areas of eucalypt woodland died as a result of this severe drought. (see photo next page)

In managing grazing lands this variability in pasture growth must be taken into account. Two ways of doing this are to conservatively stock to provide a "buffer" in drought years or to adjust numbers from year to year to better match forage supply.

3. Grazing as a disturbance and its impacts on plants

There is no simple answer to the question of how grazing affects plant growth as it depends on the timing and intensity of grazing and on the scale at which grazing occurs. Grazing has both short-term and long-term effects. During the growing season grazing removes green leaf. This reduces the amount of leaf area able to store energy via photosynthesis and, as a consequence, plant growth rate declines. Fortunately, many grasses can recover quickly by producing more leaf shoots and drawing on energy reserves stored in the roots. Some species are much better than others at coping with grazing. For example, black spear grass is less sensitive to grazing than is kangaroo grass.

Nevertheless, repeated grazing of plants over a period reduces their root vigour As a result, individual tussocks get smaller and smaller and may eventually die.

Repeated defoliation of plants also reduces seed production. Seed production by native perennial grasses is very modest even when the pasture is healthy and productive. A reduction in seed supply through grazing is likely to decrease the number of new plants that are recruited into the pasture, which may affect the long-term survival of the species.

Grazing also reduces ground cover, which is essential in protecting the soil from the erosive forces of water and wind. Maintaining ground cover at a minimum of 40% is essential for minimising losses of water, sediments and nutrients from the system and for maintaining effective cycling of water and nutrients as described earlier.

Dead trees at Fanning River Station following the severe drought of the 1990s

Effect of defoliation on root vigour with lightly clipped spear grass on the left compared with frequently clipped spear grass on the right

High ground cover

Low ground cover

4. Diet selection

Grazing animals do not use pasture evenly

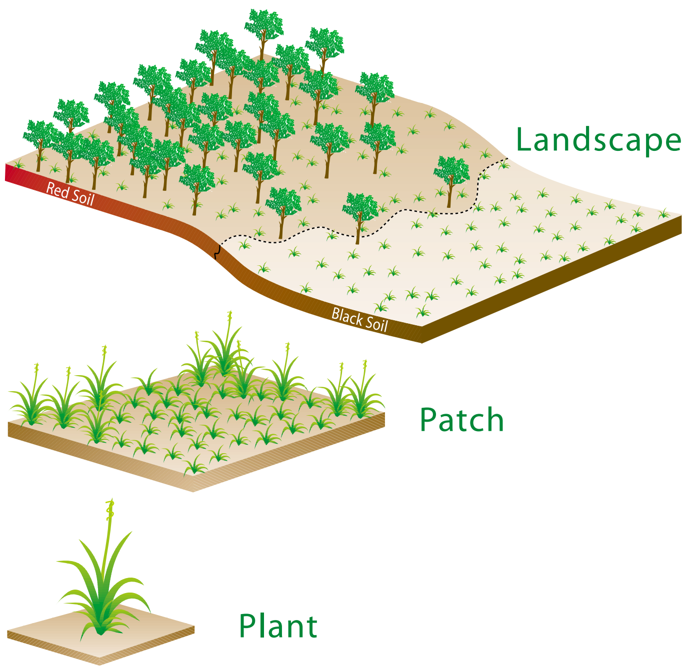
Preferential grazing of a black soil community next to red soil vegetation

Grazing animals do not use pasture evenly. They actively select certain plant parts over others (eg. leaf over stem) and prefer certain species to others (eg. black spear grass is usually eaten before wire grass). Grazing animals such as cattle also patch graze, which results in areas of 10-30 m in diameter being kept short and leafy. Patch grazing can help maintain a higher diet quality but patches tend to degrade over time.

At the paddock scale animals have preferences for different land types. For example, black soils and frontage country are preferred to lighter hilly country. Areas of land that have been recently burnt are also usually grazed by cattle in preference to unburnt areas. As a result of this uneven use, changes in vegetation and land condition can occur fairly rapidly.

Example of patch grazing in native pasture on goldfields soils

Diet selection occurs at the plant, patch and landscape scales



Speargrass being grazed with nearby wire grass plants left ungrazed

5. Pasture utilisation

Pasture utilisation is the percentage of pasture growth in a year that is consumed by cattle

A key concept in managing pastures to maintain perennial grasses is that of **pasture utilisation**. We define pasture utilisation as the percentage of pasture growth in a year that is consumed by cattle. With a set stocking regime, pasture utilisation will vary from year to year according to rainfall variability and the amount of pasture grown.

Why is pasture utilisation important? Different pasture types have different sensitivities to grazing. We can use pasture utilisation to define grazing thresholds that lead to a change in a pasture community. For example, one pasture may begin to lose 3P grasses when utilisation exceeds 20%, whereas in another pasture community loss of valuable species may not occur until utilisation exceeds 40%.

PASTURE UTILISATION

Assume there is a stocking rate of one adult cow (450 kg) to 10 ha of land. This animal will eat approximately 3,000 kg of dry forage per year. The amount consumed per ha is therefore 300 kg dry forage per year. If we now assume that the pasture produces, on average, 1,500 kg / ha of dry forage per year, then pasture utilisation is:

$$\text{Pasture utilisation \%} = \frac{300}{1,500} = 20\%$$

Courtesy P. Stevenson

Fire in an open woodland community

Selective grazing of patches after mosaic burning in the dry season

6. Fire

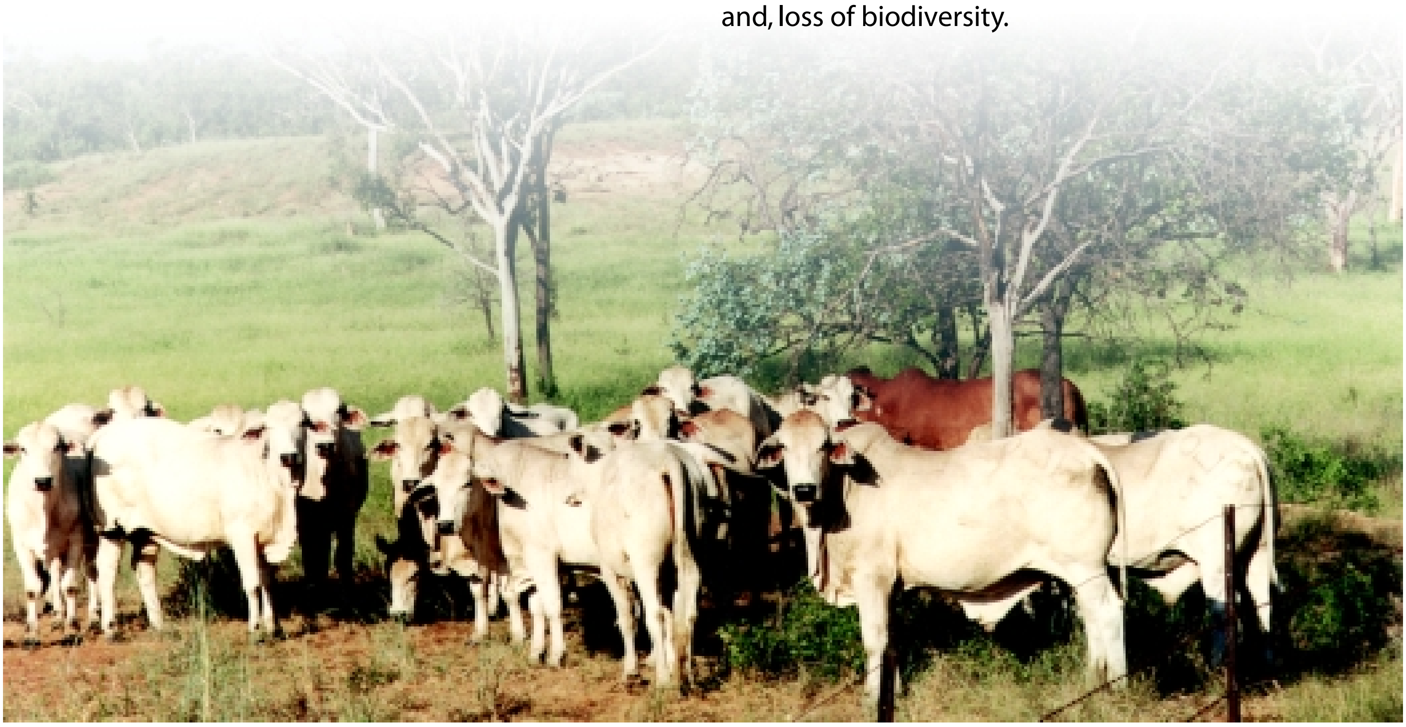
Fire can play an important role in determining the composition of the woodlands, especially the balance between grasses and woody plants.

Most fires are confined to the grass layer where they remove accumulated dry material. Some plant species are killed but the perennial tussock grasses survive fires. Fires produce good seedbed conditions for germination and the establishment of new plants. Fires can kill seedlings, saplings and small trees and damage large trees. However, large trees are often not killed and they recover by sprouting from the base. Thus fire reduces the amount of woody material and favours the grass layer; exclusion of fire for long periods can lead to the development of dense woodlands.

The green pick following a fire is of high nutritive value and, in the short-term, can boost animal performance. Fire can also alter the grazing distribution of animals when parts of a paddock are burnt.

7. Clearing or killing trees

Clearing or killing trees can greatly improve forage production and cover where both woodland density is moderate to high and soils are fertile. Fertile soils provide the nutrients that allow the grasses to exploit the water previously used by the trees but now available to them. However, the potential negative effects of tree clearing include: vigorous re-growth that requires regular follow-up treatment; changes in the water cycle that may lead to raised water tables and salinity; loss of the "nutrient-pumping" effect of trees, which provides added nutrients and improved soil fertility under the canopies of trees; and, loss of biodiversity.



THE ECOGRAZE STUDY

Background

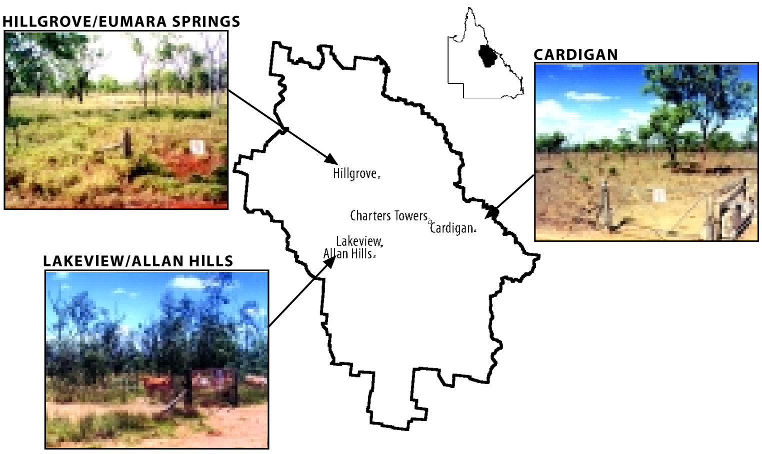
In practice, the only means of manipulating pasture composition are grazing, spelling and fire. The ECOGRAZE study, initiated in 1992, looked at how these factors could be used to improve the condition of deteriorated pastures and to prevent pastures in good condition from degrading. The focus of the project has been to understand how pastures in different conditions respond to grazing, spelling and fire and, from this understanding, develop grazing management options.

Pasture types vary considerably across the region and the region also experiences great variation in annual rainfall. Because of these regional characteristics, the study included a number of country types and was run over a number of years to experience a wide range of seasons.

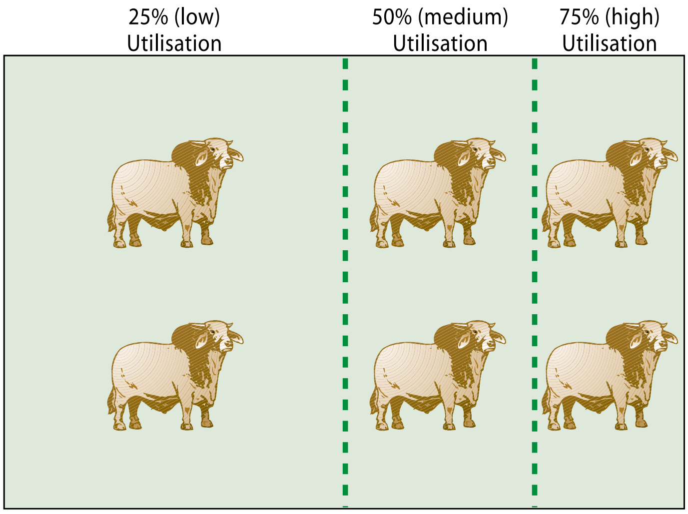
Location

Study sites were established on three important land types identified in north-east Queensland; the infertile red and yellow earths (Lakeview/Allan Hills), the moderate fertility Goldfields country (Cardigan) and the fertile red basalt soils (Hillgrove/Eumara Springs).

Location of the three ECOGRAZE study sites in the Charters Towers region



Paddock sizes were altered to achieve different utilisation rates



An example of treatment paddocks with a 75% utilisation paddock on the right and a 50% utilisation paddock on the left

An animal grazing in one of the experimental paddocks at Cardigan

Grazing treatments

Grazing plots were established on each of the three land types with land in condition States I and II. State I (good condition) was dominated by 3P grasses, such as black spear grass, desert mitchell grass, kangaroo grass and Queensland blue grass. State II (deteriorated condition) still had 3P grasses present but there were more increaser perennial grasses, such as wire grass, and annual grasses such as fairy grass and button grass. State I tended to have a continuous cover of grass, while in State II there were significant bare patches and scalds.

States I and II were chosen by selecting commercial paddocks near each other that had different grazing histories but were otherwise similar in land type. State I land had received low grazing pressure in the preceding decade relative to State II land. State II showed significant loss of 3P grass species but was still responsive to “improvement” via grazing management. At the three locations State I was separated from State II by up to 10 km. This was not ideal because of potential differences in rainfall between States I and II but was the most practical way of achieving differing land condition states on the same soil/vegetation type.

At each site and in each land condition state, three different utilisation rates were imposed: 25% (low); 50% (medium); and 75% (high). Utilisation means the percentage of forage grown in a year that is consumed - e.g. if one-quarter of the forage grown in a year is consumed the utilisation rate is 25%. The above rates represented conservative to very high grazing pressures. To achieve these different rates, paddock sizes were varied – e.g. 75% utilisation paddocks were 1/3 the size of 25% utilisation paddocks. Because the amount of forage growth varied from year to year, the number of stock in each treatment was adjusted from time to time to maintain target utilisation rates in above- and below-average seasons.

Wet season spelling started after the first significant rainfall event (>50 mm over two days) from November onwards. Paddocks were spelled for eight weeks and then the cattle were reintroduced.

Individual paddocks varied in size from about 1 ha to 5 ha. This paddock scale was good for studying pasture composition and soils, yet cost effective in establishment and maintenance. Brahman or Brahman-cross steers were used to graze the paddocks.

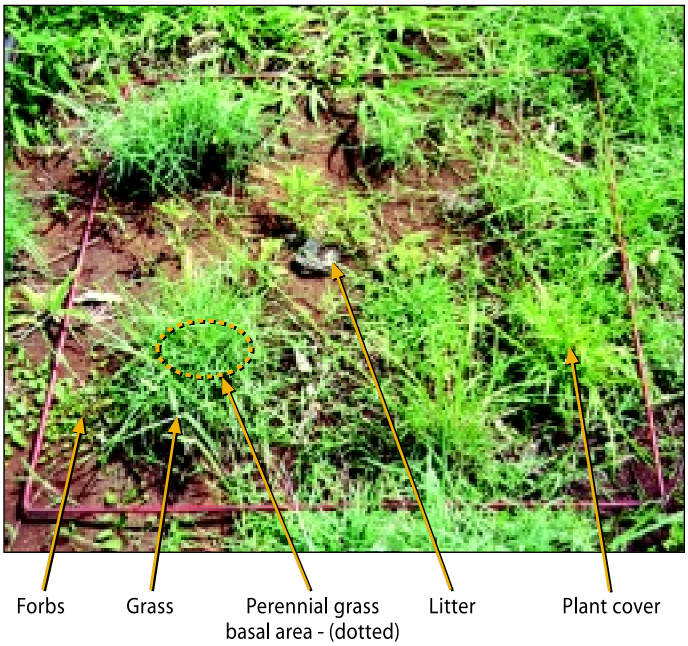
Measurements

All pastures were sampled at the end of each growing season (April-May) and at the end of each dry season. Full botanical surveys were conducted in each paddock. The data were collected by measuring vegetation in fifty to eighty (the number used depended on paddock size) 50cm x 50cm metal quadrats spread throughout each paddock. Measurements included:

- a record of all species encountered in each quadrat (species abundance)
- relative amount of each species in each quadrat (species composition)
- the amount of pasture on offer (pasture biomass)
- the relative amount of grazing of each species in each quadrat (defoliation)
- the percentage of ground occupied by the crown of perennial grasses (perennial grass basal area)
- percentage groundcover (plants and litter)

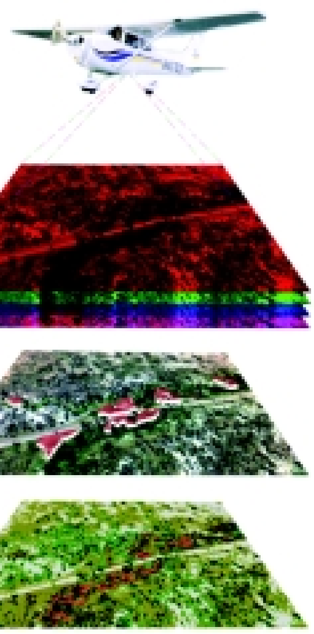
In addition to these annual measurements, video data were collected from the paddocks at the Cardigan site in 1996. Video cameras mounted in a light aircraft were used to collect these data at a pixel resolution of 20cm and 50cm. These data provided information on vegetation type and cover at the whole paddock scale, which allowed us to examine spatial patterns in the vegetation and to see how "leaky" the landscapes were under a range of grazing treatments. A "leaky" landscape is one that has insufficient grass and/or litter cover to prevent significant loss of water and nutrients from the system. Using our earlier definition of land condition, leaky landscapes are those in relatively poor condition because rainfall is not being used effectively to grow forage. Soil samples were also collected to understand how soil nutrients differed between grazing treatments and to better quantify the role of perennial grass tussocks in the cycling of nutrients and carbon in the landscape.

A quadrat showing some of the attributes measured in the annual pasture sampling

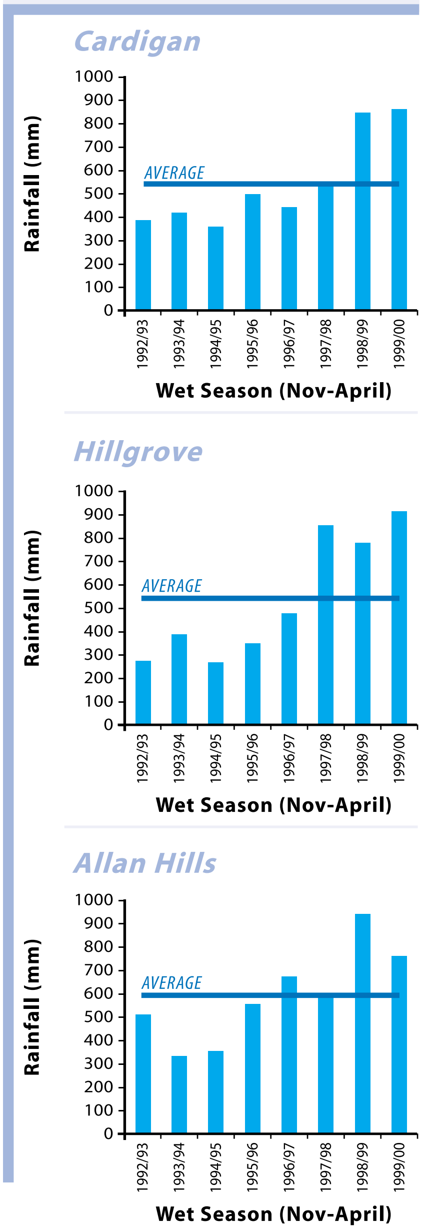


Field data collection using hand held computers

The videography process



Wet Season Rainfall



Wet season rainfall (Nov-April) recorded at the study sites

The Findings

Climate

Severe drought was experienced for the first four years of the study (1992-96) and this extended dry period coincided with persistent El Niño conditions. This sequence of dry years was the worst in recorded history and the extent of the drought was evident by the widespread death of eucalypts throughout the region. These drought years were followed by an "average" year and then three good wet seasons (1998-2000), which were consistent with La Niña conditions in the Pacific Ocean. The sequence of dry and wet years that occurred during the study provided a good contrast for evaluating different grazing management strategies.

Frequency of extended droughts (>24 months) at Charters Towers from 1882-2000 (adapted from Rainman)

Drought	Period	Duration (months)	Total rainfall (mm)	Average SOI
1	Feb 1883 to Mar 1886	38	1219	-3.4
2	Apr 1887 to Mar 1889	24	781	-6.5
3	Jan 1901 to Dec 1905	60	2294	-2.1
4	Jan 1914 to Jan 1916	25	844	-5.2
5	Mar 1918 to Mar 1920	25	739	-5.4
6	Feb 1925 to Mar 1927	26	1008	-1.7
7	Feb 1930 to Jan 1933	36	1136	-0.4
8	Feb 1934 to Jan 1936	24	768	0.8
9	Jan 1951 to Dec 1952	24	799	-1.5
10	Mar 1991 to Jan 1997	71	2007	-6.3

Maintaining 3P grasses in good condition pastures

For land that was in good condition (State I) at the start of the study, there were two grazing strategies that were able to maintain the dominance of 3P grasses. These were:

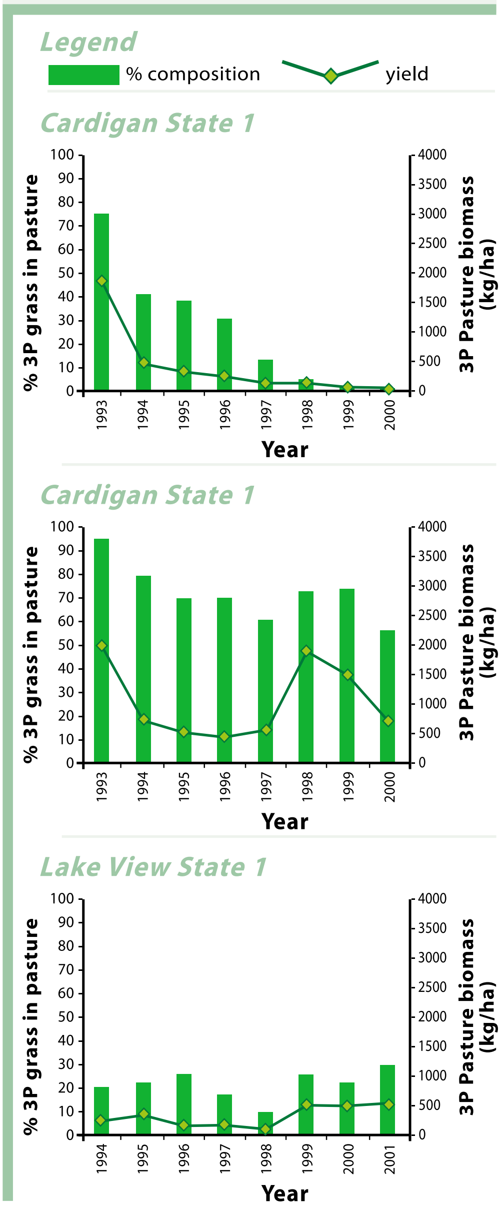
1. Continuous stocking at 25% utilization

2. Spelling the pasture for the first 6-8 weeks of the wet season and then utilizing 50% of the pasture

> **Land was maintained in good condition by continuous stocking at 25% utilization or early wet season spelling followed by 50% utilization**

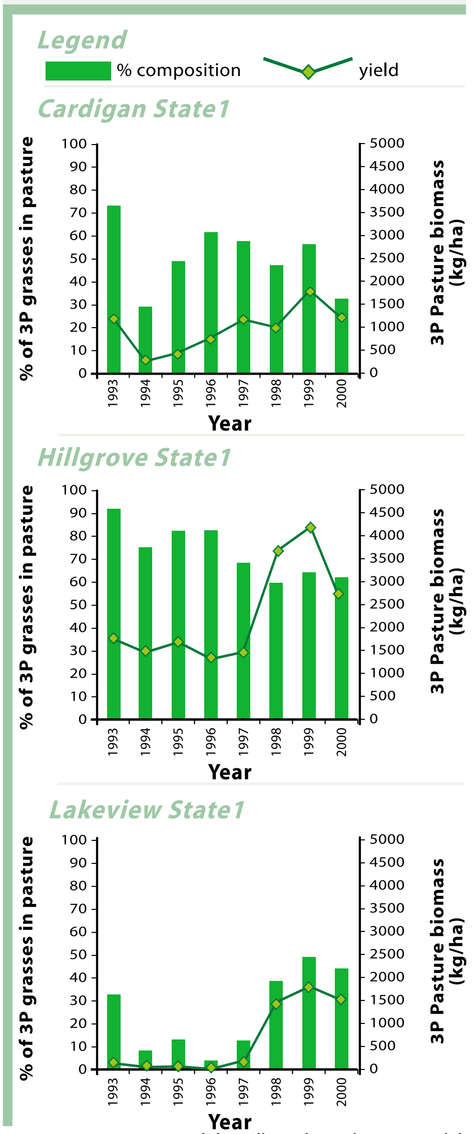
Despite severe drought conditions for the first four years of the study, 3P grasses remained dominant in these grazing treatments. However, the vigour of 3P grasses declined during the drought (as evidenced by the rapid decline in basal area of perennial grasses), recovering only with the wetter period experienced towards the end of the study.

Composition & pasture biomass of 3P grasses - 75% utilisation



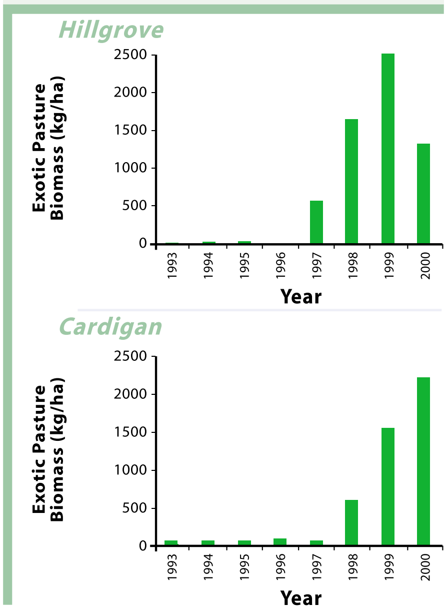
Percentage composition (bars) and pasture biomass (lines) of 3P grasses in State I condition land in response to 25% utilization.

Composition & pasture biomass of 3P grasses - 50% Utilisation + Wet Season Spelling



Percentage composition (bars) and pasture biomass (lines) of 3P grasses in State I condition land in response to 50% utilization plus wet season spelling.

Increase in exotic grasses



Increase in exotic grasses in the State I 25% utilisation treatments at Hillgrove and Cardigan which highlights their increase in the good seasons following drought

Based on previous studies in the region we expected the continuous stocking at 25% utilization grazing strategy to be sufficiently conservative to maintain the 3P grasses. However, the wet season spelling regime followed by moderate utilization (strategy 2 above) proved to be surprisingly effective at maintaining 3P grasses. This strategy provides some good opportunities to increase productivity whilst maintaining pasture health.

The challenge for managers is to design and implement a wet season spelling program into their grazing operation. This is likely to require additional paddocks and a greater degree of management intervention and pasture monitoring. While a short rest every year might not be practical for all operations, a rest for the whole of the wet season every three or four years might be a feasible and effective alternative. The practical implications of the different grazing management strategies are discussed in Section D. What is clear, however, is that adequately resting pastures during the wet season is an important strategy in maintaining 3P grasses.

Invasion by exotic grasses

At Cardigan and Hillgrove the percentage of 3P grasses in the pasture actually declined in the wet period following the drought, even though production of these grasses increased. This decrease in the proportion of 3P grasses was attributable to the invasion of exotic pasture grasses (Indian couch *(Bothriochloa pertusa)* at Cardigan and buffel grass *(Cenchrus ciliaris)* at Hillgrove) in the wet years following the drought. The decline in vigour of 3P grasses during the drought was such that seed of the exotic grasses was able to germinate and plants became established in the ensuing wet seasons before the natives had time to recover and out-compete the exotics.

If the aim of grazing management is to maintain a healthy native pasture it may not be possible to keep exotic grasses out during extended droughts

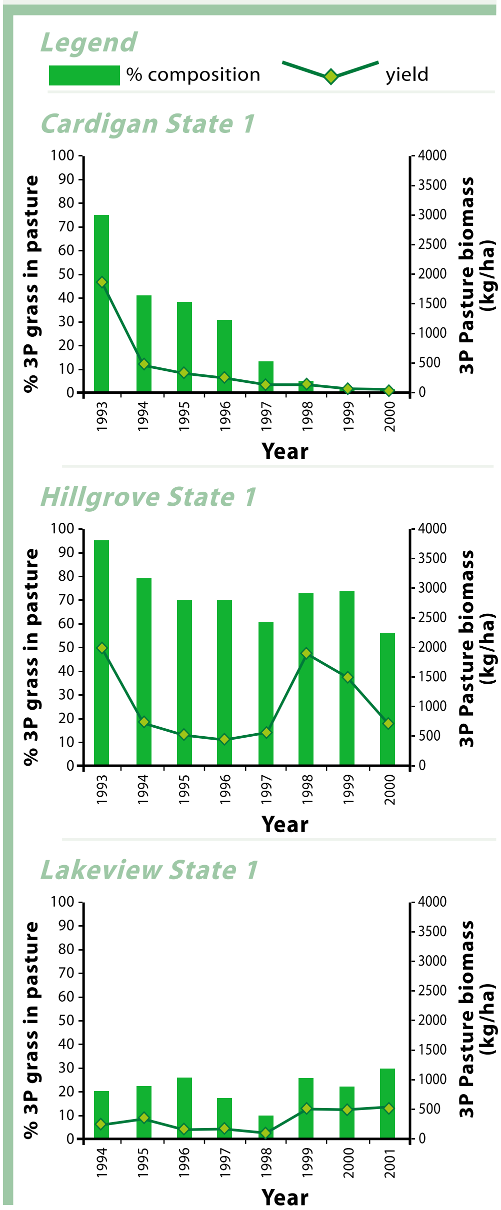
This interaction between natives and exotics has implications for managing pasture condition. For example, maintenance of a healthy *native* pasture may not be possible if exotics are present locally and there is a viable seed bank to take advantage of the weakened native perennials during extended droughts. Alternatively, where the aim of management is to establish introduced grasses in native pasture, there may be a window of opportunity at the end of a lengthy drought. Introduced grasses are difficult to establish without soil cultivation because of the competition provided by native grasses but, as indicated above, the native perennials may not provide much competition if they have been weakened by drought.

Loss of 3P Grasses

3P grasses, which dominated pastures in good condition at the start of the study, were greatly reduced under continuing high levels of utilization (75%). Initially, 3P grasses were resistant to this grazing pressure but after a couple of years their populations declined dramatically. At Hillgrove, which is a high fertility basalt soil, the 3P grasses recovered well when good seasons returned in the late 1990s. To a lesser extent, there was also some recovery at the Lakeview site. However, there was no such recovery at Cardigan and, by the end of the study, there were no 3P grasses remaining in the 75% utilization treatments at this site. The different result between sites highlights the role of soil fertility and soil condition in pasture systems. At Hillgrove the pastures suffered as a result of high grazing pressure, but the soil remained in good condition. As a result, pastures had the opportunity to recover in good seasons. Indeed, during these good seasons pasture growth was such that it was difficult to achieve 75% utilization - the pasture kept "getting away" from the cattle. However, at Cardigan, because both pasture and soil were degraded by heavy grazing, there was little chance for 3P grasses to recover even when, towards the end of the study, climatic conditions were more favourable.

Loss of 3P grasses leads to low rainfall effectiveness and the soil-pasture system becomes "desertified"

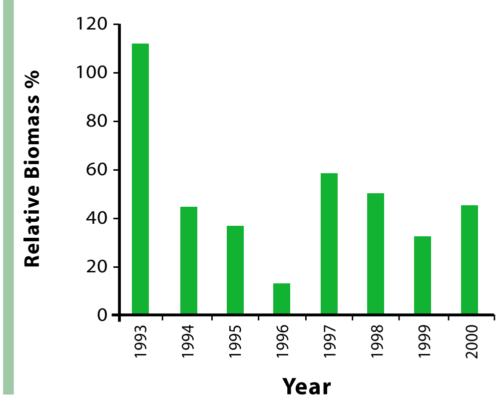
Composition & pasture biomass of 3P grasses - 75% utilisation



Decline in 3P grasses in response to heavy utilisation

Fenceline contrast between 75% utilization paddock and ungrazed area outside in 1997. Both areas were in the same condition at the start of grazing in 1993.

Declining Pasture Productivity



Relative pasture growth of 75% utilization paddocks compared with 25% utilization paddocks at the Cardigan site.

Exclosure cage showing the amount of grass growth in a wet season in a 75% utilization grazing treatment.

As 3P grasses are lost the productivity of pasture declines because the 3P grasses are initially replaced by less productive annual grasses and forbs. More importantly, the loss of tussocks and ground cover results in much higher run-off and low infiltration rates, which effectively "desertifies" the soil-pasture system. This is highlighted by pasture production data which show the relative pasture productivity in the 75% utilization paddocks compared with the 25% utilization paddocks at the Cardigan site.

The result of this declining productivity is that it takes fewer and fewer stock to maintain high utilization rates. This was noticeable in the grazing study, where the number of grazing days needed to achieve 75% utilization became less each year relative to the 25% utilization treatment.

Despite the return of better seasons commencing in 1996/97, pasture productivity in the 75% treatments at Cardigan and Lakeview did not recover to match that of the 25% utilisation treatments. This highlights that a decline in land condition is not a short-term effect and that pastures generally cannot "bounce-back" immediately upon the return of good seasons. Where a decline in land condition also results in soil deterioration it can take some time for the water and nutrient cycles to be restored. At Hillgrove, where the basalt soil is much more resilient, pasture productivity did recover in the good seasons following drought. This outcome further illustrates the role of soil condition in maintaining healthy productive pastures.

Number of grazing days in each year for Cardigan site 25% and 75% utilization treatments. Paddocks were designed so that the 25% and 75% utilization treatments would have the same number of grazing days to achieve their target utilization if they had the same pasture productivity

Year	Grazing days 25%U	Grazing days 75%U
1993	165	165
1994	137	110
1995	128	100
1996	110	64
1997	137	92
1998	183	128
1999	198	135
2000	275	183

Another reason for the rapid disappearance of 3P grasses under high grazing pressure is that cattle like to eat them. Cattle show strong preferences for 3P grasses particularly during the early part of the wet season. Unfortunately, this time coincides with the period when the 3P grasses are most vulnerable to grazing.

Recovering deteriorated pastures

Recovery of 3P grasses in pastures that were in poor condition at the start of ECOGRAZE in 1992 was achieved with the same grazing strategies that *maintained* 3P grasses in good condition land, i.e. conservative stocking (25% utilization) or wet season spelling followed by a higher level of utilization (50%).

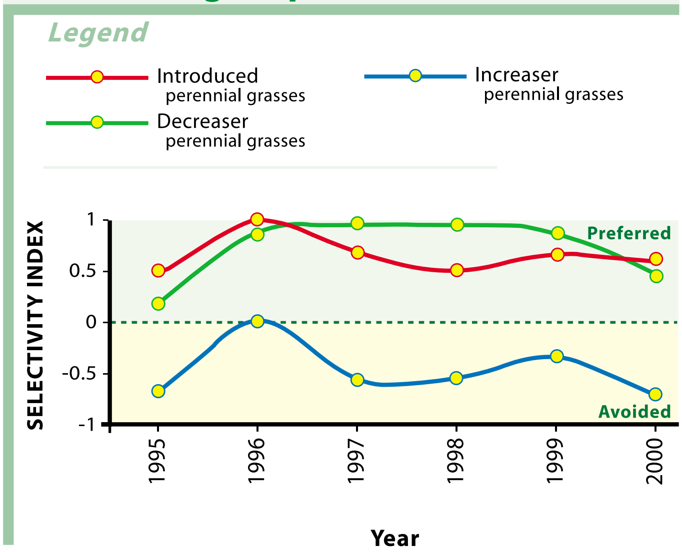
Grazing management, not climate, is the most important determinant of pasture condition

Climate determines the amount of pasture grown from year to year and the vigour of individual plants, but it is grazing pressure that largely determines pasture composition

The recovery of 3P grasses was significant even during the drought years of 1992-96. This highlights the fact that grazing management, not climate, is the most important determinant of both pasture condition and the level of retention of 3P grasses. Climate markedly influences the amount of pasture grown from year to year and the vigour of individual plants, but it is grazing pressure that largely determines pasture composition.

After five years of either 25% utilization or 50% utilization with wet season spelling there appeared to be full recovery of forage biomass and pasture composition at the paddock scale.

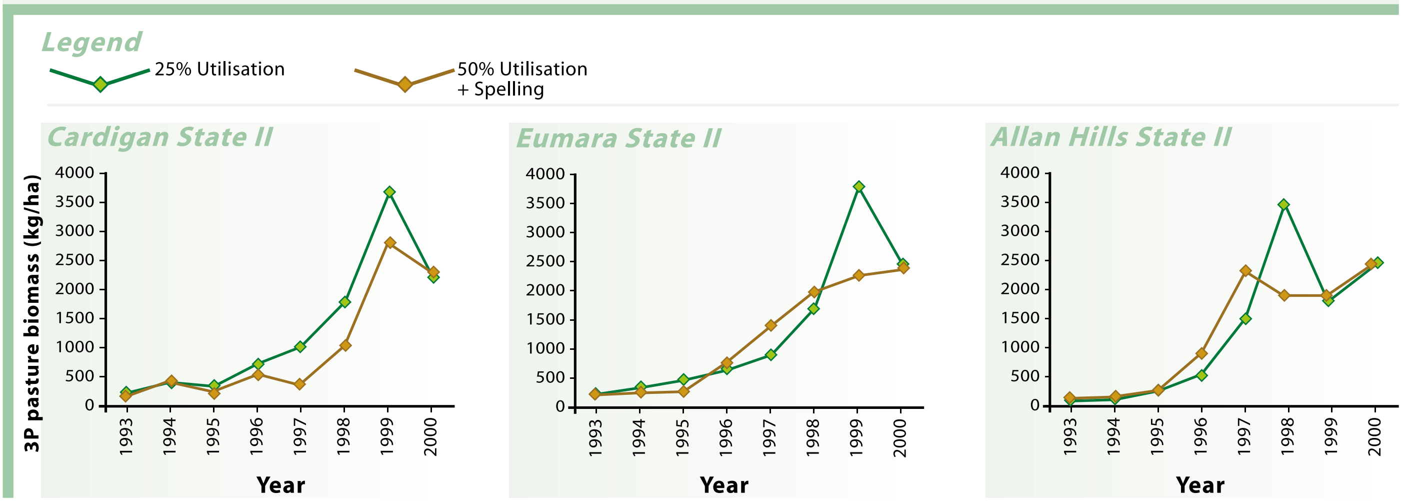
Preference of different plant functional groups



Preference of different plant functional groups at the Cardigan site over the life of the study. Selectivity index values above zero indicate increasing preference for that plant group while values below zero indicate relative avoidance.

Photo showing recovery of 50% utilization paddock at Cardigan State II site -the photo above is 1993, while below the photo is 1998, after five years of low utilisation.

Recovery of 3P grasses from paddocks initially in poor condition



Recovery of 3P grasses with the 25% utilization and 50% utilization with spelling treatments in paddocks that were in poor condition at the start of the study

Although the paddocks had recovered in terms of overall productivity and composition, they appeared to be very patchy compared with State I good condition pastures. The patches were distinct in that there were areas, 5-20m across, where very large perennial grass tussocks were separated by large scalded areas supporting short annual grasses.

Illustration of the patchy recovery of 3P grasses

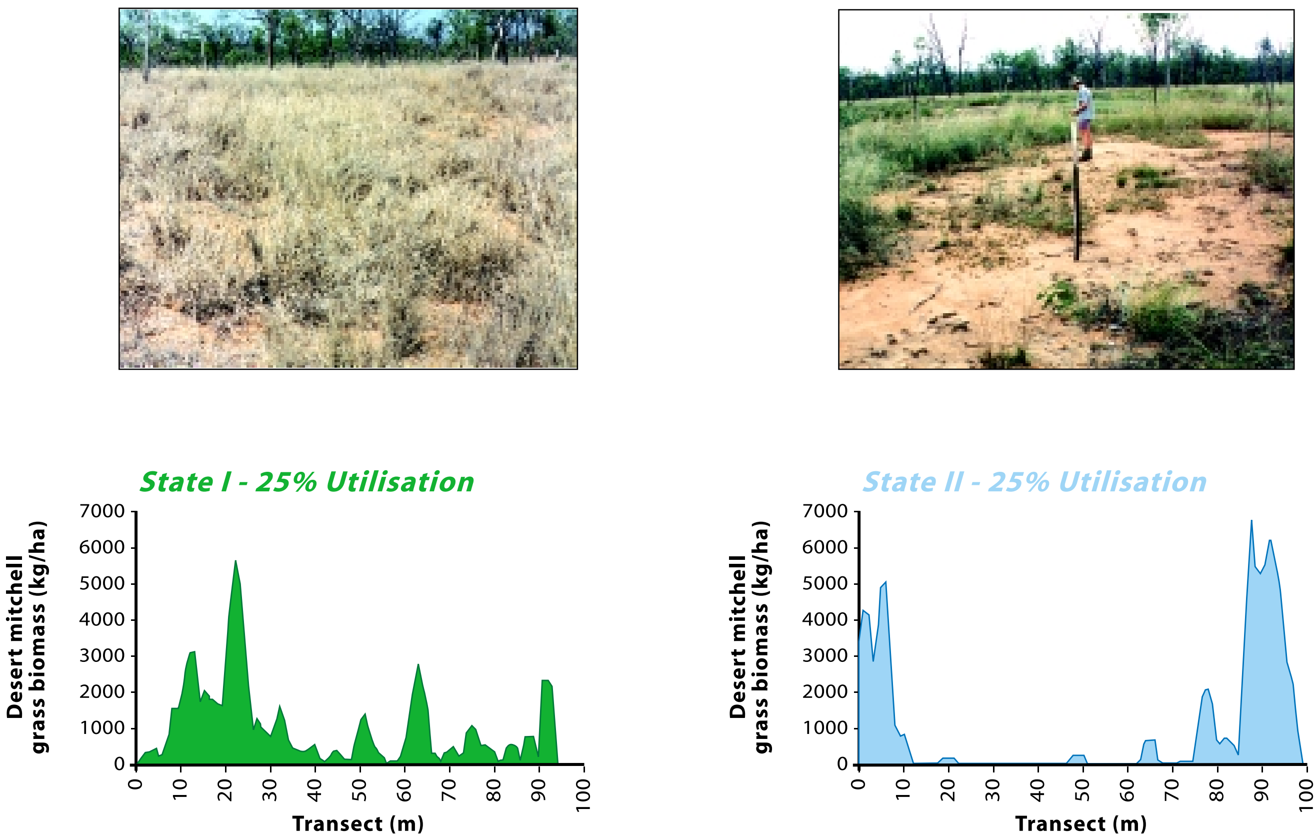


Illustration of the patchy recovery of 3P grasses. The figure on the left (green) shows the relatively even distribution of desert mitchell grass along a 100 m transect in a 25% utilization paddock in State I. The figure on the right (blue) shows the patchy distribution of desert mitchell grass along a similar transect, but in a 25% utilization paddock in State II after a number of years of recovery.
Both transects had the same total biomass of desert mitchell grass.

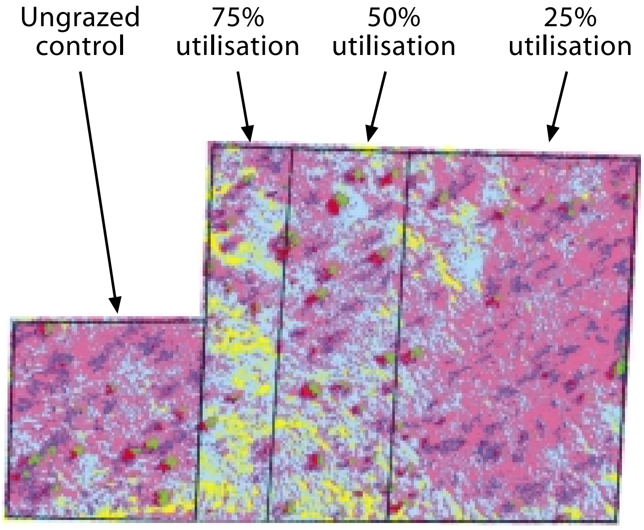
Animal selectivity appeared to reinforce this patchiness, with cattle concentrating much of their grazing in the short annual grass patches and leaving ungrazed many of the vigorous but rank perennial grass patches.

It is likely that these bare patches shed water and nutrients that were captured down-slope by the tussock grass-dominated patches.

Where perennial grasses have been greatly reduced and there are few tussocks, the loss of ground cover means that water, sediments and nutrients leak from the pasture. This results in a loss of pasture productivity because rainfall is not used effectively. When the pasture has partially recovered there is no system leakiness, but there is still significant movement of sediments and nutrients between bare areas and dense vegetation patches.

Videography data from the Cardigan site demonstrate the distribution of perennial grasses at the paddock scale when the pasture-soil system is in degraded, partially recovered or stable states.

Patterns of vegetation at the paddock scale highlighting the patchiness



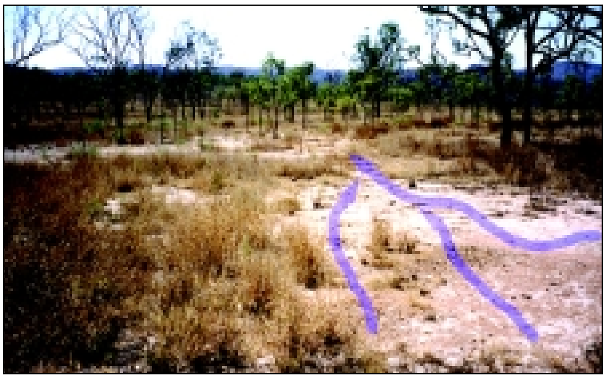
Patterns of vegetation at the paddock scale highlighting the patchiness.

Yellow = bare soil,

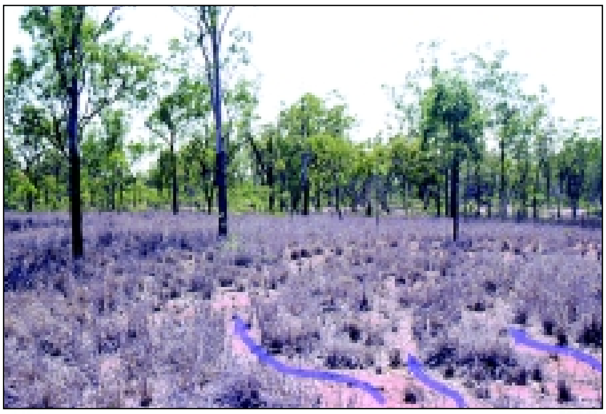
Pink = perennial grasses,

Light Blue = annuals and litter.

Landscape "leakiness"



A 'leaky' system sheds water and nutrients, reducing pasture productivity.



A 'stable' system traps water and nutrients within perennial grass tussocks.

The story of recovery from State II to State I over the eight years of the study is that good grazing management can bring about restoration of 3P grasses

It is likely that the pasture will make the transition from patchy recovery to full recovery either very slowly through gradual expansion of the dense perennial grass patches or more rapidly if there are very favourable climatic conditions that allow perennial grasses to germinate and establish despite the unfriendly soil environment associated with large bare patches. Such favourable climatic conditions were experienced from 1998-2000, when the wet seasons were good not only in terms of total amount of rainfall but also in terms of their long duration. The resulting good soil moisture conditions enabled newly germinated perennial grasses to persist.

The story of recovery from State II to State I over the eight years of the study demonstrates the fact that good grazing management can bring about recovery of 3P grasses, ensuring that the pasture is productive and no longer leaks valuable water and nutrients. However, for the soil to fully recover, with perennial grasses establishing on even scalded patches, there may need to be a sequence of *very* favourable years.

Grazing and species diversity

The importance of developing grazing strategies that help conserve biodiversity is increasingly being recognised. Biodiversity is the variety of all living organisms and the ecosystems to which they belong. Some plant and animal species are sensitive to grazing and it is important to understand how species respond to grazing so that management strategies that protect the sensitive species can be developed. The small size of our experimental paddocks in the ECOGRAZE study made them unsuitable for comprehensive biodiversity studies but we were able to measure the effects of grazing on herbaceous plant species diversity, which is one component of biodiversity.

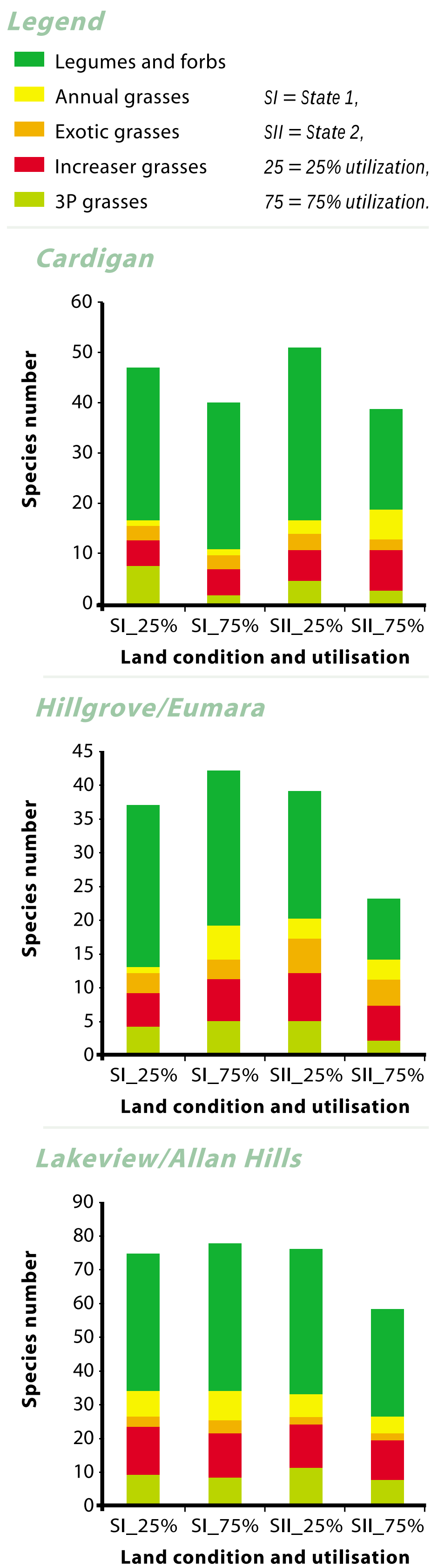
At the Hillgrove and Lakeview sites grazing had little effect on species diversity in paddocks that were initially in good condition and grazed heavily (75% utilization). Even though the abundance of 3P grasses was greatly reduced in these treatments, nearly all of the species remained in the paddocks. However, at the Cardigan site there was a significant reduction in diversity of 3P grasses as a result of heavy utilization.

The relatively minor effect of heavy grazing on species diversity after eight years is not that surprising. The reduction in biomass and abundance of 3P grasses in response to heavy grazing creates gaps for new plants. As a result, there is often little early change in diversity. Indeed, it is not uncommon for plant diversity to *increase* in the short term in response to grazing. However, prolonged heavy utilization can lead to a loss of plant species. This is highlighted in the results for the heavily grazed paddocks that were in poor condition at the start of the study. At all three sites, plant species diversity was significantly reduced. Legumes, forbs and 3P grasses accounted for most of the reduction in plant diversity. As it is not uncommon for native legumes and forbs to decrease as perennial grasses decline, keeping 3P grasses abundant in pastures helps maintain the presence of minor species like forbs and native legumes.

Prolonged heavy utilization can lead to a loss of plant species diversity

There were interesting site differences in plant species diversity with an inverse trend between soil fertility and plant diversity; the low fertility site (Lakeview/Allan Hills) had the greatest diversity and the fertile basalt soils at Hillgrove/Eumara had the lowest diversity.

Species diversity in plant functional groups



Species diversity in plant functional groups at the three study sites. The numbers represent species per paddock and are the average of 1999-2000 for Hillgrove and Cardigan and 2000-01 at Lakeview/Allan Hills.

Loss of pasture productivity and soil carbon

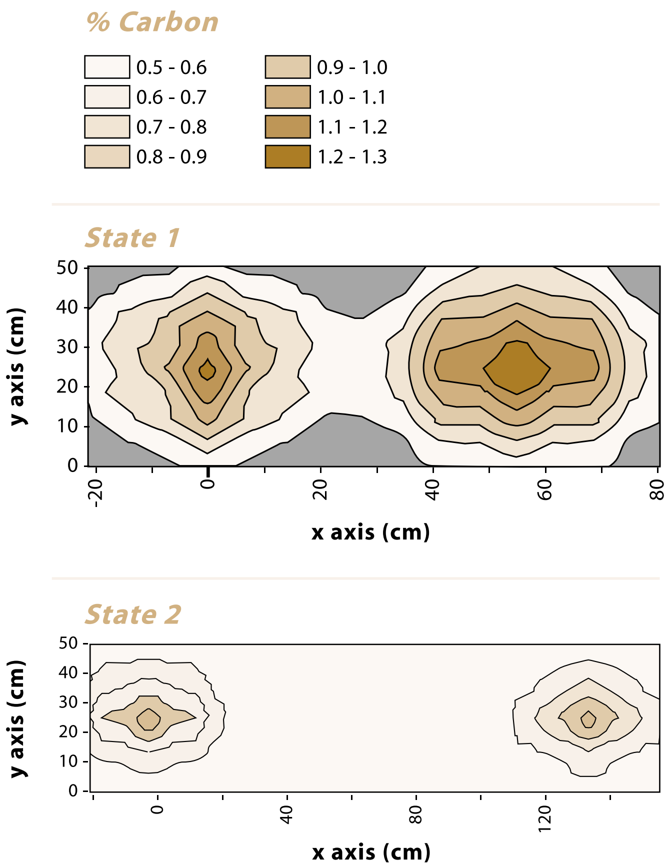


Illustration of the distribution of soil carbon in the top 10cm of soil between good condition State I (top figure) and poor condition State II (bottom figure) The concentric rings represent individual perennial grass tussocks.

Grazing management and the storage of carbon

The tropical savannas of northern Australia store about one third of Australia's terrestrial carbon. Good management of this carbon store could be important in limiting Australia's greenhouse gas emissions. Trees are the highly visible form of carbon storage and they receive a lot of attention. However, perennial grasses are also important in terms of carbon storage because their roots and associated organic matter make a valuable contribution to soil organic carbon.

To understand how grazing affects soil carbon through changes in pasture composition we sampled the soil in a number of the grazing treatments at the Cardigan site. The results showed that most of the soil organic carbon is found beneath perennial grass tussocks and that the amount declines rapidly with increasing distance from the tussock. When pasture is in good condition, there is much carbon beneath each tussock and, because tussocks are reasonably close together, the decline in organic carbon in the inter-tussock space is not great. However, when perennial grasses have been weakened through overgrazing there is a significant decline in soil carbon. In such situations, the amount of carbon beneath tussocks is lower and there are large gaps between tussocks with little carbon in the inter-tussock space.

Managing pasture condition to maintain 3P grasses has the added benefit of looking after soil carbon reserves

At the paddock scale, overgrazing greatly reduces soil carbon reserves. Managing pasture condition to maintain 3P grasses has the added benefit of maintaining soil carbon reserves. If carbon trading increases in importance there may be some opportunities for producers to become involved and to receive additional returns (incentives, premium on beef etc) from good grazing management practices that generate public benefits.

SECTION D DEVELOPING PRACTICAL GRAZING STRATEGIES

The ECOGRAZE study shows that both conservative stocking with continuous grazing and a rotational grazing system that includes some wet season spelling will help to maintain 3P grasses in pasture or help them to recover after degradation. ECOGRAZE also shows that wet season spelling may provide some opportunity for a modest increase in overall carrying capacity without negatively affecting land condition. In this section we discuss the practical implications of these different grazing strategies.

Regardless of grazing system used the most important driver of animal production and land condition is the overall stocking rate

Regardless of the type of grazing system used, the most important driver of animal production and land condition is the overall stocking rate. Stocking rate is the actual number of animals on a specific area for a specific period of time (usually from days up to a year). Carrying capacity is defined as the stocking rate that a particular paddock or series of paddocks or property can support for a number of years without damaging land condition. Carrying capacity varies with land condition and intensity of management (fencing, water development, grazing management regime). It also varies through time when there are extended runs of years of below or above average rainfall.

Carrying capacity varies with land condition and intensity of management

Calculation of carrying capacity is an important first step in developing grazing strategies to meet production and land condition goals. Carrying capacity can be calculated according to target utilization rates (the percentage of pasture eaten relative to the amount grown). For example, based on ECOGRAZE findings, with continuous grazing, a long-term utilization rate of 25% is ideal for maintaining 3P grasses. Because different country types vary in their productive capacity, they will have different carrying capacities.


Courtesy P. Stevenson

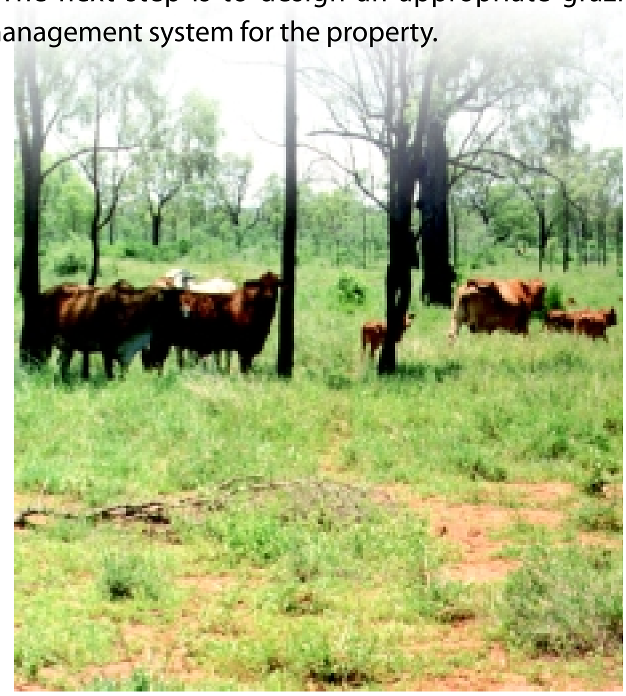
Effect of type of country and land condition on carrying capacity

Country	Land condition	Average annual pasture growth (kg/ha)	Average consumption (kg/head/year) based on 25% utilisation	Carrying capacity (ha/head) assuming annual intake of 3000 kg/head
Basalt	Good	2400	600	5.0
Basalt	Deteriorated	1680	420	7.1
Goldfields	Good	1700	425	7.0
Goldfields	Deteriorated	1020	255	11.8
Red/yellow earth	Good	1200	300	10.0
Red/yellow earth	Deteriorated	720	180	16.7

The above calculations assume that there is sufficient water available for the animals to be well distributed throughout the paddock. Discount factors would have to be applied on the carrying capacity calculation if not all of the paddock was accessible either for reasons of distance from water or terrain. To achieve good animal distribution paddocks should not be more than about 2000 ha in size and the distance to water should not be more than about 2 km.

Very few paddocks in extensive beef operations are homogenous; invariably they comprise a number of land types each with different pasture productivities. This variation in pasture productivity also needs to be factored into carrying capacity calculations.

The next step is to design an appropriate grazing management system for the property.



Grazing management systems

Continuous grazing

For many pastoralists, a continuous grazing system with conservative stocking rates may be the most appropriate strategy for their enterprise. Such a system has the advantage that it may not require any additional capital investment, although some fencing and/or water development may be required in large paddocks in order to improve grazing distribution. In terms of animal production the majority of studies have shown that continuous grazing and more intensive rotational grazing systems differ little when they have the same stocking rate and where distance from water is not a factor in continuously grazed paddocks. Where relatively inflexible rotational grazing systems are used, animal performance can in fact be worse than continuous grazing.

A continuous grazing system with conservative stocking rates may be the most appropriate strategy for many enterprises

The main disadvantage in continuous grazing systems is that uneven animal distribution can lead to overgrazing in certain parts of even lightly stocked paddocks. This is especially a problem in paddocks with diverse land types that differ markedly in grazing preference. Grazing management is then constrained by having to adjust stocking rates in line with the most susceptible parts of the paddock.

Unlike continuous grazing strategies, rotational grazing strategies that employ wet season spelling allow the whole paddock to be rested so that all parts recover. An alternative to rotational grazing in order to achieve more uniform grazing, is fencing by land type. This, however, involves capital expenditure and may not be practical. Mosaic burning can be used to shift the grazing patterns of animals around a paddock but it requires considerable management acumen and a good network of either natural or prepared fire breaks.

Rotational grazing systems to achieve wet season spelling

In the last 60 years considerable effort has been put into developing rotational grazing systems that provide some rest to the pasture. These systems range from fairly simple, large paddock rotations to highly intensive time-controlled grazing systems, of which cell grazing is the best known in Australia. In this book we focus on some fairly simple grazing systems that allow a wet season spelling program to be implemented rather than on the more intensive systems, which require a good deal of training and experience.

Rotational grazing strategies that employ wet season spelling allow the whole paddock to be rested so that all parts recover

(i) Two paddock system

In this simple system, Paddock A is grazed during the wet season while Paddock B is rested. During the dry season both paddocks are grazed. In the next wet season Paddock B is grazed and Paddock A is rested. This provides a wet season rest every second year for each paddock, but puts all the grazing pressure on one paddock during the wet season. An advantage of this system is that little additional fencing and water development is required.

		Paddock A	Paddock B
Year 1	Wet Season	GRAZE	REST
	Dry Season	GRAZE	GRAZE
Year 2	Wet Season	REST	GRAZE
	Dry Season	GRAZE	GRAZE

(ii) Simple three paddock system

In this system, one paddock is spelled for the entire wet season while the other two paddocks are grazed. At the end of the wet season the stock are spread evenly over all three paddocks. In the next wet, the second paddock is rested. The cycle is completed after three years when the third paddock is rested for the wet season.

In this way, paddocks receive a complete rest every third wet season, which should allow good recovery, but there is quite a bit of grazing pressure on the other two paddocks for an extended period of time. The system is fairly easy to manage as it fits in with mustering rounds at the end of the wet and dry seasons.

		Paddock A	Paddock B	Paddock C
Year 1	Wet Nov-Apr	REST	GRAZE	GRAZE
	Dry May-Oct	GRAZE	GRAZE	GRAZE
Year 2	Wet Nov-Apr	GRAZE	REST	GRAZE
	Dry May-Oct	GRAZE	GRAZE	GRAZE
Year 3	Wet Nov-Apr	GRAZE	GRAZE	REST
	Dry May-Oct	GRAZE	GRAZE	GRAZE

(iii) Two herd/three paddock "ECOGRAZE" system

This grazing system best incorporates the results of the ECOGRAZE study. Under this system, Paddock A is rested in the early wet season, while Paddocks B and C are grazed. Paddock B is then rested for the late wet season while Paddocks A and C are grazed. Paddock C is then rested for the dry season and the next early wet season while Paddocks A and B are grazed. Paddock A is then rested for the late wet season and the rotational cycle continues in this fashion for the three years of the full rotation.

The timing and length of the early and late wet season grazing and of the rest periods needs to be flexible. Early wet season spelling should commence after the first significant rains in November/December and should continue for six to eight weeks, depending on how effectively the early rains promote vegetative growth of perennial grasses. Similarly, the late wet season rest should typically last until March/April, but will depend on the length of the growing season.

The advantage of this grazing system is that all paddocks get some wet season rest two years out of three. The early wet rest is particularly good for vegetative perennial grass recovery, while the late wet rest aids both seed set and vegetative recovery. By having paddocks rested for the dry season (May-October) and for the following early wet season, fire can be used to reduce either exotic or native woody plant cover. Paddocks that are burnt in the dry are then rested for the early wet season. This overcomes any problems of animals overgrazing freshly burnt country. However, the downside of not grazing after a fire is that animals can't take advantage of the green pick that boosts animal performance.

		Paddock A	Paddock B	Paddock C
Year 1	Early Wet	REST	GRAZE	GRAZE
	Late Wet	GRAZE	REST	GRAZE
	Dry	GRAZE	GRAZE	REST
Year 2	Early Wet	GRAZE	GRAZE	REST
	Late Wet	REST	GRAZE	GRAZE
	Dry	GRAZE	REST	GRAZE
Year 3	Early Wet	GRAZE	REST	GRAZE
	Late Wet	GRAZE	GRAZE	REST
	Dry	REST	GRAZE	GRAZE

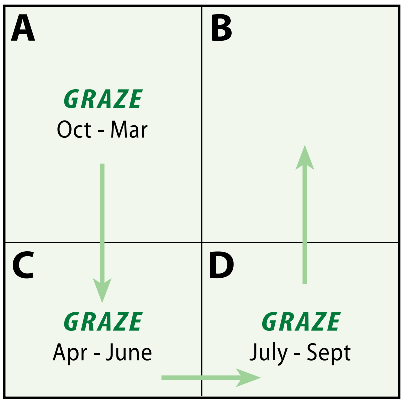
This system of rest and grazing would permit a fire every three years, although many properties may only need fire every six to nine years.

Under conditions of severe drought it would be possible to suspend the dry season spell and allow animals to graze all paddocks. In terms of aiding perennial grass recovery, resting during the dry season is not very important, so an interruption to the rotational grazing system at this time would not be damaging. However, it is essential that the wet season spelling rotation is maintained.

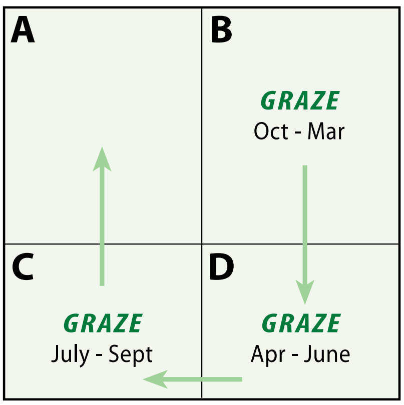
The main management challenges of this grazing system are the timing and length of the early wet season rest, and the ability to move animals during the wet season. Clearly some adaptive management is required in implementing this system.

(iv) One herd/four paddock system[1]

Year 1



Year 2



This system uses one herd and four paddocks of unequal size. Paddocks A and B are twice the size of Paddocks C and D. The single herd grazes Paddock A during the growing season (October, November-March) and then moves into Paddock C for the first three months of the dry season (April-June). Paddock D is then grazed for the remainder of the dry season (July-September) before animals move to the large Paddock B for the next wet season. The rotational direction is then reversed for the next cycle. This system provides spelling for a whole wet season every second year, but considerable grazing pressure is placed on paddocks grazed during the wet season, as one-third of the area supports the whole herd for six months.

[1]Grazing system developed by Resource Consulting Services, Yepoon

LAND CONDITION, GRAZING STRATEGIES and ECONOMICS

If producers are to adopt grazing management recommendations that sustain the native pasture resource it is important we assess the financial consequences of such recommendations.

We have assessed the economic implications of managing land in various land condition states by linking a pasture production model (GRASP) to a spreadsheet model of farm economics. In GRASP we used 100 years of historical climate data for Charters Towers to predict annual pasture and animal production for land in various conditions. This production data was used to drive branding and mortality rates and sales in a spreadsheet model of enterprise economics. For all of the scenarios presented in this section our "test" property was 28,000 ha in size and on moderate fertility soils. The key outputs from this spreadsheet model are gross margin per head and per hectare, farm cash flow and return on capital. In the model, costs and prices of beef were based on an average of ABARE data from 1996-2000.

The test beef enterprise used in modeling scenarios

Property size: 28,000 ha
Country type: Moderate fertility, eg. Goldfields country, with intact woodland
Average rainfall: 650 mm
Useable area of property for grazing: 24,000 ha
Land value: $70/ha
Improvements: $400,000
Overhead Costs: $150,000 per annum
Non-cattle income: $15,000 per annum
Non-family labour: $32,000 per annum

Herd management
Bull/breeder ratio: 3%
Target steer/bullock weight: 580kg
Target weight of surplus heifers: 350kg
Weaning weight: 170 kg
Cow culling age: 6 or 7 years depending on season
Supplementary feeding: Initially M8U but in extended dry spells fortified molasses

Land condition and enterprise economics

In the first series of simulations we assumed that land condition remained constant for the 100 years in each of three land condition states – that is, the land was in State I (good condition), or State II (deteriorated condition) or State III (degraded condition) for the entire 100 year period and didn't change from one state to another.

In our model herd we tried to maintain around 3,600 head, if branding percentages and mortality rates permitted. The results for these first series of simulations are shown in the table (right).

State I is financially the most stable and while State II can be economic it is more variable and risky

Land condition and farm economic performance

	State I	State II	State III
% perennials in pasture	90	70	32
Pasture growth (kg/ha/year)	1,730	1,462	938
Soil loss (kg/ha/year)	590	1,060	2,310
Herd number	3,600	3,410	1,910
Cattle sold per year	662	709	281
Supplement costs $/year	$17,000	$64,800	$72,800
Cash return $/year	$38,000	$35,000	-$95,000
% years –ve cash flow	17	25	58

While State I is considerably more productive than State II in terms of pasture growth, the difference is not as great in animal production or economic performance. This is because the greater proportion of annual grasses and forbs in State II affords a higher diet quality. Consequently, when seasons are good and forage is not limiting, animal production and cash flow is relatively high. However, in poorer seasons in State II forage quantity can be more limiting, leading to high supplementary feed costs and reduced economic performance. State II experiences a higher percentage of negative cash flow years and faces much greater enterprise risk. However, the main disadvantage of State II condition land is that, with further inappropriate management, it can shift to State III, a State that is highly unproductive and unprofitable.

In summary, State I is financially the most stable of the three States. While State II can be profitable, the level of profit is more variable and there is considerable risk of moving to a highly unprofitable, degraded land condition.

Are rotational grazing systems cost-effective?

We compared continuous grazing with rotational grazing in 100 year simulations using what appeared to be 'safe' utilisation rates based on the ECOGRAZE findings. (a long-term average 25% for continuous grazing and an average of 35% utilisation for rotational grazing with a wet season spelling regime). The feedback effects of grazing on perennial grasses was included so that the long-term sustainability of the grazing systems could be tested.

The rotational grazing system used in the simulations was the simple three paddock system. Under this system, one paddock was rested from November to the end of April, then all paddocks were grazed over the dry season, and then the second paddock rested in the following wet season and so on, with the full cycle taking three years.

The stocking rates were:

(a) Continuous stocking at 25% utilisation (one cow/7 ha)

(b) Continuous stocking at 35% utilisation (one cow/5ha)

(b) Wet season spelling regime with an average utilisation of 25% (one cow/7ha)

(c) Wet season spelling regime with an average utilisation of 35% (one cow/5ha)

It was assumed that $100,000 would need to be spent on fencing and water in order to implement the rotational grazing system on our 28,000 ha case study property. This $100,000 was borrowed from the bank at an interest rate of 10%.

The financial performance of the various stocking strategies is shown in the table opposite.

At the long-term safe utilization of 25%, continuous grazing is more profitable than rotational grazing because of the loan repayments associated with infrastructure developments. However, the continuous stocking strategy is not sustainable if average utilization is increased to 35%. This is because there are sequences of years when utilisation rates are high and the pasture deteriorates to the point where it does not recover in subsequent years. The result is a crash in financial performance as a result of the loss of 3P grasses from the system.

In contrast, the rotational grazing system at 35% utilization *is* sustainable because the rest provided to paddocks every third wet season allows recovery of 3P grasses. Soil loss is higher with this grazing strategy but the amount lost is not a concern. Because more animals are carried there is a greater reliance on supplementary feeds. The result is that this rotational grazing system is more profitable than continuous grazing at 25% utilization, although both systems return reasonable cash flows.

The results of the ECOGRAZE study indicate that a wet season spelling regime can support higher utilisation rates without damaging the key perennial grasses than can continuous grazing. However, for most enterprises, the introduction of a rotational grazing system that incorporates a wet season spelling regime is likely to involve some infrastructure development in the form of fencing and new waterpoints. Also, higher utilization rates will lead to reduced individual animal performance, which may affect the ability of cattle to reach target market specifications.

Based on simulation studies (with underlying assumptions), rotational grazing systems that incorporate wet season spelling can be more profitable than continuous grazing. However, because rotational grazing systems require more management effort and may require some capital expenditure on infrastructure, to be successful they need to be well planned and management needs to be flexible.

Economic performance of continuous grazing and wet season spelling strategies

	Continuous grazing – 25% utilisation	Continuous grazing – 35% utilisation	Wet season spelling –25% utilisation	Wet season spelling – 35% utilisation
Pasture growth (kg/ha/year)	1,730	1,195	1,765	1,683
Soil loss (kg/ha/year)	590	2,291	548	861
Herd number	3,600	4,200	3,600	5,000
Cattle sold per year	662	688	675	892
Supplement costs $/year	$17,000	$128,000	$12,000	$61,000
Cash return $/year	$38,000	-$114,000	$37,000	$57,000

Rotational grazing systems that incorporate wet season spelling can be more profitable than continuous grazing

A wet season spelling regime can support higher overall utilisation rates than continuous grazing without damaging the key perennial grasses

CONCLUSIONS

The ECOGRAZE study has been a successful long-term study which has developed innovative management options to enhance the condition of grazing lands in the open eucalypt woodlands of northern Australia. It has focused on developing grazing management guidelines that can be used by industry to recover land that has deteriorated through overuse or prevent degradation of pastures currently in good condition. An important aspect of the research has been its location on five commercial grazing properties on different country types in north-east Queensland. This allows extrapolation of the results to a wide area across northern Australia. Another important part of the research was to be able to communicate concepts of land condition and this was successfully achieved by using a simple framework to explain land condition states and the factors (grazing, climate, fire) that drive the transitions between states.

The key findings of the research have been:

- Grazing management, not climate, is the key driver of land condition and pasture health
- Land was maintained in good condition by continuous stocking at 25% utilization or early wet season spelling followed by 50% utilization
- As perennial grasses are lost through overgrazing, rainfall effectiveness declines, pasture productivity is reduced and the system becomes desertified
- Continuous stocking at 25% utilization or early wet season spelling followed by 50% utilization recovers native tussock perennial grasses in poor condition pastures, even during drought years
- The value of wet season spelling is enormous and where a wet season spelling regime can be implemented it can provide increased flexibility to enterprise management
- Wet season spelling can be implemented using fairly simple two, three or four paddock grazing systems
- Cash flows between good and deteriorated pasture condition were on average not greatly different but pastures in a deteriorated condition gave more variable returns and there were more years in which losses occurred. If deteriorated pastures become degraded, the loss of productivity and increased supplementation costs can lead to huge financial losses
- Where wet season spelling is introduced and overall utilisation rates can be sustainably increased, then cash flows can be improved even allowing for the capital costs of infrastructure developments such as water and fencing

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APPENDIX 1

GLOSSARY OF TERMS USED IN THIS PUBLICATION

3P grasses - palatable, productive, perennial native grasses

ABARE - Australian Bureau of Agricultural Resource Economics

annual – a plant that normally completes its life cycle in one year. In the wet-dry tropics, a plant that grows and sets seed each wet season, then dies off by early dry season

basal area (of perennial tussock grasses) – the area of ground occupied by the crown of perennial tussock grasses

biodiversity - the variety of all living organisms and the ecosystems to which they belong

biomass – see pasture biomass

carbon storage – refers to the ability of terrestrial (land-based) systems to store organic carbon. Forests, woodlands and grasslands are all important stores of organic carbon. Root systems are significant organic carbon stores and in grasslands most organic soil carbon is stored beneath perennial grass tussocks

carbon trading – the opportunity for companies or countries to buy or sell "carbon credits" associated with potential organic carbon stores (forests, woodlands etc.) to offset the impacts of greenhouse gas emissions from other sources

carrying capacity - the average stocking rate that can graze a particular paddock or series of paddocks or property over a number of years without damaging land condition

climate variability – the year to year variability in rainfall, temperature and other climatic factors within a region - in particular, variability in the amount and distribution of rainfall received

continuous grazing – grazing of paddocks (often by a set number of animals) for 12 months or longer without a spell

decomposers - organisms (e.g. soil microbes, termites) that gain energy by consuming dead organic material such as dead plant and animal tissue, dung, urine etc

defoliation – the removal of plant material (leaves, stems etc.) by animals during the grazing process

degradation (of grazing land) - the loss of capacity to grow and sustain cattle, either now or in the future

desertification (of soil-pasture system) – the loss of plants (especially perennial plants) from a system leading to loss of topsoil and soil nutrients vital in sustaining plant and animal life and future recovery

ecological processes – the biological, physical and chemical processes which sustain an ecosystem

ecosystems - complex communities of organisms, interacting within their environment

El Niño – originally referred specifically to a warming of the sea off the coast of Peru, now more generally used for the unusual warming of a large area of the eastern equatorial Pacific Ocean.

ENSO – (El Niño-Southern Oscillation) is a composite term referring to the whole suite of events associated with negative SOI episodes

Exotic - plants and animals introduced (deliberately or accidentally) from another region or country

forage – plant material (from pasture and browse) available to the grazing animal

forbs – non-grass, herbaceous (non-woody) plants which occur in pastures

forest country – the woodland communities of north-east Queensland dominated by Eucalypts, with a perennial tussock grass understorey

genus – a sub-division within a (plant or animal) family or sub-family containing one or more species

granodiorite – the underlying geological material from which the granitic goldfields and Dalrymple soils of the region are derived

grazing pressure – the relationship between the available pasture biomass and the number and class of stock grazing that pasture, whether it be a whole paddock or a particular land or pasture type within a paddock

ground cover - the percentage of ground covered by plant material and litter

herbaceous layer – the vegetation layer occupied by grasses and forbs (i.e. the pasture)

herbivores - organisms that feed essentially on plants (e.g. cattle, sheep, kangaroos)

igneous – rock derived from magma intrusions into the earth's crust

increaser (pasture species) – a pasture species that increases in abundance under sustained grazing relative to 3P species

infiltration (of rainfall) – the soaking or penetration of rain into the soil. The rate of rainfall infiltration depends on the amount and intensity of rainfall, slope and ground cover, which influence the ability of the soil-pasture system to trap and hold such rainfall

La Niña - used to refer to the opposite of an El Niño, or events associated with positive values of the SOI

land condition - the capacity of grazing land to respond to rain and produce useful forage

landscape –a description of local-scale features which usually extends beyond the paddock or property scale and may encompass several vegetation communities and topographic features e.g. from ridge-top to river

land type – the broad-scale soil/vegetation types within a region e.g. the goldfields country, basalt country, red and yellow earths of the Dalrymple region

leaching – the movement of nutrients from the upper layers of soil to lower soil layers and into groundwater

legumes – broadly speaking, plants of the "pea" family (Fabaceae) but also including wattles (Acacia), Cassia and other species of the Mimosaceae and Caesalpinaceae families. Legumes have the ability to capture or "fix" atmospheric nitrogen in root nodules to enhance their growth and so are valuable both as source of protein for grazing animals and nitrogen for pasture growth

mosaic burning – the practice of patch burning, often as a cool burn, where only areas of rank pasture growth are burnt, leaving previously grazed areas unburnt. Following new wet-season growth, cattle grazing is focused on the newly burnt areas, effectively "spelling" previously grazed areas

native pastures – the natural pastures or grasslands of the region, in contrast to introduced or improved pastures

naturalized - in plant terms, those species which were introduced (deliberately or accidentally) many years ago and have now spread widely within the region of their own accord

nutrient transport – the movement of soil nutrients by water or wind, from their current location in the landscape

nutrients – in pasture terms, chemical compounds or elements essential for healthy plant growth.

organic matter – matter comprised of complex carbon-based compounds, derived from plant or animal material

palatable – in pasture/grazing terms, plants which are attractive to or preferentially grazed by stock

pasture biomass – the quantity of pasture produced or available for grazing, usually expressed in kilograms or tonnes per hectare of dry matter

pasture composition – the relative amount of each species within the pasture, usually expressed and a percentage of the total pasture biomass

pasture condition - the botanical composition and density of pasture plants and other vegetation

pasture utilisation - the percentage of pasture growth in a year that is consumed by cattle

pasture vigour - the health or vitality of the pasture plants, especially the 3P plants in grazing lands

perennial – in pasture terms plants that live for several years and do not rely exclusively on regeneration from seed each year (as do annuals)

photosynthesis – the process by which plants use the sun's energy to synthesise complex carbohydrates (starches etc.) from carbon dioxide, water and nutrients

plant functional groups – groupings of plant species that have a similar functional role in grazing terms. In grazing systems these might include the 3P (palatable, perennial and productive) grasses, increaser perennial grasses, annual grasses, exotic (introduced) grasses, native and exotic legumes and forbs

quadrats – sampling units (usually metal frames) used by researches to measure pasture attributes such as pasture yield and composition, ground cover, basal area etc

rehabilitation (of grazing land) – the process of bringing deteriorated grazing land back to full productive capacity, through a program of resting and conservative stocking

rotational grazing – the practice of systematically rotating the use of paddocks for grazing, to either spell paddocks, even out or maximize the use of available feed across a property

scalds – bare areas within a paddock, where the soil surface has sealed due to loss of plant cover, topsoil and water infiltration capacity, making plant establishment and growth difficulty

sedimentary – in geological terms, rock derived from long-term deposition of sediments in shallow seas over geological time

sediments – the heavier fractions of soil transported and deposited into streams, rivers and eventually oceans during the processes of erosion

soil condition - to the capacity of the soil to absorb and store rainfall, to store and cycle nutrients, to provide appropriate habitat for seed germination and plant growth, and to resist erosion

soil organic carbon – the carbon derived from organic (plant and animal sources) stored in the topsoil, usually close to plant root systems. Soil organic carbon is important in maintaining good soil condition

SOI (Southern Oscillation Index) - the SOI is a measure of the relative difference in atmospheric pressure between Darwin and Tahiti

species - a group of interbreeding plants or animals in which there are no major consistent differences

species abundance – the number and variety species present in an area.

spelling – the resting from grazing of paddocks, for part or all of a season

spreadsheet model – a computer based tool which allows researchers or consultants to test a range of ecological or economic scenarios over short or long term periods, using data gained from experiments, long term climate and production records etc. Spreadsheet models use packages such as Excel to operate and display the output of such models

standing crop – equivalent to pasture biomass – the amount of pasture available for grazing

state – the condition of land, in terms of pasture-soil system health and vigor, usually expressed as a class e.g. state I, state II etc

State-and-transition models – descriptive models which aim to explain the likely mechanisms and pathways by which land can move from one condition of state to another.

stocking rate - the actual number of animals on a specific area for a specific period of time

stoloniferous – plant growth that takes the form of runners or stolons to form lawn-like swards e.g. blue couch, Indian couch etc.

supplementary feeds – materials fed to stock to boost their intake of essential minerals, protein or energy, to supplement what is already available from pasture e.g. urea/molasses, salt and phosphorus based licks, cotton seed meal etc

top feed – feed which stock derive from eating shrub/tree leaf and stem

transect – a line through a paddock along which researchers sample or record vegetation and other attributes in the course of studies such as the ECOGRAZE project

transition – the pathways by which land moves from one state or land condition to another

understorey – in forest or woodland country, the vegetation layer beneath the trees i.e. the herbaceous (pasture) layer

unpalatable – in grazing terms, pasture species unattractive to or avoided by stock

utilisation – see pasture utilisation

videography – the use of video recording techniques to capture images - in this case aerial images of paddocks, properties etc. for the purpose of assessing land condition

vigour – see pasture vigour

APPENDIX 2 *"LIST OF PASTURE SPECIES RECORDED ON ECOGRAZE SITES AT CARDIGAN, HILLGROVE, EUMARA SPRINGS, LAKE VIEW AND ALLAN HILLS"*

** Indicates presence at that site*

FAMILY	GENUS	SPECIES	Cardigan State I	Cardigan State II	Hillgrove State I	Eumara State II	Lake View State I	Allan Hills State II	Common name
"PALATABLE, PERENNIAL, PRODUCTIVE (3P) GRASSES"									
Poaceae	*Bothriochloa*	*decipiens*	*	*	*	*	*	*	*pitted blugrass*
Poaceae	*Bothriochloa*	*ewartiana*	*	*	*	*	*	*	*desert mitchell or desert bluegrass*
Poaceae	*Capillipedium*	*parviflorum*			*				
Poaceae	*Dichanthium*	*fecundum*	*	*	*	*	*	*	*curly bluegrass*
Poaceae	*Dichanthium*	*sericeum*	*	*	*	*	*	*	*Queensland bluegrass*
Poaceae	*Digitaria*	*ammophila*	*	*			*	*	
Poaceae	*Digitaria*	*brownii*	*	*	*	*	*	*	*cotton panic*
Poaceae	*Digitaria*	*divaricatissima*		*			*	*	
Poaceae	*Eriochloa*	*procera*					*	*	*cupgrass*
Poaceae	*Eriochloa*	*pseudoacrotricha*					*	*	*cupgrass*
Poaceae	*Eulalia*	*aurea*		*			*		*silky browntop*
Poaceae	*Heteropogon*	*contortus*	*	*	*	*	*	*	*black speargrass*
Poaceae	*Heteropogon*	*triticeus*			*	*	*	*	*giant speargrass*
Poaceae	*Panicum*	*decompositum*	*	*	*	*	*	*	*native millet*
Poaceae	*Panicum*	*effusum*	*	*			*	*	*hairy panic*
Poaceae	*Sehima*	*nervosum*	*	*					*white grass or rat's-tail grass*
Poaceae	*Sorghum*	*plumosum*					*	*	*plume sorghum*
Poaceae	*Themeda*	*avenacea*			*	*	*	*	*native oatgrass*
Poaceae	*Themeda*	*triandra*	*	*	*	*	*	*	*kangaroo grass*
INCREASER NATIVE PERENNIAL GRASSES									
Poaceae	*Aristida*	*calycina*	*	*	*	*	*	*	*dark wiregrass*
Poaceae	*Aristida*	*holathera*	*	*	*	*	*	*	*erect kerosene grass*
Poaceae	*Aristida*	*inequiglumis*					*	*	*feathertop three awn*
Poaceae	*Aristida*	*ingrata*					*	*	
Poaceae	*Aristida*	*jerichoensis*	*	*	*	*	*	*	*Jericho wiregrass*
Poaceae	*Aristida*	*latifolia*			*	*	*	*	
Poaceae	*Aristida*	*lazarides*		*			*	*	
Poaceae	*Aristida*	*muricata*	*	*	*	*	*	*	
Poaceae	*Aristida*	*pruinosa*					*	*	
Poaceae	*Aristida*	*schultsii*						*	
Poaceae	*Aristida*	*sciuroides*	*	*	*		*	*	
Poaceae	*Aristida*	*superpendens*			*		*	*	
Poaceae	*Chloris*	*pectinata*			*	*	*	*	*comb windmill grass*
Poaceae	*Chryspogon*	*fallax*	*	*	*	*	*	*	*golden beard grass*
Poaceae	*Cymbopogon*	*bombycinus*				*	*	*	*silky oil grass*
Poaceae	*Dichanthium*	*aristatum*	*			*	*	*	*Angleton grass*
Poaceae	*Enneapogon*	*gracilis*						*	
Poaceae	*Enneapogon*	*polyphyllus*	*	*	*	*	*	*	*bottlewashers*
Poaceae	*Eriachne*	*obtusa*	*				*	*	*northern wanderrie grass*
Poaceae	*Neurachne*	*mitchellania*					*	*	
Poaceae	*Paspalidium*	*distans*	*	*	*	*	*	*	
Poaceae	*Paspalidium*	*rarum*		*	*	*	*	*	*rare paspalidium*
Poaceae	*Sporobolus*	*actinocladus*		*			*	*	*katoora or ray grass*
Poaceae	*Sporobolus*	*creber*					*	*	
Poaceae	*Tripogon*	*lolliformis*	*	*	*	*	*	*	*five minute grass*
INTRODUCED (EXOTIC) PERENNIAL GRASSES									
Poaceae	*Bothriochloa*	*pertusa*	*	*	*	*	*	*	*Indian couch*
Poaceae	*Cenchrus*	*ciliaris*	*	*	*	*	*	*	*buffel grass*
Poaceae	*Cenchrus*	*setiger*			*				*birdwood grass*
Poaceae	*Chloris*	*barbata*	*	*	*	*	*	*	*Rhodes grass*
Poaceae	*Chloris*	*inflata*	*		*	*	*	*	*purpletop rhodes grass*
Poaceae	*Chloris*	*virgata*					*		*feathertop rhodes grass*
Poaceae	*Melinis*	*repens*	*	*	*	*	*	*	*red natal grass*
Poaceae	*Urochloa*	*mosambicensis*	*	*	*	*	*	*	*sabi grass or Urochloa*
ANNUAL GRASSES									
Poaceae	*Alloteropsis*	*cimicina*						*	*cockatoo grass*
Poaceae	*Brachiaria*	*dictyoneura*					*	*	
Poaceae	*Brachiaria*	*holosericea*					*		
Poaceae	*Brachiaria*	*pubigera*	*	*	*		*	*	
Poaceae	*Brachiaria*	*windersii*	*	*	*	*	*	*	
Poaceae	*Brachyachne*	*convergens*	*	*	*	*	*		*native couch*
Poaceae	*Dactyloctenium*	*radulans*	*	*	*	*	*	*	*button grass*
Poaceae	*Digitaria*	*ciliaris*	*	*	*	*	*	*	*summer grass*
Poaceae	*Digitaria*	*gibbosa*		*					
Poaceae	*Echinochloa*	*colona*		*	*	*	*	*	*awnless barnyard grass*
Poaceae	*Ectrosia*	*sp*						*	*hare's foot grass*
Poaceae	*Eragrostis*	*brownii*	*				*	*	*lovegrass*
Poaceae	*Eragrostis*	*cumingii*			*		*	*	*lovegrass*
Poaceae	*Eragrostis*	*elongata*		*	*	*	*	*	*lovegrass*
Poaceae	*Eragrostis*	*lacunaria*					*	*	*lovegrass*
Poaceae	*Eragrostis*	*pilosa*						*	*lovegrass*
Poaceae	*Eragrostis*	*sororia*	*	*	*	*	*	*	*woodland lovegrass*
Poaceae	*Eriachne*	*armitii*						*	
Poaceae	*Iseilema*	*vaginiflorum*			*				*red Flinders grass*
Poaceae	*Mnesithea*	*formosa*	*	*		*	*	*	*silkytop grass*
Poaceae	*Mnesithea*	*granularis*	*	*	*		*		
Poaceae	*Perotis*	*rara*		*	*	*	*	*	*comet grass*
Poaceae	*Schizachyrium*	*fragile*	*	*			*	*	*fire grass*
Poaceae	*Setaria*	*apiculata*		*		*	*	*	
Poaceae	*Setaria*	*surgens*					*		*annual pigeon grass*
Poaceae	*Sporobolus*	*australasicus*	*	*	*	*	*	*	*fairy grass, Australian dropseed*
Poaceae	*Sporobolus*	*caroli*	*	*	*	*	*	*	*yakka grass, fairy grass*
Poaceae	*Tragus*	*australianus*	*	*	*	*	*	*	*small burr grass, sock grass*
Poaceae	*Urochloa*	*panicoides*	*	*	*	*		*	*liverseed grass*

FAMILY	GENUS	SPECIES	Cardigan State I	Cardigan State II	Hillgrove State I	Eumara State II	Lake View State I	Allan Hills State II	Common name
NATIVE LEGUMES									
Caesalpiniaceae	*Chaemachrista*	*absus*	*	*	*	*	*	*	
Caesalpiniaceae	*Chaemachrista*	*mimisoides*					*		*mimosa cassia*
Fabaceae	*Aeschynomene*	*brevifolia*	*						
Fabaceae	*Cajanus*	*confertiflorus*	*				*		
Fabaceae	*Cajanus*	*marmoratus*			*	*	*	*	
Fabaceae	*Cajanus*	*scarabeoides*	*	*	*		*		
Fabaceae	*Crotalaria*	*brevis*	*	*					
Fabaceae	*Crotalaria*	*calycina*		*					
Fabaceae	*Crotalaria*	*juncea*	*	*	*			*	
Fabaceae	*Crotalaria*	*medicaginea*	*	*	*	*	*	*	*trefoil rattlepod*
Fabaceae	*Crotalaria*	*montana*	*	*	*	*	*	*	
Fabaceae	*Crotalaria*	*nova-hollandii*		*					*New Holland rattlepod*
Fabaceae	*Desmodium*	*filiforme*		*			*		*narrow necklace pea*
Fabaceae	*Desmodium*	*muelleri*		*	*	*	*		*Mueller's necklace pea*
Fabaceae	*Desmodium*	*sp. undescr*		*	*	*	*	*	
Fabaceae	*Galactia*	*muelleri*	*	*	*	*	*	*	
Fabaceae	*Glycine*	*tabacina*	*	*	*	*	*	*	*Glycene pea*
Fabaceae	*Glycine*	*tomentella*	*	*	*	*	*	*	*woolly or rusty glycene*
Fabaceae	*Indgastrum*	*parviflorum*						*	
Fabaceae	*Indigofera*	*colutea*	*	*	*	*	*	*	*sticky indigo*
Fabaceae	*Indigofera*	*hirsuta*	*	*	*	*	*	*	*hairy indigo*
Fabaceae	*Indigofera*	*linnaei*	*	*	*	*	*	*	*Birdsville indigo*
Fabaceae	*Indigofera*	*linifolia*	*	*	*	*	*	*	*white balls, round pod indigo"*
Fabaceae	*Indigofera*	*parvifolia*	*	*	*	*	*	*	
Fabaceae	*Indigofera*	*pratensis*	*	*		*	*	*	*forest indigo*
Fabaceae	*Pycnospora*	*lutescens*			*	*		*	
Fabaceae	*Rhyncosia*	*minima*	*	*	*	*	*	*	*Rhyncosia*
Fabaceae	*Sesbania*	*aculeata*	*						
Fabaceae	*Sesbania*	*cannibina*	*						*Sesbania pea*
Fabaceae	*Tephrosia*	*dietrichiae*		*				*	
Fabaceae	*Tephrosia*	*filipes v latifolia*		*			*	*	
Fabaceae	*Tephrosia*	*juncea*	*		*			*	
Fabaceae	*Tephrosia*	*rosea*		*	*	*	*	*	*Flinder's River poison*
Fabaceae	*Vigna*	*lanceolata*	*	*	*	*	*	*	*Malogo bean*
Fabaceae	*Vigna*	*vexillata*			*	*		*	*native mung bean*
Fabaceae	*Zornia*	*dyctiocarpa*	*	*	*	*	*	*	*Zornia*
Fabaceae	*Zornia*	*floribunda*					*	*	*Zornia*
Fabaceae	*Zornia*	*muelleriana*		*	*	*	*	*	*Zornia*
Fabaceae	*Zornia*	*muriculata*		*	*	*	*	*	*upright Zornia*
Mimosaceae	*Neptunia*	*gracilis*					*	*	*low sensitive plant*
Mimosaceae	*Neptunia*	*monosperma*					*		*tall sensitive plant*
EXOTIC LEGUMES									
Fabaceae	*Aeschynomene*	*indica*				*		*	
Fabaceae	*Alysicarpus*	*vaginalus*		*					*buffalo clover*
Fabaceae	*Macroptilium*	*atropurpureum*				*			*siratro*
Fabaceae	*Stylosanthes*	*hamata*	*	*	*	*	*	*	*verano*
Fabaceae	*Stylosanthes*	*humilis*	*	*	*	*	*	*	*Townsville stylo*
Fabaceae	*Stylosanthes*	*scabra*	*	*	*	*	*	*	*seca stylo*
Fabaceae	*Stylosanthes*	*viscosa*			*				*sticky stylo*
NATIVE FORBS									
Acanthaceae	*Brunoniella*	*acaulis*	*	*	*	*	*	*	*cobbler's pegs*
Acanthaceae	*Dipteracanthus*	*australicus*						*	
Acanthaceae	*Rostellularia*	*adscendens*	*	*	*	*	*	*	
Aizoaceae	*Trianthema*	*triqueta*		*	*	*	*	*	
Amaranthaceae	*Alternanthera*	*augustifolia*	*	*	*	*	*	*	
Amaranthaceae	*Alternanthera*	*denticulata*		*			*	*	
Amaranthaceae	*Alternanthera*	*micrantha*	*	*			*	*	
Amaranthaceae	*Alternanthera*	*nana*	*	*	*	*	*	*	
Apocynaceae	*Parsonsia*	*lanceolata*	*	*	*	*	*	*	
Asclepiadaceae	*Marsdenia*	*viridiflora*	*	*	*	*		*	
Asteraceae	*Bidens*	*bipinnata*						*	
Asteraceae	*Blumea*	*saxitilis*			*		*	*	
Asteraceae	*Camptacra*	*barbata*	*	*	*	*			
Asteraceae	*Chrysocephalum*	*apiculatum*					*	*	
Asteraceae	*Helichrysum*	*ramosissimum*	*	*			*	*	
Asteraceae	*Peripleura*	*hispidula*					*		*fuzzweed*
Asteraceae	*Pterocaulon*	*redolens*	*	*	*	*	*	*	
Asteraceae	*Pterocaulon*	*serrulatum*		*		*			*fruit salad plant*
Asteraceae	*Pterocaulon*	*sphacelatum*						*	*fruit salad plant*
Asteraceae	*Vernonia*	*cineria*	*	*					
Asteraceae	*Vittadinia*	*hispidula*	*	*			*	*	
Asteraceae	*Wedelia*	*spilanthoides*	*	*	*		*	*	*yellow daisy*
Boraginaceae	*Heliotropium*	*cunninghamii*					*	*	*heliotrope*
Boraginaceae	*Heliotropium*	*penninsularis*					*	*	*heliotrope*
Boraginaceae	*Heliotropium*	*pauciflorum*	*	*	*	*	*	*	*heliotrope*
Boraginaceae	*Trichodesma*	*zeylanicum*		*					*camel bush, cattle bush*
Campanulaceae	*Wahlenbergia*	*caryophylloides*		*	*	*	*	*	*native bluebell*
Capparaceae	*Cleome*	*viscosa*	*						*tick weed*
Caryophyllaceae	*Polycarpaea*	*corymbosa*	*	*	*	*	*	*	*snow weed*
Chenopodiaceae	*Epaltes*	*australis*	*		*	*	*	*	*batchelor's buttons*
Chenopodiaceae	*Maireana*	*microphylla*	*	*		*		*	
Commelinaceae	*Murdannia*	*graminea*						*	
Convolvulaceae	*Bonamia*	*media*					*		*common Bonamia*
Convolvulaceae	*Evolvulus*	*alsinioides*	*	*	*	*	*	*	*tropical speedwell*
Convolvulaceae	*Ipomoea*	*coptica*	*	*	*	*	*	*	
Convolvulaceae	*Ipomoea*	*eriocarpa*	*	*	*	*	*	*	
Convolvulaceae	*Ipomoea*	*gracilis*		*					
Convolvulaceae	*Ipomoea*	*plebeia*	*	*	*	*	*	*	
Convolvulaceae	*Ipomoea*	*polymorpha*	*	*	*	*	*	*	
Convolvulaceae	*Ipomoea*	*pusilla*		*	*				

FAMILY	GENUS	SPECIES	Cardigan State I	Cardigan State II	Hillgrove State I	Eumara State II	Lake View State I	Allan Hills State II	Common name
NATIVE FORBS CONTINUED									
Convolvulaceae	*Jacqmontia*	*paniculata*	*	*	*	*	*	*	*snake stem*
Convolvulaceae	*Merremia*	*tridentata*						*	
Convolvulaceae	*Polymeria*	*ambigua*	*	*	*		*	*	*creeping Polymeria*
Convolvulaceae	*Polymeria*	*calycina*					*	*	
Convolvulaceae	*Polymeria*	*pusilla*					*	*	
Cucurbitaceae	*Cucumus*	*sp*	*	*	*	*	*	*	*native cucumber*
Cucurbitaceae	*Mukia*	*maderaspetana*			*				
Dilleniaceae	*Hibbertia*	*longifolia*			*	*	*		
Euphorbiaceae	*Chamaesyce*	*drummondii*	*	*	*	*	*	*	*caustic weed*
Euphorbiaceae	*Chamaesyce*	*mitchelliana*	*	*	*	*	*	*	
Euphorbiaceae	*Chamaesyce*	*vachellii*	*	*	*	*	*	*	
Euphorbiaceae	*Phyllanthus*	*amarus*					*	*	
Euphorbiaceae	*Phyllanthus*	*carpentariae*					*	*	
Euphorbiaceae	*Phyllanthus*	*fuernrohrii*			*		*	*	
Euphorbiaceae	*Phyllanthus*	*hebecarpus*	*		*		*	*	
Euphorbiaceae	*Phyllanthus*	*maderspatensis*	*	*	*	*	*	*	*spurge*
Euphorbiaceae	*Phyllanthus*	*simplix*	*	*	*	*	*	*	
Euphorbiaceae	*Phyllanthus*	*virgatus*	*	*		*	*	*	
Euphorbiaceae	*Poranthera*	*microphylla*					*	*	
Goodeniaceae	*Goodenia*	*armitiana*						*	*fine Goodenia*
Goodeniaceae	*Goodenia*	*byrnsii*						*	*Byrne's Goodenia*
Goodeniaceae	*Goodenia*	*glabra*						*	
Goodeniaceae	*Goodenia*	*pilosa*						*	
Goodeniaceae	*Goodenia*	*sp*		*			*	*	
Liliaceae	*Thysanotus*	*banksii*						*	*fringed lilly*
Liliaceae	*Thysanotus*	*tuberosus*						*	*fringed lilly*
Loganiaceae	*Mitrasacme*	*connata*					*	*	
Malvaceae	*Abelmoschus*	*moschatus*		*					
Malvaceae	*Abutilon*	*fraseri*			*				
Malvaceae	*Abutilon*	*oxycarpum*	*		*			*	
Malvaceae	*Hibiscus*	*meraukensis*		*	*	*			*merauke Hibiscus*
Malvaceae	*Hibiscus*	*trionum*	*	*	*	*	*	*	*bladder ketmia*
Malvaceae	*Malvastrum*	*americanum*	*		*	*	*		*Malvastrum*
Malvaceae	*Malvastrum*	*coromandelianum*		*	*	*	*	*	*Malvastrum*
Malvaceae	*Sida*	*cordifolia*	*	*	*	*	*	*	*flannel weed*
Malvaceae	*Sida*	*fibulifera*	*	*	*	*		*	*silver sida*
Malvaceae	*Sida*	*rhombifolia*		*			*	*	
Malvaceae	*Sida*	*rohlenae*	*	*	*	*	*	*	*shrub sida*
Malvaceae	*Sida*	*spinosa*	*	*	*	*	*	*	*spiny sida, Paddy's lucern*
Malvaceae	*Sida*	*subspicata*	*	*	*	*	*	*	*spiked sida*
Malvaceae	*Sida*	*trichopoda*	*	*	*	*	*	*	*high sida*
Nyctaginaceae	*Boerhavia*	*domini*		*			*		*tar vine*
Nyctaginaceae	*Boerhavia*	*schonburgkiana*	*	*	*	*	*	*	*tar vine*
Nyctaginaceae	*Boerhavia*	*sp. undescribed*				*	*	*	*tar vine*
Onagraceae	*Ludwigia*	*octivalvis*	*				*	*	*willow primrose*
Onagraceae	*Ludwigia*	*perennis*	*		*	*	*	*	*upright primrose*
Phormiaceae	*Dianella*	*sp*		*					
Polygalaceae	*Polygala*	*linarifolia*	*	*	*	*	*	*	
Portulacaceae	*Portulaca*	*filifolia*	*	*	*	*	*	*	*pigweed*
Portulacaceae	*Portulaca*	*interranea*					*	*	*pigweed*
Portulacaceae	*Portulaca*	*oleracea*	*	*	*	*	*	*	*pigweed*
Primulaceae	*Anagallis*	*pumila*	*					*	
Rubiaceae	*Spermacoce*	*brachystema*	*	*	*	*	*	*	*blue heads*
Scrophulariaceae	*Buchnera*	*linearis*						*	
Scrophulariaceae	*Striga*	*parviflora*						*	
Solanaceae	*Solanum*	*dianthophorum*	*	*				*	*nightshade*
Solanaceae	*Solanum*	*spp.*	*	*	*			*	*nightshade*
Sterculiaceae	*Melhania*	*oblongifolia*	*	*	*	*	*	*	*velvet Hibiscus*
Sterculiaceae	*Waltheria*	*indica*	*	*	*	*	*	*	*Waltheria*
Thymelaeaceae	*Pimelea*	*seriocostachys*					*	*	*Pimelia*
Thymelaeaceae	*Thecanthes*	*sanguina*		*				*	
Tiiaceae	*Corchorus*	*tridens*	*	*		*		*	
Tiiaceae	*Corchorus*	*trilocularis*	*	*	*	*		*	*wild jute*
Tiiaceae	*Grewia*	*latifolia*	*	*	*	*	*	*	
Tiiaceae	*Grewia*	*retusifolia*	*	*	*	*	*	*	*dog's balls*
Violaceae	*Hybanthus*	*enneaspermus*	*	*	*	*	*	*	*spade flower*
Xanthorrhoeaceae	*Lomandra*	*multiflora*	*	*	*	*	*	*	
Zygophyllaceae	*Tribulus*	*micrococcus*	*		*	*			
Zygophyllaceae	*Tribulus*	*pentanelrus*	*	*	*		*	*	*caltrop*
Zygophyllaceae	*Tribulus*	*terrestris*	*	*	*	*			*caltrop, goathead burr*
EXOTIC FORBS									
Amaranthaceae	*Gomphrena*	*celusioides*	*		*	*	*		*gomphrena weed*
Asteraceae	*Acanthospermum*	*hispidum*			*	*			*star burr, goats head*
Asteraceae	*Eclipta*	*prostrata*		*				*	
Asteraceae	*Emilia*	*sonchifolia*					*	*	
Asteraceae	*Tridax*	*procumbens*				*		*	*Tridax daisy*
Boraginaceae	*Helitropium*	*indicum*						*	*heliortope*
Chenopodiaceae	*Salsola*	*kali*	*	*	*	*			*soft roly-poly*
Euphorbiaceae	*Chamaesyce*	*hirta*	*	*				*	*khaki weed*
Lamiaceae	*Ocimim*	*americanum*	*	*					*native basil*
Papavaraceae	*Argemone*	*mexicana*					*	*	*Mexican poppy*
Portulacaceae	*Portulaca*	*pilosa*	*	*	*	*	*		*pigweed*
SEDGES									
Cyperaceae	*Bulbostylus*	*barbata*	*	*	*	*	*	*	*dainty sedge*
Cyperaceae	*Cyperus*	*cornicus*	*	*	*	*	*	*	*nutgrass*
Cyperaceae	*Cyperus*	*distans*	*	*	*	*	*	*	*nutgrass*
Cyperaceae	*Cyperus*	*perangustu*	*	*			*		*nutgrass*
Cyperaceae	*Fimbristylus*	*sp*	*	*	*	*	*	*	*fringe rushes*
Cyperaceae	*Gahnia*	*sieberiana*						*	
Cyperaceae	*Scleria*	*sp*						*	