final report

Project code: B.NBP.0375

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Date published: February 2013

ISBN: 9781741919820

PUBLISHED BY
Meat & Livestock Australia Limited
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NORTH SYDNEY NSW 2059

Sustainable development of Victoria River District (VRD) grazing lands

Meat & Livestock Australia acknowledges the matching funds provided by the Australian Government to support the research and development detailed in this publication.

Abstract

This project investigated the potential for pastoral intensification in the Victoria River District (VRD) of the NT to increase the profitability of the northern beef industry in the face of rising costs. The results suggested that intensification can increase a property's profitability without adverse effects on land condition or biodiversity in the short term. The keys to this are the use of sustainable pasture utilisation rates and appropriate development of paddocks and water points. Grazing management based on set pasture utilisation appeared to be the most profitable grazing system. The use of advanced technologies such as telemetry to manage water points can offer improvements in efficiency and cost savings. About half the properties in the VRD have the potential for intensification because they currently operate with pasture utilisation rates below the recommended 20%. Intensification of these properties could see an increase in cattle numbers in the VRD of about 154,000 AE, generating an additional annual gross margin of about $17m. The project identified a series of guidelines for the sustainable development of properties and also a number of recommendations for the protection of biodiversity under pastoral intensification.

Executive summary

The beef industry in many parts of northern Australia has historically been an extensive, low input system, with relatively low outputs per unit land area. Properties are large and are made up of large paddocks with sparse water points. Consequently there has been little control over cattle grazing, resulting in poor distribution of grazing across the landscape. This has meant there are areas where considerable amounts of pasture go unused, while other areas near water points can be overgrazed. On some properties average stocking rates across the landscape have been kept relatively low because of the poor grazing distribution.

In recent years there has been increasing interest from producers in intensifying their production system in the face of a tightening cost-price squeeze where costs are increasing faster than prices received. The opportunity offered by intensifying the production system emerges from the creation of smaller paddocks and establishment of more water points that increase the landscape area and hence forage that are readily accessible to cattle. This effectively means there is an increase in pasture availability that should allow an increase in livestock numbers and greater livestock production without increasing grazing pressure on areas already being grazed.

Prior to this project our knowledge of the factors determining the optimal development and management of an intensified production system was poor. This project addressed the following the key questions affecting property intensification in the Victoria River District (VRD) of the Northern Territory, one of the most productive beef producing areas in northern Australia:

- What is the optimum level of pasture utilisation in terms of balancing livestock production with the maintenance of good land condition?
- What are the optimum levels and configurations of infrastructure development (i.e. paddock size and number and spacing of water points) to achieve more uniform grazing distribution, and what are the effects on land condition and livestock production?
- Do other grazing management methods (e.g. cell grazing and wet season spelling) offer benefits in terms of increased livestock production and/or better land condition that are not possible with the method of continuous stocking used on most properties?
- How will an intensified production system affect the maintenance of biodiversity on grazed lands, and if there are likely to be adverse effects what strategies are required to maintain biodiversity under an intensified system?
- Can innovative technology (remote management of water points, for example) be integrated into an intensively-developed commercial business to reduce or maintain the cost of production?
- What is the regional potential for property development in the VRD, and what are some of the implications?
- What are the economic and environmental trade-offs for different property development scenarios?

To address these questions a large commercial-scale study was carried out over four years on an area of approximately 320 km^2 (Wave Hill land system, with black cracking clay soils) on Pigeon Hole Station in the VRD. Most of the site was in ‘C’ land condition. The study included five annual utilisation rates, six paddock configurations, four grazing management systems and ten biodiversity exclosures. This work was supplemented by a study of different pasture utilisation rates in small paddocks at Mt Sanford Station, which adjoins Pigeon Hole.

Briefly, the overall project objectives were to:

1. Inform all producers in the VRD of locally-derived relationships between pasture utilisation and pasture and livestock performance.
2. Understand the key factors influencing sustainable grazing in the VRD, including optimal levels and systems of pasture utilisation, cattle grazing distribution patterns, the role of

paddock design and water placement, and the impact of pastoral development on biodiversity conservation.
3. Identify management guidelines for sustainable and profitable pastoral development.
4. Inform north Australian beef producers of the relationship between grazing behaviour, land condition and animal production, and provide the information and decision support tools to improve financial and land management performance on their properties.

Overall, this study found that more intensive development of the black soil pastures in the VRD is practically and economically feasible where annual pasture utilisation rates are currently less than 20%. Our analysis indicated that an intensified system can generate a return on invested capital of 8.7% compared with 5.4% for an undeveloped commercial system.

In the pasture utilisation studies at Mt Sanford and Pigeon Hole financial returns per unit land area increased with increasing utilisation rate (up to 47% and 32% annual pasture utilisation at Mt Sanford and Pigeon Hole, respectively). However, at Mt Sanford annual pasture utilisation rates up to 20-25% were considered to be sustainable in the long term providing it is possible to achieve relatively uniform grazing distribution within paddocks. At this level of utilisation no adverse effects were observed on pasture productivity, ground cover or livestock production, whereas the combination of higher utilisation rates (36-43%) and a poor wet season appeared to degrade the land resource and reduced subsequent weaner production. At Pigeon Hole there were only subtle effects of the different utilisation rates, but above 19% utilisation several criteria related to minimum cover or pasture biomass targets were not met, or there was a weak trend of declining land condition.

Reducing paddock size was the most effective way of improving grazing distribution and increasing the use of pasture resources across the landscape. Establishing additional water points in large paddocks was less effective at improving grazing distribution, in part because cattle still had considerable choice in where they grazed. There were no differences in pasture condition amongst the paddock configurations and no systematic effect on individual animal performance. Although the smallest paddock (9 km^2) gave the highest return on invested capital (8.3%) compared with other paddock configurations (next best was 7.5%), this is considered an anomaly since the cost for reducing paddock size is disproportional for paddocks smaller than about 40 km^2. Consequently, to make most effective use of pasture resources in the VRD it is recommended that producers aim for a paddock size of 30-40 km^2 with two well-spaced water points. In larger paddocks, waters should be about 5-6 km apart. It is important to note that reducing paddock size is not particularly effective at improving the uniformity of grazing within the resulting paddocks – area and patch selection still occurs to some extent regardless of paddock size.

There were no marked differences in the performance of the different grazing management systems. The study suggested that wet season spelling might have the potential to marginally improve livestock production above that of set stocking due to slightly better weight gains, but this improvement in livestock performance did not flow through to improved economic performance because of the greater capital costs associated with the system. Notably, wet season spelling did not produce any improvement in pasture condition as had been expected based on reports from other studies. Set pasture utilisation at an annual rate of 20% was the best performing system in economic terms and appeared to have no adverse effects on land condition during the study. It is also notable, however, that there was no marked improvement in land condition from any of the grazing pressures or methods applied during the 4 years of the trial. Despite some advantage in carrying capacity, cell grazing was the least profitable system due to the added capital and operational costs. It also created additional work for staff and produced no pasture production benefits.

Within the five years of the study there was no obvious effect of different utilisation levels, or different grazing systems, on the biodiversity within the paddocks. These results are consistent with other evidence that black-soil grasslands are one of the ecosystems in northern Australia most resilient to the impacts of grazing on biodiversity. However, changes in native plant and animal populations in response to changes in grazing regimes are likely to be gradual, only becoming evident over longer time periods than this grazing study, and particularly following a period of poor seasons. After five years there was some evidence that plant and animal composition in the exclosures was diverging from that in grazed lands and, in particular, the abundance of some grazing-sensitive species was starting to increase within the exclosures. The impacts on biodiversity are likely to become more pronounced if a high proportion of the land-type is subject to intensification, particularly over longer (decades) time scales. A number of recommendations are made in the report to protect biodiversity values in the context of broad-scale intensification.

Some newer technologies can offer substantial improvements in efficiency and cost-savings in an intensified production system, although they can require specific skills and some adaptation to incorporate successfully into the management system. These systems include telemetry for remotely managing water points, water medicators for providing dietary supplements, and in some circumstances electric fencing. Savings of ~$20,000+ per year were achieved using water point telemetry in the examples presented. An intensified production system also requires a reassessment of mustering techniques and facilities such as stock yards and laneways to maximise efficiency gains.

An economic and environmental analysis of six intensification scenarios suggested that installing more water points is likely to generate the greatest gains in return on capital with the smallest environmental trade-off. Scenarios involving wet season spelling and cell grazing showed no improvement in return on capital compared with current practice, but the former produced a substantial environmental benefit through improvements in pastures and soils. Some of these findings were not borne out by the field studies at Pigeon Hole, however.

Already a number of properties in northern Australia are moving towards intensifying their production system. It is likely this project increased the level of interest in property development in the more extensive areas of the northern beef industry. We expect the guidelines for the sustainable development of properties generated by this project will influence the nature of intensification on individual properties. It is estimated that about half the properties in the VRD have the potential for intensification. The rest appear to already have annual pasture utilisation rates in excess of the recommended 20%. It is estimated that intensification of the properties with the potential for development could see an increase in cattle numbers in the VRD of about 154,000 AE, generating an additional annual gross margin of about $17m.

Finally, a note of caution is required because the long-term effects of intensification on land condition, potential livestock production and biodiversity are not known. Ecological change in rangelands can be slow and/or episodic and difficult to detect because of large environmental variation, and although this study detected no adverse effects over four years, this is a relatively short time period in the context of changes in rangeland condition.

Acknowledgements

This project would not have been possible without the strong support of Heytesbury Beef (the owners of Pigeon Hole station) and the many associated people. Russell and Sonya Teece managed Pigeon Hole during the project's conception and establishment and for all but the final year of the project. Their support, advice and enthusiasm were crucial to the project, as were their skills and knowledge in designing and establishing the infrastructure and management systems required. This required enormous amounts of work by them. Especially important was that they also provided a welcoming and supportive environment for us to conduct our work.

Lindy Symes was a vital part of keeping various aspects of the project on track at the station and oversaw the day-to-day running of the project, coordinated the collection of the livestock production data, maintained many of the data records and provided helpful advice. The Queensland Department of Employment, Economic Development and Innovation provided time for Lindy to assist with managing the livestock production database in the latter stages of the project.

Mark Tarrant and Leeanne Witcher (nee Goody) contributed much to the establishment of the project (including assisting with the establishment of the infrastructure), and with pasture sampling and various other tasks. Mark developed the GIS maps of the paddocks which were needed for navigation and for the data analysis.

Jim Coulthard, Janet Holmes á Court, Simon Holmes á Court, Paul Holmes á Court and Rusty and Julie Richter also provided considerable advice and support for the project on behalf of Heytesbury Beef. Heytesbury Beef funded the infrastructure development required for the project, and provided staff to assist with running the project. In addition to those staff mentioned individually, other Pigeon Hole staff including head stockmen and ringers (and cooks) also provided much needed help and logistical support. This included assistance with data collection on livestock production and the deployment and recovery of the GPS cattle collars.

Over the years a large number of people suffered the extreme heat to assist with collecting the pasture data and we wish to express our gratitude for their commitment to a tedious task. Our thanks go to (In alphabetical order) Brett Abbott, Ruth Allen, Andy Bubb, Pippa Clarke, Jeff Corfield, Kym Croot, Trish Cowley, Robert Eager, Jon Edgar, Michelle Foate, Dave Hadden, Megan Hoskins, Annemarie Huey, Harmony James, Sally Leigo, Lyn Lowe, Rebecca Mather-Brown, Debbie Mullins, Trudi Oxley, Caz Pettit, Britt Ramage, Kath Ryan, Jon Schatz, Peter Shotton, Sarah Streeter, Lindy Symes, Mark Tarrant and Leeanne Witcher. Some of these people helped out for almost every sampling occasion. Initially Leeanne, and subsequently Jon Schatz and then Caz coordinated the allocation of transects to observers during pasture sampling.

Jeff Corfield helped to devise the pasture sampling protocol early in the study, assisted with data collection and provided advice on numerous aspects of the project. We thank Brett Abbott for developing the software for collecting the pasture data directly to hand-held computers.

Robert Eager deserves special mention for the many (probably hundreds) of hours spent error-checking the pasture data sets, summarising them and doing initial analyses. He also did the majority of the GIS work required for spatial analysis of the pasture data. Similarly, Robert did most of the GIS work on the GPS collar data to allow the analysis of cattle locations in relation the various environmental attributes. In doing this work Robert often contributed useful suggestions about how best to analyse the data. Robert, Jon Edgar and Bill West participated in the observations of cattle behaviour out in the paddock to allow calibration of the activity sensors in the GPS collars, and also helped with the processing and analysis of the data.

Mark Hearnden also deserves a special mention. Mark was crucial to the analysis of the livestock production data. He worked under considerable pressure to help tidy up and make sense of a large, complicated and sometimes messy data set. He clarified the questions that needed to be asked of the data, devised methods for answering those questions, did the analyses and then provided the results in an easily understood format. How he managed to maintain his patience and commitment to the task (especially when some analyses needed to be repeated) is a mystery. Warren Müller provided statistical advice on various aspects of the analysis of the pasture data (as did Mark) and conducted some of the statistical analyses. We thank Mark and Warren for their expertise, interest and efforts.

Diana Bryce did some of the GIS work in initially setting up the pasture transects. Renée Golding and Jon Edgar helped with tidying up and analysing the livestock production data. Kate Richardson developed the land type map for the site and Bob Karfs provided advice related to land types and assessment early in the study. Ian Cowie from the Northern Territory Herbarium identified a number of plant specimens for the pasture sampling team.

A large number of people assisted with the extremely taxing and often tedious fieldwork associated with biodiversity monitoring at Pigeon Hole, but particular thanks go to Damian Milne and Jenni Risler for their exceptional efforts. Jenni also made a major contribution to the identification of plant specimens and refining the vegetation dataset. Other field assistants included Martin Armstrong, Bryan Baker, Kym Brennan, Taegan Calnan, Leanne Coleman, Nicole Cranston, Gay Crowley, Peter Dostine, Sally Dowdell, Marion Duclaux, Juliette Germain-Fandre, Birgit Hallenstein, Louise Harrison, Brydie Hill, Ulrike Lang, Donna Lewis, Chris Lindenmuller, Jerome Loinard, Dominique Lynch, Lindley McKay, Richard Mercer, Jerome Petit, Kelly Spena and Sean Webster. Ant specimens were sorted by Richard Mercer, Charmaine Tynan and Robyn Spry and identified by Tony Hertog and Alan Andersen (CSIRO Sustainable Ecosystems, Darwin).

John Childs, Wayne Hall, Rodd Dyer and Mick Quirk provided much guidance and support for the project on behalf of MLA, and at times demonstrated inordinate levels of patience. John's input was especially valuable in the early years of the project in terms of the excellent technical support he gave and articulating MLA's expectations for the project. Advice from Dennis Poppi (The University of Queensland) on various aspects of the project but particularly the grazing systems study is also very much appreciated.

Adam Liedloff and Leanne Coleman were responsible for taking some excellent photos and video footage of various aspects of the field studies that were useful in publicity activities to promote the work and its findings.

Numerous camp cooks provided much needed sustenance and company (and often entertainment) for the pasture sampling team. We thank Shirley Ross, Emma Woodward, Dianne Bryce, Vibe, Daphne and Ken. Some cooks even spoilt us by providing scones, jam and cream out in the paddock whilst pasture sampling!

Many people also helped with and supported the Mt Sanford project. Field pasture and cattle data were collected by the following people: David La Fontaine, Rebecca Mather Brown, Tim Schatz, Diana Bryce, Trisha Cowley, Michelle Foate, Pippa Krafft (nee Clark), Angus Payne, Megan Hoskins, Annemarie Huey, Scott McIntyre, Caroline Pettit (nee Smith), Trudi Oxley, Britt Ramage and Geoff Roeser.

David La Fontaine managed the Mt Sanford research project from 2000 to 2002. Britt Ramage, Geoff Roeser and Robert Kelly managed the research site on a daily basis, attending to infrastructure maintenance and cattle management.

Special thanks to Paul and Jane Stone, managers of Mt Sanford Station, and their stock camps who assisted with cattle mustering and processing for the research trial.

Funding for this research was provided by Heytesbury Beef, Meat and Livestock Australia, CSIRO, the Northern Territory Government, the Victoria River District Conservation Association and the Tropical Savannas Cooperative Research Centre. This support is gratefully acknowledged.

Cam MacDonald and Mick Quirk reviewed an earlier draft of the report and provided many useful comments and suggestions for improving the report.

The Pigeon Hole project was a truly collaborative effort, and it was a privilege and pleasure to work with the various research teams and the people who supported the project.

Abbreviations and definitions

General

AE	Animal equivalent (a 450 kg steer or non-lactating non-pregnant Brahman breeder at maintenance)*
BCS	Body condition score
BHE	Breeding herd efficiency
DM	Dry matter (refers to pasture biomass)
DMD	Dry matter digestibility
DNRETA	NT Department of Natural Resources, Environment and the Arts
EBIT	Earnings before interest and tax
FNIRS	Faecal near infra-red spectroscopy
GLM	Grazing Land Management package (extension resource)
IVDMD	In vitro dry matter digestibility
LWG	Liveweight gain
MDS	Multiple dimensional scaling (ordination analysis)
PGBA	Perennial grass basal area
ROIC	Return on invested capital
TSDM	Total standing dry matter
VRD	Victoria River District

Treatment designations

U15%	15% pasture utilisation
U20%	20% pasture utilisation (also the 'set utilisation' and the GR2 treatments)
U25%	25% pasture utilisation
U30%	30% pasture utilisation
U40%	40% pasture utilisation
CG	Cell grazing
CGC	Cell grazing control
SS	Set stocking
WSS	Wet season spelling
GR1	Grazing radius 1 km (also the One water treatment)
GR2	Grazing radius 2 km
GR3	Grazing radius 3 km
One water	9 km^2 paddock with one central water point
Two waters	34 km^2 paddock with two water points
Multiple Waters	57 km^2 paddock with five water point

AE conversions

1 AE = 450 kg steer or dry cow at maintenance
1 breeder = 1.25 AE
1 bull = 1.5 AE
1 weaner = 0.75 AE

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1 Introduction

1.1 Background

Pastoral landscapes in northern Australia (Queensland, the Northern Territory, and northern rangelands of WA) are facing rapid change as momentum builds to intensify the extensive beef cattle production system. A primary driver of this push to intensify production is that, like in all other sectors of Australian agriculture, costs are rising faster than returns. Intensification offers the potential to improve productivity per unit area and increase flexibility to improve grazing management and land condition. A perceived potential for increasing stocking rates has been seen as a way of addressing this cost-price squeeze and is a key factor in intensification. This was apparent from a 1997 survey of stocking rates in 134 paddocks in the Victoria River District (VRD) of the Northern Territory that reported that pasture utilisation rates averaged 13% on black soil areas and 21% on red soils (Dyer *et al*. 2003). These utilisation rates are considered low to moderate.

Although average utilisation rates are low to moderate, actual utilisation rates experienced within paddocks can vary markedly from these averages. This is in large part because the paddocks in northern Australia are large (often >100 km^2) and water points are sparse. This results in an uneven distribution of grazing pressure with areas close to water being overgrazed, while far from water pasture utilisation is very low. Many cattle producers have recognised the potential for the development of properties to allow increases in stocking rates through more effective use of available forage. In a recent survey of cattle producers in the Katherine region (Oxley 2006), producers estimated that carrying capacity could be increased by 25% by 2011 and 42% by 2016 as current development plans are implemented. Eighty percent of producers reported having immediate plans to develop further water points and subdivide paddocks.

Over recent years the demand for beef from the live export trade into south-east Asia has been stable and this has given the northern beef industry added confidence. This buoyancy has contributed to rapidly increasing land prices as demand for land strengthens. Increasing land prices have also created pressure to increase production and minimise costs to achieve reasonable returns on capital. Much of the northern Australian rangelands have had above average seasons over the last 25 years, although northern Queensland has been an exception. These favourable seasons are also influencing plans to intensify production. Despite increasing costs, sustained good prices for cattle and beef from the late 1990s until recently have provided the economic means to implement more intensified production systems (Ash and Stafford Smith 2003).

1.2 Genesis of this project and regional context

This project was initiated in 2002 by Heytesbury Beef, a commercial cattle company. Heytesbury Beef is a privately owned large-scale cattle business that in 2002 managed 200,000 head of cattle over 21,086 km^2 of native pasture in northern Australia. At the time the project began Heytesbury Beef, like many other pastoral businesses, was looking to identify strategies to improve the efficiency and profitability of these pastoral businesses, to offset the ongoing cost-price squeeze. This cost-price squeeze was being driven by an unprecedented increase in key operating costs over a period of about 10 years, including the cost of labour, fuel, transport and supplementation. Economic modelling suggested that one of the more effective ways to increase the efficiency and profitability of these businesses was to increase the stocking rate of the business. Increasing the stocking rate and herd numbers diluted the fixed cost of the business and in many cases reduced the variable costs per animal through improved efficiency. An example of this is mustering costs, where the cost of mustering a paddock with 1,000 head is very similar to the cost of mustering a paddock with 1,500 head, resulting in a significantly lower mustering cost per head. The challenge was to identify ways to increase stocking rates in a sustainable fashion.

Results from a 7-year small-paddock experiment by the NT Department of Primary Industry on Heytesbury Beef's Mt Sanford station in the Victoria River District suggested that annual pasture utilisation levels of up to 22% were sustainable on native pastures on the basalt-derived black soils of the region. In comparison, the estimated level of annual pasture utilisation on Mt Sanford at this time was in the order of 10%. These data suggested there was the capacity to double the stocking rate without degrading the pastures. If it were possible to achieve this on a commercial scale, this would significantly improve the profitability of the pastoral businesses in the region.

Doubling the stocking rate within commercial businesses using the existing level of infrastructure was not considered sustainable. At the time, typical levels of property development in the VRD (average paddock size of 130 km^2 with two or three water points; Oxley 2006) were inadequate to support an increase in stocking rates because of the problem of uneven grazing distribution. It was found that increasing the stocking rate per paddock caused greater pasture degradation near the water points, increased the incidence of soil erosion and resulted in a decline in livestock productivity. This raised the question of how the stocking rate could be sustainably doubled under experimental conditions but could not be achieved on a commercial scale. It was anticipated that grazing would need to be more evenly distributed across paddocks, as occurred in the small experimental plots at Mt Sanford, in order for a doubling of stocking rates to be sustainable at commercial scales.

To better understand how higher stocking rates could be sustainably achieved within a commercial-scale business Dr Steve Petty from Heytesbury Beef convened a series of workshops with many of the key pasture and animal scientists working across northern Australia. These workshops reviewed the results from the Mt Sanford experiment and focused on the factors influencing sustainable stocking rates on a commercial scale. The key issues raised at these technical workshops were:

- What are the optimum levels of pasture utilisation for the key pasture types in this region?
- What are the optimum levels of infrastructure development to achieve uniform grazing distribution?
- Do more intensive grazing systems allow higher sustainable levels of pasture utilisation than the current continuously-grazed and, for all intents and purposes, set-stocked system used in commercial businesses?
- Can extensively grazed areas in northern Australia be more intensively developed without causing pasture degradation and/or a decline in biodiversity?
- Can more efficient infrastructure designs and innovative technology be integrated into intensively developed commercial businesses to reduce or maintain the cost of production?

In 2002 Heytesbury Beef approached Meat and Livestock Australia (MLA) to develop a joint venture research project to address the issues raised by the technical workshops. An important feature of this proposal was that the research was to be undertaken at a commercial scale. MLA agreed to develop the joint venture project and provided a funding model for 50:50 funding between MLA and Heytesbury Beef. This provided the funds for the management of the experimental program. Heytesbury Beef also provided $1 million in capital to develop the experimental complex on Pigeon Hole station in the VRD. The VRD is located in the north-west of the Northern Territory and is an important cattle-producing region in northern Australia because of its productive pastures and extensive area. Pigeon Hole was selected as it provided a site with pastures in moderate condition (B and C using the 'ABCD' land condition criteria), which was considered to be 'typical' of the commercial pastoral businesses in the region at the time.

The VRD has a long history of use for pastoral purposes, with cattle first being introduced to the region in the late 1800s. Rainfall in the region was 20-30% above the long-term average during the 11-year period leading up to the start of this project in 2003. As a result there has been a general increase in vegetative cover, including in the perennial grasslands of the black soil areas, and landscape function and species diversity appear to have been maintained or improved (Karfs and Trueman 2005).

The study was undertaken at an unprecedented scale. It involved approximately 350 km^2 of land and around 5000 head of cattle. The experimental complex was developed in 2002 and 2003, requiring the establishment of 213 km of fencing (including 145 km of barb wire fencing and 68 km of electric fencing), 14 new water points, a new set of yards and upgrading of the existing infrastructure on the southern portion of Pigeon Hole. Additional staff were appointed at Pigeon Hole to assist with running the project.

Key staff from CSIRO, NT Department of Primary Industry and Fisheries, NT Department of Natural Resources, Environment and the Arts, and the University of Queensland provided significant scientific contributions to the technical workshops. These organisations also became key partners in the joint venture program and provided significant amounts of funding and many support staff. These groups worked co-operatively to conduct many components of the experiment and provided the majority of the scientific and technical input to the project.

Pasture and biodiversity data collection commenced in May 2003 and livestock production data collection commenced in April 2004. The project was managed by a Technical Committee with representatives from all of the joint venture organisations including MLA and Heytesbury Beef. This experiment was concluded in October 2007.

1.3 Project objectives and hypotheses

Four overarching objectives were identified for the project. These related to understanding the key factors influencing pastoral development and its management in northern Australia and increasing beef producers' awareness of these issues. The objectives were:

By completion of the project:

1. One hundred percent of producers in the VRD will be aware of locally derived relationships between pasture utilisation and pasture and animal parameters, including the impact of variable levels of pasture utilisation on pasture dynamics, pasture condition trends and pasture sustainability.
2. The key factors and processes influencing sustainable grazing at the paddock scale in the VRD, Northern Territory will have been identified and understood, in particular: optimal levels and systems of pasture utilisation; the distribution patterns of grazing cattle; the role of pastoral development options of fencing, paddock design and water placement; and, the impact of pastoral development options on biodiversity conservation.
3. Management guidelines for achieving sustainable and profitable pastoral development will have been identified.
4. Twenty percent of beef producers in northern Australia will be aware of the relationship between grazing behaviour, land condition and animal production and have the information and decision support tools to implement change on their properties to improve financial and land management performance.

These objectives were supported by three overarching hypotheses:

1. More intensively developed paddocks result in greater evenness of use, increased utilisation, increased animal production per hectare and increased profitability.
2. Landscape diversity and multiple waters/small grazing radius give both high animal production per head and high animal production per hectare.
3. Intensification of grazing through increased utilisation and evenness of use leads to a decline in biodiversity compared to large paddocks with few water points.

1.4 Research activities

Five key areas of research activity were initiated to test the project's hypotheses and provide an understanding of the issues surrounding intensification of the pastoral system that would underpin sustainable development of the northern beef industry. To develop an understanding of the regional implications of this research an assessment of the potential for property development in the VRD was conducted. An assessment of the ecological and economic trade-offs of a number of development scenarios was also commissioned.

1.4.1 Activity 1 - Identifying optimum levels of pasture utilisation

There is currently little local information on sustainable carrying capacity in the study region. Knowing what proportion of annual pasture growth can be utilised by cattle is a fundamental part of sustainable grazing management and the aim of this activity was to determine the sustainable pasture utilisation rate for the dominant land system in the region. This knowledge should allow the development of properties based on realistic estimates of productive capacity of the landscape, and help avoid over-development of the land as occurred in parts of the eastern savannas (Stokes 2004). The earlier research at Mt Sanford suggested that annual pasture utilisation rates of about 20-25% were sustainable over the medium term (Cowley *et al*. 2007), but this research occurred in small experimental paddocks where grazing was distributed relatively uniformly within them. It was not known how these results would translate to larger commercial paddocks where grazing is distributed unevenly.

Key hypotheses for this activity were:

1. Decreasing large paddock size and distance to water enables increases in average pasture utilisation rates, animal production per hectare and profitability, whilst maintaining or improving land condition.
2. At the 2000 ha scale there is an optimum utilisation rate beyond which animal production and land condition decline.
3. In 2000 ha paddocks with a grazing radius of 3 km, evenness of grazing does not vary with utilisation rate.

1.4.2 Activity 2 – Enhanced understanding of grazing distribution for improved paddock design and water placement

Cattle properties in northern Australia are typically very large and, as mentioned earlier, have poorly developed infrastructure (i.e. fences and water points). As a result, paddocks are large and water points are widely separated. For example, the average paddock in the VRD is 130 sq. km with only two or three water points, but paddocks can be up to 160 sq. km (Oxley 2006). Fisher (2001) reported that 40% of the VRD is greater than 4 km from water. Because the resulting uneven grazing distribution causes overgrazing and pasture degradation around water points and in other preferred areas and very low utilisation elsewhere, overall stocking rates are often kept relatively low to limit pasture utilisation in favoured parts of the landscape. This means overall use of available forage can be limited. Since smaller paddocks can result in more even grazing distribution (Hart *et al*. 1993), subdividing large paddocks may bring about more effective use of available pasture. Alternatively, increasing the number of water points in large paddocks may have a similar effect. These developments offer the opportunity to increase livestock production and profitability partly because more effective use of available pasture should allow more stock to be carried.

The optimum paddock configuration (i.e. size of paddock and number of water points) for a region is likely to be influenced by several factors including cost, effectiveness at improving grazing distribution, and effect on land condition and livestock production. An understanding of cattle foraging behaviour and the effects of paddock size, water point number and landscape features (e.g. soil type, location of water and preferred plant communities) is required to develop paddock configurations that improve grazing distribution and the effective use of available forage.

This research activity involved two studies, one investigating the effect of grazing radius (essentially the distance cattle can graze from water) and the other the effect of paddock size and landscape diversity on grazing distribution, land condition and livestock production.

Key hypotheses for the grazing radius study were:

1. There is an optimum maximum distance to water for evenness of use and land condition.
2. There is an optimum maximum distance to water for animal production.

Key hypotheses for Grazing Distribution/Spatial Diversity Study were:

3. Increasing spatial scale and landscape diversity reduces coupling between utilisation rate and animal production per head such that the usual linear decline in animal production per head with increasing utilisation rate observed at small spatial scales is dampened at large spatial scales.
4. Increasing landscape diversity will result in more uneven use and more land in poor condition (independent of distance to water).

1.4.3 Activity 3 - Grazing systems

In the northern beef industry paddocks are usually stocked continuously at stocking rates that remain approximately the same from year to year (referred to as a ‘set stocking’ grazing system). This is the most widely used grazing system because of its ease of implementation, but it does have a number of shortcomings as a grazing system. As mentioned above, because cattle use the land within paddocks unevenly, set stocking can result in localised overgrazing and pasture degradation, and poor use of available forage. Variable pasture production in years receiving different amounts of rainfall can also result in a mismatch between livestock numbers and pasture availability when stocking rates are not adjusted. This can mean forfeiting potentially higher livestock production in years of high pasture growth and overgrazing in years of low pasture growth. Overgrazing can result in a loss of palatable perennial grasses, increases in shrub abundance, and increased run-off and soil loss (Ash *et al.* 1997). In the long term these effects will reduce the productive potential of the pasture leading to lowered livestock production.

An alternative to set stocking is the use of a grazing system that involves variation in stocking rates and/or periods of rest from grazing. There are numerous grazing systems that have these features but they are all generally designed to redistribute grazing pressure temporally or spatially and so provide better control of grazing frequency, intensity and period (Briske *et al.* 2008). This can mean the ability to reduce grazing pressure at times when perennial plants are especially vulnerable to defoliation, and improved distribution of grazing across the landscape. However, the effectiveness of such alternative grazing systems in maintaining land condition and improving livestock production in northern Australia’s savanna grasslands is unknown. These grazing systems can also be expensive operations to install and manage, especially the more intensive ones that involve numerous small paddocks and frequent movements of livestock.

This research activity evaluated four grazing systems in the context of an intensified production system. We aimed to develop an understanding of the response of pastures and livestock production under the following grazing systems: set stocking, set utilisation (at 20% annual utilisation), wet season spelling and cell grazing.

The key hypotheses for this activity were:

1. Grazing systems that involve regular rotation of livestock around a series of paddocks allow the use of higher pasture utilisation rates and hence generate higher livestock production than set stocking.
2. Grazing systems that involve periods of rest result in better pasture condition than set stocking.

3. Higher costs associated with developing and managing more intensive rotational grazing systems are offset by higher livestock production so that these systems are more profitable than set stocking.
4. Grazing systems that adjust stocking rates to match annual pasture production result in better pasture condition than set stocking with no reduction in livestock production.

1.4.4 Activity 4 - Implications of pastoral development options for biodiversity conservation

In northern Australian rangelands, pastoral lands play an important role in biodiversity conservation. Due to the lack of broad-scale land clearing and retention of native perennial pastures, many biodiversity values persist in the very extensive areas under pastoral management. Because of the very important role of 'off-reserve' conservation in the maintenance of biodiversity in the Australian rangelands, there is a general recognition within the pastoral sector that sustainable pastoral use includes the maintenance of regional biodiversity values.

Recent research suggests that in most rangeland regions (including the Mitchell grasslands) there are grazing-sensitive species amongst many plant and animal groups that are only abundant in water-remote or lightly-grazed areas (Biograze 2000). The 'best-practice' pastoral management approach of increasing the number of stock watering points and spreading grazing load evenly across the landscape may in fact conflict with the ideal management approach for these native 'decreaser' species. This issue is likely to be of particular significance where there is an intensification of pastoral use at a property or regional scale. In this case, specific management actions may be required to safeguard biodiversity values, such as setting aside a portion of the property for conservation management. Currently, however, there is little specific data to inform decisions about how large such 'conservation areas' should be, or how they should be managed. Additionally, further data are required for individual land types and species-groups on what the threshold of pasture utilisation is before declines in decreaser species are observed, and at what scales of evenness of use impacts on biodiversity are most pronounced.

The purpose of this research activity was to understand the effects of pastoral intensification on biodiversity values and ascertain the requirements for maintaining biodiversity values to ensure that intensification of pastoral use can be managed in an ecologically sustainable manner.

Key hypotheses for this activity were:

1. There is a threshold of pasture utilisation (at a paddock level), above which there are marked declines in biodiversity values.
2. It is practical and cost-effective to integrate 'conservation areas' of high quality habitat into an intensified pastoral property that achieve desired biodiversity outcomes.
3. The size of conservation areas required to sustain local wildlife populations will vary between taxa, but appropriate minimum areas can be identified.
4. It is possible to develop biodiversity indicators that can be integrated with pasture/land condition monitoring to guide adaptive management.

1.4.5 Activity 5 – Innovative technology to improve business efficiency

The development of smaller paddocks and more water points in an intensified production system increases the workload associated with monitoring and maintaining the additional infrastructure – with the implication of higher labour, vehicle and fuel costs. Smaller paddocks (and hence more, smaller mobs of cattle) also increase costs associated with mustering and moving cattle. These higher operating costs needs to balance with improvements in productivity per unit area or a reduction in operating costs per head. More efficient infrastructure designs and innovations to reduce the cost of production are likely to be an essential part of an intensively developed pastoral business. In particular, the recent advances in electronic technology appear to offer substantial potential for remotely monitoring and managing water points.

In order to minimise potential increases in cost per head, this activity investigated strategies and infrastructure options that are likely to reduce the operating costs of an intensively developed pastoral business. These included:

1. Using telemetry to reduce the cost of monitoring and maintaining water points;
2. Using laneways and additional yards to reduce mustering costs;
3. Using more efficient mustering options (e.g. helicopters and planes or more ringers);
4. Using water medicators to reduce the cost of providing dietary (N and P) supplementation.

1.4.6 Assessment of development potential in the Victoria River District

Major development of the cattle industry in the VRD would have substantial ramifications for the industry and regional development. Besides potentially increasing the value of the industry in the region, there would be effects on markets, the demand for labour and other regional services (e.g. road transport and shipping ports). To develop an understanding of some of the likely regional implications and assessment of the potential for industry development was conducted. This was based on a comparison of current pasture utilisation rates across the VRD with recommended rates, taking into account factors previously not considered (e.g. accessibility of land to cattle, distance from water, and different land type utilisation potentials).

1.4.7 Analysis of economic and environmental tradeoffs

The intensification of grazing on pastoral properties is likely to have both environmental and financial impacts. It is unlikely that the environmental and financial impacts will both always be positive, and tradeoffs will be required to meet both environmental and financial objectives. To assist the task of making sound choices, the nature of these trade-offs and their magnitude need to be identified and assessed.

To better understand the trade-offs that might be required in an intensified production system to meet both environmental and financial objectives, an assessment of the ecological and economic trade-offs of a number of development scenarios was conducted. This analysis was performed using an assessment framework that calculates and compares the environmental and financial performance of a property under a proposed management change with that of the current operation.

2 General methods and experimental approach

This chapter describes the overall approach to the study, the location and characteristics of the study sites, and seasonal conditions during the study. Methods that were common to several components of the study are also described here. Methods specific to particular components of the project are presented in the relevant chapters.

2.1 Study location

The primary study of intensification options for beef enterprises occurred at Pigeon Hole station in the Victoria River District of the Northern Territory. However, this report also presents the findings of the study mentioned earlier (see Section 1.2) of sustainable utilisation rates in small experimental paddocks at Mt Sanford station. Pigeon Hole and Mt Sanford stations adjoin each other (Fig. 2.1).

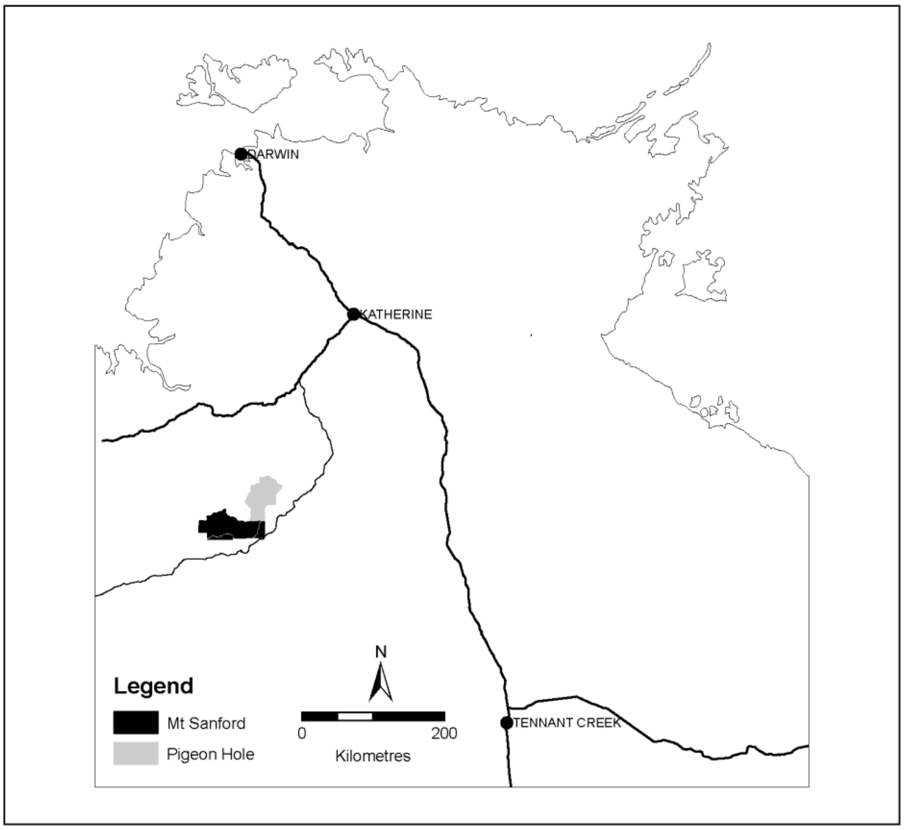


Fig. 2.1. Locality map of Pigeon Hole and Mt Sanford stations, in the Northern Territory.

The primary study site on Pigeon Hole station is described in the following sections. The Mt Sanford site is described in Chapter 3 as part of the pasture utilisation study.

2.2 Site description

2.2.1 Land system, vegetation and climate

An area of approximately 320 km^2 on the southern end of Pigeon Hole station was selected for the study. This area is on the Wave Hill land system. This system is comprised of gently undulating downs country intersected by ephemeral creeks. The creeks flow only for short periods during the wet season but they may hold water in deeper holes for several months in the early dry season. Soils are predominantly black cracking clay soils (self-mulching vertisols that develop deep cracks as they dry out) derived from weathered basalt. It is one of the more fertile and productive systems for cattle grazing, and is considered to be relatively resilient to grazing.

On the black soils, the ground layer vegetation is a mix of (in approximate order of decreasing overall abundance) annual grasses including annual sorghum (*Sarga timorense* syn. *Sorghum timorense*) and Flinders grass (*Iseilema* spp.), perennial grasses including feathertop wiregrass (*Aristida latifolia*), ribbon grass (*Chrysopogon fallax*), native millet (*Panicum decompositum*), curly bluegrass (*Dichanthium fecundum*) and Mitchell grass (*Astrebla* spp.), and perennial and annual forbs in varying abundance. White grass (*Sehima nervosum*), bottlewashers (*Enneapogon* spp.) and assorted forbs tend to dominate the red soil patches. The area is only sparsely wooded with species of *Terminalia* and *Eucalyptus*.

Pigeon Hole is in the hot, wet-dry tropical savannas. Rainfall is strongly seasonal in this area, with 95% of annual rainfall usually occurring between October and March inclusive. Mean annual (July-June) rainfall at the Pigeon Hole homestead is 752 mm (13-year average). The longer term average may be below 752 mm, since records from other locations in the region suggest rainfall over the last decade has generally been higher than the long-term average. For example, the long-term average at Victoria River Downs is 652 mm.

2.2.2 Site history, land condition and development for the project

Prior to the study, the Pigeon Hole research site was managed as part of the Pigeon Hole commercial business. This area had been grazed for at least 100 years as part of the Victoria River Downs Station. Over the 10 years leading up to the study the area had been fenced into four large paddocks: Villiers (107 km^2), Bullock Paddock (91 km^2), Steven’s Creek paddock (89 km^2) and Racecourse paddock (52 km^2) (Fig. 2.2). There were six man-made permanent water points across the four paddocks and two natural permanent water points (a water hole in each of Bullock and Racecourse). The poor distribution of water dictated the grazing distribution of these paddocks in the dry season, with anecdotal evidence of heavy grazing occurring near Villiers bore, No. 12 bore, No. 13 bore, Four Corners bore and No. 5 bore particularly at the end of each dry season. The area in the vicinity of the Racecourse pump-out tended to be used only lightly by cattle. No. 9 bore only provided water for 12 months in 1991 and the bore hole dried up after the 12 months pumping.

In general, the study site was in C (i.e. fair) land condition (as per the Grazing Land Management package) at the start of the study, with about 60-70% of quadrats per paddock being rated as C condition. The remainder of the site was largely in excellent (A) or good (B) condition, with only a small fraction (<10%) in poor (D) condition.

The paddocks were continuously grazed and set stocked with an annual stocking rate in the order of 9.5 AEs per km^2 or 3,220 AEs across the four paddocks. The area was considered to be well developed for commercial paddocks. This is approximately 400 AEs per water point. It should be noted that this stocking rate assumed 100% of the paddocks were available to be grazed, which was not the case, given the poor water distribution.

Fires regularly entered the area from the National Park to the west, resulting in the paddocks typically being burnt on average 1 in 3 years. An intense fire affected a large area of Steven’s Creek, Bullock and Racecourse paddocks in November 2002 prior to the commencement of the project.

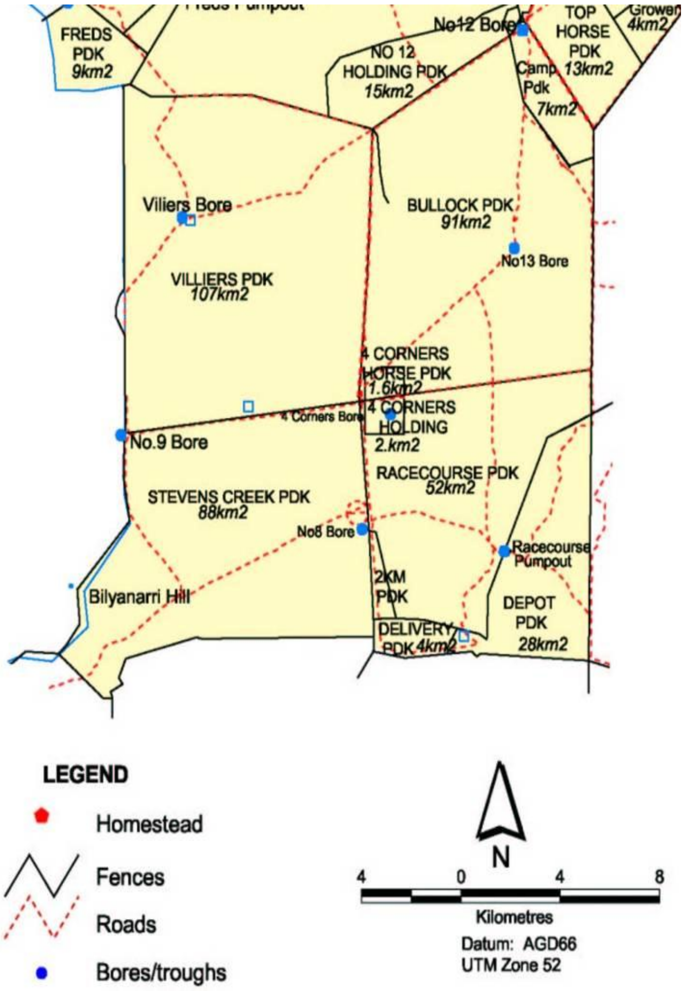


Fig. 2.2. The layout of the Pigeon Hole research site before the establishment of the new paddocks and water points for the research.

Considerable development of the site occurred for this project, including subdivision of the original four paddocks and the establishment of additional water points. Given the aim of testing a range of development and grazing management options at commercial scales, it was not possible to replicate any of the treatments, so each treatment was applied to a single paddock (although the two grazing systems that involved stock rotation consisted of a number of smaller paddocks). The paddock layout of the site after development and allocation of treatments to paddocks are presented in Fig. 2.3. Some paddocks represented different treatments for different experiments. Detailed information on the allocation of treatments to paddocks and land condition at start of study is presented in the chapter for each experimental activity.

The development of the paddocks and water points was completed by September 2003 (except for the cell grazing complex). The paddocks were stocked and managed according to the new grazing management practices for the study from October 2003. The cell grazing treatment began in January 2004. The site and cattle continued to be managed and run on a commercial basis by the property owners during the study.

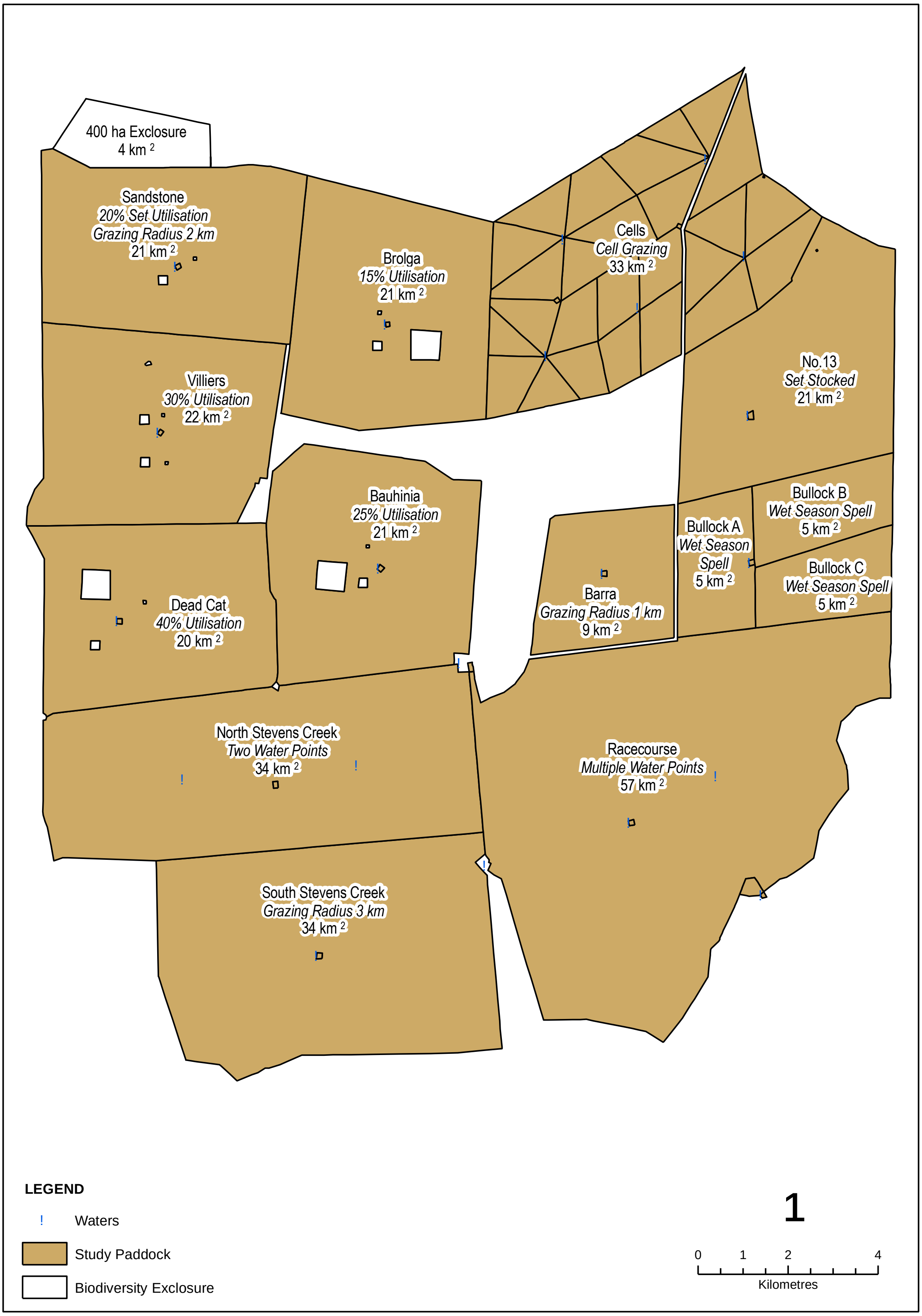


Fig. 2.3. Layout of the experimental site and treatment paddocks at Pigeon Hole following development of the infrastructure.

2.2.3 Soils

The study site was dominated by the black vertisol soils characteristic of the Wave Hill land system, but included areas of minor soil types. A soil map of the site was developed (Fig. 2.4) by combining an aerial photo-interpretation (prepared by K. Richardson, NT Govt) and on-ground data collected during pasture surveys during the study. This identified four broad categories of soil: black, red (generally associated with low ridges), riparian (associated with creeks) and intermediate (a broad category including soils that were a transition between black and red or black and riparian soils).

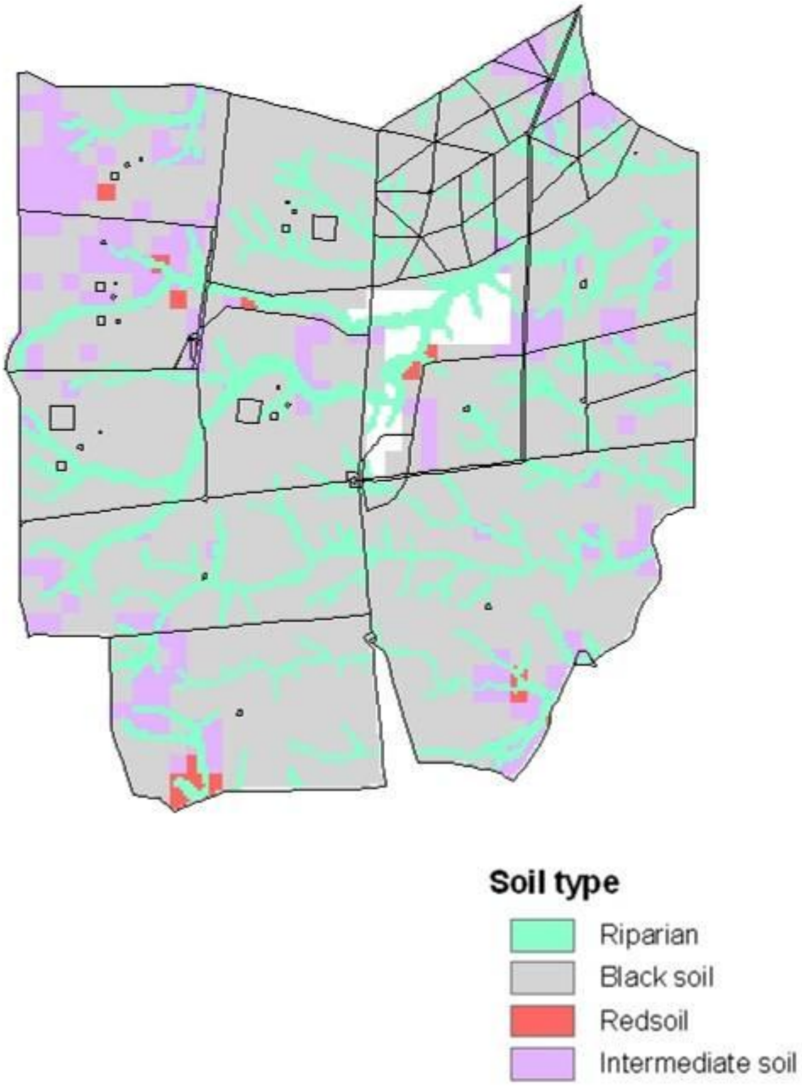


Fig. 2.4. Soil map developed for the study site.

2.3 Livestock

2.3.1 Type of livestock

Beef enterprises in the VRD are generally breeder operations using Brahman or Brahman cross cattle, and this was the case for this project. The same breeders remained in each paddock throughout the study, except where the culling of individuals was required. In addition to the breeders, around 25 steers were run in each paddock as 'indicator' steers, to give a reliable measure of liveweight change in growing animals. A number of 'dummy' animals (spayed cows and/or young heifers) were included in each paddock to allow for the adjustment of stocking rates to achieve the desired utilisation rate without changing the number of breeders. No data were collected on the dummy animals.

2.3.2 General herd management

Breeders were mustered twice annually, at the end of the wet season (April-May) and late in the dry season (September-October). Breeders were culled on barrenness (non-pregnant and non-lactating), temperament, injury or age (10 years) and were continuously mated at 4%. All breeding stock was vaccinated against C & D botulism strains at the May muster and a booster vibriosis vaccination was given to bulls at the October muster.

A minimum weaning weight of 120 kg was used at both weaning rounds in all years. Calves (progeny <120 kg) were generally castrated, branded and dehorned prior to being returned to the breeding herd.

Nitrogen and phosphorus supplementation was provided year-round by automatic water medication at water troughs, although supplement blocks were provided in Bullock and Racecourse paddocks since some waters in these paddocks were natural waterholes.

2.3.3 Stocking rate adjustment

Stocking rates were largely adjusted on an annual basis. Cattle numbers were adjusted at the first round muster in April-May each year based on an estimate from the GRASP pasture growth model (Littleboy and McKeon 1997) of standing pasture biomass at the end of the preceding wet season. To guard against exceeding desired utilisation rates, the number of cattle returned to each paddock at this time was generally the same as had been mustered or fewer. Paddock pasture yield estimates made in May (see later) were then used to adjust cattle numbers before the second muster (September-October) according to the number required to achieve the desired annual pasture utilisation rate.

2.4 Seasonal conditions

Pasture growth in tropical savannas is influenced by the amount of rain, the timing of rainfall during the wet season (Swemmer *et al*. 2007) and the length of the wet season (Cook and Heerdegen 2001). Annual rainfall (July to June) during the study was close to the average of 752 mm in the first year, below average in the second and last years, and well above average in the third year (Fig. 2.5). Importantly, no extremes (either very low or very high rainfall, or extended wet or dry periods) in seasonal conditions were experienced, although in 2005-2006 rainfall was about 40% higher than average. Monthly rainfall during the study is presented in Fig. 2.6.

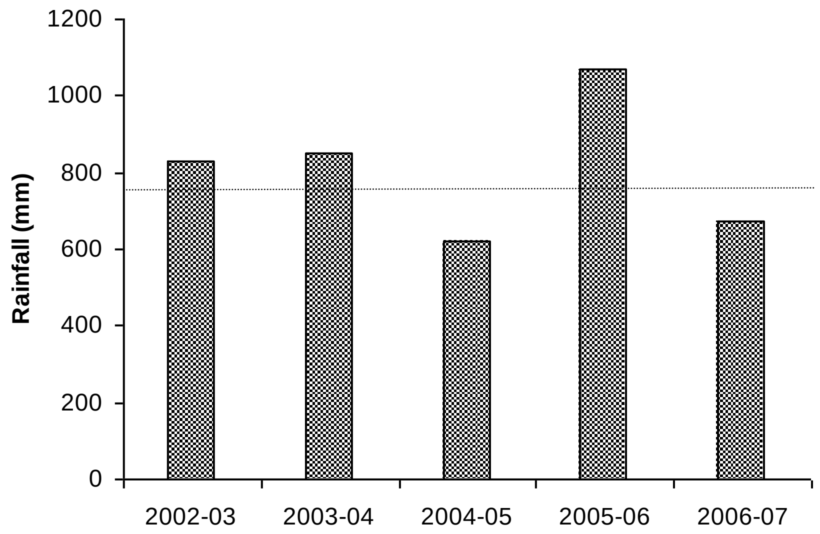


Fig. 2.5. Wet season rainfall (July-June) at Pigeon Hole homestead during the study period (2003-2007) and for the wet season immediately preceding the study. The horizontal line indicates the 13-year average.

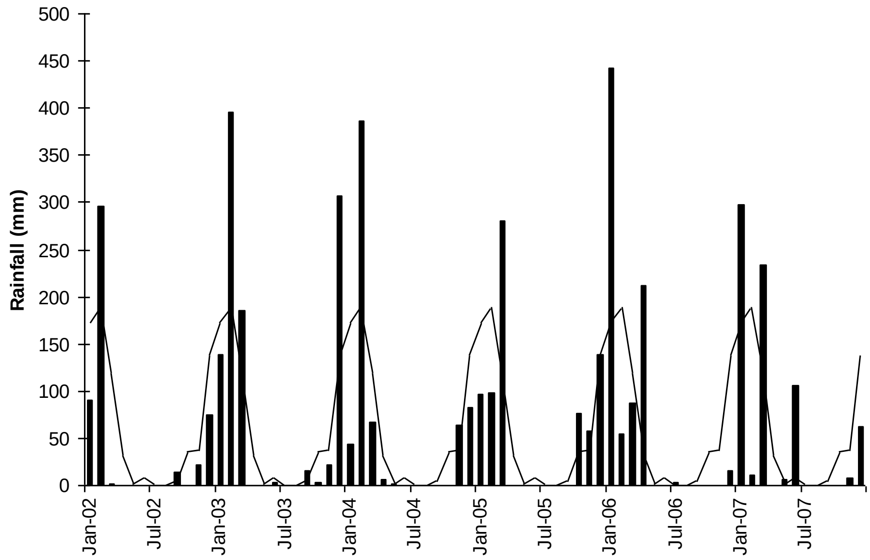


Fig. 2.6. Actual (bars) and mean (line) monthly rainfall at Pigeon Hole Station from 2002-2007. The treatments were begun in October 2003.

For this study the wet season was defined to have started when there was at least 50 mm of rain over 14 days, and the finish as the final day of the wet season when at least 50 mm of rain fell in the preceding 14 days. The rainy season varied between 77 and 193 days duration during the years of the study (Table 2.1).

Table 2.1. Start and end of the wet (or 'rainy') season, wet season duration and rainfall during the 'defined' wet season at Pigeon Hole for the years of the study and the preceding year.

	2002-03 (pre-study)	2003-04	2004-05	2005-06	2006-07	Average
Wet season start	Dec 3	Dec 12	Dec 24	Oct 18	Jan 13	Dec 7
Wet season finish	Mar 10	Apr 1	Mar 23	Apr 28	Mar 30	Mar 31
Duration (days)	98	112	90	193	77	114
Rainfall amount (mm)	806	809	551	1069	542*	753

* note that rainfall during the 'defined' wet season for 2006-07 was substantially lower than the annual July-June rainfall for that year (see Fig. 2.5) due to a large rainfall in June 2007.

Average standing biomass in May (as an approximate estimate of annual pasture growth) varied between approximately 1480 and 2770 kg/ha dry matter during the four years the grazing treatments were in place (Fig. 2.7). Pasture growth was not explained by a simple linear relationship with annual (July-June) rainfall. Although annual rainfall was average to above average, growth was quite low in the 2002-2003 and 2006-2007 wet seasons (20th and 40th percentile respectively). Pasture growth in 2004-2005 was near the median, while 2003-2004 and 2005-2006 were around the 70th percentile.

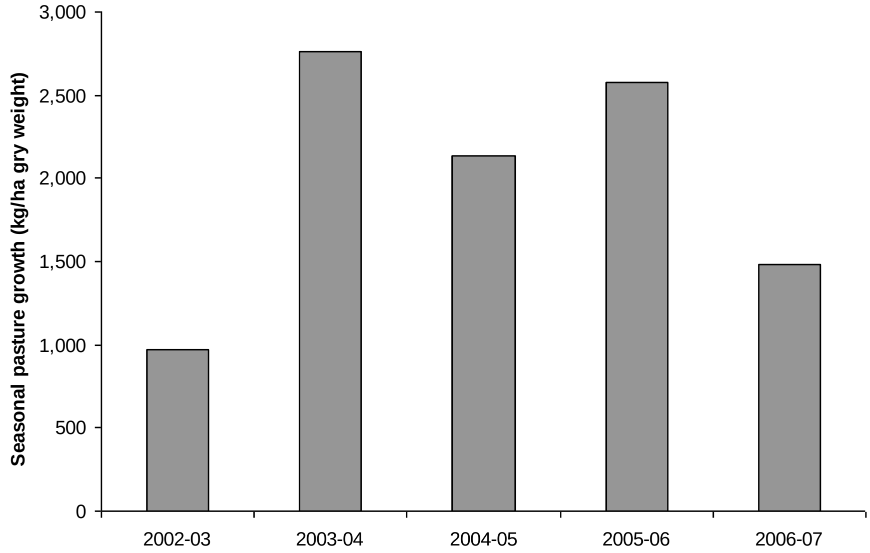


Fig. 2.7. Standing pasture biomass (kg/ha dry matter) in May of each year averaged over all paddocks at the study site for each growing season.

Poor pasture production in the wet season preceding the study (2002-2003) was because much of the rain arrived late in the season (February; Fig. 2.6 and Fig. 2.7). In 2004-05 the growing season was also relatively short, rainfall was below average and much of the rainfall occurred very late in the season, although good rains in December 2004 meant pasture production was better than in 2002-2003. Longer growing seasons with above average rainfall were responsible for good pasture growth in 2003-2004 and 2005-2006. A short, late wet season in 2006-2007 resulted in low pasture growth for the final wet season of the study.

Occasional wildfires started by lightning burnt portions of the study site and reduced pasture availability in some grazing treatments. In particular, a large fire burnt about half of the study site in late 2002 about 10 months before the study began, and about a third to a half of Villiers and Dead Cat paddocks in January 2005.

2.5 Data collection and analysis

2.5.1 Pasture and understorey vegetation

2.5.1.1 Field methods

Pasture surveys were conducted twice a year, at the end of the wet (May) and dry (October) seasons, using a modified Botanal method (Tothill *et al*. 1992). This involved visual estimation of pasture attributes by a team of observers, with observers' estimates of some of those attributes being calibrated or standardised amongst observers. Table 2.2 presents a list and brief explanation of the attributes estimated.

Table 2.2. Pasture and related variables visually estimated for each quadrat in the modified Botanal procedure.

VARIABLE	Description	Comments
Species present	Top five species present in order of biomass (weight) rank in each quadrat	Only the 23 most common species were included. Minor species were lumped together in functional groups as 'other species'.
Species composition	Percentage composition (by weight) of each of the top five species in quadrat	
Species defoliation	Percentage defoliation (i.e. cattle grazing) category of top five species according to percentage defoliation categories 0, 0-5, 5-25, 25-50, 50-75, 75-100%	
Overall quadrat defoliation	Overall defoliation for whole quadrat according to above defoliation categories	Incorporates defoliation of species not included in top five species
Herbage biomass	Total yield of dry standing herbage biomass (estimated as equivalent biomass in kg/ha)	Excludes any detached plant material. Observers' estimates calibrated.
Perennial grass basal area	Basal area of perennial tussock grasses as a percentage of quadrat area according to percentage categories 0, <1, 1-3, 3-5, 5-7.5, 7.5-10%	
Total projected vegetative cover	Total vegetative ground cover (herbage cover + litter) as a percentage of quadrat area	Manure included, rock cover excluded. Observers' estimates standardised to the overall mean.
Land (soil) type	Dominant land type within 10 m radius of quadrat; possible choices are black soil, red soil, intermediate, creek line, and riparian	Intermediate soils were between red and black soils, and other soil types not fitting into the other categories. Creek line referred to quadrats actually located in rocky creek beds.
Fire	Yes/no according to whether quadrat had been burnt since the last wet season	
Patch type	If quadrat was located within one of three patch types (riparian, new grazed, old grazed)	New grazed patches were areas with abundant palatable perennial grasses with >50% defoliation. Old grazed patches had lost most palatable perennial grasses, increased bare ground and forbs and short-lived species
Latitude and longitude	Location of quadrat downloaded directly from GPS	

Sampling occurred in a 100 x 500 m grid across each paddock. These points were sampled as N-S transects 500 m apart. Navigation along transects was by GPS between permanent northern and southern waypoints. At each 100 m point along each transect a 2 x 2 m 'virtual' quadrat (i.e.

the quadrat perimeter estimated by eye) was located. Quadrat locations were not permanently marked, so the position of quadrats may have varied on different sampling occasions according to GPS error (i.e. approximately ±5 m). Data were entered directly into hand-held computers.

The choice of a 100 m interval was based on preliminary sampling over part of the study site in October 2002, prior to the study commencing. This work showed that substantial patchiness occurred in the pasture layer at a scale of between 75 and 150 m. As evenness of grazing was a point of interest in the study, this meant that sampling should occur at an interval of less than 150 m. However, sampling on a 100 x 100 grid was beyond the resources available to the project, so the 100 x 500 m grid was settled on as being feasible.

All paddocks were sampled on each occasion except at the final sampling when two paddocks were excluded because those treatments (cell grazing and multiple waters) had been discontinued prior to the previous sampling.

2.5.1.2 Data analysis

Preliminary data processing

Extensive error checking was carried out on each data set. Yield estimates were calibrated using harvested calibration standards (dried at 80°C for 48 hours). Cover estimates were standardised across observers by rescaling estimates according to the mean estimated cover of all observations. This assumes observers were spread relatively uniformly across the study paddocks and treatments (which was achieved as well as possible).

To allow for analyses based on distance from water, the distance of each sampling point (i.e. quadrat) to the closet water point was calculated in ArcView using a combination of cost-distance and Euclidean distance methods where appropriate.

Pasture data – testing effects of treatments

The unreplicated experimental design and the initial inherent variability between paddocks presented a considerable challenge in analysing these data and interpreting the results. These shortcomings in the study design meant that usual statistical analyses testing for an effect of treatments would not be informative. Instead, the effects of the different grazing treatments were best assessed by testing for the emergence of different trends in pasture attributes (i.e. yield, composition, cover, perennial grass basal area and defoliation) over time amongst treatments (paddocks). Split-plot-in-time analysis of variance was used to test these effects, with a significant year x treatment interaction suggesting treatments were having different effects on pasture variables. Transects (not quadrats) were taken as the sampling unit, using the mean value of attributes for each transect at each sampling. Separate analyses were completed for each of the experiments (i.e. grazing radius, grazing distribution, grazing systems and pasture utilisation rates) for end-of-wet season (i.e. May) and end-of-dry season (i.e. October) data. The May data is most likely to show differences that reflect more lasting change in land condition or productivity rather than contemporary short-term grazing impacts.

The effect of distance to water on pasture defoliation in each of the treatments was examined with Analysis of Covariance (using a generalised linear model in Genstat). A number of other statistical analyses were used to test for additional specific effects in particular experiments. These are described in the relevant chapters.

Multivariate analyses (multidimensional scaling and ANOSIM) were used to compare species composition (based on percent composition by weight) between treatments and examine shifts in species composition over time. Changes in the abundance of functional groupings of pasture species were also examined graphically.

2.5.2 Livestock performance and dietary quality

2.5.2.1 Field methods

Livestock performance in each treatment was assessed in terms of a range of primary attributes (e.g. liveweight gain, branding percentage, body condition score, pregnancy rate and mortality), and numerous secondary measures derived from the primary data (e.g. inter-calving interval).

The primary data were gathered at the two musters each year. Herds from the various paddocks were usually processed within a week of each other. Month of pregnancy, lactation status (wet or dry), body condition score and liveweight were recorded for all breeders at each muster. Month of pregnancy was determined by rectal palpation. Lactation status of breeders was determined by visual assessment of udders. The body condition of the animal was visually assessed according to a nine point system where 1 is emaciated and 9 is over-fat (Holroyd 1978). Liveweights were recorded electronically and were adjusted according to the length of time the cattle were off feed and water before weighing. Liveweights and body condition score were also recorded for the indicator steers.

Branding and weaning rates for a paddock were calculated as the total number of calves branded/weaned in a year (i.e. summed across the two musters each year) as a percentage of the number of breeders in the paddock.

Cattle dietary quality (percent crude protein, dry matter digestibility and the proportion of non-grass material in the diet) was estimated monthly using faecal near-infrared spectroscopy (FNIRS; Coates 1999). In each paddock up to 15 separate faecal samples were collected from fresh cow pats near water points and combined to make a composite sample for analysis. In the largest paddock with multiple water-points (Racecourse paddock) separate composite samples were collected from several water points to assess the diversity in dietary quality across the paddock. Monthly sampling did not occur on a few occasions due to heavy rains or other management commitments.

2.5.2.2 Data analysis

A range of statistical tests were used to analyse the livestock production data. Many livestock production attributes were compared amongst treatments using Analysis of Variance. Generalised linear modelling was used for the analysis of branding and weaning rates and a generalised linear model (with Poisson distribution) was used for the analysis of inter-calving interval.

Since the grazing treatments were not replicated, individual animals have been used as the sampling unit for many of the analyses.

Breeder liveweights were corrected for pregnancy status before analysis (O'Rourke *et al.* 1991)

2.6 Estimation of actual pasture utilisation rates and pasture growth

Actual pasture utilisation was calculated retrospectively for each treatment for each growing season. This was used as an independent variable in many of the analyses. Pasture utilisation and growth were calculated as follows:

$$Utilisation = \frac{estimated\ intake}{estimated\ pasture\ growth}$$

Estimated intake = sum of monthly intakes from the beginning of the wet season to the start of the following wet season.

$$Estimated\ intake = stocking\ rate\ x\ \ intake\ (month\ )_{WSS} + \ stocking\ rate\ x\ intake\ (month\ )_{WSS+1} + \ ... + \ stocking\ rate\ x\ intake\ (month\ )_{n}$$

Where $(month\ )_{WSS}$ = The first month of the wet season, which is calculated as the first month where there is 50 mm of rainfall in less than 15 days.

And $(month\ )_{n}$= the last month of the dry season.

Intake was assumed to be 8 kg DM/AE/day, where an AE is a 450 kg non-lactating non-pregnant Brahman breeder at maintenance.

Estimated growth = estimated intake from the beginning of the wet season until yield was estimated in May + TSDM in May.

$$Estimated\ growth = \left(intake\ (month\ )_{WSS} + \ \ ...\ intake\ (month\ )_{May}\right) + \ TSDM\ in\ May$$

The average of the calculated utilisation rates across all years for each treatment paddock was used for analysis and these rates are referred to in the text, unless otherwise stated.

This method of calculating utilisation ignores carryover material, detachment and trampling effects and no allowance was made for the unpalatable proportion of the pasture. Modelling the trial could better estimate these processes and may provide a more accurate representation of utilisation of pasture growth.

Pasture utilisation rates for each paddock are presented in the respective chapters describing each experiment. More detailed information on the actual utilisation rates (including year to year variation is presented in **Error! Reference source not found.**.

2.7 Economic analysis

An economic analysis was conducted to compare the financial performance of the various management options within experiments (the different paddock configurations for example), and in some cases to make a comparison with a typical commercial operation using common industry practices (i.e. without any intensive development). The operation on the two-thirds of Pigeon Hole station that was not included in the study provided the typical commercial comparison. Typical features were the use of large paddocks (60-190 km^2) with only a few water points (two to three per paddock) and continuous stocking with stocking rates of 10 AE/km^2. Further details are provided in the chapters for each of the experiments.

3 Safe pasture utilisation

3.1 Key messages

- Six annual pasture utilisation rates (13, 21, 23, 31, 39 and 42%) were assessed over six years in small (4-8 km^2) experimental paddocks at Mt Sanford.
- Individual animal production was close to its peak at pasture utilisation rates of 21% but declined at higher utilisation rates. Although livestock production per land area was greater at higher utilisation rates, the risk of land degradation increased.
- A poor season in 2003 led to a major decline in animal production per area across all utilisation rates until 2005. Reduction in production per area was highest at higher utilisation rates.

- Land condition was maintained at a utilisation rate of 23%. The higher utilisation rates combined with a poor wet season appeared to degrade the land resource and reduced subsequent weaner production.
- To assess what pasture utilisation rate is appropriate in larger commercial paddocks the performance of five annual pasture utilisation rates (13, 17, 19, 24 and 32%) was assessed over four years in paddocks of approximately 20 km^2 at Pigeon Hole.
- As with the Mt Sanford study, livestock production per land area at Pigeon Hole was greater at higher utilisation rates.
- There were only subtle effects of the different utilisation rates on the pasture, but above 19% utilisation several criteria related to minimum cover or pasture biomass targets were not met, or there was a weak trend of declining land condition.
- The results suggest that an annual pasture utilisation rate of about 20% (19% for poorer condition sites and 23% for better condition sites) is sustainable in the long term on the black cracking clay soils of the Wave Hill land system providing it is possible to achieve relatively uniform grazing distribution within paddocks.

3.2 Introduction

The proportion of annual pasture growth that can be optimally utilised by grazing animals (otherwise known as proper use factor [de Leeuw *et al.* 1993], and the harvest coefficient [Galt *et al.* 2000]) is a fundamental part of determining carrying capacity and sustainable grazing management (e.g. Johnston *et al.* 1996, de Leeuw and Tothill 1993, Bartels *et al.* 1993, Hunt 2008). Recommended levels of utilisation of annual growth vary for land types and regions. In the Burdekin region of northern Queensland 25% utilisation of annual growth (Ash *et al.* 2011), or 20-25% of growth that occurs in 70% of years (O'Reagain *et al.* 2008) is recommended for Eucalypt woodland pastures, while values of 22% of average annual growth are recommended for Mitchell grasslands in Queensland (Grazing Land Management - Mitchell grass downs version 2007) and 30% of average annual growth for black speargrass pastures in central Queensland (Orr *et al.* 2010).

Previous studies in the Victoria River District have found current average industry utilisation rates to be relatively low at around 12% (Dyer *et al.* 2003) and 16% of median annual pasture growth (Cobiac 2006a). A grazing trial at Mt Sanford that finished in 2000 showed that with additional infrastructure and better management utilisation rates of up to 23% were sustainable over the medium term (Cowley *et al*. 2006, 2007). These paddocks were sufficiently small such that grazing was relatively uniformly distributed within them. However it was not known if higher utilisation rates would be sustainable and how these results would translate to larger commercial paddocks where grazing may be less evenly distributed.

The aim of this activity was to provide objective estimates of sustainable pasture utilisation in the Victoria River District. This knowledge will facilitate property development based on realistic estimates of productive capacity of the landscape, and help avoid over-development of the land as has occurred in some parts of the eastern savannas (Stokes *et al*. 2006), leading to unviable property sizes.

Key hypotheses for this activity were:

1. Smaller paddock size enables increases in average utilisation rates, animal production per hectare and profitability, whilst maintaining or improving land condition.
2. There is an optimum utilisation rate beyond which animal production and land condition decline.

The most appropriate experimental approach was to derive a response curve relating animal production and a number of pasture variables to a range of utilisation levels. Utilisation was defined as the amount of pasture consumed in a year as a percentage of total pasture growth. The utilisation rates used needed to cover the range from conservative levels (c. 10%) up to levels that were not expected to be sustainable in the long-term (c. 45%), but which may offer high levels of animal production per unit area in the short-term. There needed to be at least five utilisation rate treatments so that a reasonable response curve could be derived.

Two experimental scales were adopted to meet the needs of this utilisation study. The optimal pasture utilisation was examined at two separate experimental locations situated 50 km apart, at Pigeon Hole and Mt Sanford stations. Both sites were on a similar land type – open grasslands growing on fertile black cracking clays.

3.3 Mt Sanford

3.3.1 Site description

The smaller scale trial was on the Wave Hill land system black cracking clays at Mt. Sanford Station, approximately 500 km south-west of Katherine in the NT, in an open savanna grassland dominated by (in order of decreasing average yield) *Dichanthium spp.*, *Iseilema spp.*, *Aristida latifolia*, *Astrebla spp.*, and *Chrysopogon fallax* (Figure 3.1).

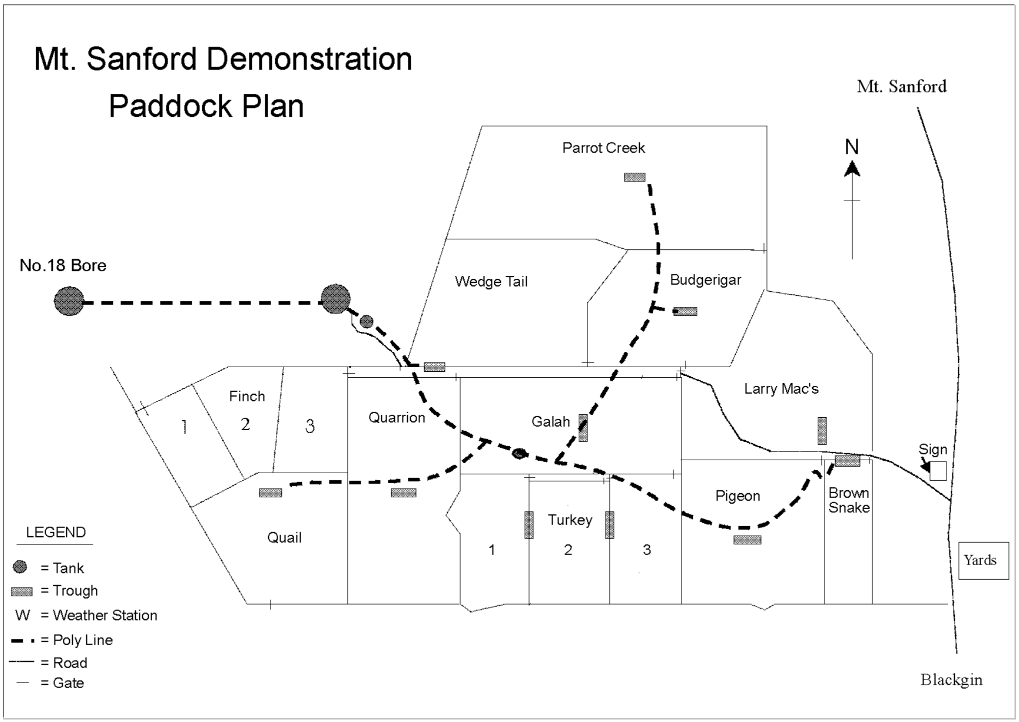


Figure 3.1. Layout of the Mt Sanford study site.

3.3.1.1 Paddock characteristics

The six paddocks varied in size, land type composition and water placement (Figure 3.1, Table 3.1).

Table 3.1. Mt Sanford paddock characteristics.

Utilisation treatment	Size (sq km)	Maximum distance to water (km)	Fire	% Black soil	%Red soil	% Hill
13%	7.6	1.7		100	0	0
21%	5.9	1.6		83	17	0
23%	4.3	1.0		92	5	3
31%	5.0	2.9	Rotationally burned 1996-2000	34	36	30
39%	8.0	2.0		96	0	4
42%	4.4	2.4	Half burned in October 1999 and other half burned in October 2000	63	29	8

3.3.1.2 Site vegetation

Qualitative observations of the site suggest it was generally in B condition, with 52% of total yield in April being perennial and 62% palatable, (see Table 3.2 for average composition across the site), ground cover levels in April usually between 70-80%, and woody canopy cover ranging from 1-2%. There was considerable variation in species composition between trial paddocks (Table 3.3), with *Astrebla spp*. varying between 2.5 - 19.7% of total yield.

Table 3.2. Top species contributing to yield at Mt Sanford station. Average of all years and sites in May (2001-2006).

Species	Proportion of total yield in May
Iseilema spp.	18%
Aristida latifolia	17%
Dichanthium sericeum	14%
Astrebla spp.	8%
Chrysopogon fallax	8%
Dichanthium fecundum	5%
Eulalia aurea	4%
Panicum decompositum	2%
Brachyachne convergens	2%
Heteropogon contortus	2%
Flemingia pauciflora	1%
Sesbania spp.	1%
Trichodesma zeylanicum	1%
Enneapogon spp.	1%

Table 3.3: Species composition (% yield) in different trial paddocks at Mt Sanford station. Average of all years in May (2001-2006).

13%	% yield	21%	% yield	23%	% yield	31%	% yield	39%	% yield	42%	% yield
Iseilema spp.	32.5%	*Iseilema spp.*	15.3%	*Dichanthium sericeum*	17.8%	*Aristida latifolia*	26.4%	*Iseilema spp.*	27.9%	*Dichanthium sericeum*	19.5%
Dichanthium sericeum	13.7%	*Aristida latifolia*	14.6%	*Iseilema spp.*	16.8%	*Astrebla spp.*	19.7%	*Aristida latifolia*	18.2%	*Aristida latifolia*	17.3%
Aristida latifolia	13.3%	*Eulalia aurea*	12.9%	*Aristida latifolia*	15.3%	*Dichanthium sericeum*	11.7%	*Dichanthium sericeum*	12.1%	*Chrysopogon fallax*	8.5%
Astrebla spp.	6.7%	*Dichanthium sericeum*	11.1%	*Astrebla spp.*	13.5%	*Chrysopogon fallax*	10.3%	Other herbs	8.0%	*Iseilema spp.*	8.2%
Chrysopogon fallax	6.6%	*Sorghum timorense*	11.0%	*Chrysopogon fallax*	7.1%	*Iseilema spp.*	4.7%	*Chrysopogon fallax*	5.8%	Other herbs	7.1%
Other herbs	6.0%	*Chrysopogon fallax*	8.6%	Other herbs	6.2%	Other herbs	4.6%	*Astrebla spp.*	5.2%	*Dichanthium fecundum*	6.2%
Dichanthium fecundum	4.7%	*Dichanthium fecundum*	5.3%	*Dichanthium fecundum*	5.6%	*Panicum decompositum*	3.1%	*Dichanthium fecundum*	3.7%	*Heteropogon contortus*	5.1%
Panicum decompositum	2.6%	Other herbs	5.0%	*Brachyachne convergens*	2.3%	*Dichanthium fecundum*	2.9%	*Flemingia pauciflora*	3.4%	*Eulalia aurea*	4.5%
Sorghum timorense	2.6%	*Astrebla spp.*	3.4%	*Panicum decompositum*	2.1%	*Enneapogon spp.*	2.6%	*Eulalia aurea*	2.4%	*Ophiuros exaltatus*	3.7%
Trichodesma zeylanicum	1.8%	*Sesbania spp.*	2.2%	*Heteropogon contortus*	1.8%	*Brachyachne convergens*	2.2%	*Brachyachne convergens*	1.9%	*Flemingia pauciflora*	3.3%
Sesbania spp.	1.4%	*Brachyachne convergens*	1.3%	*Trichodesma zeylanicum*	1.6%	*Heteropogon contortus*	1.5%	Native Legumes	1.5%	*Sorghum timorense*	3.0%
Native Legumes	1.4%	Native Legumes	1.3%	*Enneapogon spp.*	1.3%	Native Legumes	1.3%	*Corchorus sidiodes*	1.3%	*Astrebla spp.*	2.5%
Chionachne hubbardiana	1.2%	*Rhynchosia minima*	1.3%	*Gomphrena canescens*	1.2%	*Sorghum timorense*	1.0%	*Rhynchosia minima*	1.3%	*Brachyachne convergens*	2.2%
Flemingia pauciflora	0.9%	*Panicum decompositum*	1.1%	*Sesbania spp.*	1.2%	*Trichodesma zeylanicum*	1.0%	*Panicum decompositum*	1.2%	*Corchorus sidiodes*	1.6%
Rhynchosia minima	0.8%	*Tephrosia rosea*	1.0%	Native Legumes	1.2%	*Rhynchosia minima*	0.9%	*Trichodesma zeylanicum*	1.0%	Native Legumes	1.1%
Eulalia aurea	0.8%	*Enneapogon spp.*	0.9%	*Rhynchosia minima*	0.9%	*Gomphrena canescens*	0.8%	*Sesbania spp.*	0.9%	*Panicum decompositum*	1.0%
Corchorus sidiodes	0.8%	*Flemingia pauciflora*	0.8%	*Corchorus sidiodes*	0.6%	*Aristida spp.*	0.7%	*Enneapogon spp.*	0.7%	*Sehima nervosum*	0.9%
Heteropogon contortus	0.5%	*Trichodesma zeylanicum*	0.8%	*Sida spp.*	0.5%	*Corchorus sidiodes*	0.6%	*Sehima nervosum*	0.7%	*Sesbania spp.*	0.8%
Sedges	0.5%	*Corchorus sidiodes*	0.6%	*Sehima nervosum*	0.5%	Sedges	0.6%	*Tephrosia rosea*	0.5%	*Trichodesma zeylanicum*	0.7%
				Tephrosia rosea	0.5%	*Sehima nervosum*	0.5%			*Enneapogon spp.*	0.7%

3.3.1.3 Seasonal conditions

Average annual rainfall at Mt Sanford is 634mm (n=50, 1961-2010) and is strongly seasonal with 80% of annual totals typically falling between December and March.

3.3.1.3.1 Rainfall and pasture availability

Total rainfall was average to well above average during the trial (Figure 3.2, Figure 3.3). However, there was very poor growth in 2003 due to most of the rain falling towards the end of the growing season in February. This is also evident in the growth estimate (TSDM in May + estimated intake over the wet season) (Figure 3.4) where available forage (Figure 3.7) was only about 60% of most other years.

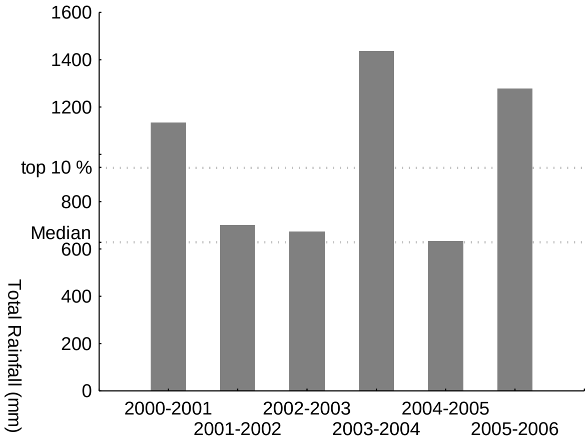


Figure 3.2. July to June rainfall at Mt Sanford, with median and 90th percentile rainfall levels highlighted for comparison.

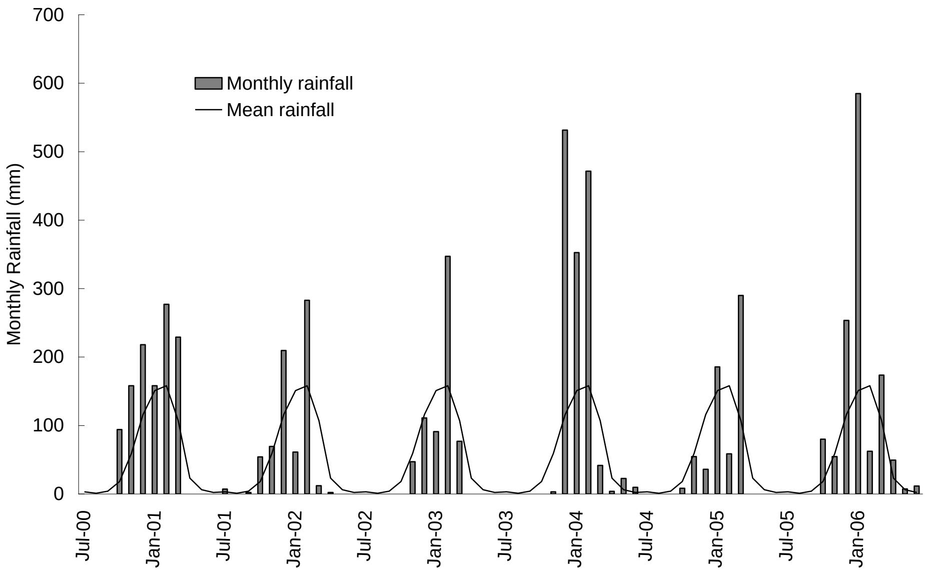


Figure 3.3. Monthly rainfall at Mt Sanford.

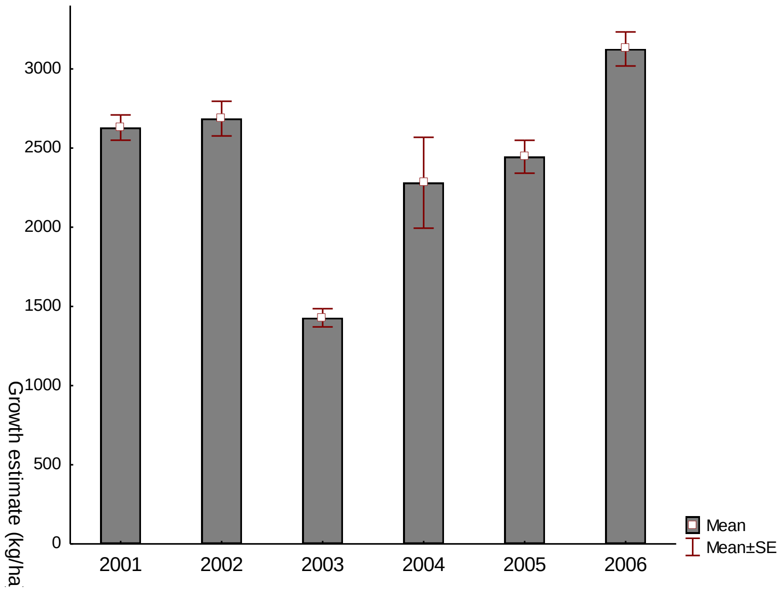


Figure 3.4. Growth estimate (kg/ha dry weight) at Mt Sanford station 2000 to 2006 (average of all treatments). Means ± standard errors.

3.3.2 Methods

3.3.2.1 Experimental design

The Mt Sanford stocking rate site was established in 1994 to investigate pasture and animal responses to stocking rate. The 1994-2000 trial had set stocking rates of 6.5, 10.5, 14 and 20.5 AE/km^2. The average estimated utilisation of pasture growth during the trial for these treatments was 7.5, 13.5, 17.5 and 22.5%. The stocking rate treatments were converted to utilisation rate treatments in 2001. Grazing management for the current experiment changed from constant stocking to constant utilisation, with animal numbers altered in May each year in response to pasture growth to achieve the desired utilisation rate. Variable stock numbers in treatment paddocks were achieved by adding or removing spayed cows to the base population of breeders. In 2002, 2003 and 2006 plant and bird diversity was also assessed in a subset of the utilisation paddocks at the site – 12, 22, 35 and 45% treatments (see Section 6.4.7 in the chapter on biodiversity).

The target utilisation rates were 12%, 16%, 22%, 28%, 35%, 45% (see Table 3.4, Figure 3.5). The Mt Sanford treatment paddocks were at a sub-commercial scale, with paddock sizes ranging from 4 to 8 km^2. Average actual utilisation rates achieved over the trial were close to target rates except for Pigeon and Quarrion paddocks which were 5 and 4% higher than target rates respectively.

Table 3.4. Summary of treatment paddocks and stocking rates used in the Mt Sanford utilisation study.

Paddock Name	Area (sq km)	Average stocking rate (AE/sq km)	Target utilisation rate (%)	Actual utilisation rate (%)*
Parrot Creek	7.6	12	12	13
Pigeon	5.9	17	16	21
Budgie	4.3	18	22	23
Wedgetail	5.0	22	28	31
Quarrion	8.0	27	35	39
Larry Mac	4.4	34	45	42

* Actual utilisation rates are used to name the treatments throughout the text from here on.

In order to achieve a constant utilisation rate, stocking rates in the experimental paddocks fluctuated with seasonal conditions during the trial (Figure 3.5, Appendix A.1, Table A.1).

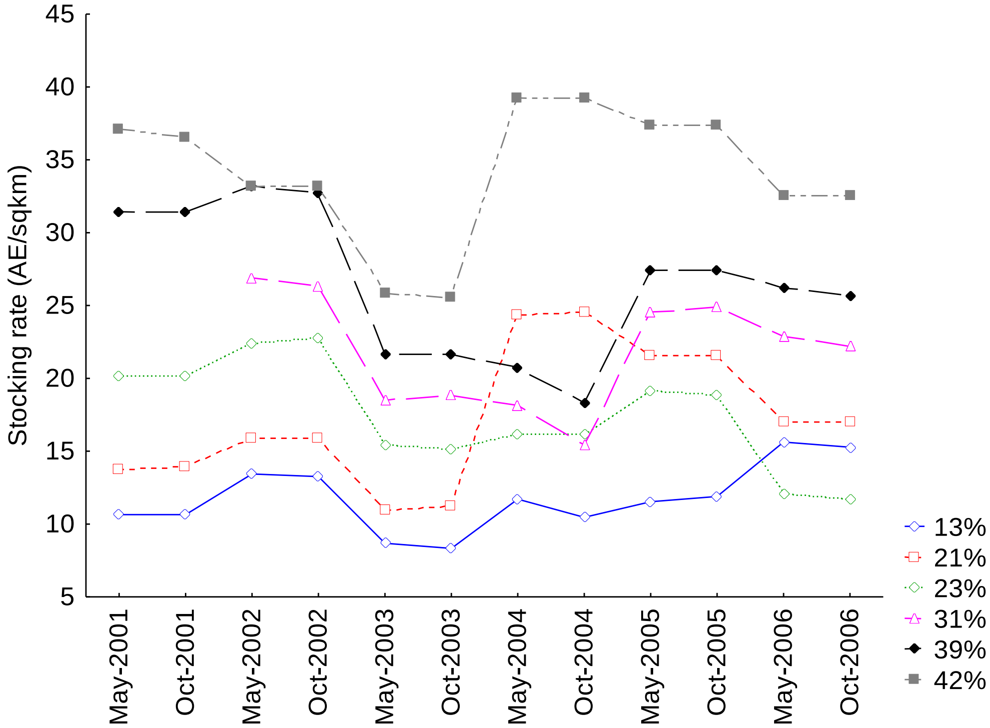


Figure 3.5. Stocking rate in utilisation treatment paddocks at Mt Sanford. Utilisation rates are average actual estimated utilisation rates.

While the average utilisation rates over the trial were equal or close to targeted utilisations, the yearly utilisation rates varied considerably (Table 3.5). For example in 2003 there was a spike in utilisation due to low pasture growth that year. Stocking rates in the target 16% and 22% utilisation paddocks appear to have been swapped for the last two years, due to incorrect animal numbers being placed in those paddocks from 2004 onwards (Appendix A.1, Table A.1).

Table 3.5. Estimated actual annual utilisation rates of annual pasture growth achieved for each target utilisation rate for treatment paddocks at Mt Sanford 2001-2006 (calculated using the method described in Section 2.6).

Target utilisation	12%	16%	22%	28%	35%	45%
2000-2001	12.4	17.4	24.4		39.0	41.2
2001-2002	12.0	17.5	23.5	32.5	40.4	44.1
2002-2003	19.9	29.5	33.3	42.0	58.4	58.9
2003-2004	10.2	14.9	20.6	31.5	35.9	35.0
2004-2005	10.5	26.0	18.6	23.1	31.2	40.4
2005-2006	12.2	19.7	15.2	23.5	30.0	34.3
Average 2001-2006	12.9	20.8	22.6	30.5	39.2	42.3

Table 3.6. Estimated actual *wet season* utilisation rates of annual pasture growth achieved for each target utilisation rate for treatment paddocks at Mt Sanford 2001-2006 (calculated using the method described in Section 2.6).

Target utilisation	12%	16%	22%	28%	35%	45%
2000-2001	6.6	9.3	13.0		21.0	22.2
2001-2002	5.6	7.8	10.4	13.8	17.6	17.8
2002-2003	10.3	14.7	16.9	20.9	30.0	27.9
2003-2004	3.9	4.2	9.2	15.1	17.2	12.4
2004-2005	4.5	12.4	7.6	8.0	11.2	18.6
2005-2006	5.5	11.4	9.6	12.8	16.0	19.0
Average 2001-2006	6.1	10.0	11.1	14.1	18.8	19.7

3.3.2.2 Breeding herd management

Breeders were mustered twice annually, at the end of the wet season and late in the dry season. Breeders were culled on barrenness (non-pregnant and non-lactating), temperament, injury or age (10 years) and were continuously mated at 4%. All breeding stock were vaccinated against C & D botulism strains at the May muster and a booster vibriosis vaccination was given to bulls at the October muster.

A minimum weaning weight of 120 kg was used at both weaning rounds in all years. Calves (progeny <120 kg) were generally castrated, branded and dehorned prior to being returned to the breeding herd.

Supplementation for N and P was provided all year round by water medication.

3.3.2.3 Data collection

Pasture sampling

Sampling design

Pastures were monitored from 10 permanent transects in each paddock marked with a star picket. Transects were placed at a range of distances from water, with the number of sites representing the proportion of black and red soil land types found within the paddock. Spinifex hills were not sampled as they were generally avoided by cattle. The first two observers walked left and right of the picket (Figure 3.6). The next two paced out 10 m in the direction away from the trough before walking a transect set at 90^{o} either left or right. Each observer assessed the pasture in a 1m^2 quadrat dropped directly in front of them every 7 paces, recording 15 quadrats per transect.

Pasture was assessed at the end of April and end of October each year.

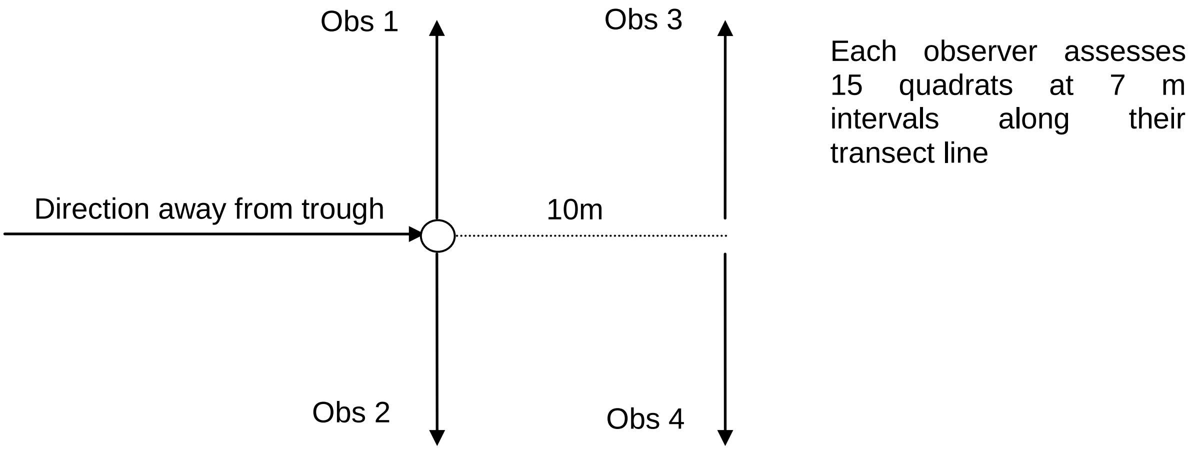


Figure 3.6. Layout of pasture measurements at each transect.

Variables

A modified Botanal method (Tothill *et al*. 1992) was used to monitor the pasture. Observations were recorded onto HP palmtop computers and included:

- Total biomass of understorey pasture ranked on a scale of 0-60;
- The six pasture species making the greatest contribution to pasture biomass. Some species were functionally grouped, such as native legumes, and some grasses were grouped according to genera.
- The percent biomass contributed by each of the top four species;
- The percentage of bare ground;
- Defoliation score, where 0 = no grazing, 1 = slight grazing, 2 = moderate grazing, 3 = heavy grazing, 4 = very heavy grazing, 5 = severe grazing.

At the end of each day of observations, biomass estimates were calibrated using 10 quadrats encompassing the full range of biomass yields on offer. These were harvested, dried at 80C for 48 hours and weighed. The equation that best fitted the observed vs. standard quadrat yields was used to correct observer yields. Data files were checked for errors prior to analysis.

Cattle data

Two musters were completed annually, usually in the months May and October with all herds being processed within a week of each other. Month of pregnancy, lactation status, body condition and live weight were recorded for all breeders at each muster. Live weight and sex were recorded for all progeny.

Month of pregnancy was determined by a trained operator via rectal palpation. To determine lactation status of breeders, udders were visually assessed and teats were stripped and the colouration of the fluid examined. The body condition of the animal was visually assessed and scored against a nine point system where 1 is emaciated and 9 over-fat (Holroyd 1978).

Live weights were recorded for all animals at the time of processing after being held overnight without feed, but with unrestricted access to water. Weights were generally recorded electronically using Tru-test or Ruddweigh weigh beams fixed beneath a weigh box. Progeny remained on their mothers prior to their live weights being recorded.

Nutrition

In order to measure the relative nutrition available to be grazed by the herds, 10-13 'indicator' steers of similar age and live weight were included in each paddock. Steers were added in May each year and replaced in May the following year. The liveweight gain of these steers was recorded at each muster to assess the impact of utilisation on liveweight gain. Faecal NIRS (Boval *et al.* 2004) was used to determine diet quality. Dung samples were collected from paddocks every three or four months throughout the year from May 2001 to May 2005.

3.3.2.4 Data analysis

Pasture

Each utilisation treatment was represented by a single paddock. Hence variables could vary significantly between paddocks as a result of inherent paddock differences. For this reason, it is the effect of utilisation treatment on change through time that was used to differentiate utilisation effects. This was assessed by the significance of the time by utilisation interaction in repeated-measures analysis of variance. Bonferroni's test was used to test post hoc differences between individual utilisation treatments. Pearson's r was used to measure correlation between variables and utilisation. Kruskal Wallis ANOVA was used to test for significant differences in dietary quality between utilisation treatments.

Cattle

Breeder liveweight was corrected for pregnancy to give empty live weight following O'Rourke *et al.* (1991). The inter-calving interval (months to calving since parturition) was estimated using pregnancy diagnosis information collected at weaning in April and October.

Breeder herd efficiency was calculated as the kilograms of weaner produced per kilogram of breeder mated.

A means model (least squares ANOVA) was used to test for utilisation and year effects for cattle parameters (Milliken & Johnson 1989) as the unreplicated treatment design within years meant that within-treatment variance was not the appropriate measure of variability with which to compare the effects of utilisation levels. Year was used as a main effect blocking variable in all models. Levene's Test and normal probability plots of standardised residuals were used to check model assumptions. Pair-wise comparisons of means were done using Bonferroni's test to determine homogeneous groups. The Type I error rate for all tests was set at the 0.05 level.

The correlation of means with utilisation was measured using Pearson's Correlation statistic (r). Spearman's Rank Order Correlation statistic (rs) was used where data were non-linearly related.

Data for 2001 was excluded from weaning rate, weaner weight and kg weaner produced per area analyses because there had not been time for treatment effects to develop.

3.3.3 Results

Twenty three percent utilisation was the optimal utilisation at Mt Sanford (Table 3.7). Above this rate, important yield and cover targets were not met, and individual animal reproduction and gain was poorest.

Table 3.7. Summary of effect of utilisation treatments on land condition and animal production per head outcomes at Mt Sanford. + = positive trend or outcome through trial, x = negative trend or outcome through trial. * Results were significantly different. No symbol denotes no consistent trend through time.

Average utilisation	13%	21%	23%	31%	39%	42%
At least 1500kg/ha in October for carrying fire (McGuffog *et al.* 2001)	+	+	+		x	x
Palatable yield in October > 230 kg to maintain intake (Littleboy & McKeon 1997)	+	+	+	+	x	x
At least 40% ground cover in October most years to reduce soil and water loss (McIvor *et al.* 1995, Scanlan *et al.* 1996)	+	+	+	x	x	x
At least 70% ground cover in October most years to maximise nutrient and water retention (Post *et al.* 2006)	+	x	x	x	x	x
Astrebla spp. yield increase*	+					
Panicum decompositum decrease*					x	x
Breeder liveweight lowest*					x	x
Weaner weight lowest*			x	x	x	x
Inter-calving interval highest*				x	x	x

3.3.3.1 Pasture

3.3.3.1.1 Yield

Yield in May fluctuated through time for all treatments, reflecting seasonal effects ($F_{5,275}$=178.91, P<0.0001, Figure 3.7). While higher utilisations tended to have lower yields in May, there was no overall significant effect of utilisation on yields ($F_{5,55}$=1.83, P=0.12). There was a significant time by utilisation effect ($F_{25,275}$=5.59, P<0.0001), so that yield in May recovered more slowly following the 2003 wet season in the higher utilisation treatments.

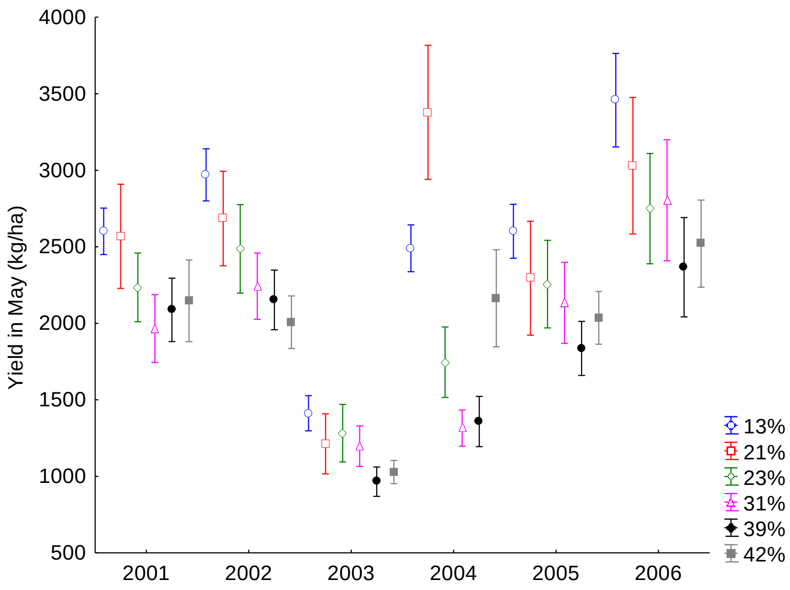


Figure 3.7. Yield in May of different utilisation rates through time at Mt Sanford. Means ± standard errors.

Yield in October did vary significantly with utilisation ($F_{5,55}$=2.803, P=0.025; Figure 3.8). Yield in October at 42% utilisation was significantly lower than yield at 13% utilisation (Bonferroni's test P=0.02). Yield in October was less than 1500 kg/ha for 39-42% utilisation in five out of six years. The yield in mid October 2003 in the 42% utilisation treatment was only about 400kg/ha. Of this less than 100kg/ha was considered palatable. Assuming cattle intake is severely limited physically at 250kg/ha this represented only 1.5 to 2 months available forage. Given the mean wet season onset at the site is late November-early December (Lo *et al.* 2007), there was a real possibility that cattle could run out of forage in this treatment. Luckily the wet season broke around mid December, but it highlighted the inherent risk of implementing 42% utilisation treatment. If the wet season had broken later, cattle would have had to be removed from the paddock or supplementary fed.

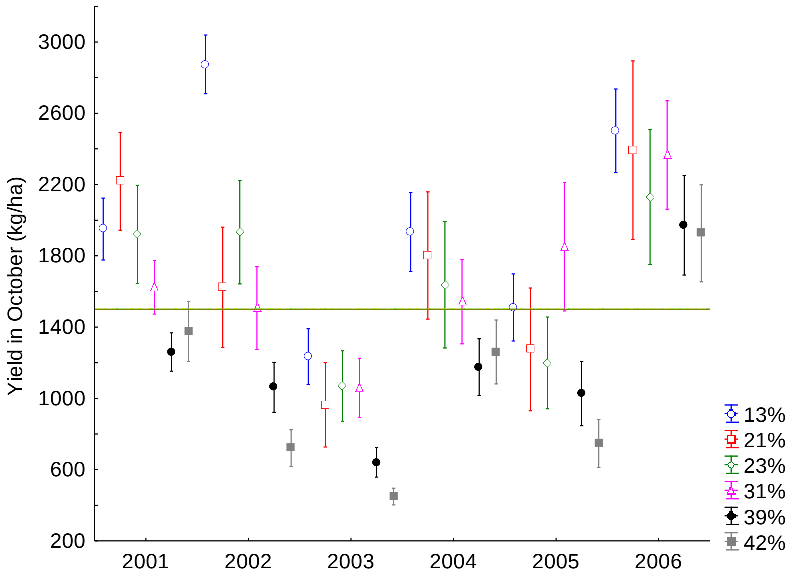


Figure 3.8. Yield in October at Mt Sanford for different utilisation treatments through time. Means ± standard errors. Line represents October yield target for fire implementation (1500 kg/ha, McGuffog *et al.* 2001).

Palatable yield

Average palatable yield was significantly lower at higher utilisation rates, reflecting higher intake (Figure 3.9, r^2 = 0.83, P=0.01, n=6). By October palatable yield was on average only 400kg/ha at 42% utilisation. The lower palatable yield in the 16% utilisation paddock reflected its poorer land condition from historical grazing impacts.

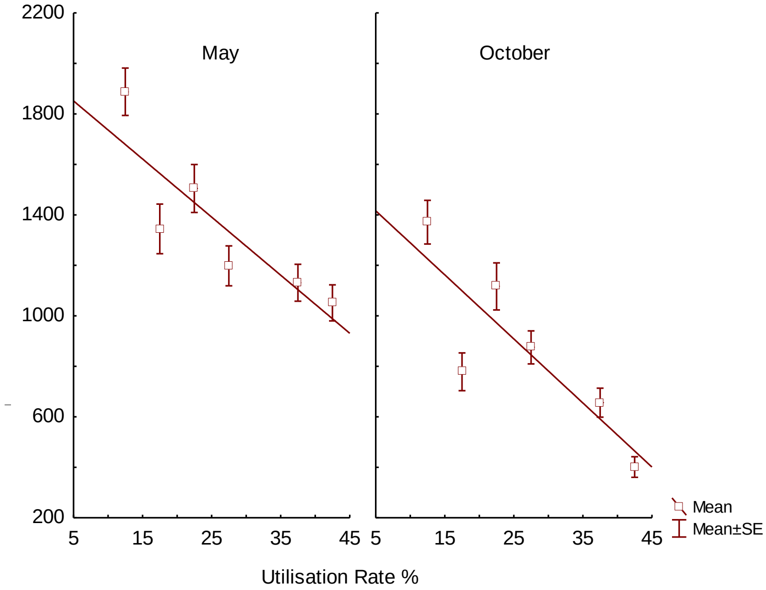


Figure 3.9. Palatable yield at Mt Sanford Station in May and October. Average of all years (2001-2006).

Palatable perennial yield

Palatable perennial yield was generally lower in the 39 and 42% treatments, although differences were not significant ($F_{5,55}$=2.112, P=0.077, Figure 3.10). Palatable perennial yield varied through time ($F_{5,275}$=33.069, P<0.0001) and there was a significant time by utilisation interaction effect on palatable yield so that palatable perennial yield increased more through time at the lower utilisation rates ($F_{25,275}$=1.576, P=0.043). By 2006, 39% utilisation had the lowest palatable perennial yield (Duncan's critical range P<0.05).

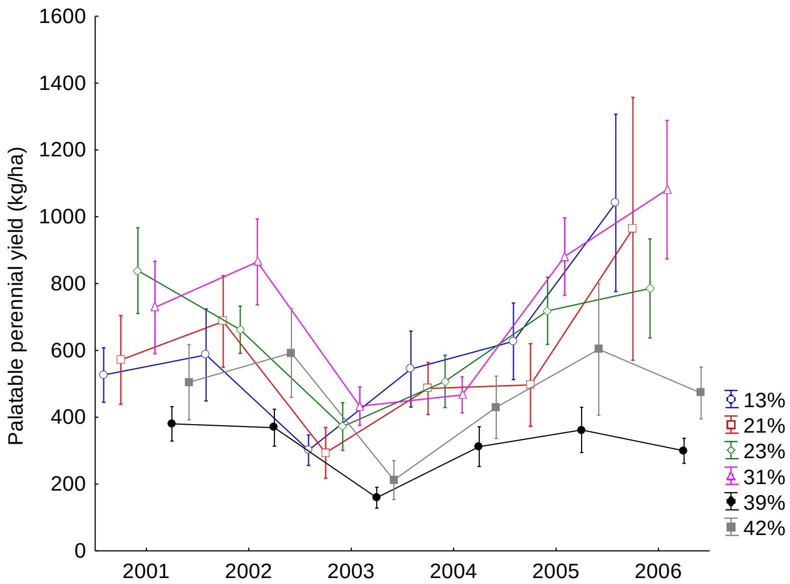


Figure 3.10. Palatable perennial yield in May through time at Mt Sanford station. Means ± standard errors.

3.3.3.1.2 Cover

Cover levels fluctuated seasonally (Figure 3.11, Figure 3.12), with less variation between utilisation treatments in the early dry than in October. Following the poor wet season in 2003, the average cover levels in October of paddocks with 31-42% utilisation were very low, averaging around 15-35%, and did not meet cover targets in 3 out of 6 years.

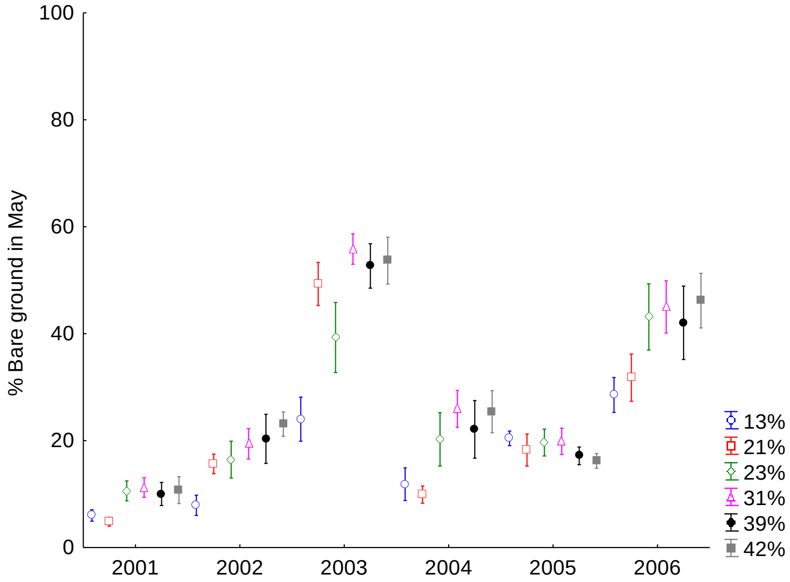


Figure 3.11. Percent bare ground for different utilisation rates through time at Mt Sanford in May. Means ± standard errors.

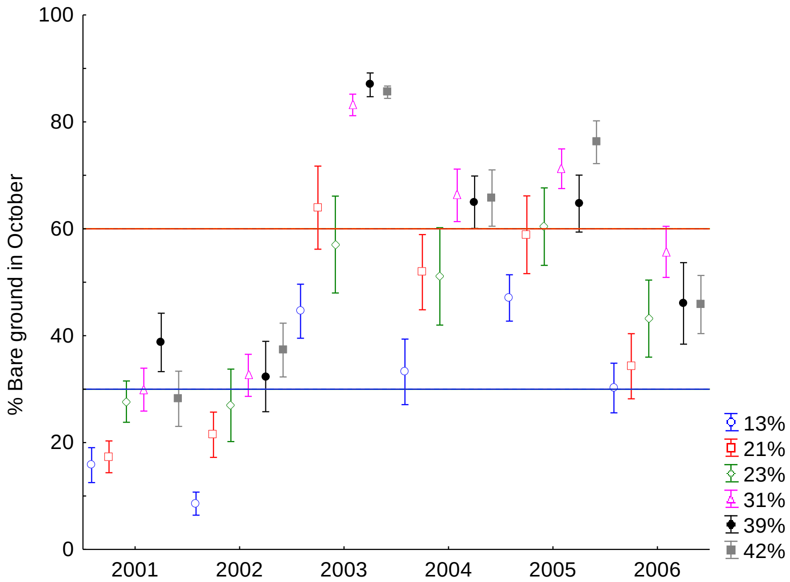


Figure 3.12. Percent bare ground for different utilisation rate treatments through time at Mt Sanford in October. Means ± standard errors. Red line represents 40% cover recommended to reduce soil and water loss (McIvor *et al.* 1995, Scanlan *et al.* 1996) and blue line represents 70% cover recommended to maximise nutrient and water retention in tussock grass pastures (Post *et al.* 2006).

3.3.3.1.3 Species frequency

There was little evidence of an effect of utilisation on plant species composition at Mt Sanford. The frequency of the dominant pasture species *Aristida latifolia*, *Astrebla* spp., *Chrysopogon fallax*, *Dichanthium sericeum* and *D. fecundum* did not significantly vary with utilisation. The only species that appeared to respond to utilisation was *Brachyachne convergens* (Fig. 3.13), which was lowest ($F_{5,55}$ = 2.69, P= 0.03) and fluctuated least ($F_{5,275}$ = 17.96, P<0.0001) at 12% utilisation. *B. convergens* increased more through time at 39 and 42% utilisation levels ($F_{25,275}$ = 3.05, <0.0001).

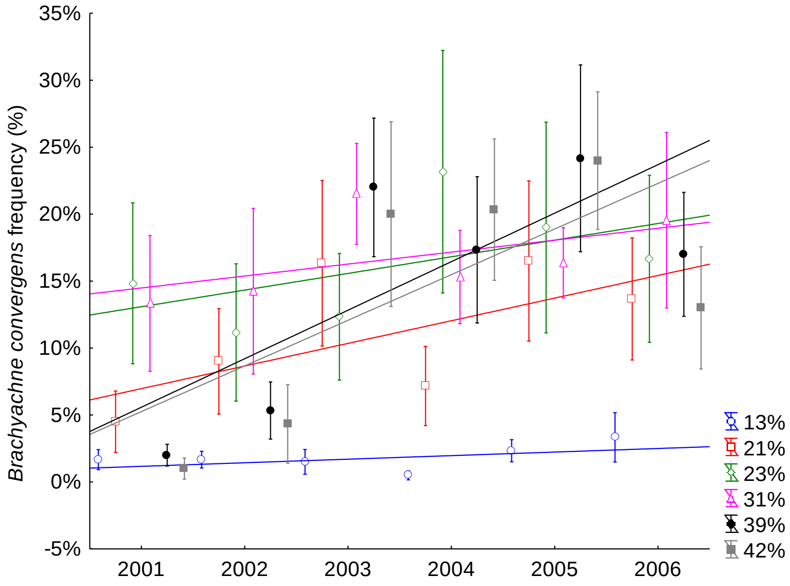


Fig. 3.13. Change in frequency of *Brachyachne convergens* frequency through time with utilisation at Mt Sanford. Means ± standard errors. Lines are linear best fit.

3.3.3.1.4 Species yield

Only *Astrebla* spp., *Brachyachne convergens* and *Panicum decompositum* yield showed any trend through time that was indicative of a response to utilisation treatments imposed (Table 3.8, Figure 3.14, Figure 3.15). *Brachyachne* yield responded similarly to *Brachyachne* frequency, increasing more through time at higher utilisation rates.

Table 3.8. Effect of utilisation treatment and time plant species yield in May at Mt Sanford. Repeated Measures ANOVA. * P< 0.05, **P<0.01, *** P<0.001. [a] ln (x+1) transformation applied to the dependent variable.

Variable	Utilisation	Time	Time * utilisation interaction
Aristida latifolia yield		***	***
Astrebla spp. yield	*	***	***
Brachyachne convergens yield[a]	**	***	***
Chrysopogon fallax yield		***	
Iseilema spp. yield[a]	***	***	***
Panicum decompositum[a]		***	**

Astrebla spp. yield was significantly lower at 42% utilisation than 23-31% utilisation (Duncan's critical range P<0.05) and increased more through time at 13% utilisation, so that by 2005, 39 and 42% utilisation treatments had significantly lower *Astrebla* spp*.* yield than 13% (Duncan's critical range P<0.05, Figure 3.14).

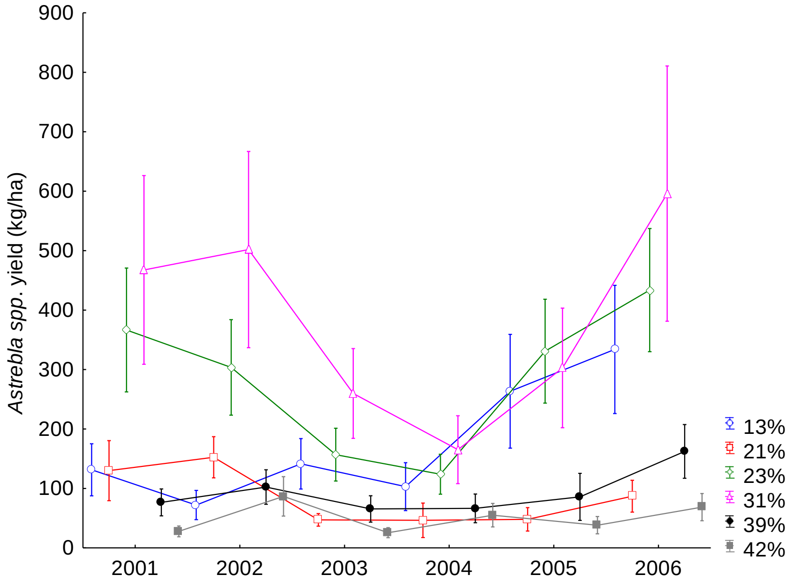


Figure 3.14. *Astrebla* spp. yield in May at Mt Sanford Station through time for different utilisation treatments. Means ± standard errors.

Panicum decompositum yield decreased most through time in 39 and 42% utilisation treatments, so that by 2006, 39 and 42% utilisation rate had significantly lower *Panicum decompositum* yield than 13, 23 and 31% utilisation (Duncan's critical range test P<0.05, Figure 3.15).

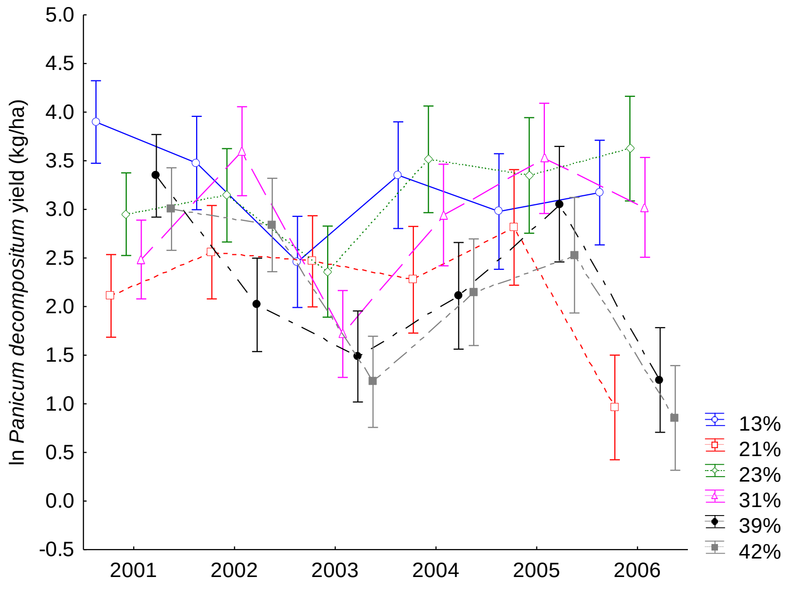


Figure 3.15. Change in *Panicum decompositum* yield in May through time for utilisation treatments at Mt Sanford station. Means ± standard errors.

3.3.3.2 Animal Production

3.3.3.2.1 Diet quality

The average (across the duration of the trial) diet quality as measured by NIRS (dietary crude protein content (CP), dry matter digestibility (DMD) and CP:DMD ratio) did not differ between utilisation treatments between 2002-2004, (Figure 3.16, Figure 3.17, Figure 3.18).

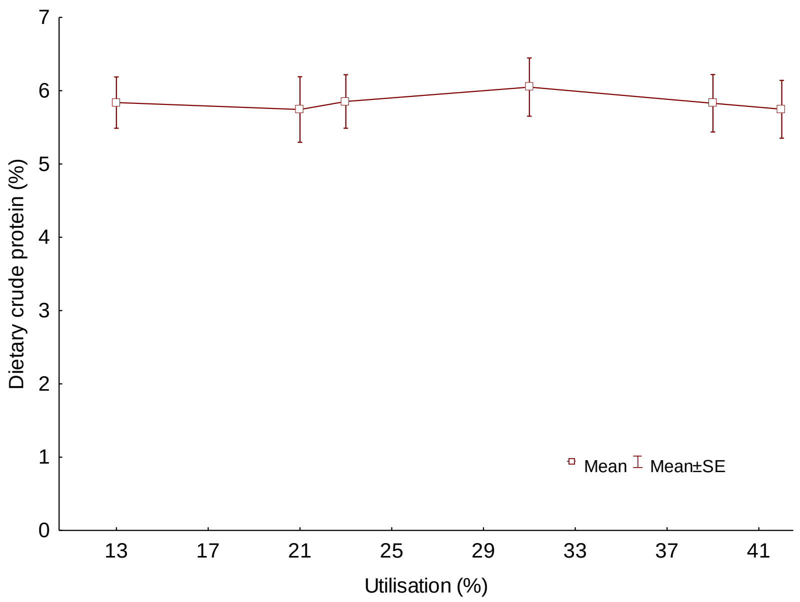


Figure 3.16. Dietary crude protein in different utilisation paddocks at Mt Sanford.

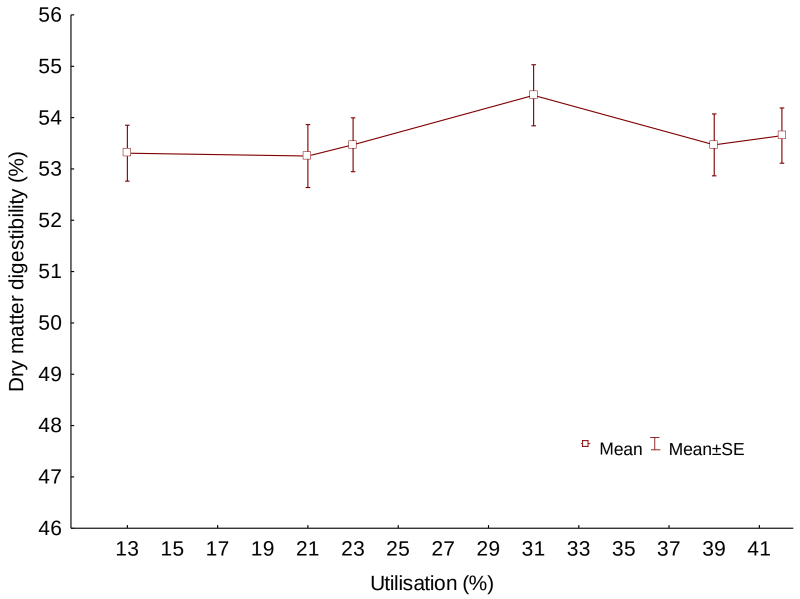


Figure 3.17. Dry matter digestibility of diet in different utilisation paddocks at Mt Sanford.

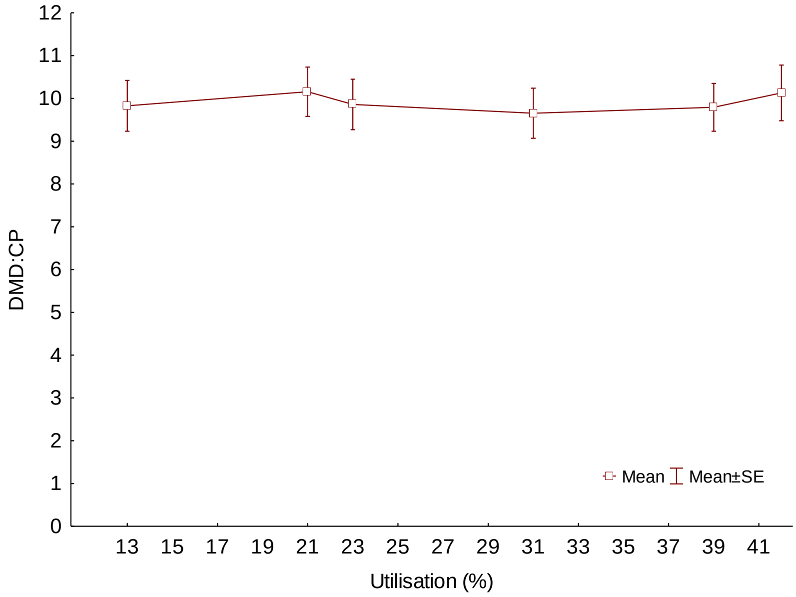


Figure 3.18. Ratio of dry matter digestibility to crude protein in different utilisation paddocks at Mt Sanford. DMD:CP >10 response to urea highly likely, DMD:CP>8 probable response to urea.

Diet quality fluctuated seasonally at Mt Sanford. Although missing data leaves extensive gaps in our understanding of forage quality during the trial (Figure 3.19 - Figure 3.21), the data for 2002 suggests crude protein was particularly limiting in that year and that diet quality was highest in 2003.

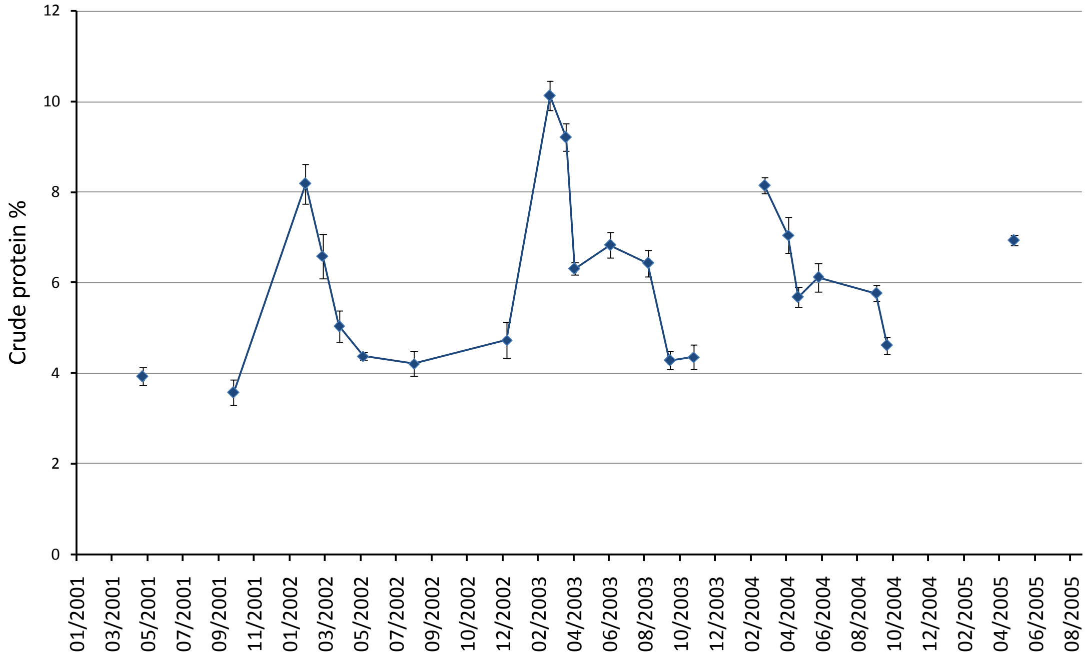


Figure 3.19. Seasonal fluctuation in estimated dietary crude protein of cattle in utilisation paddocks at Mt Sanford. Average of all utilisation paddocks. Means ± standard errors.

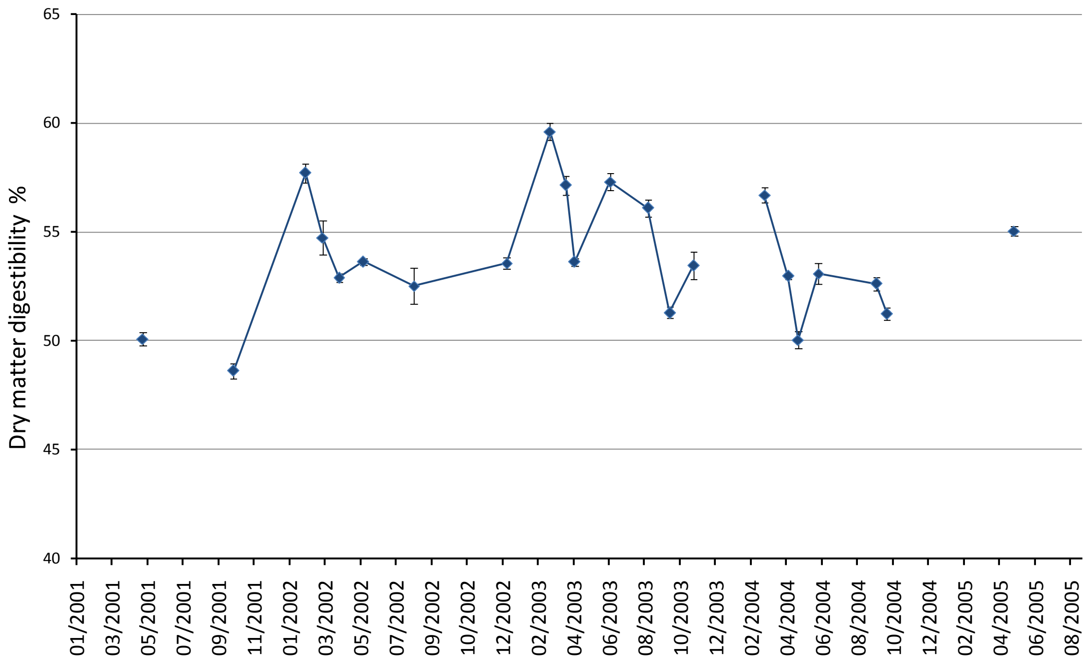


Figure 3.20. Seasonal fluctuation in estimated dietary dry matter digestibility of cattle in utilisation paddocks at Mt Sanford. Average of all utilisation paddocks. Means ± standard errors.

DMD:CP ratio suggests urea supplementation was likely to elicit a response most of the time at Mt Sanford (Figure 3.21).

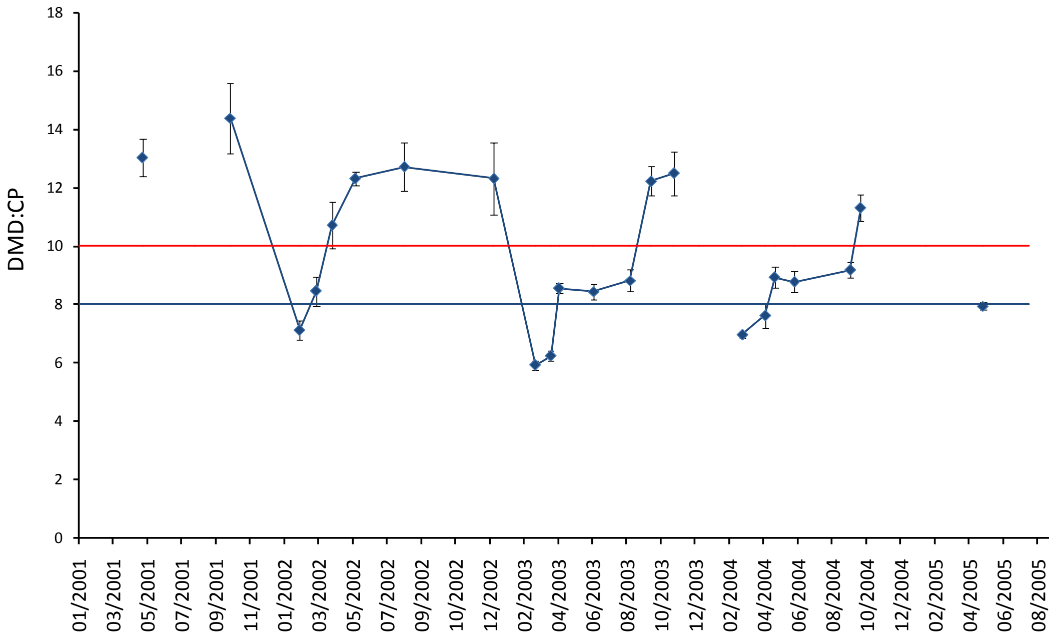


Figure 3.21. Seasonal fluctuation in the dietary ratio of dry matter digestibility to crude protein of cattle at Mt Sanford. Average of all utilisation paddocks. DMD:CP >10 response to urea highly likely, DMD:CP>8 probable response to urea. Means ± standard errors.

3.3.3.2.2 Growth

3.3.3.2.2.1 Indicator steer live weight gain

Average daily live weight gain (LWG) was significantly lower at higher utilisations (Figure 3.22, Spearman's r=-0.94, P<0.005, n=6). This relationship varied between years (Figure 3.23), and LWG was only significantly correlated with utilisation in 2004 and 2005 (r=-0.84 P<0.05 and r=-0.98, P<0.05 respectively). Liveweight gain was significantly lower in 2002 and 2004 than 2001, 2003 and 2005 (Bonferonni test, P<0.05, df=17).

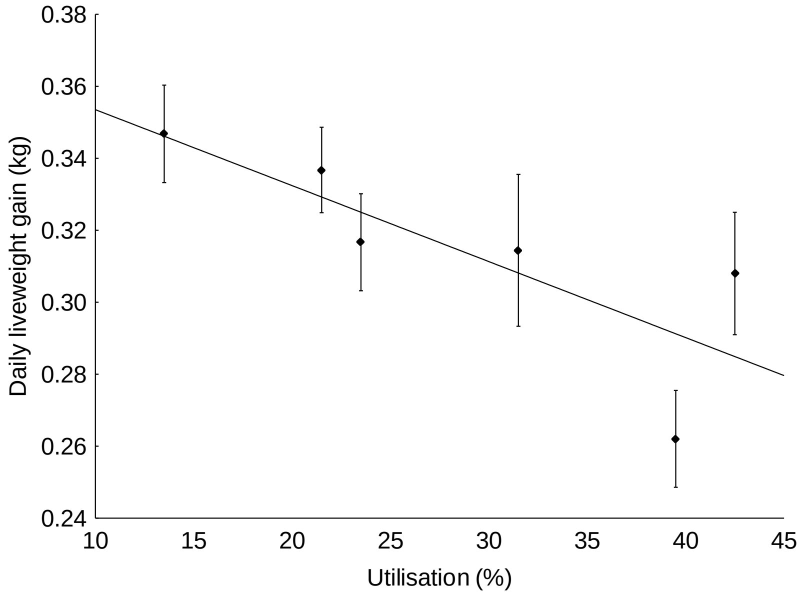


Figure 3.22. Average daily live weight gain with utilisation at Mt Sanford (2003-2005). Means ± standard errors.

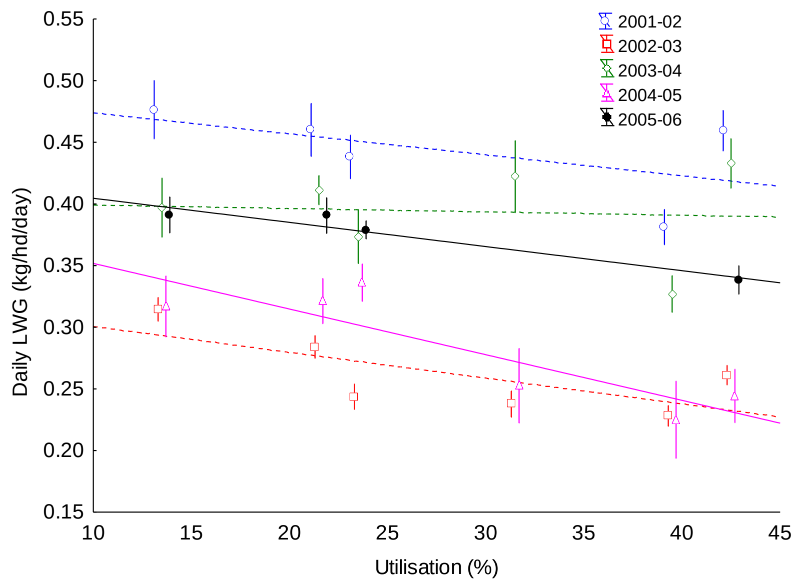


Figure 3.23. Daily live weight gain versus utilisation relationships through time at Mt Sanford. Dashed lines indicate fit not significant. Means ± standard errors.

3.3.3.2.2.2 Breeder weight

Breeders were significantly heavier in April than in October, 452 vs. 392 kg ($P<0.0001$, $F=152$, $df=1$). The average empty liveweight of breeders was negatively correlated with utilisation rate (Spearman's $r=-0.83$, $P<0.05$, $n=6$, Figure 3.24).

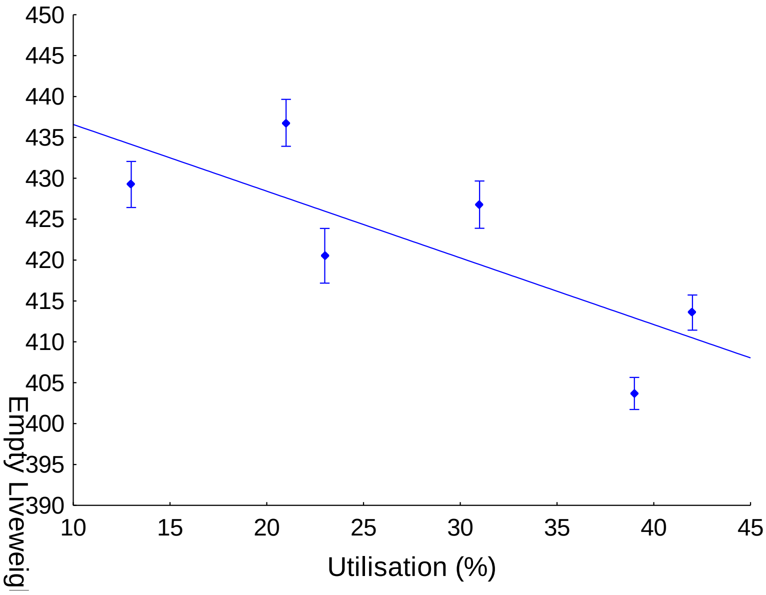


Figure 3.24. Effect of utilisation rate on average breeder weight at Mt Sanford (2002-2006). Means ± standard errors.

Unlike LWG, the relationship between breeder weight and utilisation didn't vary much between years (Figure 3.25). Average empty liveweight of breeders was higher in the last three years of the trial ($P=0.04$, $F=2.55$, $df=5$).

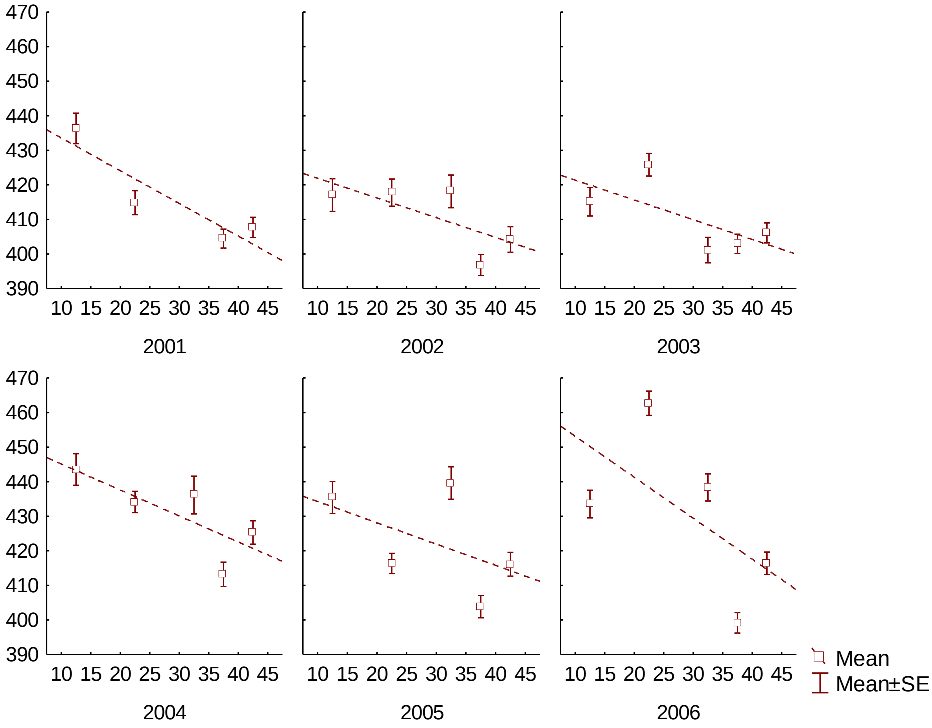


Figure 3.25. Breeder weight versus utilisation through time at Mt Sanford station. Dashed lines indicate fits not significant.

3.3.3.2.2.3 Weaner weight

The average weight of weaning round 1 calves was significantly heavier than weaning round 2 calves (189 vs. 173kg) (p<0.05, F=6.6, df=1). Weaners from lower utilisation rates (<22% utilisation) were on average 15 kg heavier than those weaned at higher utilisation rates (>22% utilisation) (t=4.36, df=4, p=0.01) (Figure 3.26).

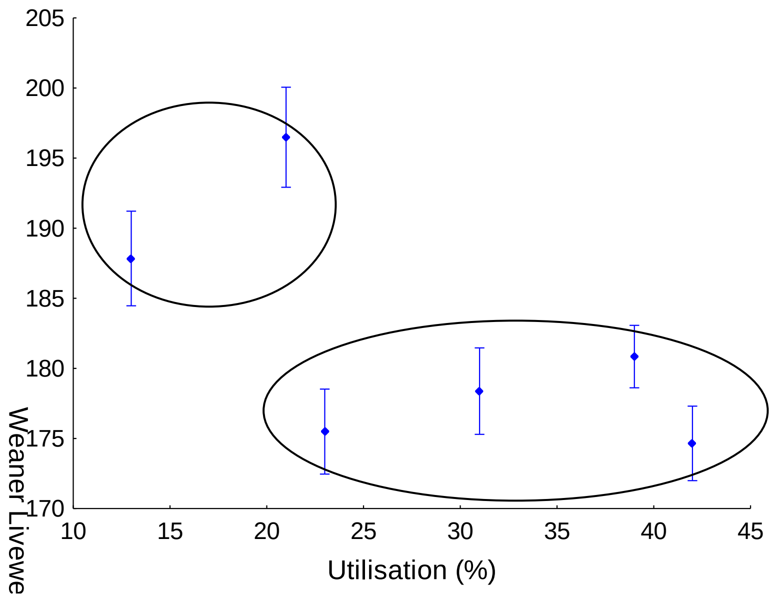


Figure 3.26. Effect of utilisation rate on average weaning weight at Mt Sanford (2003-2006). Means ± standard errors. Circled groups were significantly different.

However the impact of utilisation on weaner weight varied through time (Figure 3.27) and was most evident in the dry year of 2003.

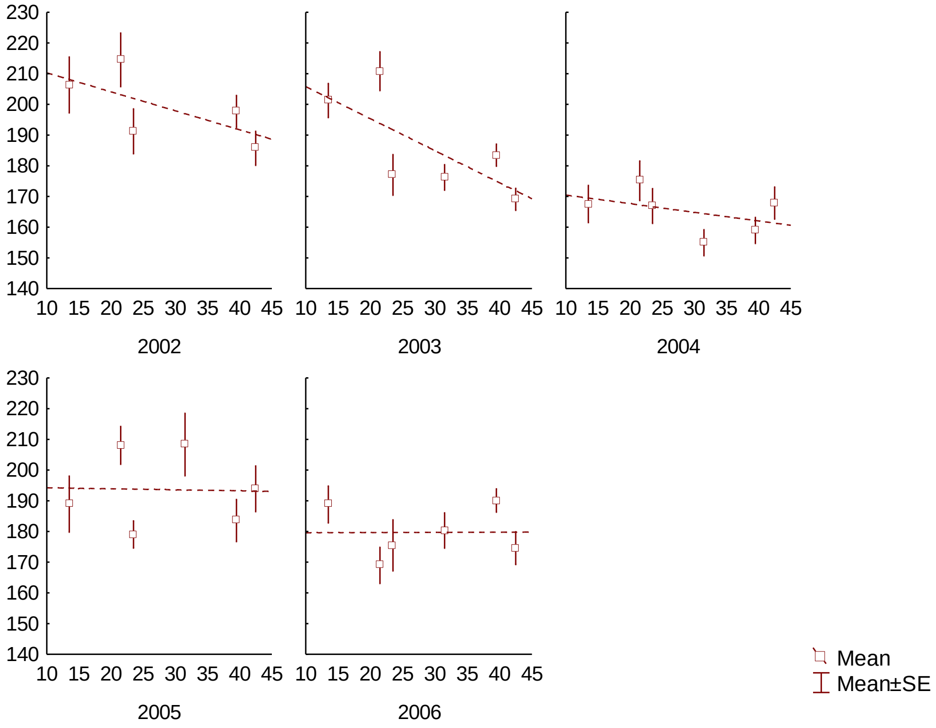


Figure 3.27. Weaner weight versus utilisation by year at Mt Sanford station. Dashed lines indicate fit not significant.

3.3.3.2.3 Fertility

3.3.3.2.3.1 Weaning Rate

Average weaning rate declined only slightly, but significantly with utilisation (Spearman's r=-0.83, P=0.04, n=6, Figure 3.28).

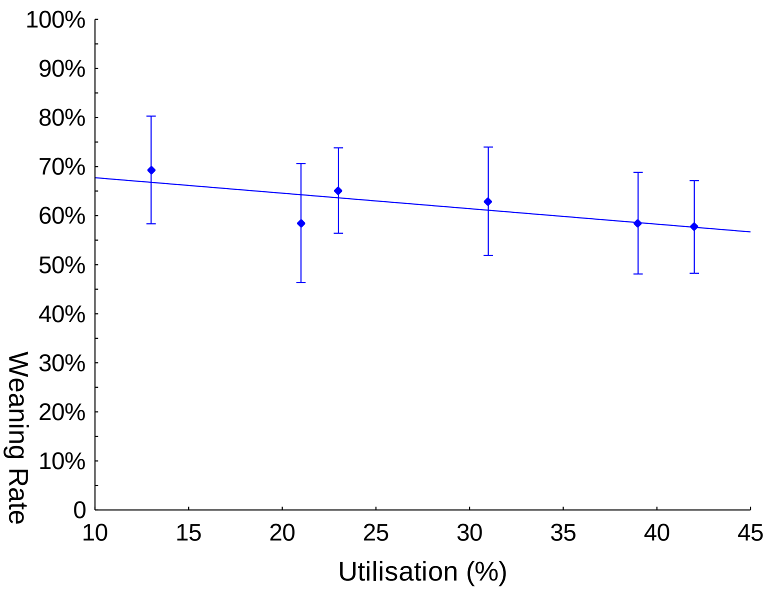


Figure 3.28. Effect of utilisation rate on average weaning rate 2002-2005 at Mt Sanford station. Means ± standard errors.

Weaning percentage varied through time (Figure 3.29). At the beginning of the trial in 2002 and 2003 weaning percentage was initially high and did not vary with utilisation rate. However following the very poor wet season of 2002/2003, weaning percentage generally dropped at higher utilisation levels in 2004 and across all utilisations (except the 23% utilisation treatment) in 2005. The 2006 weaning rate vs. utilisation trend was the inverse of 2005, as paddocks with poor weaning percent in 2005 had higher weaning the following year and vice versa. The out of season calving pattern caused by the previous dry years, resulted in fluctuating year to year weaning percentages that lasted for the duration of the trial.

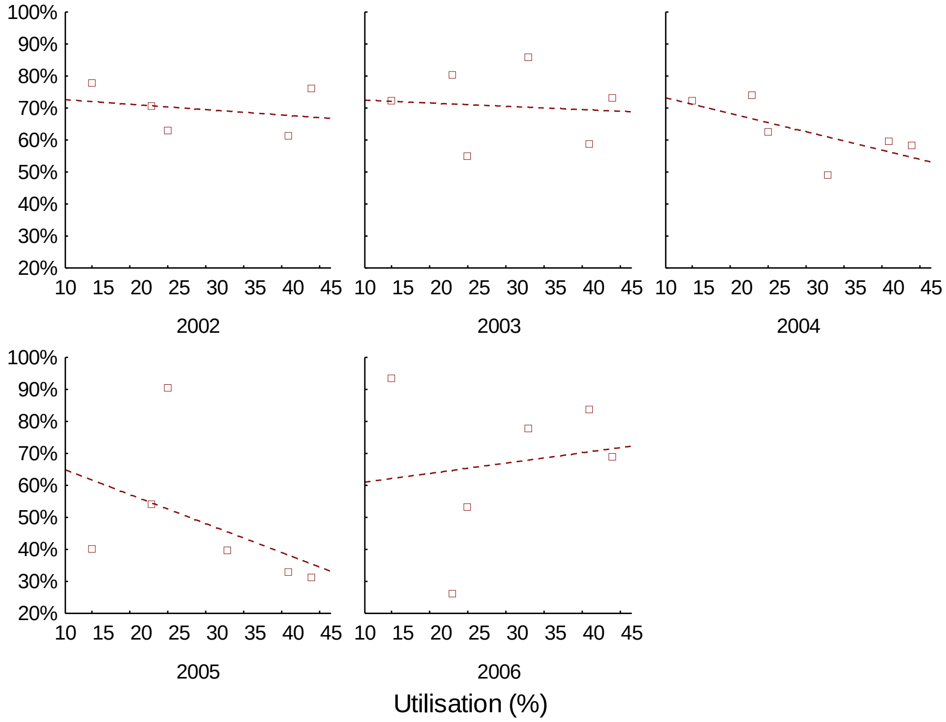


Figure 3.29. Weaning rate versus utilisation at Mt Sanford station. Dashed lines indicate fit not significant.

3.3.3.2.3.2 Inter-calving interval

Average inter-calving interval (ICI) was significantly correlated with utilisation (Pearson's r= 0.85, P=0.03, n=6, Figure 3.30), and higher utilisation treatments (> 25% utilisation) had a 1.5 month longer inter-calving interval than lower utilisation treatments (14.6 vs. 16.1 months, t=-4.44, df=4, p=0.01), indicating conception was delayed at higher utilisation rates. Only in 2003 was average ICI significantly correlated with higher utilisation (Pearson's r=0.86, p<0.05, n=6). Average inter-calving interval varied between years (F=8.26, p<0.001, df=4) and was 1 to 2 months longer in 2002 and 2004 (Bonferonni test P<0.05, df=19) than 2001 and 2005.

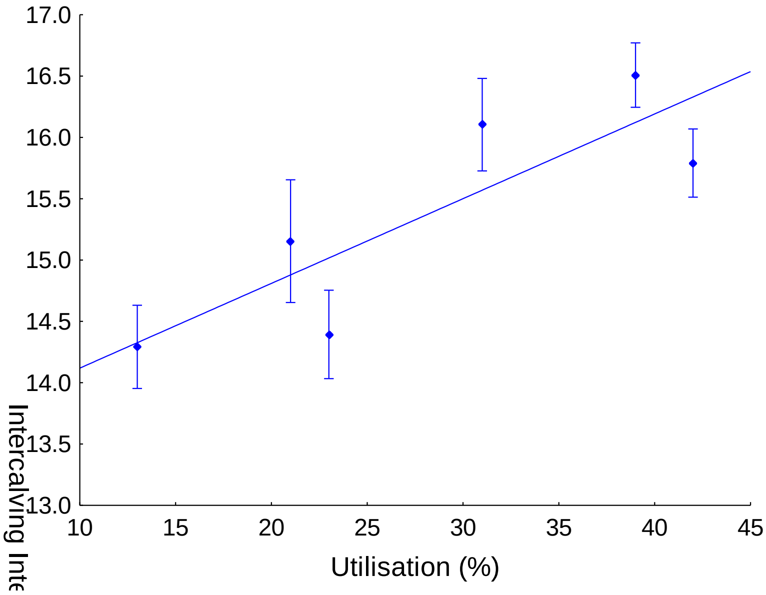


Figure 3.30. Effect of utilisation rate on average inter-calving interval at Mt Sanford station (2002-2005). Means ± standard errors.

3.3.3.2.4 Production parameters

3.3.3.2.4.1 Breeding Herd Efficiency

Average breeding herd efficiency (kg of weaner weaned per 100 kg of breeder mated), was lower at higher utilisations (Pearson's r=-0.86, P<0.05, n=6)(Figure 3.31).

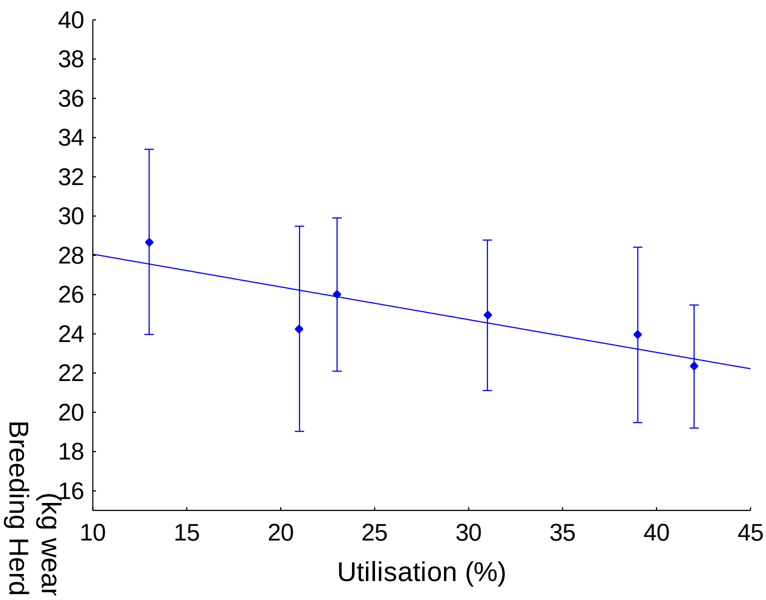


Figure 3.31. Effect of utilisation rate on average breeding herd efficiency at Mt Sanford (2002-2005). Means ± standard errors.

3.3.3.2.4.2 Weight weaned per unit land area

Despite lower breeder herd efficiency at higher utilisation rate, the average kilograms weaned per unit area (kg/km^2) increased with utilisation rate (Pearson's r=0.98, P<0.001, n=6) (Figure 3.32). The reduction in individual production per head with increasing utilisation meant that increasing utilisation by a factor of three (from 15 to 45%) increased production per area by a factor of 2.5.

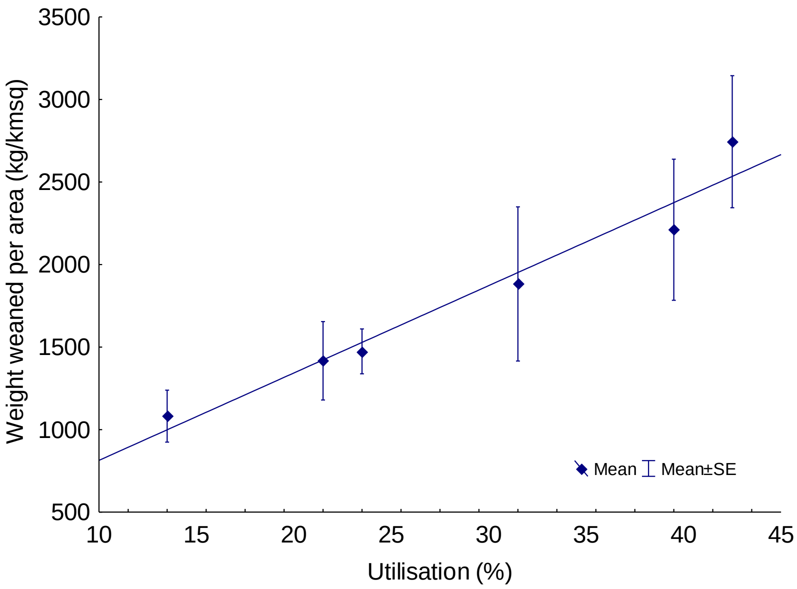


Figure 3.32. Effect of utilisation rate on average kilograms of weaner produced per square kilometre (kg/km^2) 2002-2006.

Production was more variable through time at higher utilisation rates (Figure 3.33). Weaner production per area was initially significantly higher with higher utilisation rates in 2001-2003 (Table 3.9, Figure 3.33), but following the poor wet season of 2003, weaner production per area fell across all treatments, and by 2005 there was no additional weaner production per area with increasing utilisation rate. In 2006 weaner production increased for utilisation rates up to 39%, but not beyond. The slope of the fit for each year (b in Table 3.9) suggests that following a dry year the relative efficiency of production with the additional animals in the high utilisation paddocks was reduced compared to good years. This is due to a combination of a dampened weaning percentage and weaning weight at higher utilisation rates following the low growth 2002/2003 wet season.

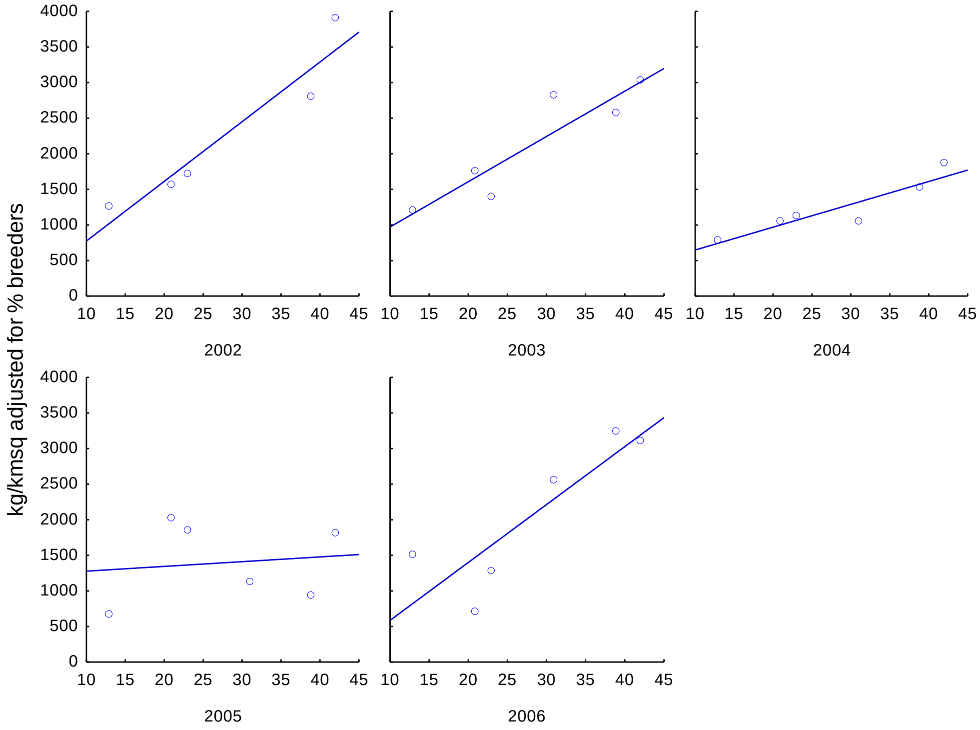


Figure 3.33. Weaner production average utilisation at Mt Sanford. Dashed lines indicate fit not significant.

Table 3.9. Summary of linear regression of weaner production versus utilisation for each year at Mt Sanford Station. B is the slope of the linear regression. Intercept was set to 0.

Year	n	b	Std. Err. of b	p-level
2002	5	82	16	0.00009
2003	6	74	16	0.00002
2004	6	42	7	0.00002
2005	6	45	10	0.006
2006	6	74	7	0.0001
Average (2003-2006)	6	54	3	0.0005

3.3.3.2.5 Economics of utilisation levels

There was no trend in earnings before interest and tax (EBIT) per AE with increasing utilisation at Mt Sanford (Table 3.10). EBIT ranged between $67-$77 per AE. The increasing turnoff with higher stock numbers in higher utilisation paddocks, lead to increasing EBIT per unit area at higher utilisation rates, despite modest decline in individual animal performance at higher utilisations.

Table 3.10. Economics of the different utilisation rates at Mt Sanford station.

Utilisation (%)	13	21	23	31	39	42
Stocking Rate (AE/kmsq)	12	17	18	22	27	34
Replacement Capital	$ 70,567	$ 70,567	$ 70,567	$ 70,567	$ 70,567	$ 70,567
Fixed Costs	$ 273,664	$ 273,664	$ 273,664	$ 273,664	$ 273,664	$ 273,664
Direct Costs	$ 546,238	$ 663,293	$ 677,568	$ 766,820	$ 882,370	$1,041,420
Total Operating	$ 890,469	$1,007,523	$1,021,799	$1,111,050	$1,226,601	$1,385,651
Livestock Revenue	$2,135,081	$2,603,167	$2,963,017	$3,493,023	$3,783,636	$4,831,399
Total Revenue	$2,156,471	$2,624,557	$2,984,407	$3,514,413	$3,805,026	$4,852,789
EBIT	$1,122,406	$1,439,692	$1,761,466	$2,165,485	$2,316,328	$3,134,736
EBIT $/AE	$72	$67	$76	$77	$68	$74
EBIT $/km^2	$787	$1,010	$1,235	$1,519	$1,624	$2,198
ROIC	5.5%	6.5%	7.8%	9.1%	9.1%	11.3%
Branding Percentage	71%	59%	67%	64%	59%	56%
Herd Mortality	1%	1%	1%	1%	1%	1%
Breeders	6,072	9,179	9,306	11,553	14,578	18,666
Total Herd	15,496	21,364	23,042	27,980	33,931	42,413
Sale Cows	759	1,147	1,163	1,444	1,822	2,333
Sale Steers	2,055	2,578	2,968	3,524	4,094	4,977
Sale heifers	1,189	1,269	1,642	1,877	2,016	2,317
Total sale kg	1,397,632	1,735,134	1,955,418	2,315,436	2,545,549	3,249,819
Production (kg sold/km^2)	1,070	1,329	1,497	1,773	1,949	2,488

3.4 Pigeon Hole

The utilisation trial at Pigeon Hole was similar to Mt Sanford, testing the effect of a range of utilisation rates on land condition and animal production. It differed from Mt Sanford in paddock size. The paddocks were larger at 20km^2, which was thought to be more representative of the commercial scale when fully developed in the region.

3.4.1 Paddock characteristics

Although Pigeon Hole utilisation paddocks were all within the Wave Hill land system (Stewart *et al.* 1970), they varied somewhat in land type and species composition (Table 3.11, Table 3.12). In particular the 17 and 19% utilisation paddocks had lower proportions of black soil and higher proportions of intermediate and red soil types. The 17% treatment was further separated from the other paddocks by the unusually high contribution of *Eulalia* to the sward, reflecting the large areas of pebbly gilgai in this paddock. Multi-dimensional scaling analysis also confirmed that the 17% utilisation paddock was quite distinct in species composition compared to the other treatments (Figure 3.45). *Sehima* also featured prominently in 17 and 19% utilisation paddocks, reflecting areas of red rocky soil.

Table 3.11. Percent of different land types in utilisation paddocks at Pigeon Hole station.

Utilisation treatment	13%	17%	19%	24%	32%
black soil	91	68	67	81	82
intermediate	3	19	15	7	7
creek line	1	2	2	2	2
riparian	4	5	7	9	8
red soil	1	6	8	1	1

3.4.1.1 Vegetation

Pigeon Hole utilisation paddocks were dominated by *Sorghum timorense* (40% (of average total yield in May)), *Aristida latifolia* (9%) and *Chrysopogon fallax* (9%) although composition varied between paddocks (Table 3.12). Palatable yield varied from 25-45% for the different paddocks.

Land condition was similar between utilisation paddocks in May 2003 (Table 3.13). Paddocks were mostly in C condition due to the low perennial grass basal area and high proportion of annuals (predominantly *Sorghum timorense*).

Table 3.12. Species composition of utilisation treatment paddocks in May at Pigeon Hole station. (Average of 2003-2007).

13%	%	17%	%	19%	%	24%	%	32%	%
Sorghum timorense	46.1%	*Sorghum timorense*	36.7%	*Sorghum timorense*	44.4%	*Sorghum timorense*	38.6%	*Sorghum timorense*	31.7%
Iseilema species	12.0%	*Eulalia aurea*	13.3%	*Aristida latifolia*	12.4%	*Chrysopogon fallax*	12.1%	*Aristida latifolia*	10.9%
Aristida latifolia	8.6%	*Sehima nervosum*	11.6%	*Chrysopogon fallax*	7.8%	*Aristida latifolia*	8.6%	*Chrysopogon fallax*	10.5%
Chrysopogon fallax	7.2%	*Chrysopogon fallax*	8.1%	*Sehima nervosum*	5.8%	*Iseilema species*	6.6%	*Iseilema species*	10.4%
Flemingia pauciflora	5.2%	*Flemingia pauciflora*	5.4%	*Iseilema species*	5.6%	*Eulalia aurea*	5.3%	*Sesbania species*	9.1%
Panicum decompositum	3.5%	*Dichanthium fecundum*	5.3%	*Flemingia pauciflora*	4.9%	*Sesbania species*	4.8%	*Flemingia pauciflora*	5.2%
Sesbania species	2.5%	*Sesbania species*	4.2%	*Sesbania species*	3.6%	*Flemingia pauciflora*	4.7%	*Eulalia aurea*	3.9%
Astrebla species	2.3%	*Aristida latifolia*	4.0%	*Panicum decompositum*	3.1%	*Dichanthium fecundum*	3.6%	*Dichanthium fecundum*	2.8%
Sehima nervosum	2.1%	*Iseilema species*	1.7%	*Dichanthium fecundum*	1.9%	*Sehima nervosum*	2.7%	*Panicum decompositum*	1.9%
Wedelia asperrima	2.0%	*Panicum decompositum*	1.3%	*Astrebla species*	1.8%	*Panicum decompositum*	1.7%	*Wedelia asperrima*	1.6%
Jacquemontia browniana	1.6%	*Eriachne obtusa*	1.1%	*Trichodesma zeylanicum*	1.3%	*Triodia species*	1.3%	*Sehima nervosum*	1.5%
Dichanthium fecundum	1.3%	*Astrebla species*	1.0%	*Jacquemontia browniana*	1.1%	*Astrebla species*	1.3%	*Astrebla species*	1.4%
Eulalia aurea	1.1%	*Jacquemontia browniana*	0.9%	Other herbs	1.0%	*Jacquemontia browniana*	1.3%	*Trichodesma zeylanicum*	1.4%
Other herbs	0.7%	*Dichanthium sericeum*	0.9%	*Wedelia asperrima*	0.9%	Other herbs	1.2%	*Jacquemontia browniana*	1.3%
Trichodesma zeylanicum	0.6%	Other herbs	0.9%	*Tephrosia rosea*	0.8%	Other perennial grasses	0.8%	Other herbs	1.1%
Cyperus species	0.5%	Other perennial grasses	0.5%	*Cyperus species*	0.8%	*Eriachne obtusa*	0.8%	*Brachyachne convergens*	1.0%
Dichanthium sericeum	0.5%	Other annual grasses	0.4%	*Brachyachne convergens*	0.7%	*Wedelia asperrima*	0.7%	*Cyperus species*	0.9%
Rhynchosia minima	0.4%	*Brachyachne convergens*	0.4%	*Phyllanthus maderaspatensis*	0.5%	Other annual grasses	0.6%	*Phyllanthus maderaspatensis*	0.9%
Phyllanthus maderaspatensis	0.4%	*Rhynchosia minima*	0.4%	*Rhynchosia minima*	0.5%	*Trichodesma zeylanicum*	0.5%	*Tephrosia rosea*	0.5%
Brachyachne convergens	0.3%	Other native legumes	0.3%	Other annual grasses	0.4%	*Brachyachne convergens*	0.5%	*Dichanthium sericeum*	0.4%
Tephrosia rosea	0.3%	*Wedelia asperrima*	0.3%	*Alysicarpus muelleri*	0.3%	*Rhynchosia minima*	0.4%	*Rhynchosia minima*	0.4%
Alysicarpus muelleri	0.2%	*Triodia species*	0.3%	*Eulalia aurea*	0.3%	*Cyperus species*	0.4%	Other annual grasses	0.4%
Other perennial grasses	0.2%	*Trichodesma zeylanicum*	0.2%	Other native legumes	0.1%	*Tephrosia rosea*	0.4%	Other perennial grasses	0.3%
Other annual grasses	0.2%	*Cyperus species*	0.2%	*Dichanthium sericeum*	0.1%	*Dichanthium sericeum*	0.4%	Other native legumes	0.2%
Other native legumes	0.1%	*Tephrosia rosea*	0.2%	Other perennial grasses	0.0%	Other native legumes	0.3%	*Alysicarpus muelleri*	0.2%
		Phyllanthus maderaspatensis	0.1%			*Phyllanthus maderaspatensis*	0.3%		
		Alysicarpus muelleri	0.1%			*Alysicarpus muelleri*	0.2%		
		Other grasses	0.1%			Other grasses	0.1%		

Table 3.13. Proportion of utilisation paddocks in different land condition classes in May 2003 at Pigeon Hole Station. Average condition score is a weighted average of productive value of different condition classes, ranging from 2-10. i.e. condition score of 13% utilisation = 4%*10 + 19%*8 + 73%*5.5 + 4%*2 = 6.0.

Utilisation %	A	B	C	D	Average condition score (/10)
Reduction in growth due to condition	10/10	8/10	5.5/10	2/10	
13	4%	19%	73%	4%	6.0
17	3%	26%	68%	4%	6.1
19	5%	24%	70%	1%	6.3
24	3%	21%	71%	5%	6.0
32	4%	29%	64%	2%	6.3

3.4.2 Methods

3.4.2.1 Experimental design

There were five utilisation treatments (target 15-40%) in unreplicated paddocks of around 21km^2 (Table 3.14).

Table 3.14. Summary of treatment paddocks and animals used in the Pigeon Hole utilisation study. Average over 2004 to 2007.

Paddock name	Area (sq. km)	Average stocking rate (AE/sq km)	Target utilisation rate (%)	Average actual utilisation rate (%)
Brolga	21	11	15	13
Sandstone	21	14	20	17
Bauhinia	21	15	25	19
Villiers	22	17	30	24
Dead Cat	20	21	40	32

Cattle numbers were adjusted each year based on standing pasture biomass at the end of the wet season (See **Error! Reference source not found.**, Figure 3.34, Figure 3.34). Adjustments were also made throughout the year as animals became available or in response to fires.

Stocking rates were not adjusted to match utilisation treatments until August 2004. After this time, the 13% utilisation paddock consistently had the lowest stocking rate but, until October 2006, stocking rate was not proportional to target utilisation. This was partly due to fires in the 32% and 24% treatments which reduced available forage in 2004-2005. This meant that stocking rates didn’t need to be very high to achieve a high level of utilisation during this time (Figure 3.34).

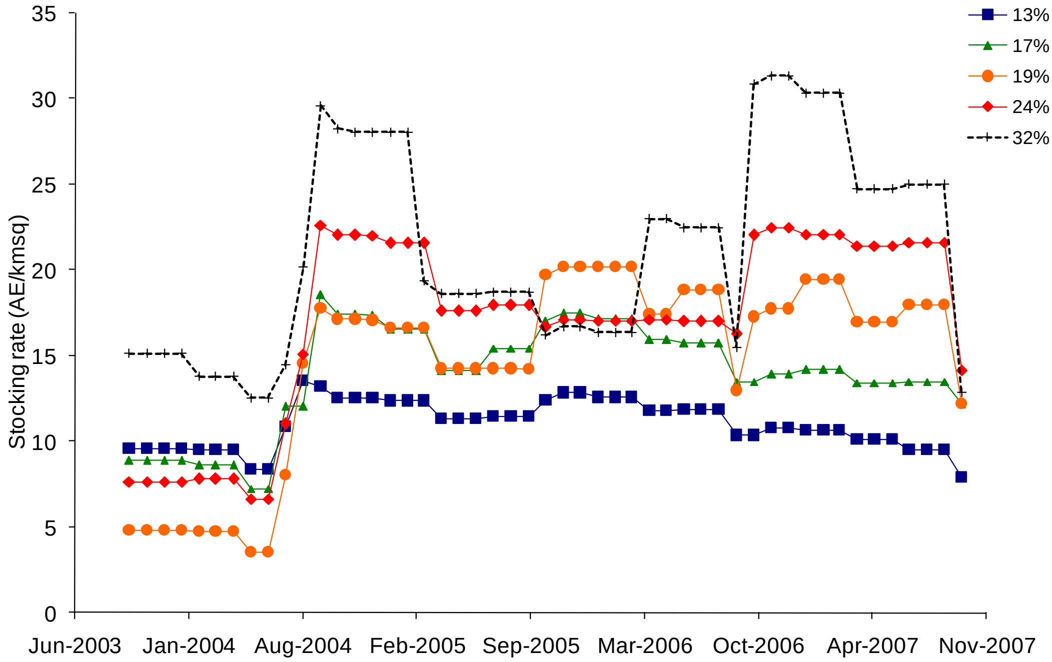


Figure 3.34. Stocking rates for Pigeon Hole utilisation treatments through time.

Despite variable stocking to try to achieve set utilisation levels, there was wide variation in utilisation between years (Table 3.15, Table 3.16). In particular 2004 utilisations were only about half target utilisations, because stocking rates were not set high enough in better seasons (See section **Error! Reference source not found.**). For an estimate of 2003 utilisations see Appendix C. For an explanation of how utilisation rates were estimated see Section 2.6.

Table 3.15. Estimated annual utilisation of annual pasture growth for Utilisation treatments by year at Pigeon Hole station.

Treatment	2004	2005	2006	2007	Average	st. dev
U15%	11	12	17	14	13	4
U20%	11	15	22	20	17	5
U25%	11	17	24	23	19	8
U30%	15	27	24	30	24	7
U40%	23	43	29	35	32	7

Table 3.16. Estimated *wet season* utilisation of annual pasture growth for Utilisation treatments by year at Pigeon Hole station.

Treatment	2004	2005	2006	2007	Average	st. dev
U15%	4	6	8	7	7	2
U20%	4	7	11	9	8	3
U25%	2	8	12	11	10	6
U30%	4	13	10	14	12	5
U40%	8	22	11	18	15	6

3.4.2.2 Data collection

See general methods section **Error! Reference source not found.** for detailed data collection and analysis methods for utilisation treatments at Pigeon Hole.

3.4.2.3 Data analysis

Land condition score was given a numeric rating for data analysis. A=10, B=8, C=5.5, D=2. The weighted average of each paddock and date was calculated, based on the number of quadrats with each condition score.

Pearson's r was used to test for significant correlations between mean variables and utilisation.

Selection index was calculated following Andrew (1986a) using the average yield and defoliation in October over the period of the trial.

3.4.3 Results

19% utilisation was the optimal utilisation rate at Pigeon Hole (Table 3.17). Above this level of utilisation, important yield and cover targets were not met, and weaner weight per head was lowest.

Table 3.17. Summary of effect of utilisation treatments on land condition and animal production indices at Pigeon Hole station. + - positive trend or outcome through trial, x - negative trend or outcome through trial. * Results were significantly different. No symbol denotes there was no consistent trend through time.

Average utilisation	13%	17%	19%	24%	32%
At least 1500 kg/ha in May to carry fire (McGuffog *et al.* 2001)				x	x
At least 40% ground cover in October most years to reduce soil and water loss (McIvor *et al.* 1995, Scanlan *et al.* 1996)	+	+			x
At least 70% ground cover in October most years to maximise nutrient and water retention (Post *et al.* 2006)	+	+		x	x
Greater decline in land condition score through time*					x
Palatable yield in October >230 kg to maintain intake (Littleboy and McKeon 1997)			x	x	x
Greatest decline in October grass basal area*					x
Change in % perennial grass*	+	+	x	+	x
Astrebla yield increase (highest but not significant)	+				
Sorghum yield increase more at higher utilisation*			x	x	x
Calf loss lowest*	+		+		
Weaner weight lowest in May 2004 and 2005*					x

Summary
- 13-17% utilisation had positive or stable species composition and cover trends and values, suggesting these rates are sustainable
- 32% utilisation had the greatest decline in land condition, species composition was negatively trending and appeared to be at higher risk of dangerously low cover levels
- 24% utilisation didn't meet yield and cover targets

3.4.3.1 Utilisation effects on land condition indices

There was a tendency for the proportion of quadrats in B condition to decline more through time in higher utilisation paddocks (Appendix C.1, Figure C.1). Average condition score declined slightly in all paddocks, but the decline was greatest in higher utilisation paddocks (Pearson's correlation P<0.05, r=-0.89, n=5) (Figure 3.35).

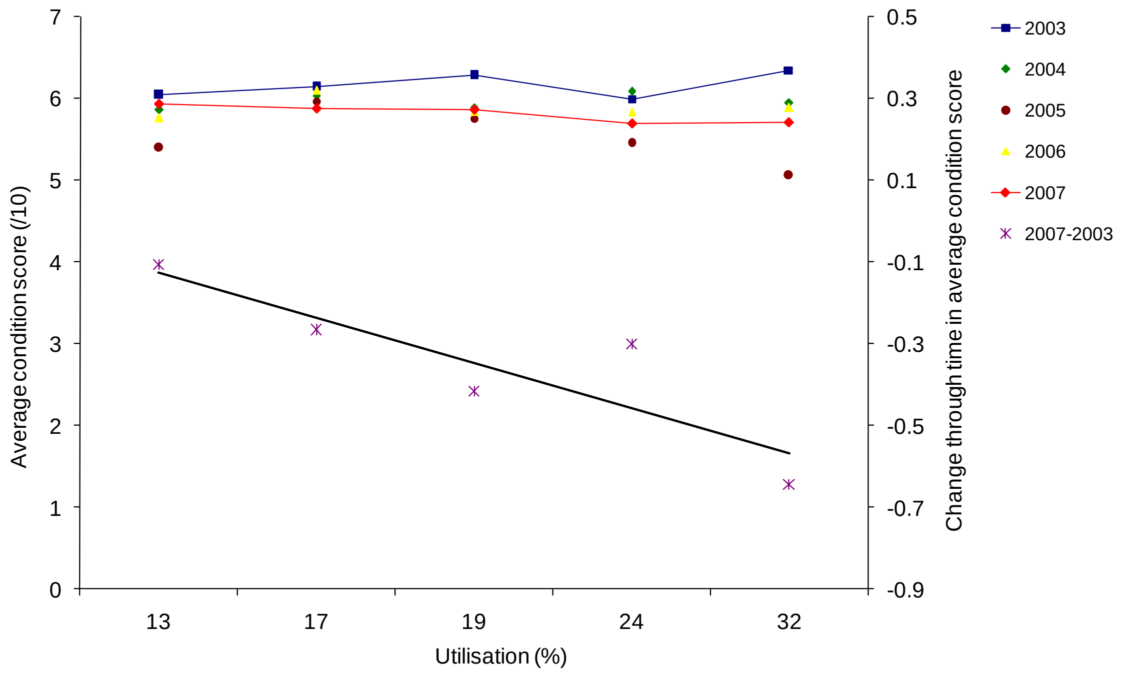


Figure 3.35. Change in average condition score through time in utilisation paddocks at Pigeon Hole station. For clarity only 2003 (start) and 2007 (end) points are joined by a line. 2007-2003 points and line show the change through time in condition score at each utilisation.

Yield, defoliation, cover and perennial grass basal area all differed significantly between years and treatments and there was a significant time by treatment interaction (Table 3.18 - Table 3.21, Figure 3.36 - Figure 3.44), although this often represented individual paddock idiosyncrasies, rather than a response to utilisation. The 400 ha biodiversity exclosure is shown for visual comparison as a 0% utilisation, although this treatment was not included in statistical analyses. 2005 was an anomalous year for yield and cover, as fires went through 24% and 32% utilisation during the 2004-2005 wet season, which resulted in much lower than usual cover and yield in these treatments in 2005 (Appendix C.2, Figure C.2 - Figure C.3).

Table 3.18. Results of the Repeated Measures ANOVA for the utilisation treatments for May pasture data from 2003-2007. *** = P<0.001, ** = P<0.01, * = P<0.05, NS = not sig.

	Yield	Defoliation	Perennial Grass Basal Area	Cover
Utilisation	***	**	***	***
Year	***	***	***	***
Utilisation*Year	***	***	*	***

Table 3.19. Results of the Repeated Measures ANOVA for the utilisation treatments for October pasture data from 2003-2007. *** = P<0.001, ** = P<0.01, * = P<0.05, NS = not sig.

	Yield	Defoliation	Perennial Grass Basal Area	Cover
Utilisation	***	***	***	***
Year	***	***	***	***
Utilisation*Year	***	***	***	***

Differences through time corresponded with variation in rainfall. Higher utilisation was generally correlated with higher defoliation and lower cover and yield, although trends were often slight, which may reflect the often similar defoliations between treatments (Table 3.20). Grass basal area was not correlated with utilisation (Figure 3.36).

Table 3.20. Effect of utilisation on average yield, cover and defoliation at Pigeon Hole station. Pearson's correlation, n=5, *P<0.05. Treatments with different letters denote significantly different treatments (LSD).

Utilisation (%)	May yield	October yield	May cover	October cover	May defoliation	October defoliation
13	2081a	1634a	75.2a	72a	5a	16a
17	2131a	1712a	69.77b	65b	7a	14a
19	1852b	1330b	75.24a	66b	12b	21b
24	1771bc	1330b	64.65c	57c	10b	23b
32	1600c	1171b	62.8c	55c	11b	31c
Pearson's r	-0.92*	-0.86 ns	-0.86 ns	-0.94*	0.71 ns	0.94*

Defoliation

Variation in defoliation between utilisation treatments was greatest in the drier years of 2003 and 2005 (Table 3.21, Figure 3.37 - Figure 3.38). Estimated defoliation was least correlated with estimated level of paddock utilisation in 2003 when the highest defoliation was in the 19% utilisation paddock, prior to trial implementation. Hence estimated defoliation is probably a better measure of relative utilisation between treatments for 2003. However from 2004 to 2007 average estimated defoliation correlated reasonably well with average estimated utilisation (Figure 3.36).

Table 3.21. Estimated defoliation in May and October for different utilisation treatments at Pigeon Hole station.

Utilisation treatment	Month	2003	2004	2005	2006	2007	Average all years 2003-2007
13%	May	6	2	6	5	8	5
	Oct	17	10	19	14	19	16
17%	May	6	3	8	8	9	7
	Oct	9	8	19	17	17	14
19%	May	31	2	10	7	9	12
	Oct	35	12	22	14	20	21
24%	May	14	3	15	7	13	10
	Oct	27	12	32	17	28	23
32%	May	13	5	16	7	14	11
	Oct	30	21	54	21	33	32

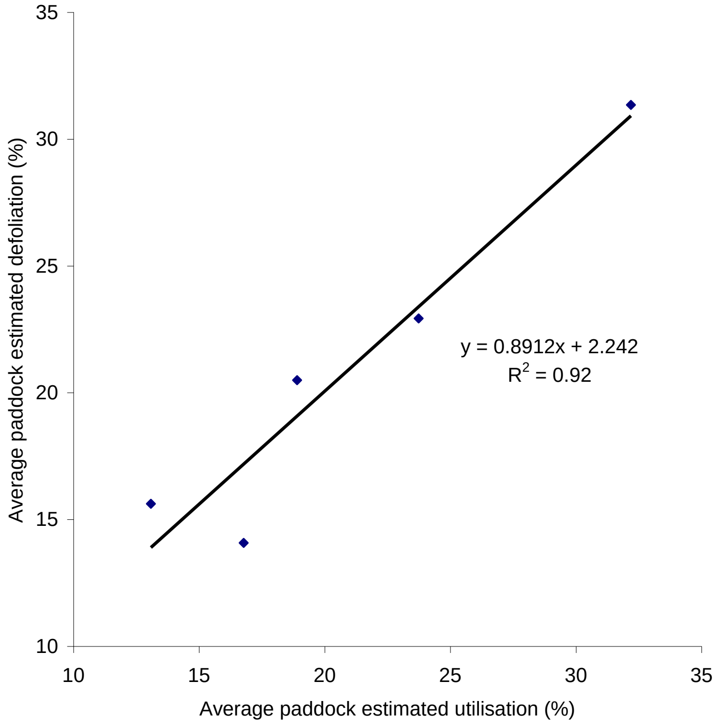


Figure 3.36. Average estimated paddock utilisation correlated well with average paddock estimated defoliation in October in the Pigeon Hole utilisation paddocks from 2004-2007.

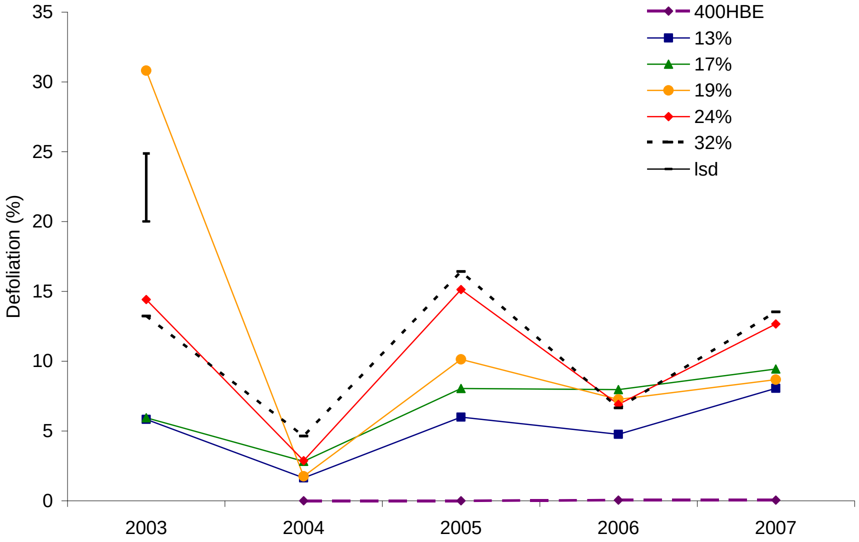


Figure 3.37. Estimated defoliation in May through time for different utilisation treatments at Pigeon Hole station. Bar shows least significant difference.

The slight defoliation in the 400 ha biodiversity exclosure is likely to be due to macropods.

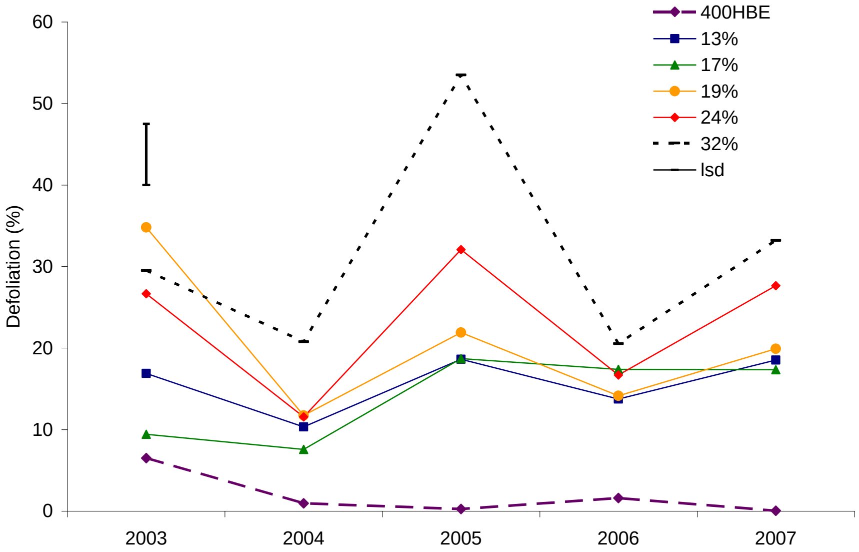


Figure 3.38. Estimated defoliation in October through time for different utilisation treatments at Pigeon Hole station. Bar shows least significant difference.

Yield

There was little evidence that higher utilisation rates were limiting potential pasture growth, as average yields in May varied little between utilisation treatments in 2006 and 2007 (Figure 3.39).

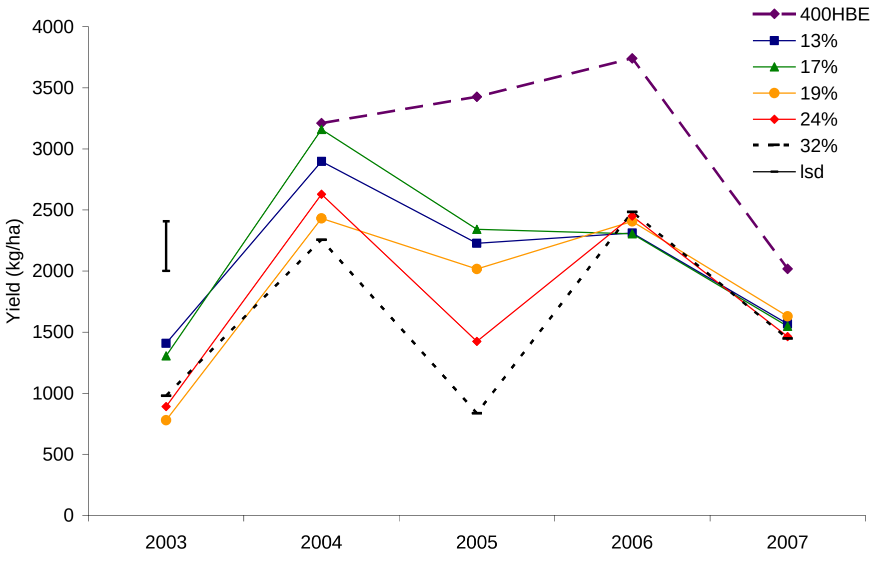


Figure 3.39. Yield in May through time for different utilisation treatments at Pigeon Hole station. Bar shows least significant difference.

By October lower yields were evident in higher utilisation rates, reflecting higher off-take in these paddocks (Figure 3.40). Total yield was less than needed to implement fire (1500 kg/ha) in May and October for 24 and 32% utilisation paddocks (Figure 3.39 - Figure 3.40).

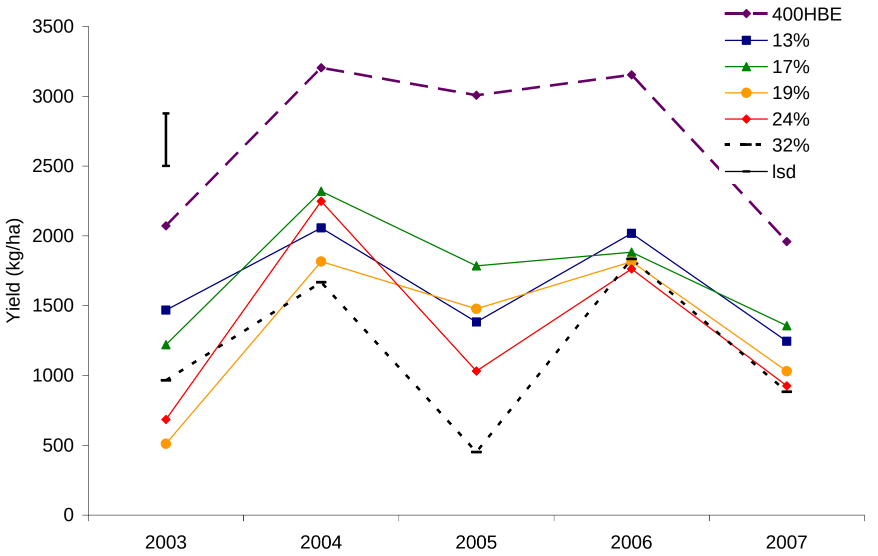


Figure 3.40. Yield in October through time for different utilisation treatments at Pigeon Hole station. Bar shows least significant difference.

Cover

There was little variation in ground cover between utilisation treatments in 2004 and 2006 (Figure 3.41 - Figure 3.42). There was also little variation in ground cover between seasons at Pigeon Hole. Even at the highest utilisation levels average cover did not fall below 40% in the late dry season, except in 2005 following fires in the 32% utilisation treatment.

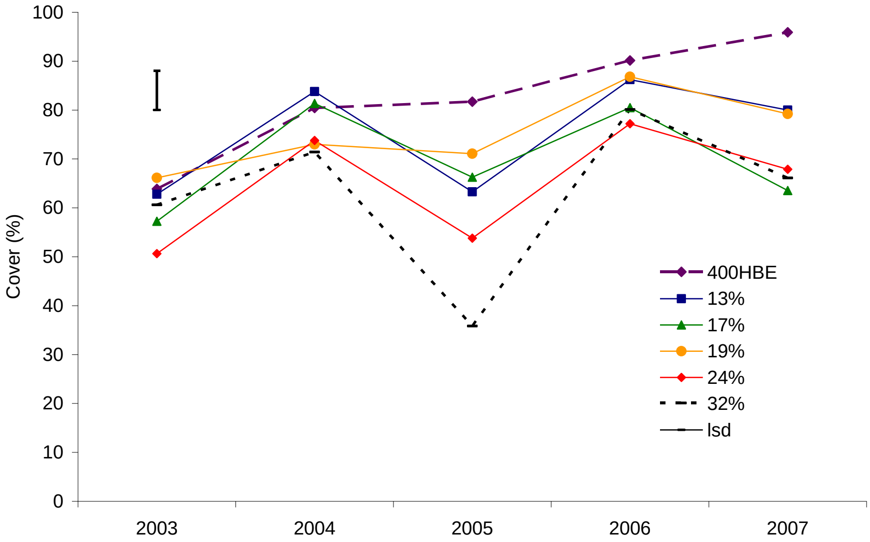


Figure 3.41. Ground cover in May through time for different utilisation treatments at Pigeon Hole station. Bar shows least significant difference.

The sudden drop in ground cover in the exclosure in 2007 (Figure 3.42) was following a fire that went through in December 2006.

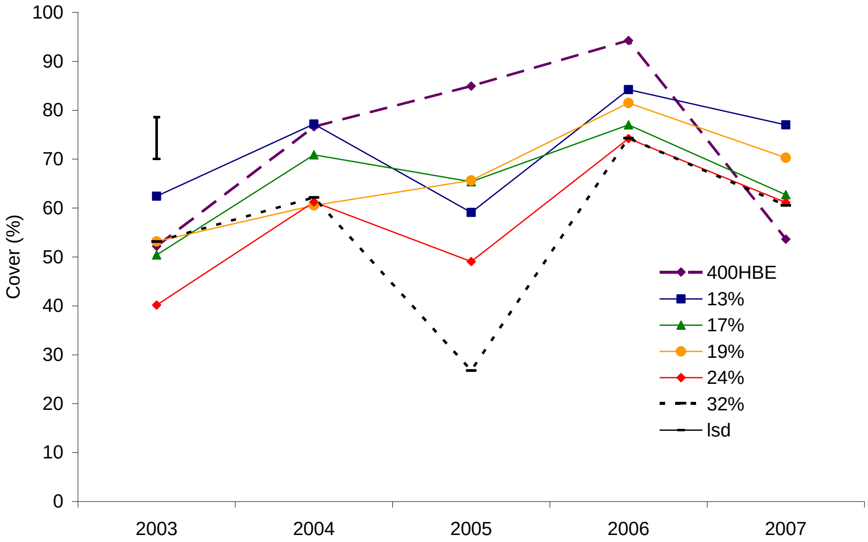


Figure 3.42. Ground cover in October through time for different utilisation treatments at Pigeon Hole station. Bar shows least significant difference. Bar shows least significant difference.

Perennial grass basal area

Perennial grass basal area fluctuated through time, but trends through time were inconsistent between treatments (Figure 3.43 - Figure 3.44). Grass basal area increased through time in the exclosure compared to the utilisation paddocks. The sudden drop in grass basal area in 2007 in the exclosure was following a fire in December 2006.

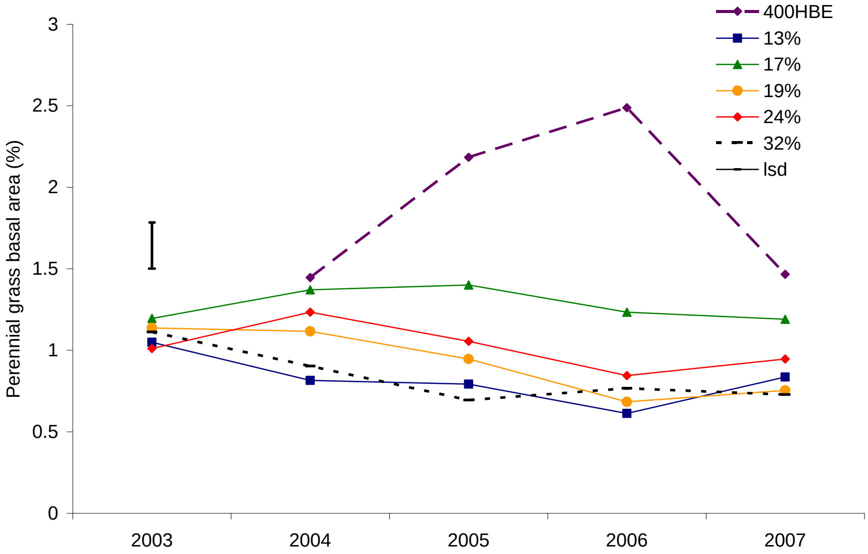


Figure 3.43. Perennial grass basal area in May through time for different utilisation treatments at Pigeon Hole station. Bar shows least significant difference.

Perennial grass basal area in October 2003 was anomalously high, (higher than May 2003) due to observer error, and is ignored for the purposes of interpretation. There was little evidence that perennial grass basal area was trending downwards in higher utilisation rates, although 32% utilisation did end with the lowest grass basal area in 2007 after being the highest ranked in 2003. Higher perennial grass basal area in the paddock with 17% utilisation reflects its high proportion (25%) of unpalatable perennial grasses.

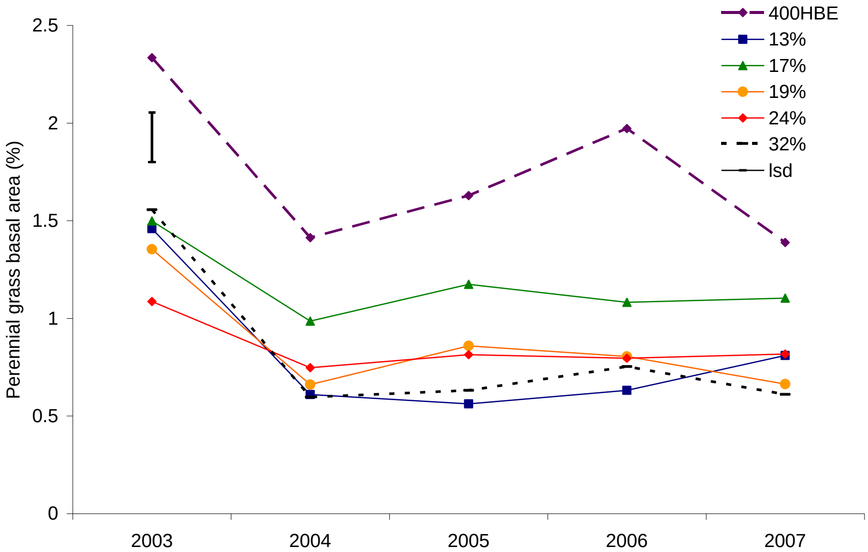


Figure 3.44. Perennial grass basal area in October through time for different utilisation treatments at Pigeon Hole station. Bar shows least significant difference.

3.4.3.2 Pasture composition

3.4.3.2.1 Similarity in species composition between sites through time

The variation in plant composition between sites in the utilisation paddocks was portrayed using ordination (Figure 3.45) and the differences between paddocks analysed using ANOSIM. Species composition varied significantly between utilisation paddocks (R statistic =0.529, p=0.001), and through time (R statistic =0.27, p=0.001). However, treatments that were initially quite different in composition in 2003 tended to stay different through time despite seasonal variation. Seasonal patterns were represented as shifts to the top right in the wetter years in 2004 and 2006 and shifts back to the bottom left in the drier years of 2005 and 2007. The exception to this was in the 19% utilisation paddock, which showed continuous shifts to the top right through the study, except for the last year. Species composition was most stable through time for the two lowest utilisations. There was no evidence that treatments were diverging in composition through time. Rather, the species composition of the highest utilisation became more similar to the lowest utilisation treatment through time. The composition of the 17% utilisation treatment was quite distinct from the other paddocks and stayed so during the trial.

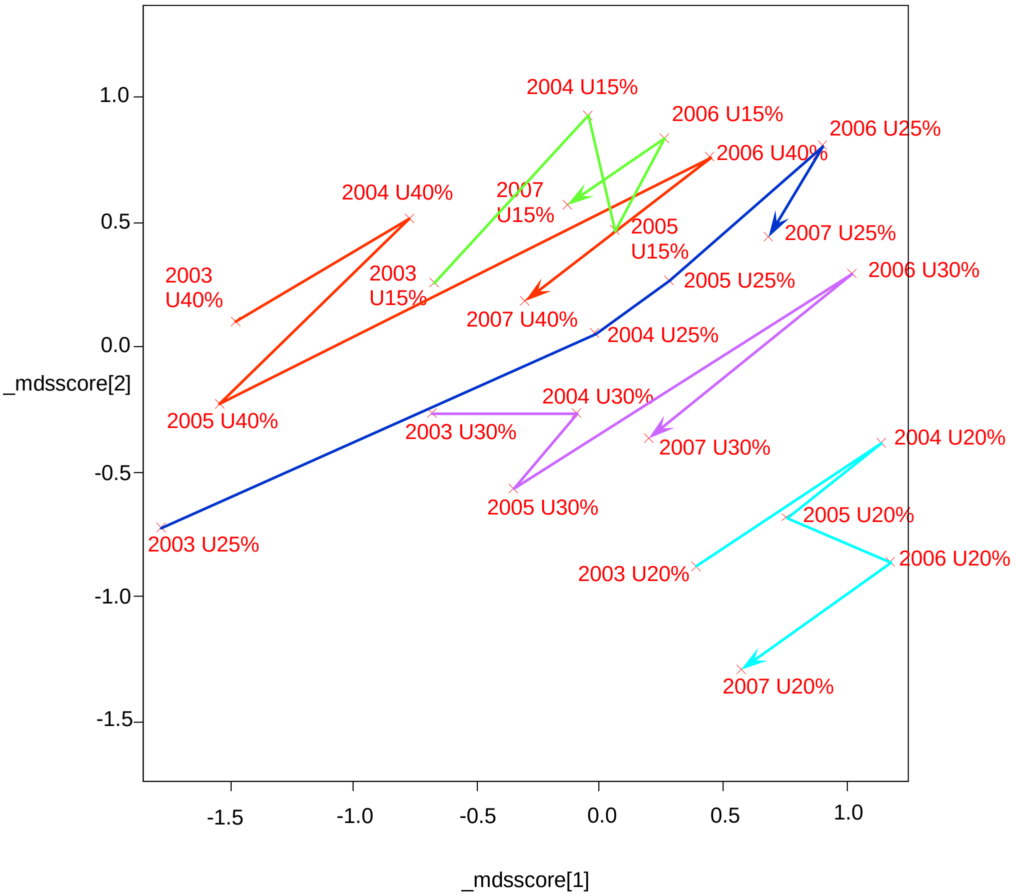


Figure 3.45: Multidimensional scaling ordination of utilisation paddocks at Pigeon Hole station through time based on % species composition of all species recorded**.** Note that target utilisations are shown on figure.

3.4.3.2.2 Functional groups

Palatable yield fluctuated through time but there was no evidence of decline in palatable yield at higher utilisations (Figure 3.46 - Figure 3.47). However, by October palatable yield was ≤ 300 kg/ha in utilisation treatments above 13% in 2003, and in the 17, 19 and 32% utilisation treatments in 2005 and the 17-32% treatments in 2007. Hence intake may have been physically limited by low TSDM at these times.

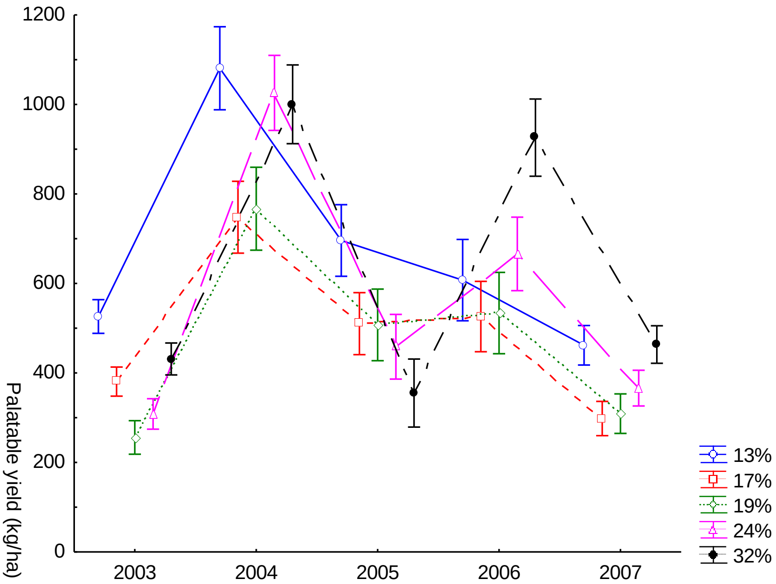


Figure 3.46. Palatable yield in May through time for different utilisation rates at Pigeon Hole station. Means ± standard errors.

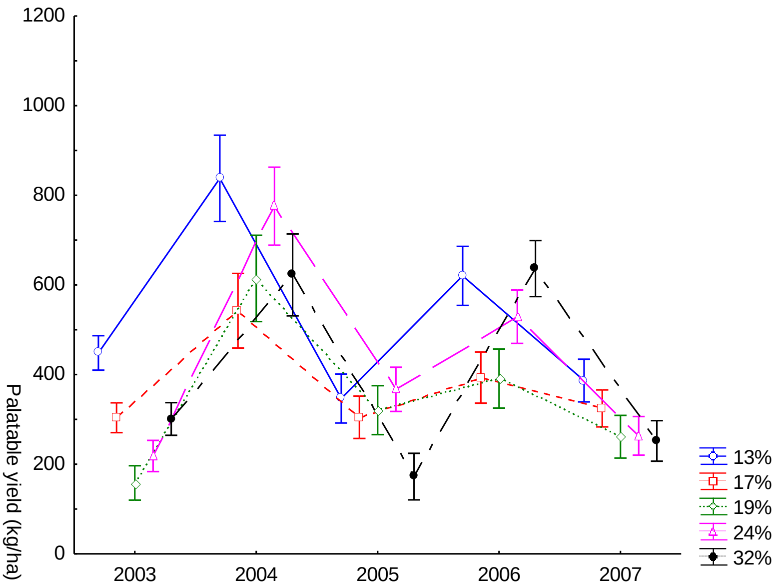


Figure 3.47. Palatable yield in October through time for different utilisation rates at Pigeon Hole station. Means ± standard errors.

Unpalatable and annual yield increased (Figure 3.48, Figure 3.50) and percent perennial grass decreased (Figure 3.49) more through time at 19-32% utilisation (Table 3.22).

Table 3.22. Plant functional groups repeated measures ANOVA results for utilisation treatments at Pigeon Hole Station. *** = P<0.001, ** = P<0.01, * = P<0.05, NS = not significant.

Functional group yield	Utilisation	Year	Utilisation*Year
Unpalatable	***	***	***
Annual	**	***	***
% Perennial grass	***	***	***

Unpalatable yield fluctuated through time and was significantly higher in 2007 than in 2003 for 19-24% utilisation (Duncan's critical range test P<0.05). Increases in unpalatable yield between 2003 and 2007 tended to be higher in higher utilisation treatments (Figure 3.48).

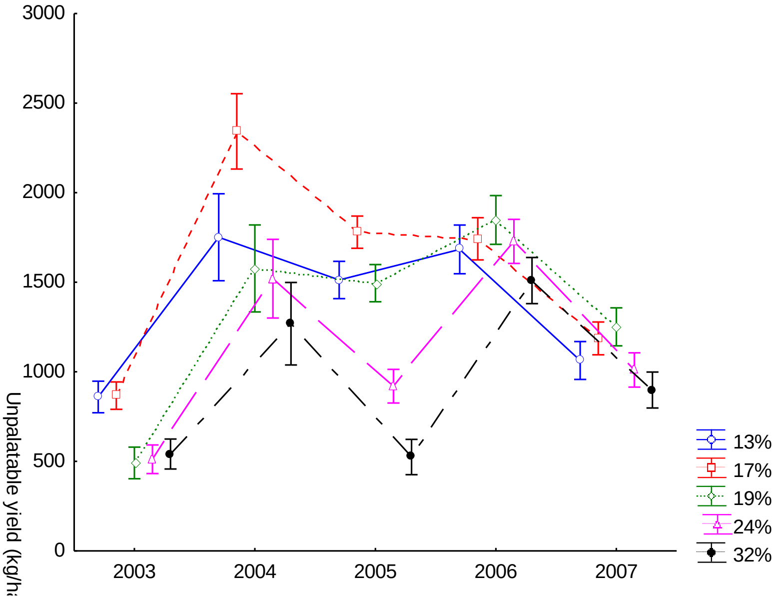


Figure 3.48. Unpalatable yield in May through time for different utilisations at Pigeon Hole station. Means ± standard errors.

There was little evidence of a decline in palatable perennials at the site (Appendix C.4, Table C.2, Figure C.8, Figure C.9).

The proportion of perennial grass in standing crop increased through time in the 13 and 17% utilisation paddocks (significantly for 17%, Duncan's critical range test P<0.05) and decreased significantly through time for the 19 and 32% utilisation paddocks (Duncan's critical range test P<0.05, Figure 3.49).

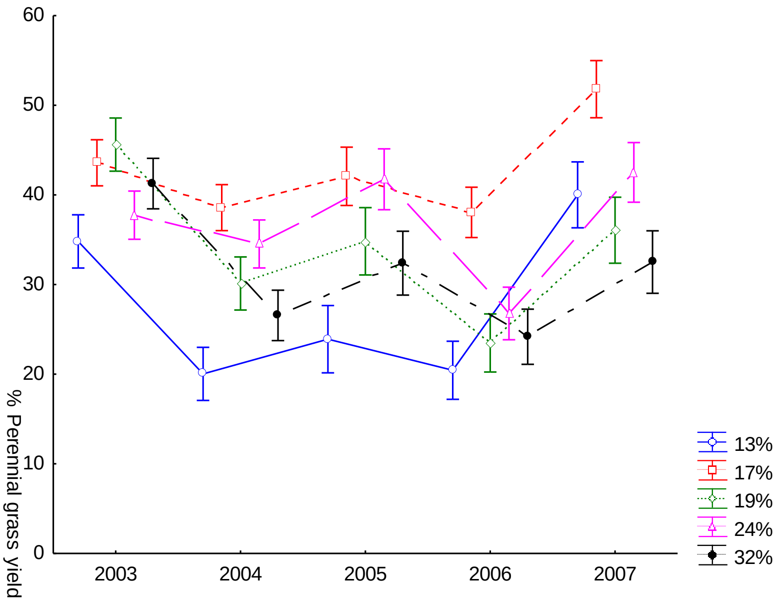


Figure 3.49. % perennial grass yield in May through time for different utilisations at Pigeon Hole station. Means ± standard errors.

Annual yield was initially higher for the lower utilisation treatments 13-17% (Duncan's critical range test P<0.05), but by the end of the trial all treatments had similar annual yield. 19-32% utilisation treatments increased more in annual yield than lower utilisations (Figure 3.50).

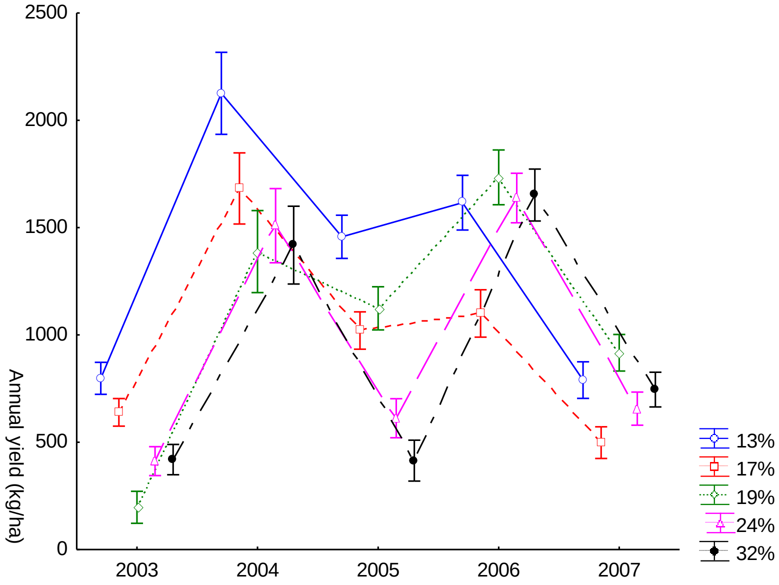


Figure 3.50. Annual yield through time for different utilisations in May at Pigeon Hole station. Means ± standard errors.

3.4.3.2.3 Grass species

Most grass species (*Aristida latifolia*, *Chrysopogon fallax*, *Dichanthium fecundum*, *Dichanthium sericeum*, *Iseilema* spp., *Panicum decompositum* and *Sehima nervosum*) did not respond to utilisation treatment at Pigeon Hole, but rather either responded similarly across treatments to seasonal fluctuations, or showed idiosyncratic paddock-related patterns (Table 3.23, Appendix C.4, Table C.3, Figure C.10 - Figure C.13).

Table 3.23. Grass species repeated measures ANOVA results for utilisation treatments at Pigeon Hole station. *** = P<0.001, ** = P<0.01, * = P<0.05, ns = not significant.

Grass species yield in May	Utilisation	Year	Utilisation*Year
√ *Astrebla* spp.	ns	**	ns
Log 10 *Brachyachne convergens*	0.053	***	**
Sorghum timorense	ns	***	***

Astrebla spp. was only 1-2% of total yield at Pigeon Hole. At 13% utilisation (Figure 3.51), *Astrebla* spp. yield increased between 2006 and 2007, so that it was significantly higher than all treatments except 19% by 2007 (Duncan's critical range test P<0.05).

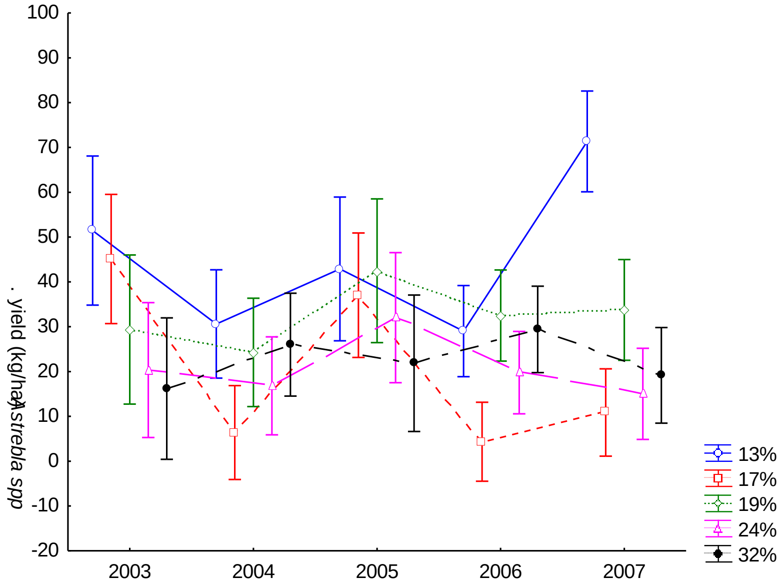


Figure 3.51. *Astrebla* spp. yield in May through time with utilisation at Pigeon Hole station. Means ± standard errors.

There was a slight but not statistically significant increase in *Brachyachne convergens* with utilisation (Figure 3.52, P=0.053). *Brachyachne* did not vary significantly between treatments in 2003, but by 2007, 13% utilisation had significantly lower *Brachyachne* yield than in all other treatments (Duncan's test, critical range P<0.05).

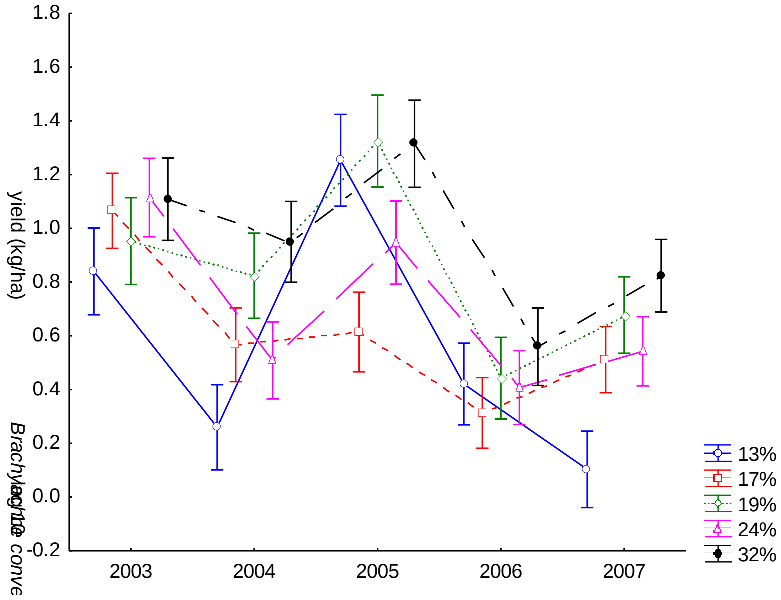


Figure 3.52. *Brachyachne convergens* yield through time with utilisation at Pigeon Hole station. Means ± standard errors.

From 2003 to 2005 *Sorghum timorense* yield was highest at 13-17% utilisation (Figure 3.53, Duncan's test, critical range test P<0.05), reflecting lower defoliation levels in these treatments (Table 3.24). However, despite the lower defoliation, *Sorghum* yield started to decline after 2004 in these treatments, relative to the higher utilisation treatments. The lowest utilisation treatments (13-17%) had similar end to start *Sorghum* yields, after initial gains in 2004, while 19-32% utilisation treatments had higher yields in 2007 vs. 2003, although only significantly at 19% (Duncan's critical range test P<0.05).

Table 3.24. Defoliation of *Sorghum timorense* with utilisation at Pigeon Hole station.

Utilisation (%)	Average *Sorghum* defoliation (%)
13	7
17	6
19	8
24	10
32	14

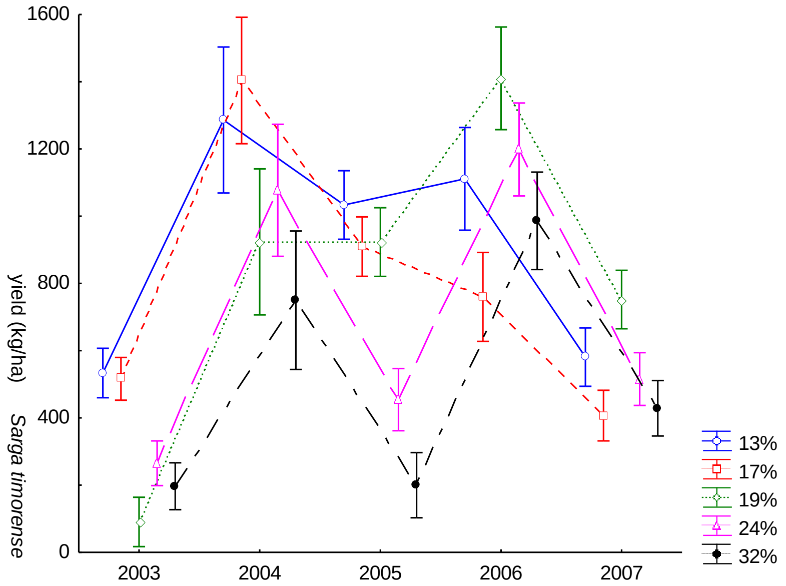


Figure 3.53. *Sorghum timorense* yield through time with utilisation at Pigeon Hole station. Means ± standard errors.

3.4.3.2.4 Forb species

Three forb species showed patterns consistent with a response to utilisation at Pigeon Hole (Table 3.25).

Table 3.25. Herb species repeated measures ANOVA results for utilisation treatments at Pigeon Hole station. *** = P<0.001, ** = P<0.01, * = P<0.05, ns = not significant.

Species	Utilisation	Year	Utilisation*Year
Log 10 *Jacquemontia browniana*	ns	***	*
√ *Sesbania* spp.	***	***	***
Log 10 *Wedelia asperrima*	***	***	***

Jacquemontia browniana increased most in the lowest utilisation treatment (Figure 3.54), so that by the end of the trial, 13% utilisation had significantly higher yield of *Jacquemontia browniana* than 32% utilisation (Duncan’s critical range test P<0.05).

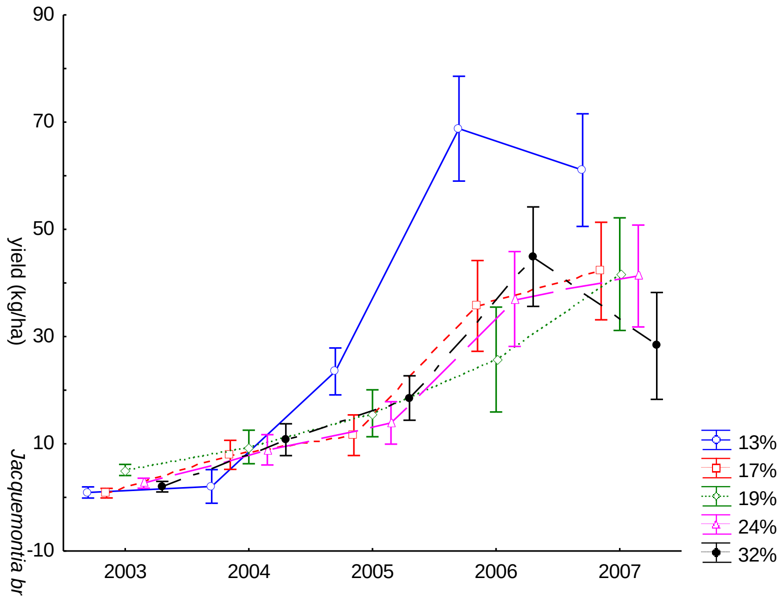


Figure 3.54. *Jacquemontia browniana* yield through time with utilisation at Pigeon Hole station. Means ± standard errors.

Sesbania spp*.* increased more through time in the 32% treatment (Figure 3.55), so that by 2006 and 2007, 32% utilisation had the highest and 13% had the lowest yield of *Sesbania spp.* (Duncan's critical range test (P<0.05).

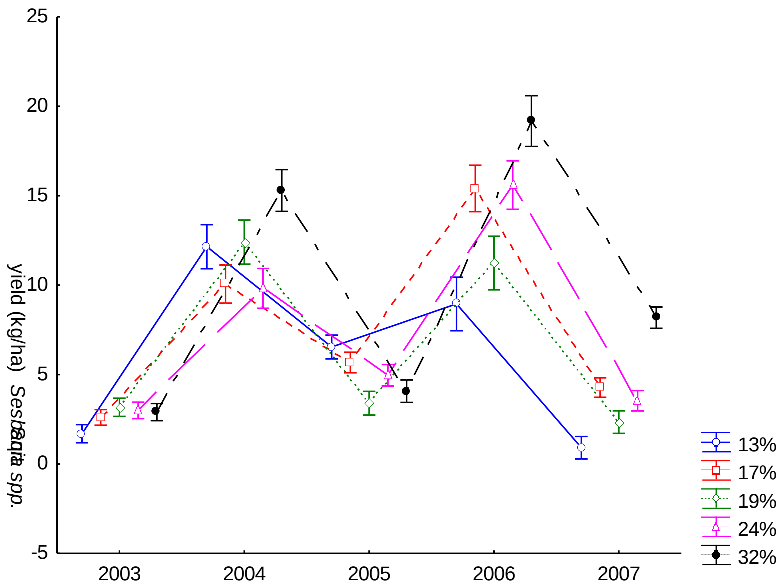


Figure 3.55. *Sesbania* spp. yield through time with utilisation at Pigeon Hole station. Means ± standard errors.

Wedelia asperrima declined most through time in the lowest utilisation treatment (Figure 3.56, Duncan's critical range test P<0.05).

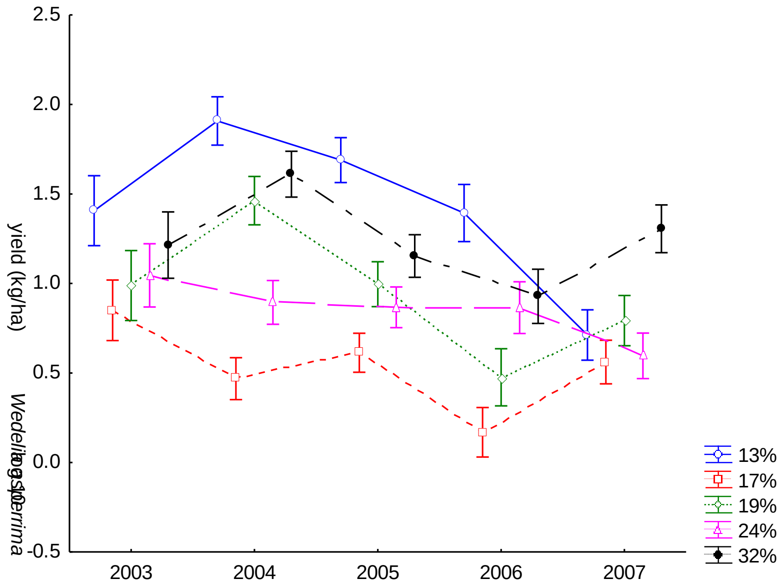


Figure 3.56. *Wedelia asperrima* yield through time with utilisation at Pigeon Hole station. Means ± standard errors.

3.4.3.3 Defoliation of pasture species

Species defoliation varied year to year and between species and utilisation treatments (Figure 3.57 - Figure 3.63, Appendix C.5, Figure C.14 - Figure C.15). Individual plants were not defoliated uniformly within a treatment. Within a paddock, the defoliation of a species typically varied from none to very high, such as for A*strebla* spp*.* (Figure 3.57). Only 13% utilisation had large numbers of undefoliated *Astrebla* plants at Pigeon Hole.

Most species had higher average defoliation in higher utilisation paddocks (Figure 3.58 - Figure 3.63). There was no evidence that more palatable species were being more defoliated over time. Rather, defoliation fluctuated seasonally with available forage and stocking rates.

Palatable perennial grasses experienced much higher defoliation than average paddock utilisation with up to 30% defoliation during the wet season and usually up to 50% defoliation by October (Figure 3.59 - Figure 3.61).

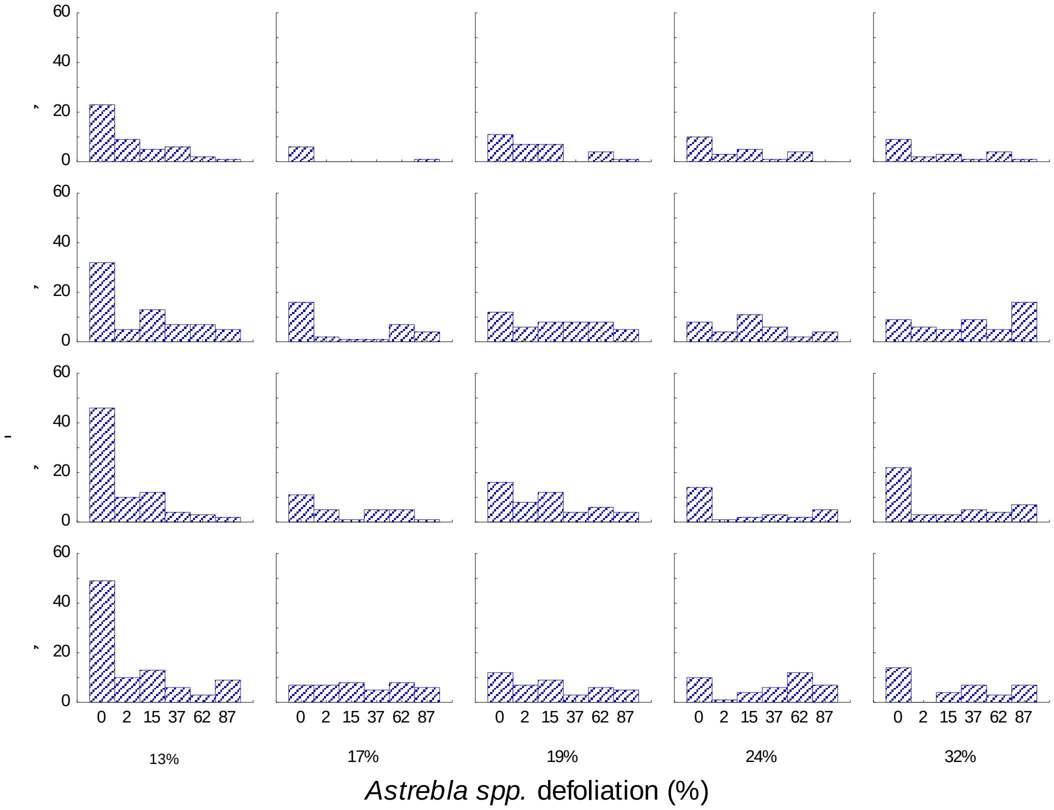


Figure 3.57. Defoliation of *Astrebla* spp*.* plants in October varied with treatment, year and within paddocks at Pigeon Hole station.

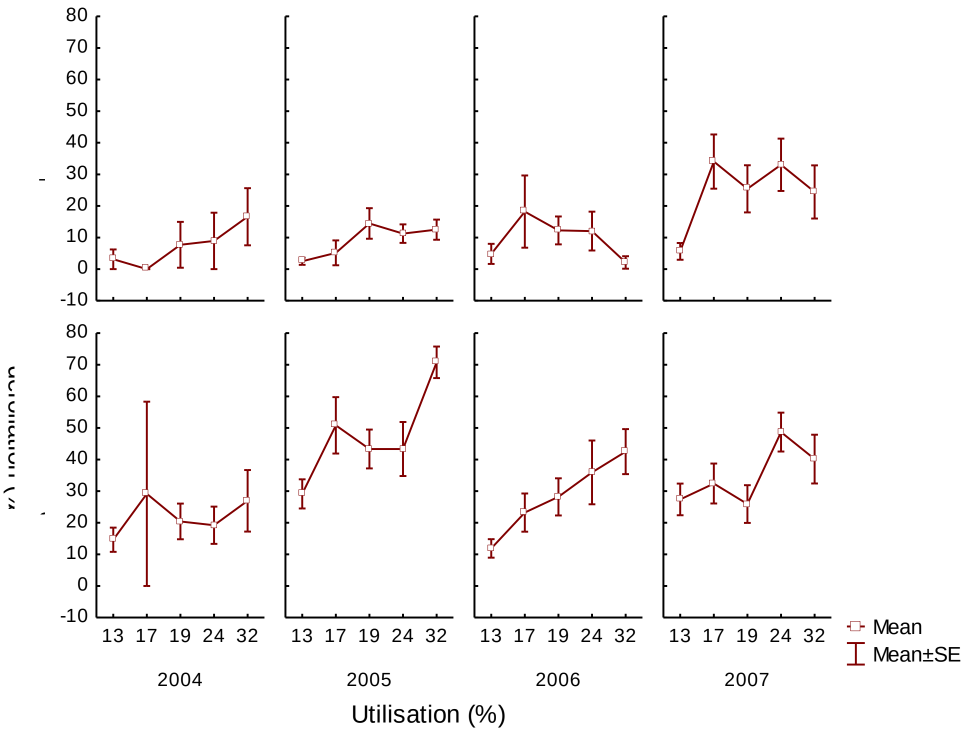


Figure 3.58. Defoliation of *Astrebla* spp*.* at different utilisation rates through time at Pigeon Hole station.

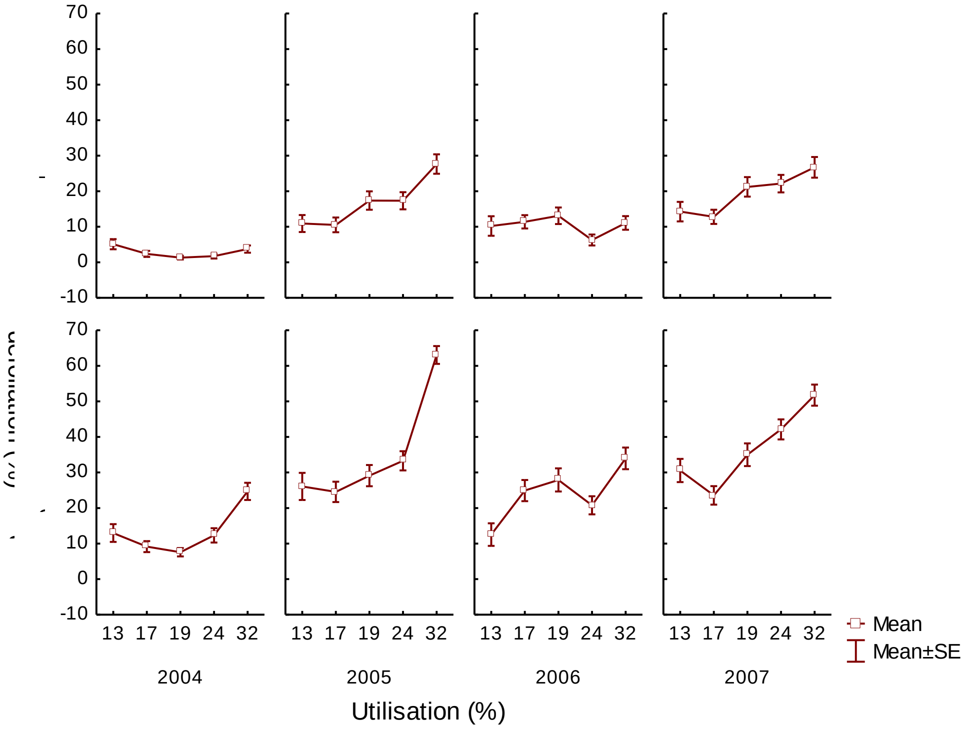


Figure 3.59. Defoliation of *Chrysopogon fallax* at different utilisation rates through time at Pigeon Hole station.

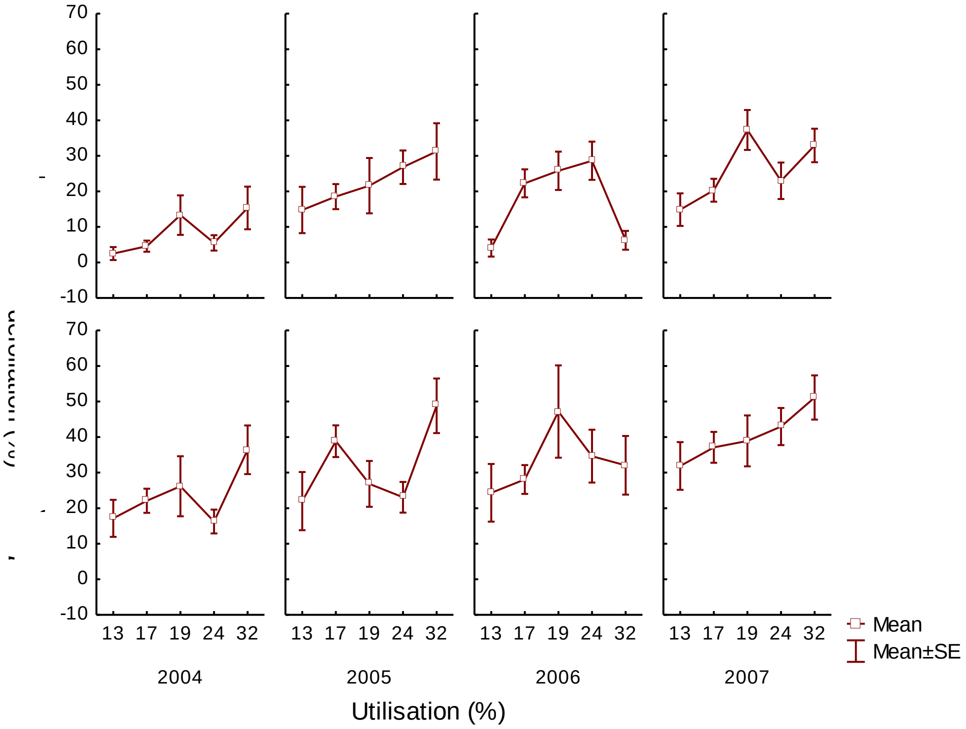


Figure 3.60. Defoliation of *Dichanthium fecundum* at different utilisation rates through time at Pigeon Hole station.

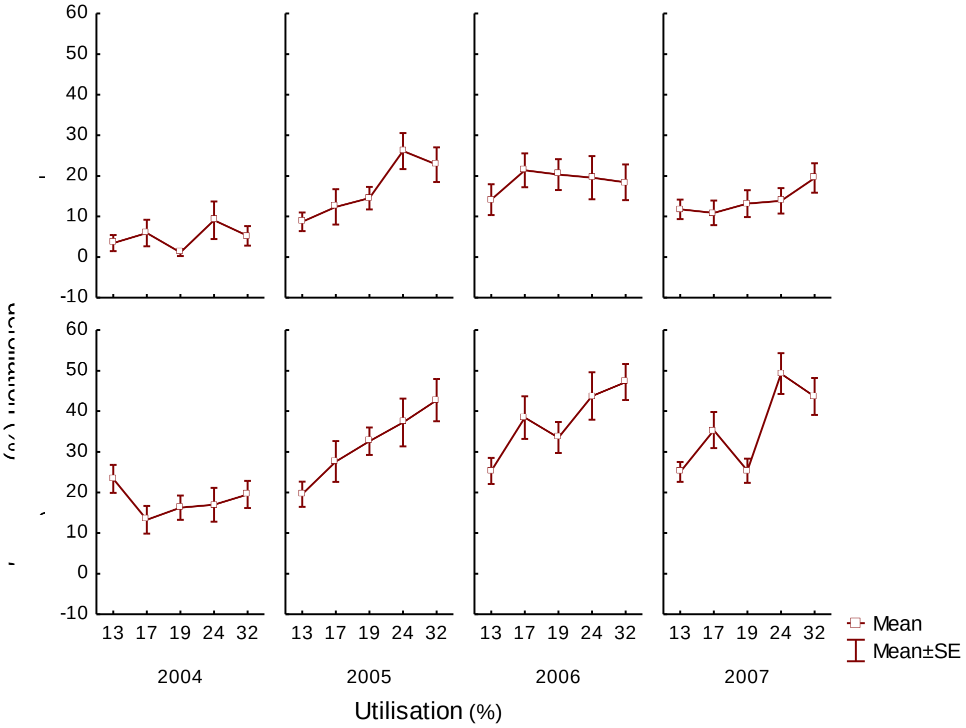


Figure 3.61. Defoliation of *Panicum decompositum* at different utilisation rates through time at Pigeon Hole station.

Conversely, unpalatable grasses experienced lower than paddock average utilisation levels at less than 5% defoliation during the wet season (Figure 3.62 - Figure 3.63). *Sorghum timorense* and A*ristida latifolia* which together made up the bulk of the standing biomass (ranging between 43-57%), were usually only defoliated up to 20% by October, which was less than half that of the palatable species, except for in the 32% utilisation paddock in 2005 following a fire, when palatable yield was very low (<200 kg/ha).

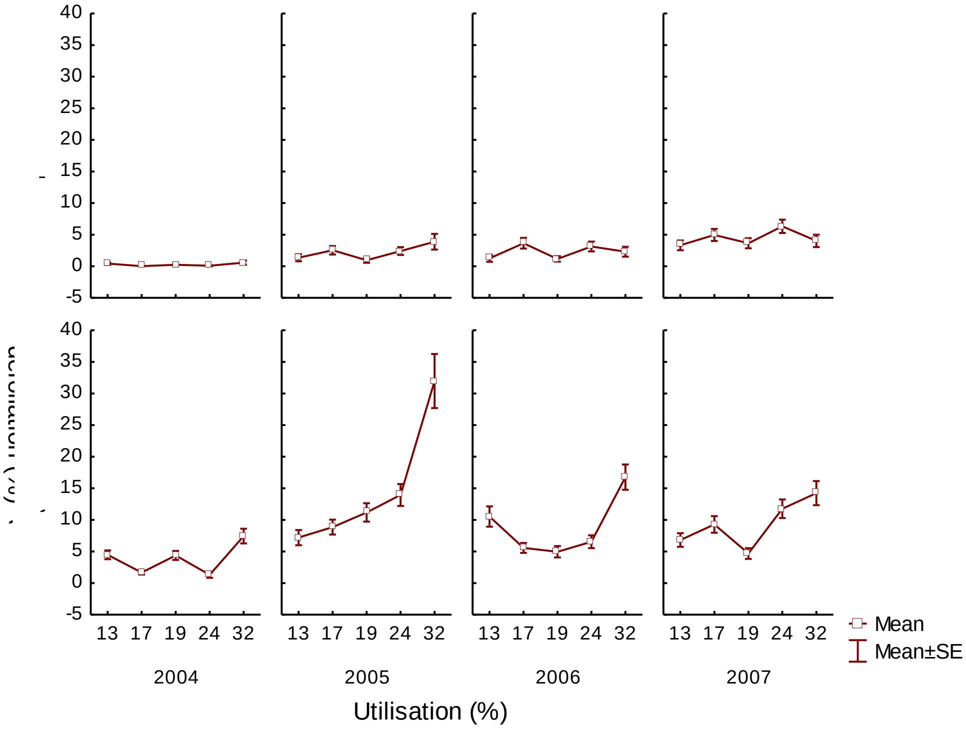


Figure 3.62. Defoliation of *Sorghum timorense* at different utilisation rates through time at Pigeon Hole station.

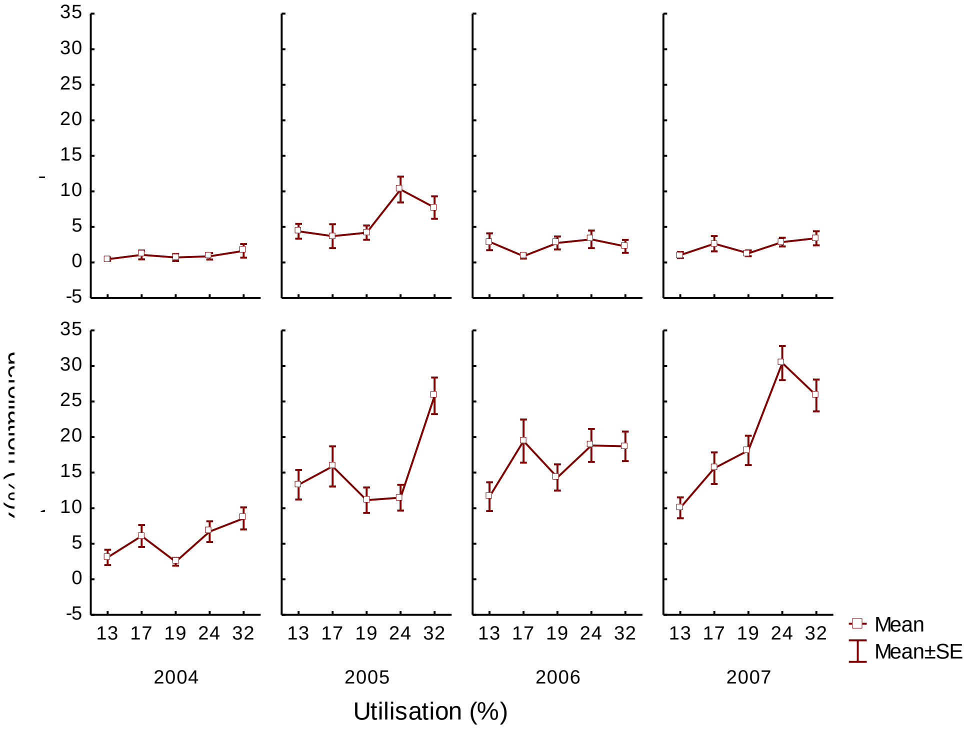


Figure 3.63. Defoliation of *Aristida latifolia* at different utilisation rates through time at Pigeon Hole station.

3.4.3.4 Selection for pasture species

Cattle preference for plant species was not correlated with utilisation (e.g. Figure 3.64 - Figure 3.67), although there was a paddock effect on selection, with lower selection for *Panicum*, *Flemingia* and *Sehima* in the 17% utilisation paddock (Appendix C.6, Figure C.16 - Figure C.17).

Sorghum timorense was avoided in May, and not or only weakly selected for in October (Figure 3.64).

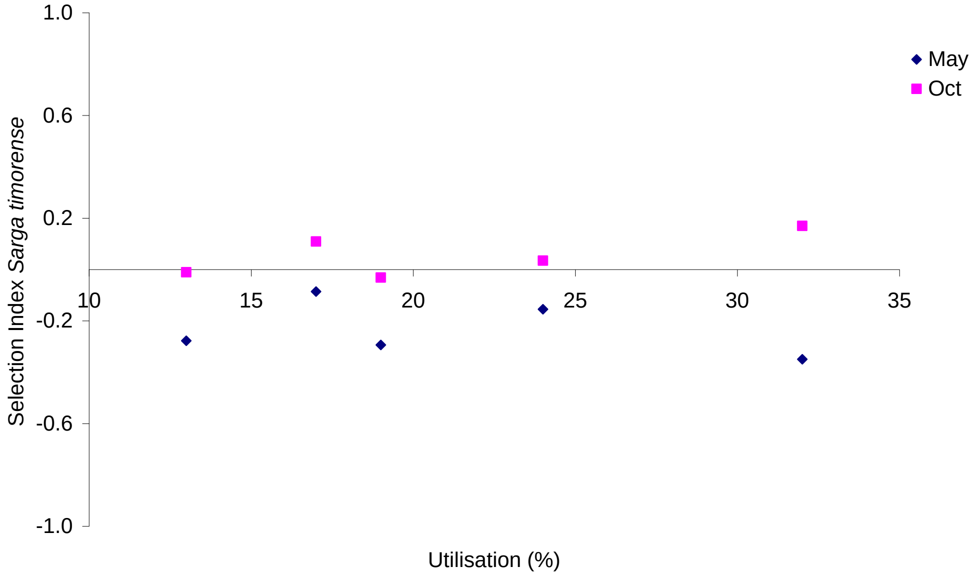


Figure 3.64. Average selection index of *Sorghum timorense* with utilisation at Pigeon Hole station.

Despite *Aristida latifolia* being an unpalatable species with only low levels of defoliation, it was still selected for (Figure 3.65), although not as strongly as more preferred palatables *Astrebla*, *Brachyachne*, *Chrysopogon*, *Dichanthium, Iseilema* spp*.* and *Panicum* (Figure 3.66, Appendix C.6, Figure C.18 - Figure C.19).

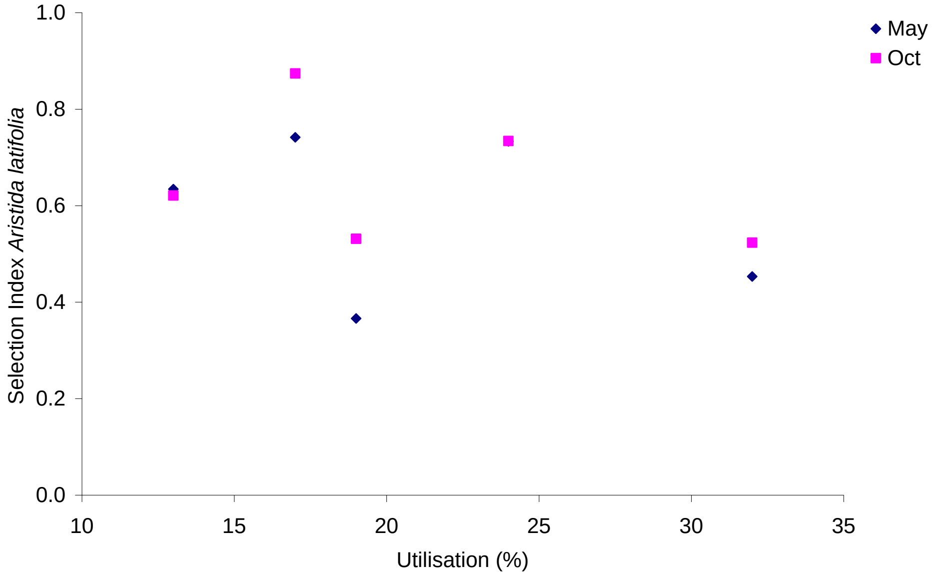


Figure 3.65. Average selection index of *Aristida latifolia* with utilisation at Pigeon Hole station.

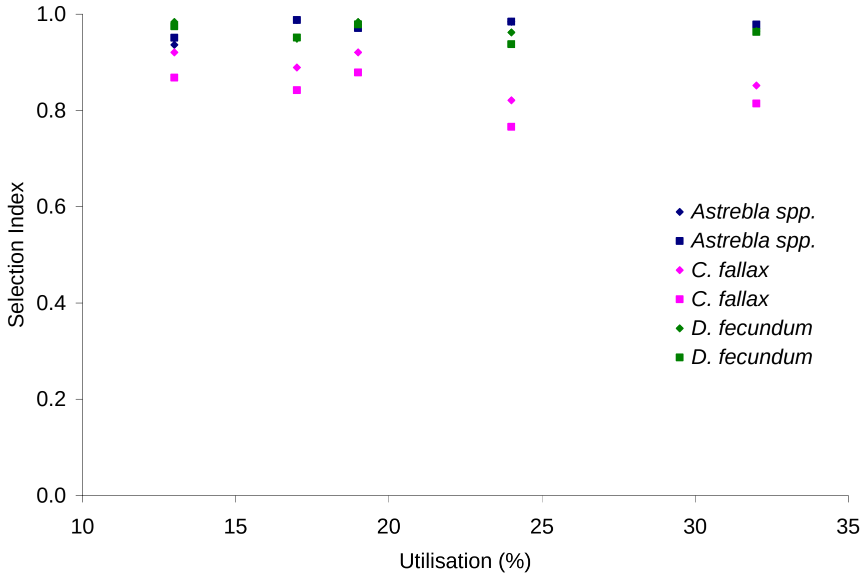


Figure 3.66. Average selection index of palatable grasses with utilisation at Pigeon Hole station. Diamonds represent selection index in May, and squares represent selection index in October.

Interestingly, even the relatively unpalatable *Aristida latifolia* was more heavily selected for as its contribution to total yield declined (Figure 3.67, May, Spearman's r = 0.97, P=.004, n=5, October, Pearson's r = -0.95, P=.01, n=5).

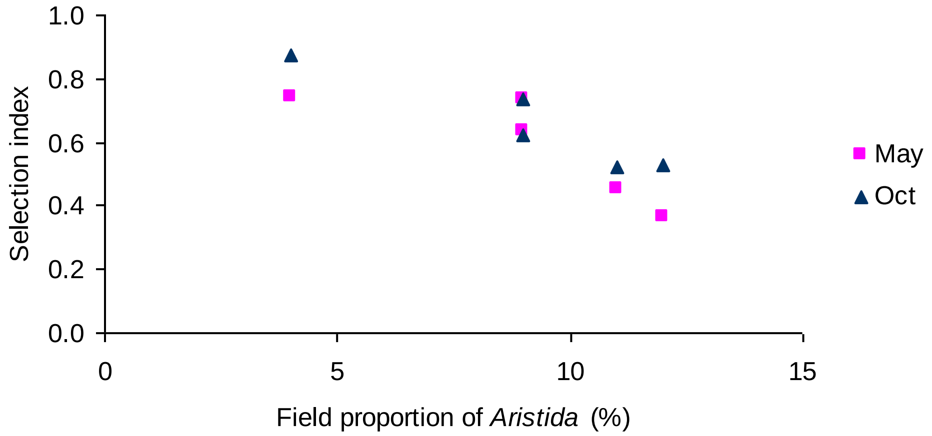


Figure 3.67. Change in selection index of *Aristida latifolia* with contribution to total yield.

3.4.3.5 Animal production

Summary

- Despite some variation in pasture composition of the different utilisation treatments, diet quality as measured through NIRS did not vary between utilisation treatments, but was higher in 2006 and 2007.
- Steer liveweight gain was independent of utilisation rate
- Weaner weight was lower at higher utilisation rate
- Branding and weaning rate was independent of utilisation rate
- Proportion pregnant and lactating was slightly higher at 13% utilisation
- Calf loss was lowest at 13 and 19% utilisation
- There was no effect of utilisation rate on inter-calving interval

- October breeder weights and proportion pregnant and lactating increased through time for all treatments. This may be reflecting better feed quality indicated by NIRS in 2006 and 2007.

3.4.3.5.1 Diet quality

Crude protein (%CP) in the diet as estimated from NIRS showed a threefold increase between dry and wet seasons for all utilisation treatments (Figure 3.68). %CP was lower in the 2004 and 2005 dry season than 2006 and 2007 dry season. This reflects the longer growing season in 2006 and the aseasonal rainfall in July 2007 which GRASP simulation suggests stimulated some new growth during the dry season (Appendix D.3.5, Table D.12).

The extended higher CP% in March and April 2005 in 32% utilisation and to a lesser extent 24% utilisation is probably due to the fire in February 2005 which burned 34 and 16% of these paddocks respectively. This is supported by the higher defoliation in the burned areas of these paddocks for the remainder of 2005 (Appendix C.2, Table C.1). The higher CP% in 32% utilisation remained for the rest of the dry season of 2005.

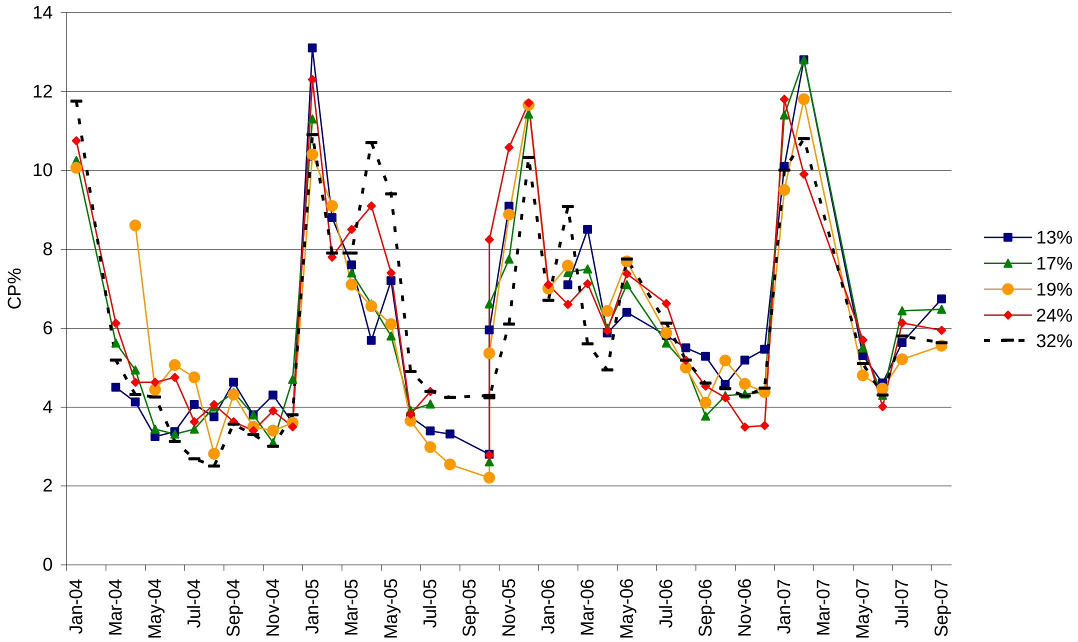


Figure 3.68. % Crude protein in cattle diet in utilisation paddocks at Pigeon Hole station from 2004-2007.

Crude protein did not significantly differ between utilisation treatments (ANOVA $F_{(4,186)}$ = 0.17, P=0.95) (Figure 3.69).

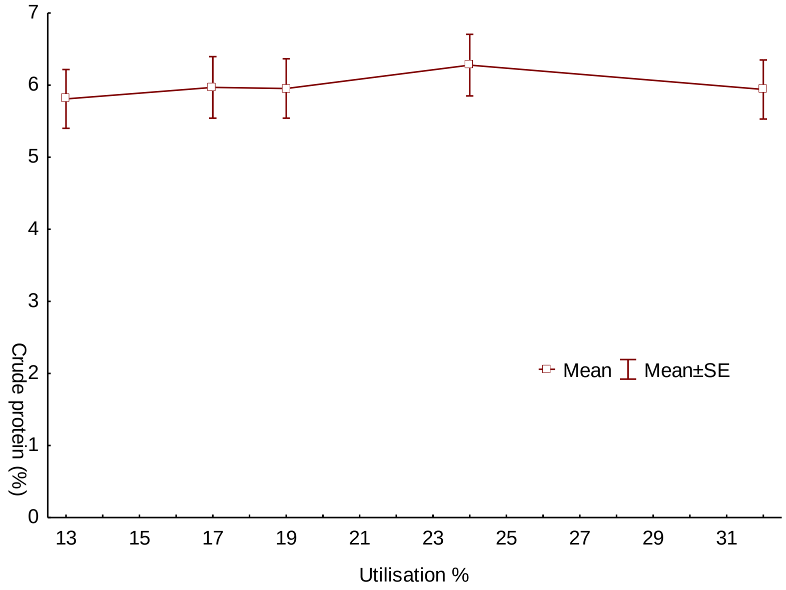


Figure 3.69. Average % crude protein in cattle diets in different utilisation treatments at Pigeon Hole station 2004-2007.

Diet dry matter digestibility (%DMD) measured through NIRS generally ranged between 50 to 65% and varied similarly through time to %CP (Figure 3.70).

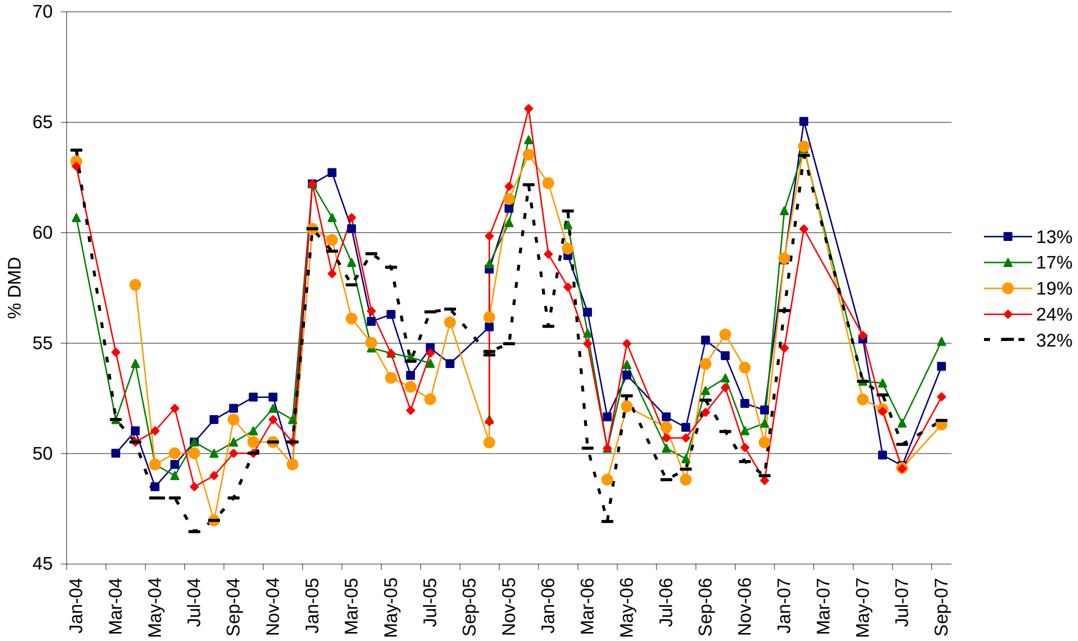


Figure 3.70. Variation in % DMD in cattle diets in utilisation treatments at Pigeon Hole station 2004-2007.

Although average %DMD was slightly lower at 32% utilisation, differences were not significant (ANOVA $F_{(4,187)}$ = 0.35, P=0.84, Figure 3.71).

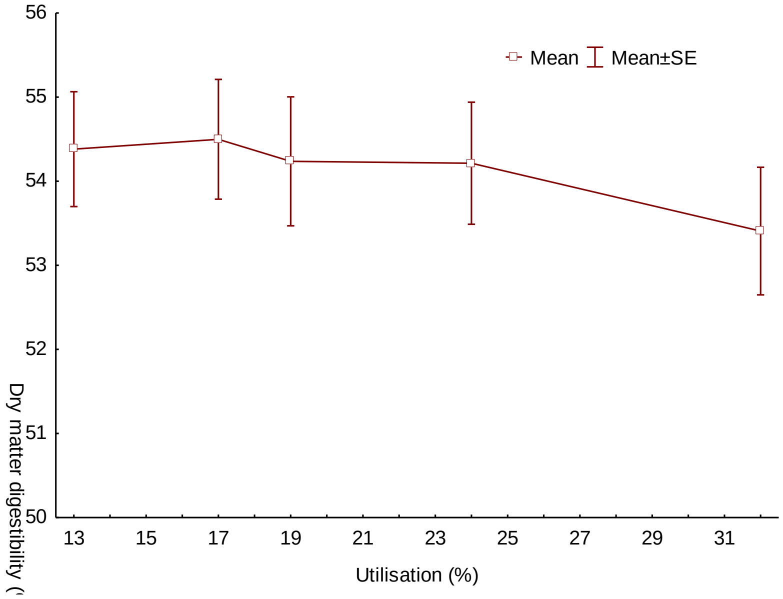


Figure 3.71. Average % dry matter digestibility in cattle diets in different utilisation treatments at Pigeon Hole station 2004-2007.

The %DMD to %CP ratio was above 10 for 8 months of 2004 and 4 months of 2005 and 2006 (Figure 3.72), which suggests a response to urea is highly likely. While only 2 months of 2007 appear to have a %DMD to %CP ratio lower than 10, this may be misleading as there was no NIRS data between February and May 2007. This suggests that forage quality for the utilisation treatments was more limiting in 2004 than 2005 and 2006. DMD:CP ratio significantly varied between calendar years: Kruskal-Wallis ANOVA by Ranks: $H_{(3,\ N=\ 191)}$ =36.33 p =0.0000 (Table 3.26).

Table 3.26. Effect of calendar year on DMD%:CP% ratio for each utilisation treatment. Kruskal Wallis ANOVA.

Utilisation	P	Significant differences
All treatments	***	2004>2005, 2006 and 2007
All treatments dry season	*	2004 and 2005> 2007
13%	**	2004>2006 and 2007
17%	ns	
19%	ns	
24%	*	
32%	*	2004>2005

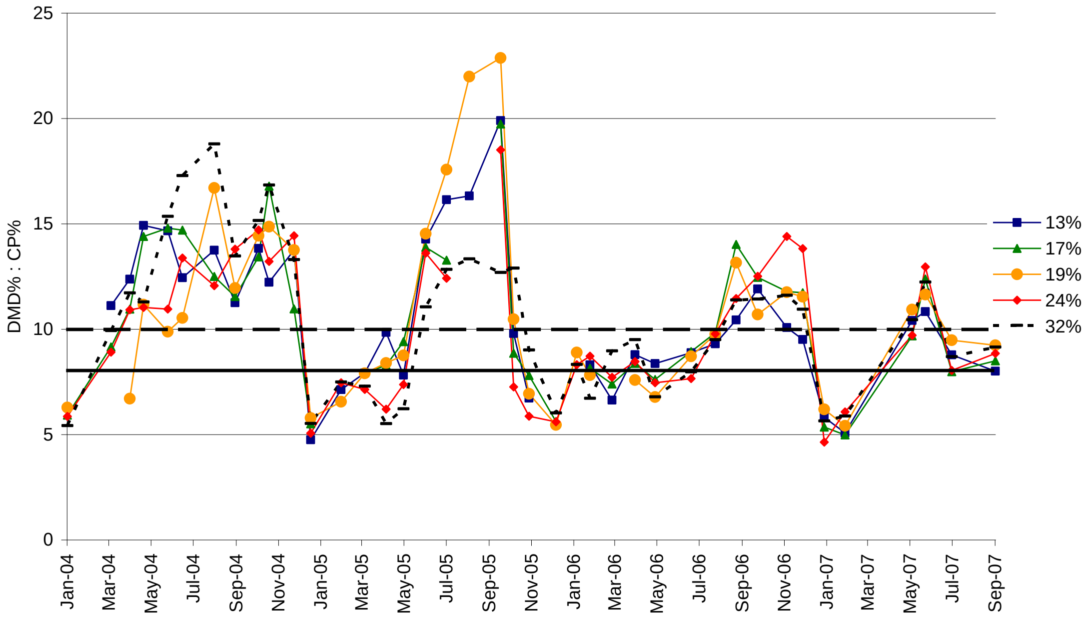


Figure 3.72. DMD%:CP% ratio for different utilisation treatments at Pigeon Hole Station 2004-2007. DMD:CP >10 response to urea highly likely, DMD:CP>8 probable response to urea.

%DMD:%CP ratio did not vary significantly with utilisation (Figure 3.73, ANOVA $F_{(4,186)} = 0.24$, p = 0.91).

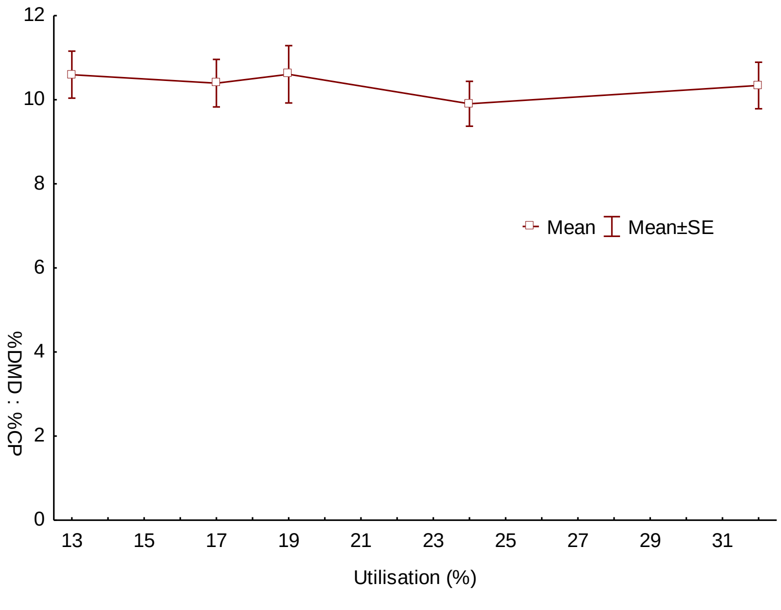


Figure 3.73. Average %DMD:%CP ratio in cattle diets in different utilisation treatments at Pigeon Hole station 2004-2007.

3.4.3.5.2 Growth

3.4.3.5.2.1 Live weight gain

Live weight gain varied significantly through time for utilisation treatments on an annual and seasonal basis. While wet and dry season live weight gain varied significantly between utilisation paddocks, there was no consistent trend in relation to utilisation (Table 3.27, Figure 3.74 - Figure 3.75).

Table 3.27. Effect of initial live weight, time and utilisation on live weight gain at Pigeon Hole station. ANCOVA results. *** = P<0.001, ** = P<0.01, * = P<0.05, ns = not significant.

Effect	Wet season LWG	Dry season LWG	Annual LWG
Initial live weight	ns	*	ns
Year	***	***	***
Utilisation	***	***	ns
Year x utilisation	***	***	**

The very low liveweight gain in 32% utilisation in the 2004-2005 wet probably reflects the combination of very high stocking rates, and low TSDM in the average 2004-05 wet season, particularly after the fire in February. Stock were removed from this paddock in February 2005 which then enabled higher compensatory liveweight gain in the following dry for the remaining animals with 1) reduced stocking rates and 2) enhanced pasture quality following fire in burnt areas.

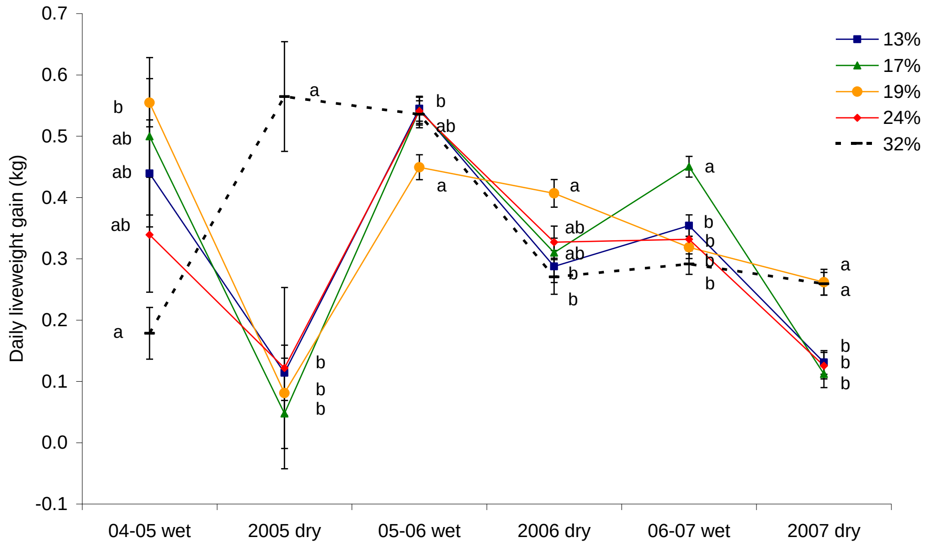


Figure 3.74. Daily live weight gain (corrected for initial live weight) by season for utilisation treatments at Pigeon Hole station. Different letters denote significant differences between treatments. Tukey HSD Test. Means ± standard errors.

The annual live weight gain did not significantly differ between utilisation treatments because there tended to be compensatory gain between seasons for paddocks, so that paddocks with a particularly low weight gain in one season would have particularly high weight gain in the following season and vice versa (Figure 3.74), so that over the whole year, there was little difference between paddocks (Figure 3.75).

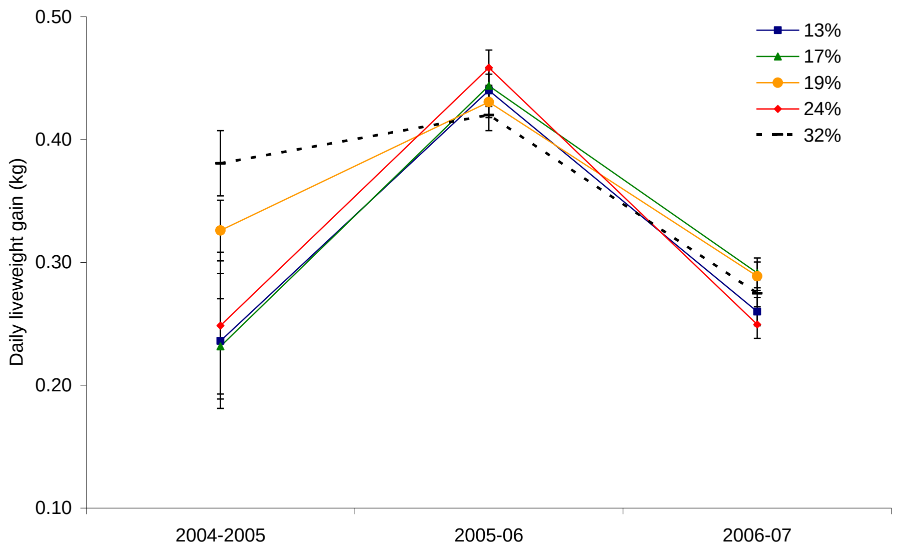


Figure 3.75. Annual daily live weight gain (corrected for initial live weight) by year for different utilisations at Pigeon Hole station. Means ± standard errors.

3.4.3.5.2.2 Body condition score of breeders

Breeder body condition score was generally lower at higher utilisation rates in May (Spearman's r = -0.9, P=0.03, n=5, Table 3.28), but this pattern did not occur in October, when there was no apparent trend with utilisation rate (Table 3.28 - Table 3.29, Figure 3.76 - Figure 3.77).

Table 3.28: Average breeder body condition score in May at Pigeon Hole station (2003-2007). Different letters denote significant differences between treatments. Tukey HSD Test.

Utilisation	13	17	19	24	32
Mean body condition score	4.75 a	4.18 b	4.66 a	4.12 b	4.04 b
Standard error	0.05	0.05	0.06	0.05	0.05

Table 3.29. Effect of utilisation and year on body condition score at Pigeon Hole Station. ANOVA results. *** = P<0.001, ** = P<0.01, * = P<0.05.

	May	October
Utilisation	***	**
Year	***	***
Utilisation*Year	***	***

In May the greatest separations in breeder body condition score between utilisation rates were in the drier years of 2005 and 2007 (Figure 3.76). In 2005 cattle in the 13% and 19% treatments had higher condition scores than those in the 17, 24 and 32% treatments. In 2007, cattle in the 13% treatment had higher body condition scores than those in 24% and 32% treatments, which had the lowest breeder body condition scores.

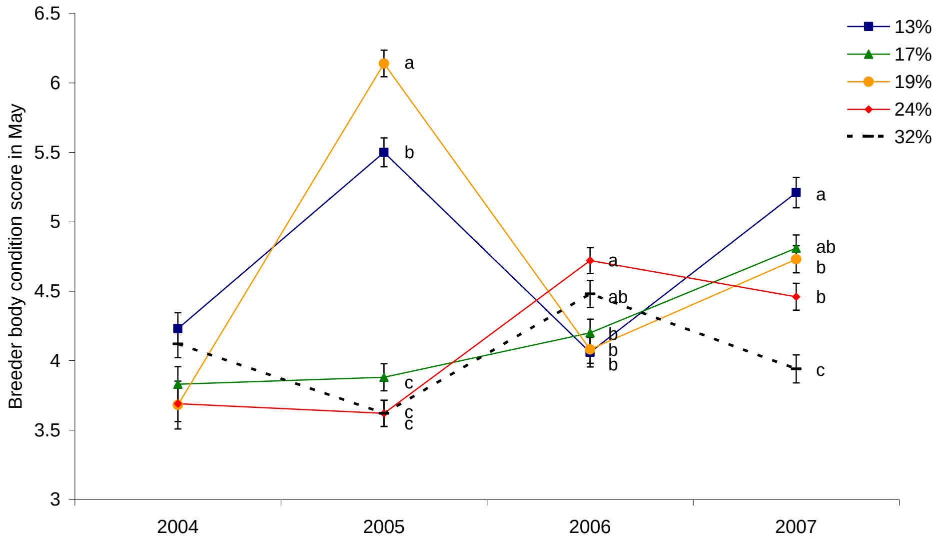


Figure 3.76. May breeder body condition score through time for utilisation treatments at Pigeon Hole Station. Different letters denote significant differences between treatments. Tukey HSD Test. Means ± standard errors.

In October, breeder body condition score was higher in the drier years 2003, 2005 and 2007 (Figure 3.77). There were differences between paddocks, but there was no consistent trend with utilisation. The higher breeder condition score in poorer years, probably reflects the lower proportion of pregnant and lactating animals in these years (see 3.4.3.5.4.3).

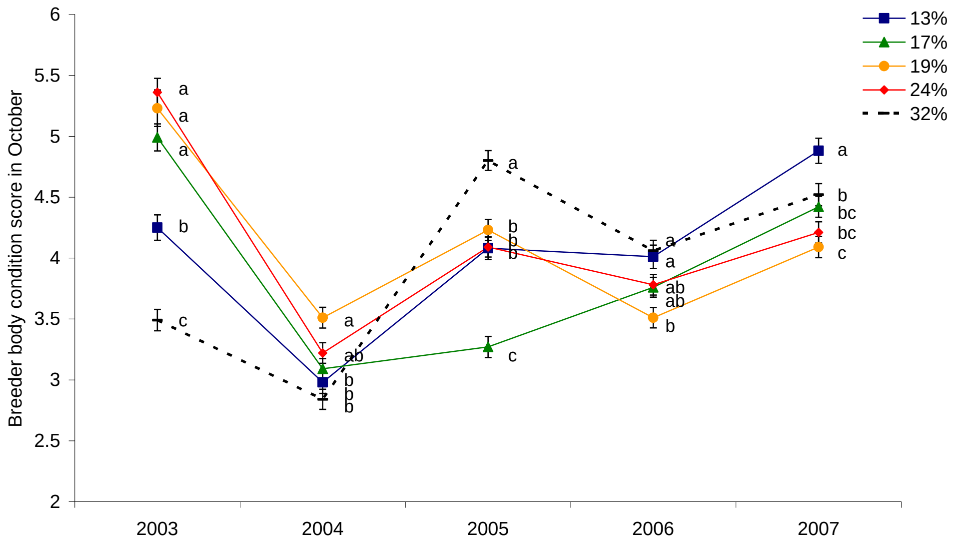


Figure 3.77. October breeder body condition score for utilisation treatments at Pigeon Hole Station. Different letters denote significant differences between treatments. Tukey HSD Test. Means ± standard errors.

3.4.3.5.2.3 Breeder weight

Breeder weights (corrected for pregnancy status) of individual utilisation treatments varied significantly, but breeder weight was not correlated with utilisation (Table 3.30, Figure 3.78 - Figure 3.79). Diet quality was better in 2006 and 2007 which may have also influenced breeder weights.

Table 3.30. Effect of utilisation and year on breeder weight at Pigeon Hole Station. ANOVA results. *** = P<0.001, ** = P<0.01, * = P<0.05, ns = not significant.

	May	October
Treatment	***	***
Year	***	***
Treatment*Year	***	***

May breeder weights were lowest in 2005 (Figure 3.78). The early weaning at 32% utilisation in early 2005 (following fire in February 2005) probably explains the higher breeder weights for this paddock in 2006.

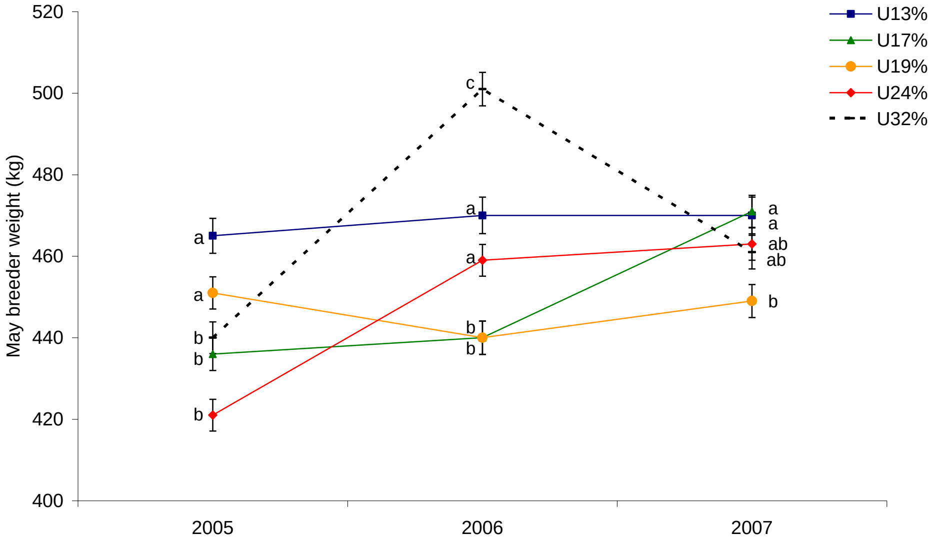


Figure 3.78. May breeder weights for utilisation treatments at Pigeon Hole Station. Different letters denote significant differences between treatments. Tukey HSD Test. Means ± standard errors.

Breeder weights in October were highest in 2006 and 2007 (Figure 3.79). This may be due to aging animals growing, as well as the better seasons in terms of forage quality in 2006 and 2007 and forage quantity in 2006.

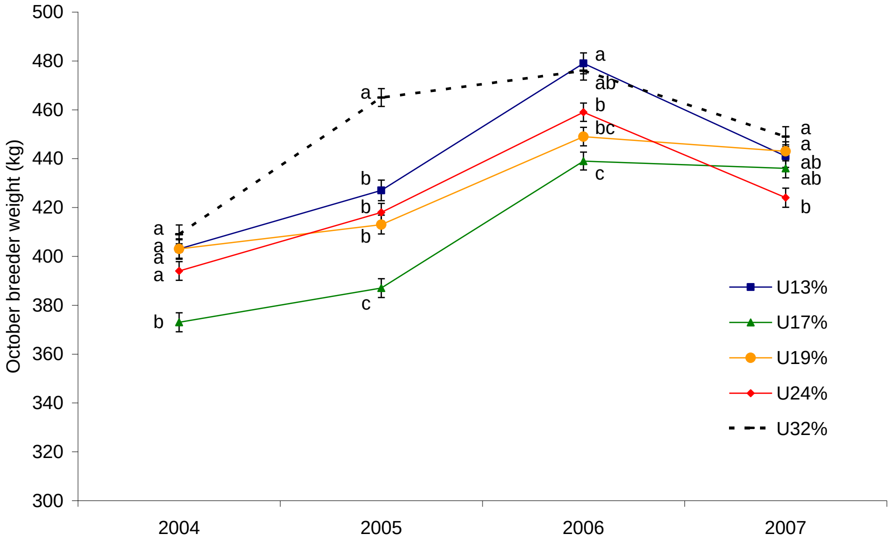


Figure 3.79. October breeder weights for utilisation treatments at Pigeon Hole station. Different letters denote significant differences between treatments. Tukey HSD Test. Means ± standard errors.

3.4.3.5.2.4 Weaner weight

Weaner weights in 2004 and 2005 (data only collected for these years) differed significantly between treatments, year and weaning round (Table 3.31, Figure 3.80). In May, weaner weight was significantly lower at higher utilisations (Pearson's correlation, p<0.001, r=-0.99, weaner weight = 253.71-1.986 * utilisation). Average weaner weight at 32% utilisation was 37kg lighter than at 13% utilisation. This result needs to be treated cautiously as it is likely that early weaning in April 2005 in 32% utilisation will have contributed slightly to this finding.

Table 3.31. Effect of utilisation and year on weaner weight at Pigeon Hole station. ANOVA results. *** = P<0.001, ** = P<0.01, * = P<0.05.

Effect	Weaner weight
Treatment	***
Year	*
Weaning Round	***
Treatment x weaning round	***

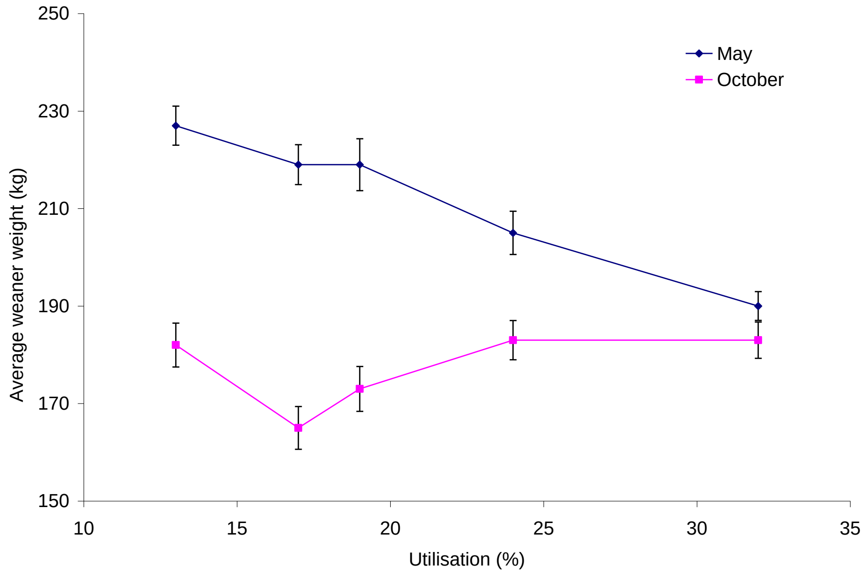


Figure 3.80. Average weaner weight in utilisation treatments in 2004 and 2005 at Pigeon Hole station. Means ± standard errors.

3.4.3.5.3 Mortality

3.4.3.5.3.1 Calf loss

Calf loss varied significantly between utilisation treatments (Binomial ANOVA, $F_{(4,15)}$=7.48, P=0.0016) with the 13 and 19% treatments having significantly lower calf loss, but calf loss was not significantly correlated with utilisation (Figure 3.81, Pearson's r=0.56, n=5, P=0.32).

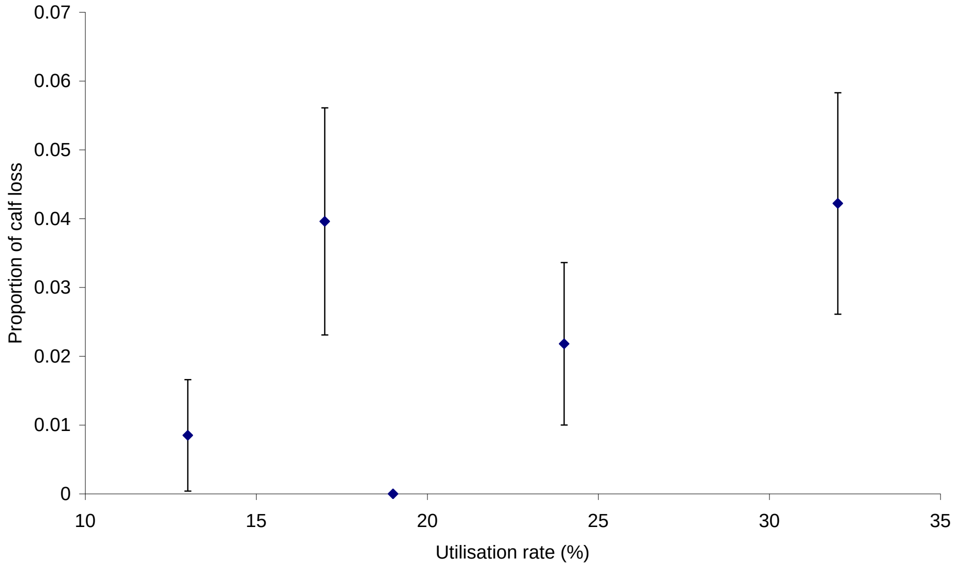


Figure 3.81. Average calf loss for different utilisation paddocks at Pigeon Hole station. Mean +/- 95% confidence intervals.

3.4.3.5.4 Fertility

3.4.3.5.4.1 Branding Rate

Branding rate was not correlated with utilisation rate (Figure 3.82).

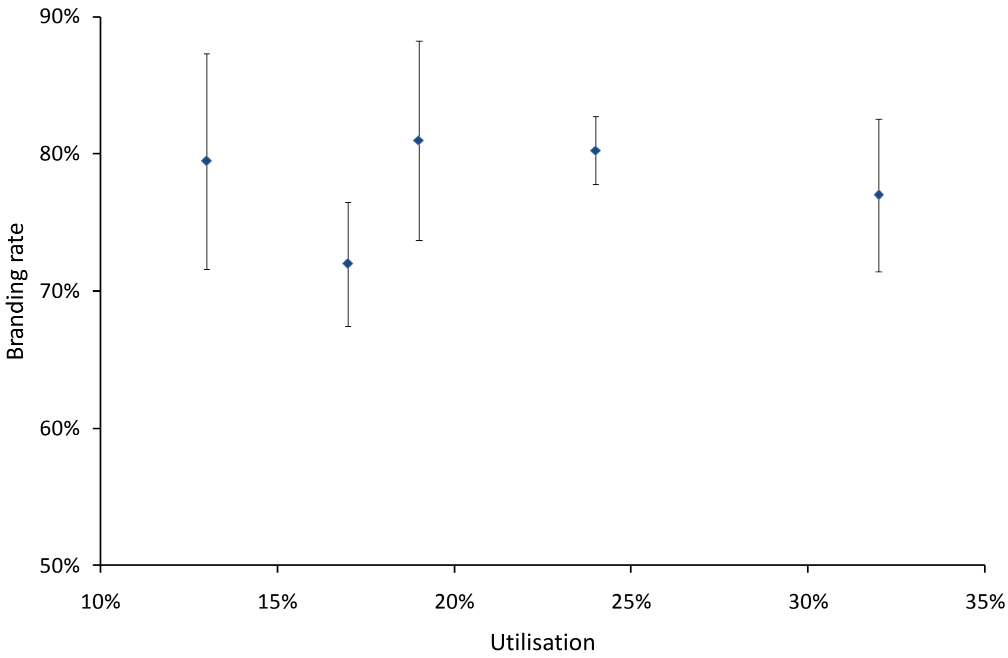


Figure 3.82. Average branding rate across all years for utilisation treatments at Pigeon Hole station. Means ± standard errors.

3.4.3.5.4.2 Weaning Rate

The particularly high weaning rate for the 32% utilisation paddock is due to early weaning in that paddock in 2005 (Figure 3.83, Table 3.32). Weaning rate did not differ between utilisation treatments either with 2005 data included or excluded (P>0.05, generalised linear model with binomial errors).

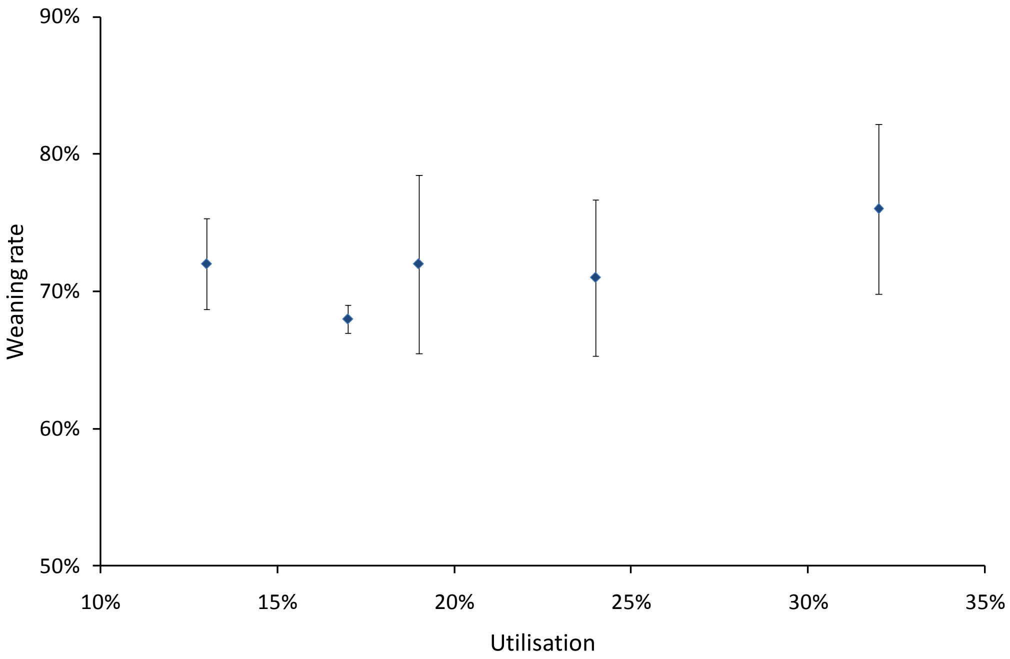


Figure 3.83. Average weaning rate across all years for utilisation treatments at Pigeon Hole station. Means ± standard errors.

Table 3.32. Weaning rate in utilisation treatments at Pigeon Hole station.

Utilisation (%)	13	17	19	24	32
2004	66%	65%	95%	91%	57%
2005	67%	67%	68%	68%	85%
2006	80%	68%	74%	72%	80%
2007	74%	70%	66%	66%	75%
Average 04, 06 & 07	73%	68%	78%	76%	71%

3.4.3.5.4.3 Proportion pregnant and lactating

There was no correlation between utilisation rate and fertility status, with highest rates in the lowest utilisation paddock, but lowest rates in 17 and 24% utilisation paddocks (Table 3.33). Significant differences between treatments are shown in Figure 3.84.

Table 3.33. Proportion pregnant and lactating in utilisation treatments at Pigeon Hole station (average 2004-2007).

Utilisation Treatment (%)	13	17	19	24	32
Average proportion pregnant and lactating	0.25	0.17	0.23	0.17	0.23

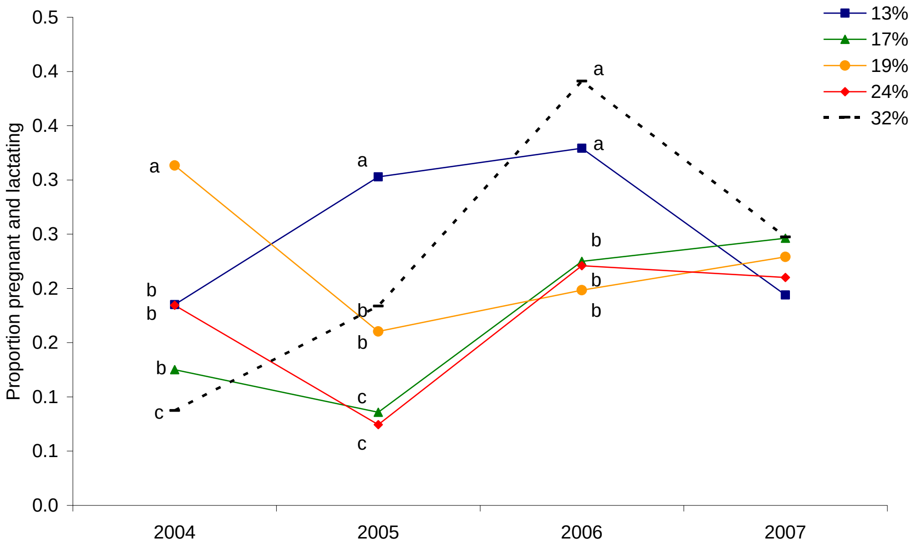


Figure 3.84. The proportion of cattle pregnant or lactating between 2004 and 2007 for utilisation treatments at Pigeon Hole station. Different letters denote significant differences between treatments. Binomial test to compare two proportions.

3.4.3.5.4.4 Inter-calving interval

Inter-calving interval did not significantly differ between utilisation treatments (Table 3.34) (P=0.10, Analysis of deviance, Gaussian model).

Table 3.34. Inter-calving interval for utilisation treatments at Pigeon Hole station.

Parameter	13%	17%	19%	24%	32%
Median	15	14	14	15	14
Mean	15.3	15.7	15.0	15.4	15.3
Proportion calving within 12 months	0.21	0.27	0.28	0.22	0.26
Proportion calving within 15 months	0.59	0.58	0.60	0.57	0.61

3.4.3.5.4.5 Calving patterns

All treatments started with peak calving at January or February, with a second calving peak in August as the trial progressed (Figure 3.85). Calving patterns were generally similar between treatments.

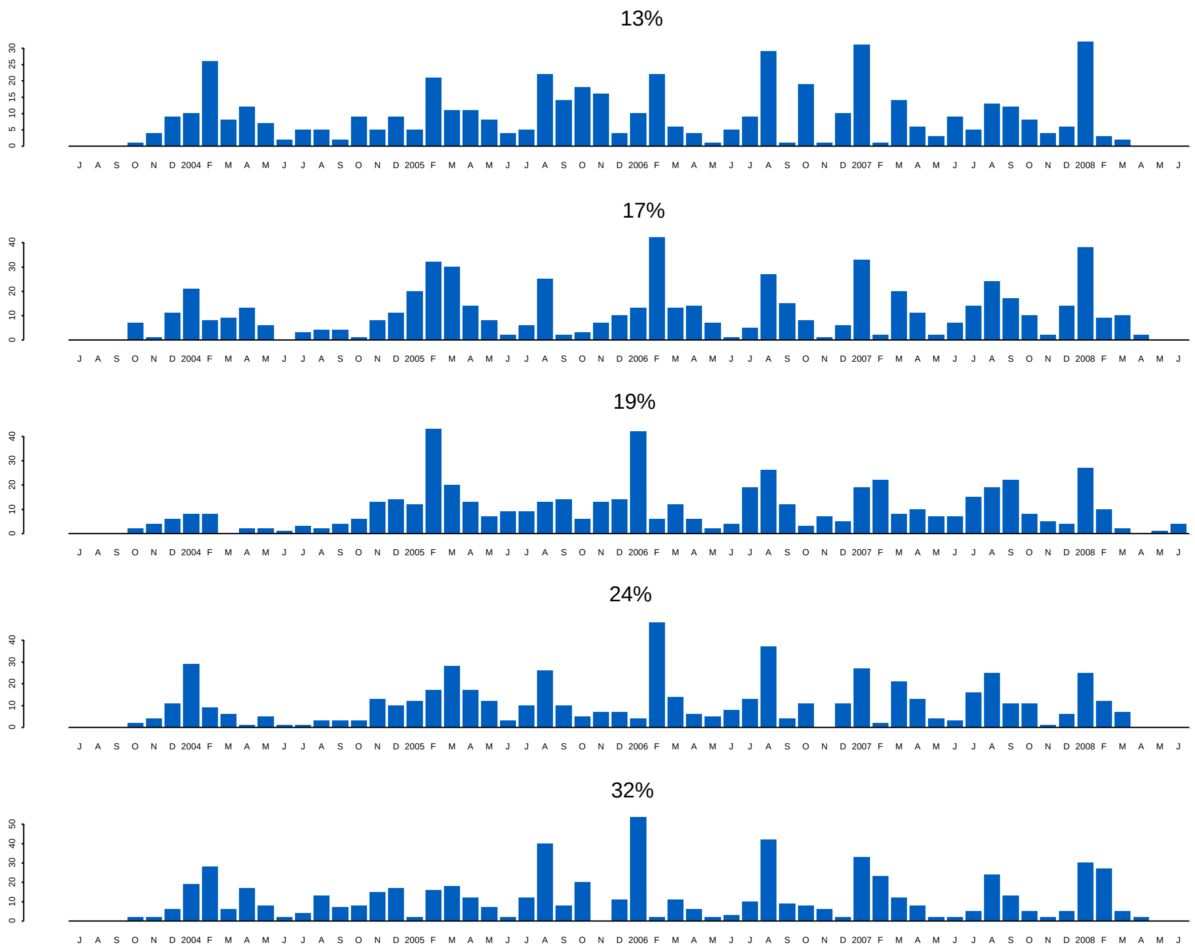


Figure 3.85. Calving patterns through time for utilisation paddocks at Pigeon Hole station. Number of calves per month.

3.4.3.5.5 Production parameters

3.4.3.5.5.1 Breeder herd efficiency

Breeder herd efficiency did not differ between treatments (Figure 3.86).

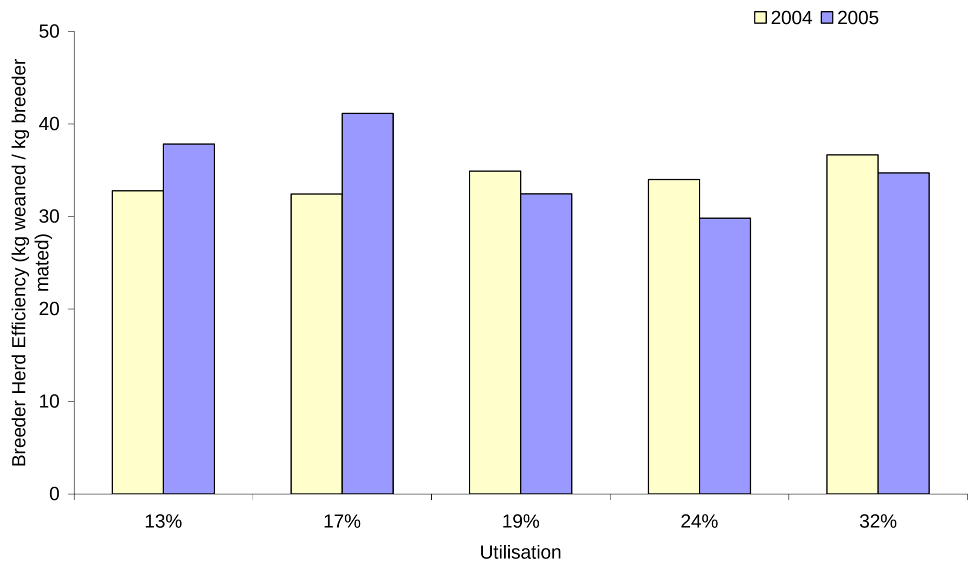


Figure 3.86. Breeder herd efficiency for different utilisation treatments at Pigeon Hole station. Based on weaner weight data from 2004 and 2005, and average weaning rate from 2004-2007.

3.4.3.5.5.2 Weight weaned per unit area

The higher stocking rates led to higher kilograms weaned per hectare with higher utilisation rates, although there was only a 60% increase in kg weaned / ha with a doubling of utilisation rate because weaner weights declined at higher utilisations (Figure 3.87).

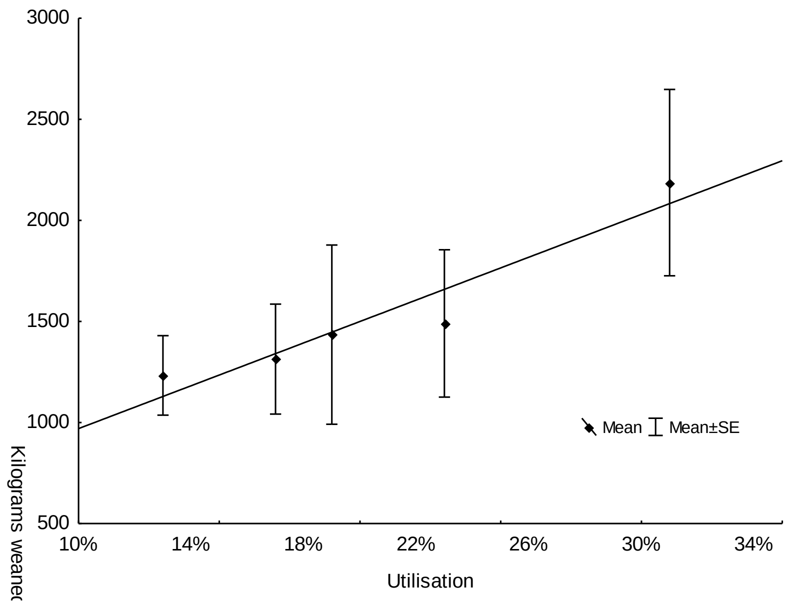


Figure 3.87. Average weaner production / area (kg/ha) at Pigeon Hole Station. Based on weaner weight data from 2004-2005 and average weaning rate from 2004-2007. Adjusted for % breeders in each treatment.

Weaner production was not static through time, but varied with the seasons (Figure 3.88). The effect of utilisation was greatest in 2007 after the high pasture growth year of 2006.

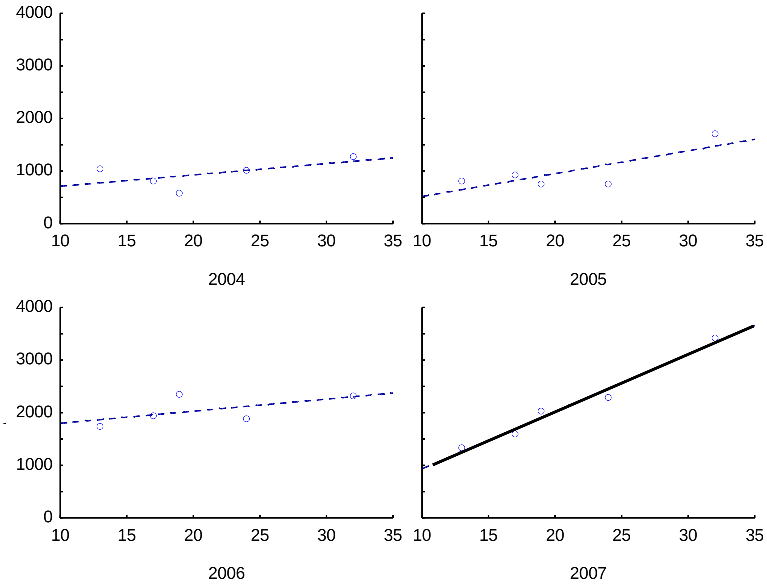


Figure 3.88. Weaner production versus utilisation by year at Pigeon Hole station. Dashed lines indicate fit not significant.

3.4.3.5.6 Economics of utilisation levels

The general lack of an effect of utilisation on individual animal performance meant that production and profit increased proportionate to stocking rate (Table 3.35). EBIT per AE ranged from $80-$100. It should be noted that over a longer time period higher utilisation levels would be expected to result in a decline in pasture condition and animal production per AE, as has been found in other longer term trials (e.g. O'Reagain *et al.* 2011).

Table 3.35. Economics of utilisation treatments during the trial at Pigeon Hole station.

Utilisation	13%	17%	19%	24%	32%
Average stocking rate	11	14	15	17	21
Replacement Capital	$70,567	$70,567	$70,567	$70,567	$70,567
Fixed Costs	$273,664	$273,664	$273,664	$273,664	$273,664
Direct Costs	$521,406	$584,282	$605,240	$647,157	$730,992
Total Operating	$865,636	$928,512	$949,471	$991,388	$1,075,222
Livestock Revenue	$2,141,163	$2,725,117	$2,919,768	$3,309,070	$4,087,675
Total Revenue	$2,162,553	$2,746,507	$2,941,158	$3,330,460	$4,109,065
EBIT	$1,154,156	$1,636,299	$1,797,013	$2,118,442	$2,761,300
EBIT $/AE	$80	$89	$92	$95	$100
EBIT $/km^2	809	1,147	1,260	1,486	1,936
ROIC	5.7%	7.7%	8.4%	9.6%	11.8%
Average branding %	78%	78%	78%	78%	78%
Herd Mortality	1%	1%	1%	1%	1%
Breeders	5,374	6,840	7,328	8,305	10,260
Total Herd	14,401	18,328	19,638	22,256	27,493
Sale Cows	672	855	916	1,038	1,282
Sale Steers	1,994	2,538	2,720	3,082	3,807
Sale heifers	1,228	1,563	1,675	1,898	2,345
Total sale kg	1,388,936	1,767,736	1,894,003	2,146,537	2,651,605
Production (kg sold/km^2)	974	1,240	1,328	1,505	1,859

3.4.4 Comparison of utilisation effects at Mt Sanford and Pigeon Hole

At Pigeon Hole total and palatable yield were lower than at Mt Sanford for similar levels of utilisation in both May and October (Figure 3.89 - Figure 3.90). Interestingly at Pigeon Hole there was no trend in palatable yield with utilisation in May or October.

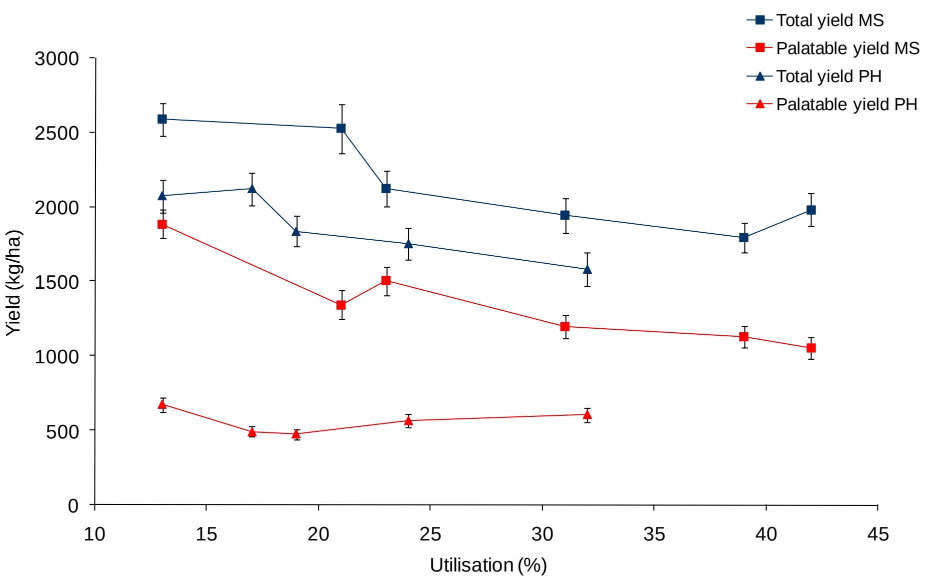


Figure 3.89. Average total yield and palatable yield in May versus utilisation at Mt Sanford and Pigeon Hole stations. Means ± standard errors.

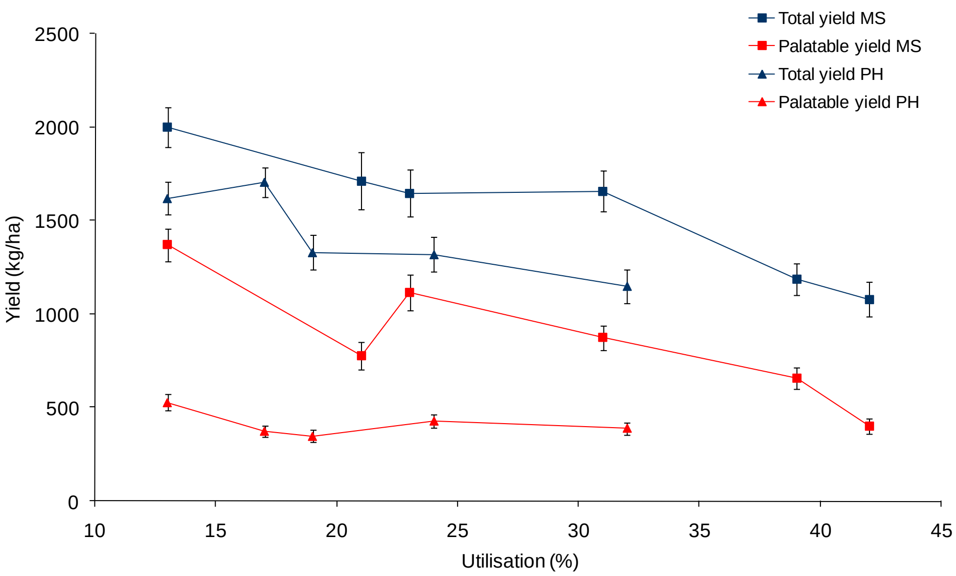


Figure 3.90. Average total yield and palatable yield in October versus utilisation at Mt Sanford and Pigeon Hole stations. Means ± standard errors.

When only the concurrent years for both studies were compared (2003-2006), average yields were about 300 kg/ha lower at Pigeon Hole than at Mt Sanford (Figure 3.91), which could reflect slightly higher rainfall at Mt Sanford during the trial (average rainfall 2003-2006 was 160mm more at Mt Sanford), or the better land condition, or inherent productivity of Mt Sanford, or both.

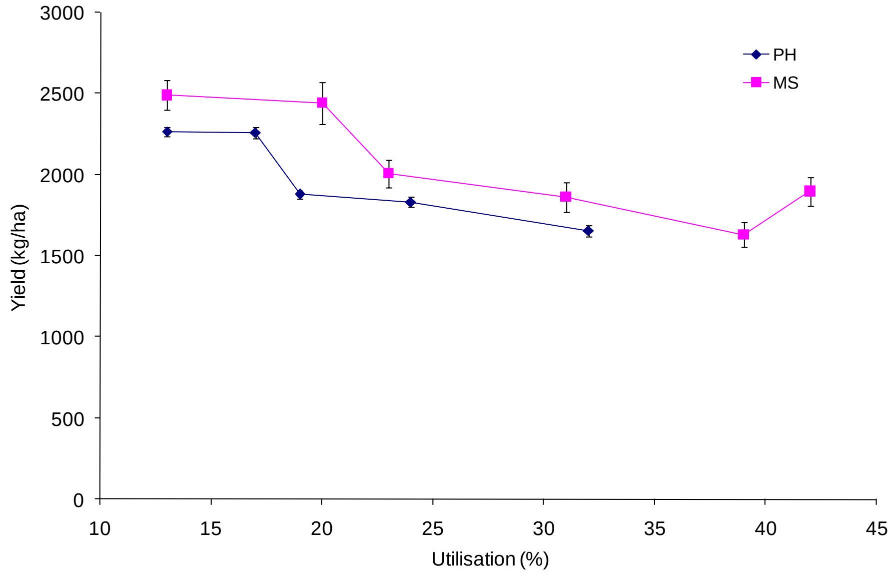


Figure 3.91. Comparison of May yields for the years when both trials were running (2003-2006). Means ± standard errors.

There was a larger difference between May and October ground cover at Mt Sanford than at Pigeon Hole (Figure 3.92).

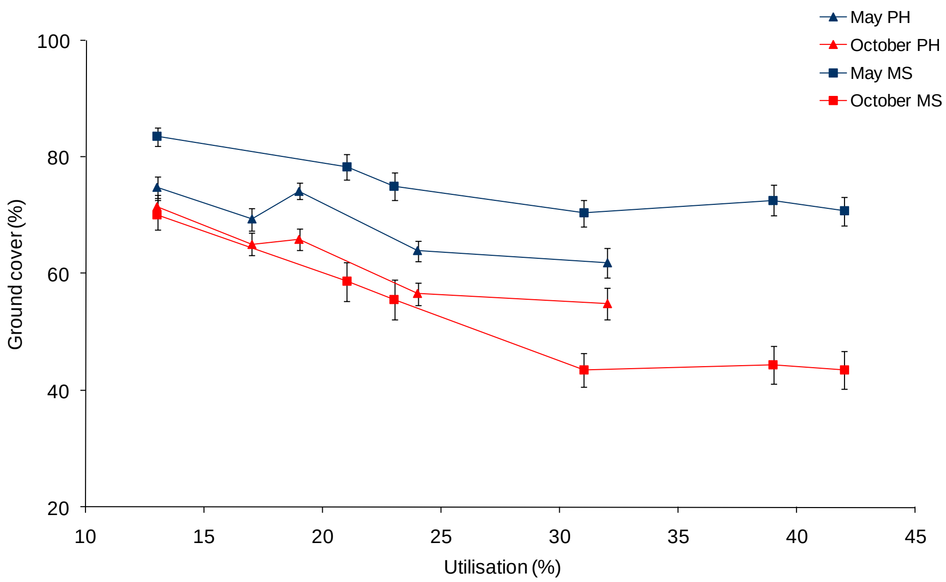


Figure 3.92. Average of all trial years cover in May and October with average utilisation at Mt Sanford and Pigeon Hole stations. Means ± standard errors.

Palatable perennial yield at Pigeon Hole was half that of Mt Sanford (Figure 3.93).

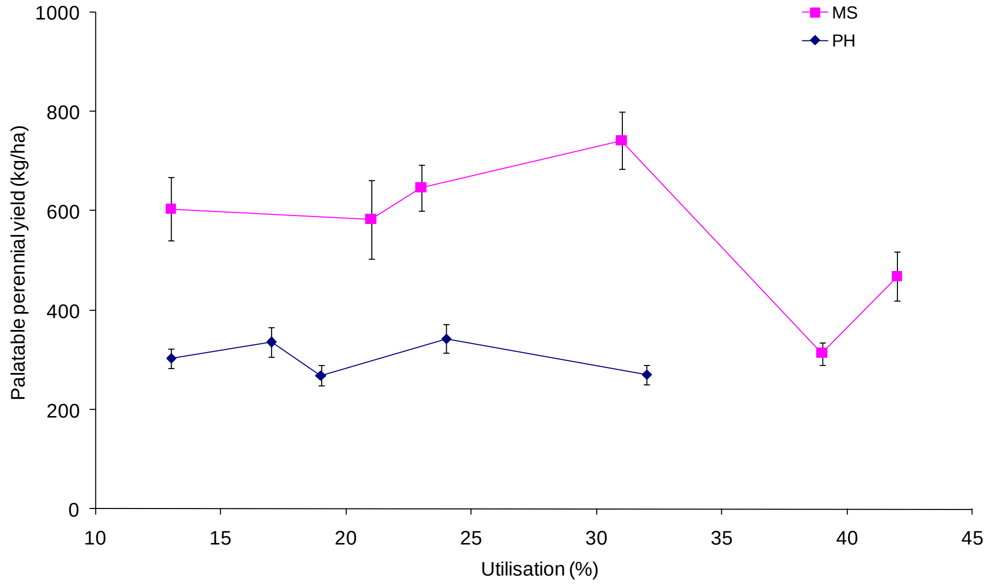


Figure 3.93. Palatable perennial yield in May with utilisation at Mt Sanford and Pigeon Hole. Average of all years. Means ± standard errors.

The Pigeon Hole herd had higher average breeder and weaner weights, weaning rate, breeder herd efficiency and production per unit area for similar utilisation rates to the Mt Sanford site (Table 3.36 - Table 3.37). Only weaner weight (which directly influences weight weaned / hectare) responded to utilisation at Pigeon Hole, while most animal production indices varied with utilisation at Mt Sanford.

Table 3.36. Average animal production indices at Mt Sanford and Pigeon Hole utilisation trials. For ease of comparison between trials, Mt Sanford treatments are separated into treatments equivalent to Pigeon Hole utilisations, and higher utilisations. Range (from lowest to highest utilisation) is shown where there was a trend with utilisation.

Animal production index	Mt Sanford 39-42% util	Mt Sanford 13-31% util	Pigeon Hole
Utilisation rate (%)	39-42	13-31	13-32
Average stocking rate (AE/km^2)	27-34	12-22	11-21
Average breeder weight (kg)	402-413	430-426	452
Average weaner weight (kg)	181-175	189-178	205-186
Average liveweight gain (kg/hd/day)	0.26-0.31	0.35-0.31	0.36
Average inter-calving interval (months)	15.8	14.1-16.1	15.1
Average weaning rate (%)	58	69-63	73
Average breeder herd efficiency (kg weaned per 100 kg breeder mated)	24	30-25	35
Weight weaned per sq km (kg)	2211-2744	1082-1883	1233-2187

Table 3.37. Percent change with doubling of grazing pressure on animal production indices at Mt Sanford and Pigeon Hole utilisation trials.

Animal production index	Mt Sanford	Pigeon Hole
Range of stocking rate tested	2.8 x	1.9 x
Range of utilisation tested	3.2 x	2.5 x
Increase in kg weaned per area		
Doubling utilisation from 15-30%	174%	160%
Doubling stocking rate from 10-20AE/kmsq	185%	195%

Liveweight gain was generally lower at Mt Sanford than Pigeon Hole, although at 13% they were almost identical (Figure 3.94). The seasons at Mt Sanford, which included a dry 2003 may have assisted to induce a production response to utilisation that was generally not observed at Pigeon Hole.

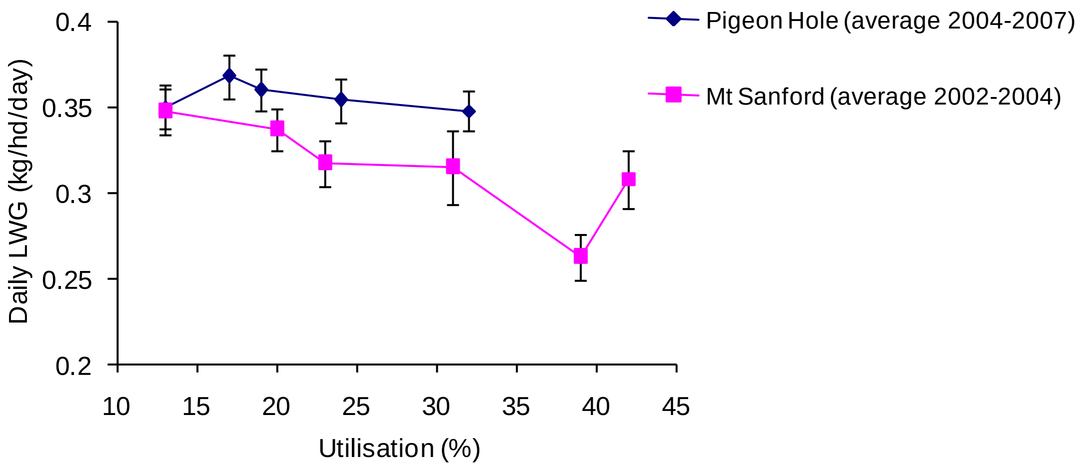


Figure 3.94. Daily live weight gain at Mt Sanford and Pigeon Hole with utilisation. Means ± standard errors.

While many cattle production indices responded to utilisation at Mt Sanford (e.g. Figure 3.95), this was not the case at Pigeon Hole, where only weaner weight and body condition score in May showed any correlation with utilisation.

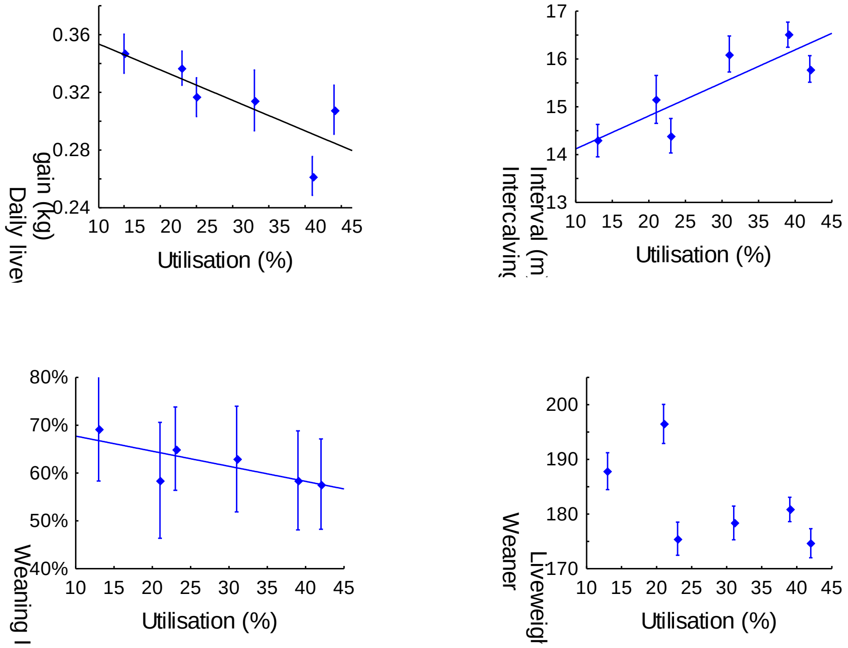


Figure 3.95. Effect of utilisation on animal growth and reproduction indices at Mt Sanford. Means ± standard errors.

Despite slightly higher total and much higher palatable yield at Mt Sanford, Pigeon Hole had slightly higher production per unit area (Figure 3.96).

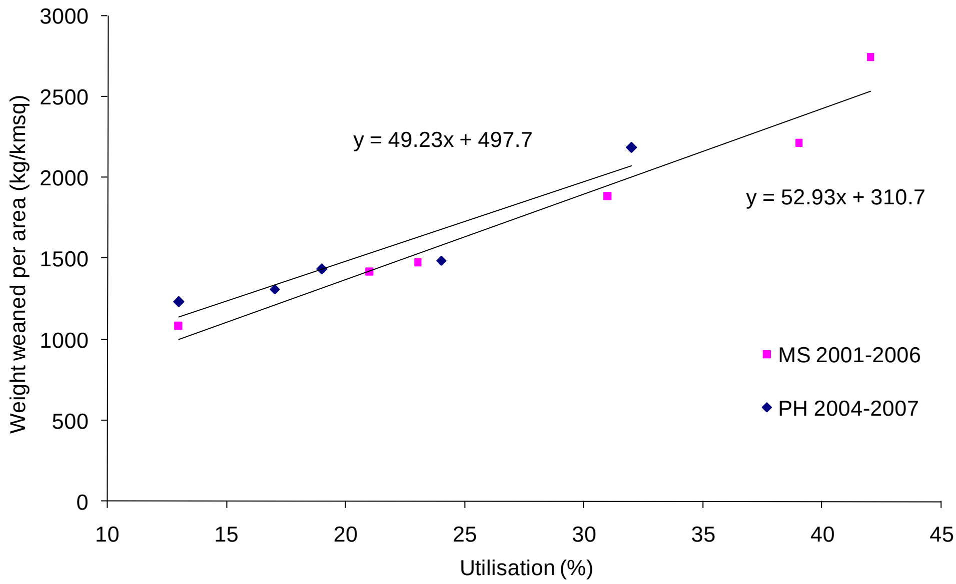


Figure 3.96. Mean kilograms weaned per unit area at Pigeon Hole and Mt Sanford Stations. Average of all years.

There was considerable variation in stocking rate required to achieve each desired utilisation rate at both Pigeon Hole and Mt Sanford, reflecting the effect of seasons and land condition on carrying capacity of landscapes (Figure 3.97 - Figure 3.98). Utilisation of 20% was achieved through stocking rates varying from 10-20 AE/km^2.

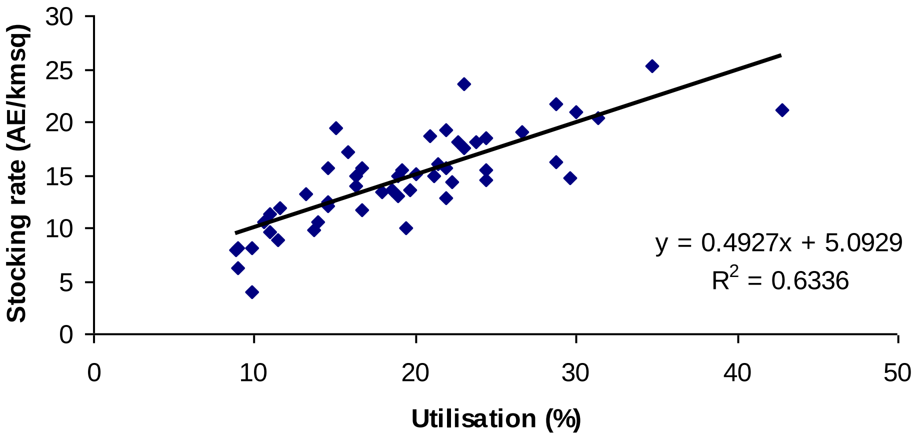


Figure 3.97. Relationship between annual average stocking rate and annual utilisation at Pigeon Hole station.

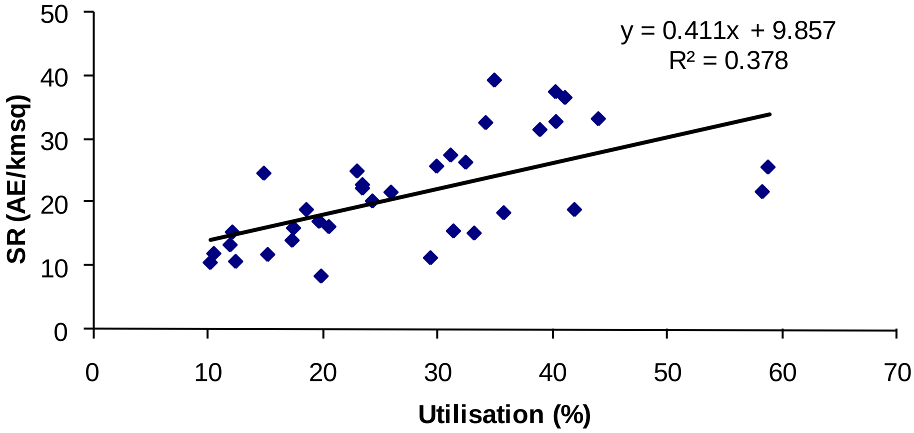


Figure 3.98. Relationship between annual average stocking rate and annual utilisation at Mt Sanford station.

Pigeon Hole had higher estimated earnings before interest than Mt Sanford on an AE and per unit area basis (Figure 3.99 - Figure 3.100), although at 13% utilisation the earnings per area was the same. This reflects the higher operating costs at Mt Sanford, which is primarily a function of the overall management systems in place on the stations, as well as the dampening effect of higher utilisation on liveweight gain and branding percentage at Mt Sanford. The earnings before interest per AE did not vary with utilisation at Mt Sanford, but increased at Pigeon Hole. This was a result of the dilution of the fixed costs as the animal numbers per unit area increased.

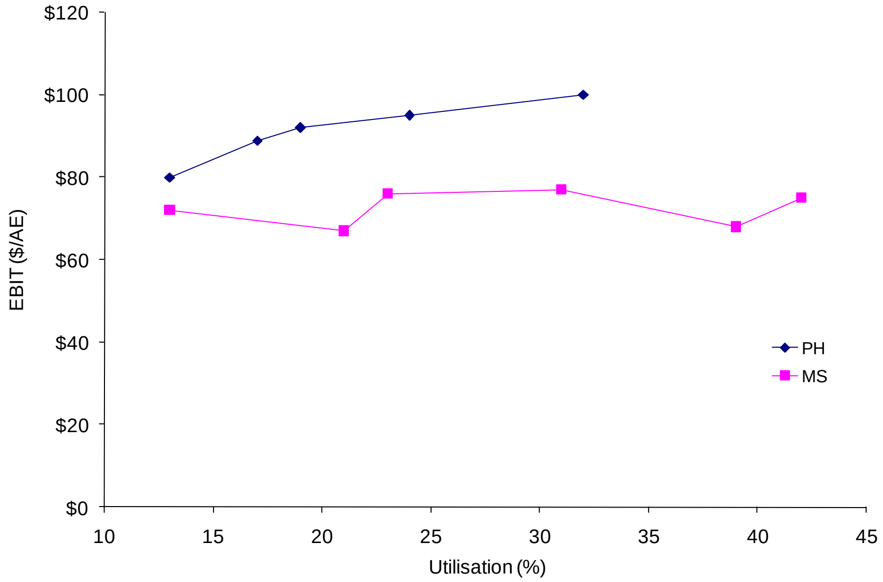


Figure 3.99. Effect of utilisation on earnings before interest and tax per animal equivalent at Mt Sanford and Pigeon Hole Stations.

The lines of best fit suggest that a 10% increase in utilisation led to an increase in EBIT per km^2 of $627 at Pigeon Hole and $487 at Mount Sanford (Figure 3.100).

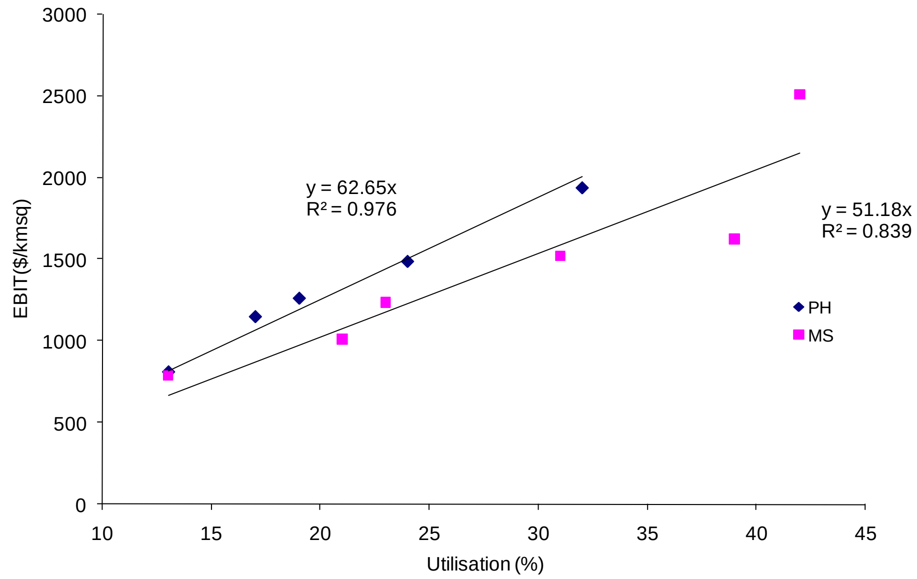


Figure 3.100. Effect of utilisation on earnings before interest and tax per area at Pigeon Hole and Mt Sanford stations.

3.4.5 Discussion - Mt Sanford and Pigeon Hole utilisation

The design of these grazing trials was not ideal. But they rarely are, due to the great cost of realistically scaled field studies (Bransby *et al.* 1988) and the variation across large areas which makes it impossible to choose or create paddocks that are similar in botanical composition, soil type and grazing history. Both studies were unreplicated, allowing individual paddock idiosyncrasies to potentially override treatment effects. This seems to have been a large factor in the Pigeon Hole results, where utilisation treatments were often statistically different, but only reflecting individual paddock differences, rather than a correlative response to the treatment of increasing utilisation. Fortunately at Mt Sanford, the duration of the trial (6 years, versus 4 years at Pigeon Hole), the smaller scale of the paddocks (perhaps contributing to a greater similarity between paddocks), and the presence of a dry year in 2003 in the middle of the trial to ‘push’ the system, or perhaps a combination of the above, did seem to allow some derivation of utilisation impacts at this site. The design does however mean that caution should be exercised in the interpretation of the results and the level to which inferences can be drawn beyond these sites.

In some ways the Pigeon Hole site can be seen as a quasi-replication of the work at Mt Sanford, albeit at a larger scale. They were both situated on the Wave Hill land system, on black cracking clay basalt-derived soils, within 50 km of each other and with similar rainfall, cattle breeds and set utilisation grazing management. But it is here that the similarities end. The paddocks at Mt Sanford were between 20 to 40 percent of the size of Pigeon Hole paddocks. Although on the same land system, the pasture composition and structure, water holding and nitrogen capacity of the sites were quite different (Appendix D.4). Higher (42% vs. 32%) and a greater number of utilisation levels (6 vs. 5) were tested at Mt Sanford, and the implementation of utilisation rates year to year was generally more faithful to the target rates than at Pigeon Hole.

The contrasting response to utilisation at Pigeon Hole and Mt Sanford invites further discussion of factors that may be influencing the different findings at the two sites.

3.4.5.1 Differences between Pigeon Hole and Mt Sanford sites

3.4.5.1.1 Site productivity

GRASP modelling suggests that the median pasture growth at Pigeon Hole sites is around 1900 kg/ha. For Mt Sanford, the modelled median pasture growth at four sites averaged 2650 kg/ha. This and the higher maximum nitrogen uptake and higher water holding capacity of the Mt Sanford sites suggests higher potential growth at Mt Sanford. When the two trials were both active between 2003 to 2006 the higher average yield at Mt Sanford may have been due to a combination of differences in rainfall (slightly higher at Mt Sanford), land condition (better at Mt Sanford), or site potential.

3.4.5.1.2 Land condition, pasture composition and structure

There were compositional and structural differences in the vegetation of the two sites. The B condition Mt Sanford site had higher average total, palatable and perennial yield than the C condition Pigeon Hole site at similar utilisation rates. The more tussocky structure of the sward at Mt Sanford was reflected in greater variation in cover between early and late dry than for Pigeon Hole at similar levels of utilisation. There were large differences between end of wet and end of dry cover levels at Mt Sanford, as annuals and forbs detached or were removed from between the perennial tussocks. The high proportion of annual sorghum at Pigeon Hole meant that in the late dry the cover did not decline much, due to the old sorghum plants falling over and contributing to high ground cover levels. This may have contributed to the lack of response to higher utilisation at Pigeon Hole as the annual sorghum litter provided a buffer to utilisation effects on ground cover, and presumably the high cover levels maintained could contribute to soil and water retention in this system, provided fire does not remove litter cover.

3.4.5.1.3 Diet quality

There is some evidence (from 6 months during 2004 when NIRS data is available from both sites), that diet quality was higher at Mt Sanford than Pigeon Hole. On average for the 6 months across 2004, crude protein and dry matter digestibility were both 2% higher and DMD:CP ratio 3 points lower at Mt Sanford than Pigeon Hole. This may have reflected higher rainfall at Mt Sanford than Pigeon Hole for that year. In 2005 when the sites had equal rainfall, there is data for only 1 month in May at both sites, but NIRS indices of diet quality were equal at that time. The high yield of Sorghum at Pigeon Hole is likely to have contributed to lower diet quality there as Sorghum can dilute N to very low levels (Appendix D), particularly in high pasture growth years, as in 2004. Despite only low defoliation of Sorghum, because it was so prevalent at the site, this meant that between 4-12% of the total diet in utilisation paddocks was Sorghum in May and 11-18% in October (when averaged across all years).

3.4.5.1.4 Effect of rainfall on utilisation impacts

Rainfall at the sites was generally average to above average, but for Pigeon Hole there were no very dry years during the period of the trial when animal production was being measured (trial cattle were not introduced until late 2003 at Pigeon Hole). This is in contrast to Mt Sanford, which had a below average growth year in 2003 right in the middle of the trial. It is the combination of drought and high stocking rates that cause degradation events, with effects on animal production only becoming obvious in subsequent droughts (Fynn and O'Connor 2000). Hence the seasonal conditions experienced during the Mt Sanford trial may have been more conducive to testing the capacity of the system under different utilisations.

At Mt Sanford the utilisation relationship was not static across years, but varied by year, depending on the season. Flatter slopes in individual animal production versus utilisation occurred with better seasons as has been found elsewhere (reviewed in Ash and Stafford Smith 1996). At Pigeon Hole, in addition to the absence of dry years, there was potentially seasonal buffering of utilisation effects at Pigeon Hole in 2006 and 2007 when the later end to the wet season extended pasture quality for a couple of months into the dry.

3.4.5.1.5 Implementation of set utilisation

Implementation of target utilisation rates was more successful at Mt Sanford. This reflects the different approach to adjusting stock numbers in the two trials. At Mt Sanford, stock numbers were adjusted following forage budgeting in April. At Pigeon Hole stock numbers were adjusted following pasture growth modelling, rather than field based forage budgeting, sometimes resulting in stocking rates not increasing enough to match desired off-take. There were also sometimes delays in adding cattle following good seasons until sometime between round one in May and right up to round two in September and later at Pigeon Hole, which meant that target utilisations were sometimes not achieved in high rainfall years. This may have reduced the ability to detect utilisation impacts at Pigeon Hole compared to Mt Sanford, because paddocks were effectively understocked in the first year in 2004 with rates ranging from only 11 to 23% utilisation and in the third year in 2006 when the two highest utilisation treatments were understocked at 24-29% utilisation. Hence every second year, the higher utilisation paddocks at Pigeon Hole were effectively only moderately utilised.

This, combined with the shorter duration of the study at Pigeon Hole, may have limited the ability to detect a threshold utilisation beyond which species composition alters and pasture and animal productivity declines.

3.4.5.2 Utilisation effect on pasture growth

While high utilisation during the wet season is known to reduce pasture growth (>50% Mott 1987; > 40% in the late wet Ash and McIvor 1998; >60% McIvor 2007; 75% annual utilisation Ash *et al.* 2011), the effect of utilisation on pasture growth at Mt Sanford and Pigeon Hole was not directly measured. However, estimated wet season utilisation was relatively low even at the highest utilisation treatments, ranging from 12 to 28% (av. 20%) at Mt Sanford and 8 to 22% (av. 15%) at Pigeon Hole. Hence it is likely that reduction in growth will have been slight if any. Although estimated growth (yield plus wet season intake in May) was sometimes lower at higher utilisations (Appendix A.2, Figure A.1 and Appendix C.3, Figure C.6), this may reflect lower carryover and higher detachment at higher utilisation rates, rather than a decrease in pasture growth. Additionally the yield in May, and number of animals the paddocks could carry were not separating through time between treatments at Pigeon Hole and Mt Sanford, which suggests there were no major effects on growth at the sites. Modelling is required to properly elucidate impacts on pasture growth.

3.4.5.3 Utilisation effects on end of year cover and yield targets

In the absence of locally derived soil cover and yield targets to maximise infiltration and minimise soil loss, North Queensland thresholds were applied to this study to assess cover levels. Cover levels of less than 40% lead to accelerated soil and water loss in northern Queensland (McIvor *et al*. 1995, Scanlan *et al*. 1996). 60% ground cover maximises infiltration on undulating duplex soils, with a history of overgrazing, in the Burdekin (Post *et al.* 2006). This increases to 70% ground cover for tussock grasslands, which is more relevant to Mt Sanford. This suggests that, at Mt Sanford, 23% utilisation is the upper level that should be applied to avoid the risk of significant soil and water loss. At Pigeon Hole cover was relatively high and stable throughout the year. All utilisation treatments had greater than or equal to 60% cover in October except in 2005 following a fire in the 32% utilisation treatment, which led to cover levels of less than 40%. It is possible the high cover of annual sorghum helped to reduce utilisation effects on soil at Pigeon Hole, reducing feedback effects on water retention and species composition. However the low perennial grass basal area of the Pigeon Hole site makes it particularly vulnerable to erosion following fires, or low rainfall. This was observed in 2003 when late heavy rain following extensive fires across the site led to high levels of runoff and severe gullying and erosion of roads and fencelines. Despite good total rainfall, the site grew only 1000 kg/ha, reflecting the poor retention of water. This compares with 2007 which had 160mm less rain than 2003, but grew 1.5 times the amount of pasture.

Low cover and yield at high utilisation levels would also contribute to lower fire frequency (McGuffog *et al.* 2001). At higher utilisation levels paddocks may need to be spelled to accumulate sufficient fuel and cover. The presence of fire at Pigeon Hole suggests that utilisation up to 32% does not preclude its implementation in the landscape. However, it is likely that the lower yields at utilisations above 19% at Pigeon Hole and 23% at Mt Sanford would reduce fire frequency and or extent (McGuffog *et al.* 2001). The strong correlation between number of fires and woody cover at Pigeon Hole and elsewhere in the VRD (Cowley *et al.* 2011) suggests this may lead to woody thickening over time.

3.4.5.4 Utilisation effects on species selection

All species were selected for except for *Sorghum* (probably due to its very low N content, 0.2% *cf.* 0.4% for *Chrysopogon* and *Aristida*, Appendix D.3.3.2, Figure D.11 - Figure D.10) and *Flemingia.* Together they made up 37-51% of the total yield. Hence even relatively unpalatable species *Aristida latifolia* and *Chrysopogon fallax* were selected for at Pigeon Hole, in contrast to studies at Manbulloo (Andrew 1986a), but similar to Scott Creek (Ash and Corfield 1998, Ash and McIvor 1998) where cattle selected for *Chrysopogon fallax* when the pasture was in state two – dominated by annuals and *Chrysopogon*.

While defoliation of species increased with average paddock utilisation, the absence of an effect of utilisation on species *selection* is in contrast to previous findings (Ash and McIvor 1998, Ash and Corfield 1998). This was probably because species composition was not affected by utilisation and selection of preferred species increases as their proportion of total yield declines (e.g. Quirk 2000). However where there was variation in abundance of a species between paddocks, species selection was higher where it was less abundant, as found for the unpalatable *Aristida latifolia* at Pigeon Hole.

3.4.5.5 Utilisation effect on pasture composition

The lower fluctuation in plant composition at Pigeon Hole through time in the lowest two utilisations suggests that pasture composition is more stable under seasonal stress when utilisation is low. The 19% utilisation treatment changed most though time, with greater increases in annual sorghum yield through time. This may reflect species composition recovery with the absence of fire in this paddock, and possibly lower utilisations compared with prior to the trial, as this paddock previously had a water point in the south eastern corner that supplied a large relatively unwatered paddock and such areas are often subject to high utilisation. However, species composition was not generally becoming more dissimilar between utilisation treatments with time, reflecting the relatively narrow range of utilisations tested and good seasons.

Some subtle impacts of utilisation were detected for some species and genera.
Three species showed either an increase at 13% utilisation, or a decline at higher utilisations.

Astrebla spp. yield increased at 13% utilisation at both Pigeon Hole and Mt Sanford, although this was not observed for *Astrebla* frequency in the biodiversity sampling (Chapter 6). This may be because there was a much higher incidence of ungrazed *Astrebla* plants (20-45% of individuals ungrazed at Pigeon Hole) at 13% utilisation (vs. 5-20% of *Astrebla* plants ungrazed at higher utilisations) and average wet season and annual defoliation of *Astrebla* was only 5% and 15-30% respectively. This is consistent with previous work that found *Astrebla* grasslands can withstand defoliation of up to 30% of TSDM (Orr and Evenson 1991). *Astrebla spp.* are known decreasers or intermediate/decreasers (Fisher 2001). The relatively low proportion of *Astrebla* at the site suggests past utilisation was greater than 13%. This study suggests that light grazing may be enough to promote recovery of *Astrebla spp*.

Jacquemontia browniana also increased at 13% utilisation at Pigeon Hole, in contrast to its generally perceived status as an unpalatable increaser (Petheram and Kok 2003), while *Panicum decompositum* decreased more through time at 39 and 42% utilisation at Mt Sanford, suggesting sensitivity to higher utilisation levels.

Four species had patterns suggesting an affinity to higher disturbance levels. *Brachyachne convergens* increased under higher utilisation (where defoliation averaged up to 70%) in both trials, consistent with previous findings (Fisher 2001, Orr and Phelps 2003). The forb *Sesbania spp.* increased most at 32% utilisation and *Wedelia asperrima* declined most at 13% utilisation at Pigeon Hole, consistent with previous findings that they are increaser species (Petheram and Kok 2003, Fisher 2001).

Despite annual sorghum being the dominant species at Pigeon Hole, it was not preferred by cattle and experienced low levels of defoliation, usually between 2-15% by October. Defoliation of sorghum was only higher than this (30%) following an extensive fire in the 32% utilisation paddock in 2005.

The relative increase of *Sorghum* under higher utilisations is in contrast to Fisher (2001) where it decreased in response to grazing. It is possible that greater defoliation of surrounding species, and opening up of the ground cover (about 15% lower for 24-32% versus 13% utilisation) gave *Sorghum* a competitive advantage in higher utilisation paddocks.

The increase in annual and unpalatable yield and the decline in the proportion of perennial grass at higher utilisation rates at Pigeon Hole are due to the increase in annual sorghum.

The relatively low defoliation of the dominant yield component sorghum meant that the more palatable species were grazed relatively heavily during the wet season with defoliation levels averaging up to 20 to 30% in May and up to 50% by October for the palatable perennial grasses. While this was much higher than average utilisation for these paddocks, levels of greater than 50% defoliation were required to reduce basal area or survival of perennial grasses elsewhere ((Orr *et al.* (1986), Mott (1987), Scattini (1973) in McKeon *et al.* (1990), McIvor (2007), White *et al.* (2008)). Hence even the higher levels of perennial grass defoliation observed at Pigeon Hole are consistent with plant persistence. Grazing trials across Queensland and northern NSW have shown it is the combination of drought *and* high utilisation that kills perennial grasses (reviewed in McKeon *et al.* 2004). Hence the relatively favourable seasonal conditions during both trials here, particularly at Pigeon Hole have probably contributed to perennial grass persistence despite moderately high utilisation levels.

Despite this there were subtle trends suggesting a potential decline in palatable perennial grasses at Mt Sanford. At Mt Sanford the palatable perennial yield in 39% and 42% utilisation treatments did not recover as well as lower utilisation paddocks following the poor 2002-2003 wet season.

Chrysopogon fallax made up 8-10% of the pasture yield at both sites and was stable across utilisations where it experienced up to an average 30% defoliation over the wet season, and up to 50% by October. This suggests it is relatively resistant to grazing as has been found elsewhere where it either did not respond to grazing (Arndt and Norman 1959, Ash and McIvor 1998, Fensham *et al.* 2000), or increased under grazing (Fisher 2001).

The absence of a response by *Aristida latifolia* to utilisation is not surprising given the very low wet season defoliations of this species at all utilisations, usually averaging less than 5%. It is also consistent with findings elsewhere in the VRD and Barkly Mitchell grasslands (Fisher 2001) where *Aristida latifolia* was most frequent at intermediate grazing levels, but in contrast to southern Qld Mitchell grasslands, where it was highest under light grazing (Orr 1980).

3.4.5.6 Utilisation effect on diet quality

The absence of an effect of utilisation on diet quality, is in contrast to previous findings at Charters Towers and Katherine (Ash *et al.* 1995), but is consistent with the relatively stable species composition across utilisation rates at the sites. At Mt Sanford the similarity in pasture quality suggests that pasture quantity must have been more limiting to animal production with higher utilisation rates at Mt Sanford, although it is possible that differences in quality between utilisation paddocks would have been apparent if data was collected for the full duration of the trial, as NIRS data was not collected for most of 2005-2006.

3.4.5.7 Utilisation and animal production

The Mt Sanford and Pigeon Hole studies were relatively unusual in that they collected both grower and reproduction data (Ash & Stafford Smith 1996). There was no indication that animal reproduction was less sensitive to utilisation than growth as suggested elsewhere (Ash and Stafford Smith 1996). At Mt Sanford there was generally a linear decline in individual animal production indices with increasing utilisation, although trends varied considerably year to year and on average were relatively modest.

Production on a per animal basis generally remains constant below a critical stocking rate threshold and decreases above this threshold (Jones and Sandland 1974, Ash and Stafford Smith 1996). Mt Sanford data suggests that this threshold is at 13% utilisation, as previous work at Mt Sanford showed no change in production with lower utilisations (MacDonald unpublished data).

Differences between Mt Sanford and Pigeon Hole animal performance

Despite the similar land type, location and grazing system, the two trials had quite different animal production responses to utilisation. Both reproduction and growth declined with increasing utilisation rate at Mt Sanford, while at Pigeon Hole, only weaner weight responded. On average, the Pigeon Hole herd performed better than the Mt Sanford herd. At Mt Sanford weaner weight, breeder weight, weaning rate and breeder herd efficiency were lower than at Pigeon Hole (this study), Victoria River Research Station (Cobiac 2006a) and at the Mt Sanford site between 1994 and 1998 in the earlier stocking rate trial (MacDonald 1999). It is possible that the larger paddocks of the Pigeon Hole trial allowed spatial buffering of utilisation effects as suggested by Ash *et al.* (2004). However the higher utilisation rates over a wider range and number of treatments and the very dry year in the middle of the trial in 2003 at Mt Sanford have probably contributed to the lower average animal production at Mt Sanford in this study.

Live weight gain
Liveweight gain was lowest in drier years (2003 and 2005 at Mt Sanford and 2005 and 2007 at Pigeon Hole) consistent with findings elsewhere in water limited environments (Ash and Stafford Smith 1996).

At 13% utilisation average live weight gains at Pigeon Hole and Mt Sanford were almost identical. At higher utilisation rates Mt Sanford average live weight gain declined about 10% with an increase in utilisation rate from 15 to 30%, which is typical of that found in research trials in extensive rangelands (Ash and Stafford Smith 1996). Live weight gain presumably declined in response to lower *quantity* of palatable yield at higher utilisations at Mt Sanford, because diet *quality* (from NIRS data) did not vary with utilisation. Although palatable yield was much lower at Pigeon Hole, it did not correlate with utilisation as often as at Mt Sanford. This may have contributed to the lack of correlation between LWG and utilisation at Pigeon Hole.

The daily live weight gains at Mt Sanford and Pigeon Hole (averages ranging from 0.26 to 0.35kg/hd) were similar to that found in Mitchell grass communities in northern NT and northwest Queensland (0.3 kg/hd/day (Bortolussi *et al.* 2005b); 0.34 kg/ha/day (studies reviewed in Bortolussi *et al.* 2005b) and 0.31 kg/hd/day for the 20-25% utilisation treatment at Wambiana (O' Reagain *et al.* 2009)), but were higher than found on red earths at similar utilisation rates at Scott Creek, Katherine (averages ranging from <0.2 to <0.3, Ash *et al.* (1995)). This may reflect the more productive nature of the fertile cracking black clays in the Pigeon Hole / Mt Sanford sites compared to the Scott Creek red earths. However there was considerable variability in live weight gain between years at Pigeon Hole and Mt Sanford (0.25-0.45 kg/hd/day), so differences may also be due to seasonal effects. The better years of live weight gains at Mt Sanford were similar to those found at Mt Sanford in the previous stocking rate trial (0.4-0.44 kg/hd/day, MacDonald 1999), and liveweight gains reported in north west Queensland and northern WA Mitchell grass (0.4 and 0.37 kg/hd/day, Bortolussi *et al.* 2005b).

Breeder weight
Similar to growers, breeders had lower weights with increasing utilisation rate at Mt Sanford possibly reflecting the lower palatable yield at higher utilisation rates during the late dry/early wet season. Over the longer term this could result in lower weaning rates since body condition is one of the main factors effecting fertility.

Decreased breeder live weight or body condition has significant impacts on herd productivity, especially if losses occur during late gestation or early lactation. Breeders under nutritional stress display increased inter-calving intervals as a result of prolonged periods of anoestrous (Jolly *et al.* 1996, Randel 1990, Rudder *et al.* 1976 and Short *et al.* 1990). They conceive later in the season (Rudder *et al.* 1976), have more out of season calves and reduced weaning rates (Braithwaite and de Witte 1999). The results from this study are consistent with this as inter-calving interval increased with utilisation rate at Mt Sanford. However, the effect of utilisation rate on inter-calving interval may not have been fully expressed at Mt Sanford as breeders were culled for sub-fertility if their inter-calving interval was greater than 24 months (i.e. non-pregnant and non-lactating in April). This would have inflated the apparent fertility of breeders at higher utilisation rates.

There was no effect of utilisation on breeder weight at Pigeon Hole, although breeder body condition score in May was lower at higher utilisations.

Weaner weight
Weaner weight was the only animal production variable to respond to utilisation at both grazing sites, which suggests it may be more sensitive to utilisation than other animal production traits.

At Pigeon Hole weaner weights were only measured during the first two years although these were representative of the seasonal conditions found throughout the trial. During this time May weaner weights declined 16% with a doubling of utilisation. The decline in weaner weight corresponded with an average 1 point decline in breeder body condition score in May (from 4.9 to 3.9), suggesting a response to declining breeder condition.

Inter-calving intervals and weaning rates
The average inter-calving interval of herds was greater than 12 months at all utilisation rates at both sites. Therefore, all herds were drifting away from the optimal calving time in the late dry/early wet season (Braithwaite and de Witte 1999) resulting in breeders either not conceiving or calving out of season under sub-optimal nutritional conditions.

Only Mt Sanford herd ICI varied with utilisation, but even at the lowest 13% utilisation, ICI at Pigeon Hole was higher than for the same utilisation at Mt Sanford.

At Mt Sanford the inter-calving intervals of herds grazing at greater than 23% utilisation rate had on average a one month longer inter-calving interval than those less than those at 23% or lower utilisation rate. A month longer inter-calving is thought to correspond to a loss of 4% weaning rate (Braithwaite and de Witte 1999). However, at Mt Sanford there was a 10% difference in weaning rate between lowest and highest utilisation treatments for only a one month difference in ICI. The lower average weaning rates at Mt Sanford may also be partly reflecting differences in herd management at the sites, as culled cows at Mt Sanford were replaced with empty heifers, while at Pigeon Hole culled cows were replaced with pregnant heifers. For most years there was no effect of utilisation on weaning rate. Weaning rate only responded to utilisation following the very dry year of 2003, and then the effect on weaning rate took two years to recover to earlier levels. The lack of a response in weaning rate at Pigeon Hole is consistent with the lack of a utilisation effect on breeder weights and inter-calving interval at Pigeon Hole and better seasons.

The order of response in production indices through the trial at Mt Sanford is instructive. Breeder weight was consistently lower at higher utilisation rates, but initially only weaner weight declined with higher utilisation with weaning rate unaffected. However, following the very dry year of 2003 weaning rate crashed, and weaner weight although low, was no longer correlated with utilisation.

This suggests that breeding herds can maintain high weaning rates with increasing utilisation provided seasonal conditions are not limiting. The lower breeder weights are expressed in smaller calves at higher utilisations. However once a threshold of stress is crossed, breeders are unable to maintain calf output, resulting in lower weaning rates rather than weaner weights. This suggests weaner weight is a more sensitive indicator of stress in a breeding herd, which is consistent with findings at Pigeon Hole where without a very dry year during the trial, weaning rates were maintained, but weaner weights and breeder condition score were lower at higher utilisations.

Breeder herd efficiency
At Mt Sanford breeder herd efficiency across all utilisation rates was below the 31 kg weaned/100 kg breeder mated for Brahman herds grazing the VRD (Cobiac 2006b). This can be accounted for by 1) the higher breeder weight at Mt Sanford and 2) the 20 kg lower minimum weaning weight used by Cobiac (2006b). Earlier weaning of calves has been shown to reduce the inter-calving interval (Sullivan and O'Rourke 1997, Jolly *et al.* 1996), and ultimately increase the weaning rate (Braithwaite and de Witte 1999), a driver of breeder herd efficiency. ICI was 13.4 months (Cobiac 2006) vs. approx. 15mths at Mount Sanford and Pigeon Hole. May breeder weights were generally higher at Mt Sanford (ranging from 435-512 kg at 20% utilisation) and at Pigeon Hole (443-463 kg, average of all utilisations) than at Kidman (425-445 kg, Cobiac 2006). Despite these differences in ICI and breeder weights, at Pigeon Hole, breeder herd efficiency was equal to or greater than at VRRS. This may be a function of the breeder herd management Pigeon Hole where culled breeders were replaced with pregnant heifers.

The higher variability in kilograms weaned per unit area at utilisations above 23% at Mt Sanford reflects the increasing sensitivity of animal production to seasons at higher utilisations. At Mt Sanford differences between breeder herd efficiency at different average utilisation rates were further masked by a decreasing average empty liveweight of breeders as utilisation rate increased. This reduction in average breeder empty liveweight was not corrected for in utilisation calculations and therefore, the full effect of utilisation rate may not have been expressed in the above study. The declining breeder empty liveweight is consistent with stocking rate trials grazed by breeding animals (Langlands *et al.* 1984).

Weaner production / area
Even where there was a decline in individual animal production with increasing utilisation at Mt Sanford, an 'optimum' utilisation rate for kilograms of weaner produced per unit area was not apparent over the time period of this study as kilograms of weaner produced per unit area (km^2) increased linearly with increasing utilisation rate. This may be a function of the short time frame of the study. However, a two fold increase in utilisation rate did not result in a doubling of kilograms weaned, due to a loss of production per breeder as utilisation rates increased.

3.4.5.8 Economics of utilisation rates

There was little economic cost to implementing higher stocking rates over the seasons experienced during the trial. The economic calculations do not include weaner weights, so for Pigeon Hole there was no profit penalty at higher utilisation rates. However in reality the lower weaner weights may mean longer time to turn off for steers and to breeding maturity for heifers which would have an economic cost.

At Mt Sanford, although production crashed in dry years at higher utilisations, this was offset by higher production in good seasons. This is similar to simulation studies for north-east Qld woodlands, where greatest production per hectare was achieved at utilisation rates greater than 35% (Ash *et al.* 2000, and initially for O'Reagain *et al.* (2009). Conversely, this is in contrast to grazing trials in northern (MacLeod *et al.* 2004) and later part of the trial for O'Reagain *et al.* (2009) and southern Queensland (MacLeod and McIntyre 1997) where higher stocking rates induced a decline in species composition, reduced live weight gain, and required destocking and or supplementary feed to keep animals alive.

The relatively short duration of the Mt Sanford and Pigeon Hole trials limited the cumulative negative effects that higher stocking can have in the longer term on pasture condition and animal production. Higher stocking rates performed best economically at Wambiana for the first five years of the trial (O'Reagain *et al.* 2011), but after this, the combination of drought and high stocking rates, led the highest stocking rate treatment to crash in land condition (O'Reagain and Bushell 2008), liveweight gain per animal (O'Reagain *et al.* 2009), and economic performance (O'Reagain *et al.* 2011). It took a further five years and six consecutive years of drought, for productive capacity (LWG/ha) of the high stocking rate treatment to be reduced below lighter stocking rates. Hence, it is only to be expected that in the current study, with its short duration and generally good seasons and relatively low utilisations that higher stocking rates were more productive and profitable.

3.4.5.9 Comparison to other utilisation and stocking rate studies

Recommended utilisation in this study is comparable to that found elsewhere for Queensland and NT extensive native rangeland pastures ranging between 15 to 30% of pasture growth (Table 3.38). Similarly a general recommendation of 25% utilisation is now used for US rangelands (Galt *et al.* 2000).

Table 3.38. Summary of other recommended utilisation studies.

Recommended utilisation (%)	Applied to what	Where	Authors
15	Average growth	Katherine NT monsoon tallgrass savanna	Ash and McIvor 1998
25	Average growth	NE Qld Eucalypt woodlands	Ash *et al.* 2011
15, 19 & 22	Average growth	SW, NE and SE Qld	Hall *et al.* 1998
15-25	Average growth	SW Qld Mulga - Mitchell grass	Johnston *et al.* 1996
30	Average growth	Central Qld Black speargrass	Orr *et al.* 2010
20-25	Growth that occurs in 70% of years	NE Qld Eucalypt woodlands	O'Reagain *et al.* 2008
25	Median growth	NT Barkly Mitchell grasslands	Walsh and Cowley 2011

The utilisation recommended here (23%) is equivalent to the 22% utilisation of annual pasture growth recommended for Mitchell grasslands in Queensland (Mitchell grass downs GLM 2007).

The average stocking rates of 15 to 18 AE/sq km required to achieve 19% and 23% utilisation during the trial at Pigeon Hole and Mt Sanford respectively were similar to those recommended in the Charters Towers region where stocking rates of greater than 16 AE / sq km led to a deterioration in native perennial pastures (McIvor and Gardner 1995).

3.4.5.10 Recommended utilisation for these sites

We were unable to detect a threshold rate at which land condition or animal production crashed during the Mt Sanford or Pigeon Hole trials. This is not unusual in grazing trials (Ash & Stafford Smith 1996), but the lack of a utilisation effect on animal production at Pigeon Hole is unusual (Ash & Stafford Smith 1996). This is probably partly due to the relatively low levels being tested compared to other studies that have tested up to 80% utilisation e.g. Orr *et al.* (1986).

Hence a weight of evidence approach has been taken to assess optimal utilisation rates, looking at the effect of utilisation on management goals such as end of season cover and yield levels for maximum soil and water conservation, as well as ability to implement fire as a management tool.

Based on this approach the 19% and 23% utilisation treatments are the highest average level recommended from Pigeon Hole and Mt Sanford respectively. That the 24% treatment at Pigeon Hole did not appear sustainable suggests the poorer condition of the Pigeon Hole site may be contributing to the slightly lower safe utilisation level found there.

3.4.5.11 Applicability of utilisation recommendations to other regions and land types

Although utilisation rate is more transferable between sites than stocking rate, it is not necessarily transferable across regions and land types (e.g. Holechek 1988, Burrows *et al.* 1991). The 19-23% utilisation recommended here is probably applicable to other cracking clays in northern Australia, although where climate variability is higher, or where there are fewer days a year with pasture growth, lower average utilisation may be more appropriate (Hall *et al.* 1998).

A paddock with a mix of pasture types with different productivity and animal preference may present problems when applying higher utilisation rates for better land types, as animals do not graze land types according to our notions of acceptable utilisation levels (e.g. reviewed in Ash and Stafford Smith 1996). This can result in overgrazing of preferred land types, and sometimes lower paddock utilisation is required to protect preferred country types (Walsh and Cowley 2011).

NT Department of Resources currently recommend lower utilisation levels for less productive and less resilient land types – 15% red soil, 10% poor red soil and 5% for spinifex based pastures. In this way our utilisation recommendations take into account both the fragility of land types, and the palatability of the pastures.

Utilisation here is applied to median pasture growth. Others have applied the utilisation rate to the pasture growth that can be expected in at least 70% of years (e.g. Johnston *et al.* 2000, O'Reagain *et al.* 2008) or even to the peak biomass (Bartels *et al.* 1993). Obviously what measure of pasture growth is being used will influence recommended utilisation rates, and care needs to be taken in the application and extension of the concept (Hunt 2008). Analysis of modelled pasture growth for different NT regions found that 25% of growth that occurs in 70% of years is roughly equivalent to 20% of median growth. Hence the Qld recommendation for 25% utilisation of growth that occurs in 70% of years (see above) is equivalent to 20% utilisation of median growth for the VRD and Barkly cracking clays.

3.4.5.12 Ease and risks with implementing set utilisation

The Mt Sanford and Pigeon Hole utilisation trials were designed to find optimal utilisation rates, rather than to demonstrate the practicality of set utilisation. The large fluctuation in numbers needed to achieve set utilisation is usually not possible (Dyer *et al.* 2003, Post *et al.* 2006), although smaller adjustments to track seasons to some degree may be useful to reduce the likelihood of land condition decline in low rainfall years, as well as taking advantage of higher rainfall years when more stock can be carried (Hamilton *et al.* 2008, Ash *et al.* 2000). Flexible stocking can have production benefits, but also requires better management skills (Ash *et al.* 2000) and it is important to have triggers in place to remove stock if numbers are high in drier years (Hunt 2008).

3.4.5.13 Recommended stocking rates to achieve 20% utilisation

The higher yields at Mt Sanford meant that higher stocking rates could be carried for the same utilisation rate compared to Pigeon Hole. At both sites the stocking rate required to achieve 20% utilisation varied considerably between paddocks and years. This is because pasture growth varies both seasonally and with land condition. This highlights the need for caution in recommending certain stocking rates for land types, when there may be variability due to land condition, site productivity or seasons that should be taken into account.

At Pigeon Hole pasture growth modelling suggests median pasture growth is around 2000 kg/ha (Appendix D.3.4). At 20% utilisation, this translates to an average stocking rate of 14 AE/km^2 over the longer term. Applying the higher stocking rates of 15-18 AE/km^2 achieved at Pigeon Hole and Mt Sanford would inevitably lead to overstocking in drier years. Pasture growth tables for different land types could be used by station managers to adjust stock numbers to seasonal conditions following Table 3.39. However the difference in growth between the 30th to 70th percentile varies between land and vegetation types (Table 3.39). At Mt Sanford the recommended stocking rate in a 30th percentile year is 16 AE/km^2 compared with 20 AE/km^2 for a 70th percentile year, hence stock adjustments up and down with season would be quite feasible In contrast at Pigeon Hole recommended stocking rate varied from 11-19 AE/km^2 between 30th and 70th percentile years, hence matching stock numbers to available forage would be more difficult to implement in the paddock.

Table 3.39. Recommended stocking rate for different seasons at Mt Sanford and Pigeon Hole stations. Assumptions - intake = 8 kg/day/AE. Pasture growth percentile estimates based on modelled growth from GRASP, using locally derived parameter sets.

	Season type	Pasture growth (kg/ha)	Utilisation (%)	Intake per AE per year	Stocking rate (AE/km^2)
Mt Sanford	30th percentile	2350	20	2920	16
	median	2650	20	2920	18
	70th percentile	2950	20	2920	20
Pigeon Hole	30th percentile	1587	20	2920	11
	median	2027	20	2920	14
	70th percentile	2821	20	2920	19

3.4.5.14 Conclusions

The weight of evidence from the Mt Sanford and Pigeon Hole trials suggests that for the utilisation rates trialled, the optimal utilisation rates were 19% for poorer condition sites and 23% for better condition sites.

While species composition and animal production were maintained even up to the highest utilisations during the four and six years of the trials, over the longer term, low cover levels and more variable animal production at utilisation rates above 19 and 23% suggest greater environmental and management risk.

The trial at Pigeon Hole was unable to detect many changes in response to utilisation. This is probably due to a combination of the following factors:

- Short duration of the trial (4 years)
- Lack of a drought year during the trial to test the system
- Inconsistent application of target utilisation rates through time resulting in only light utilisations in better years
- Relatively low utilisation rates tested across a relatively narrow range of utilisations
- A very resilient land type
- Larger paddocks, providing some degree of spatial buffering (at least in the short term)

Lessons learned
To safely implement these utilisation rates the following is recommended

1. Only apply to productive cracking clay soils
2. Reduce stock numbers in poorer seasons
3. Reduce utilisation rates for poorer condition country
4. Continue to implement fire to maintain productivity and land condition
5. To increase *Astrebla spp.* abundance, apply utilisation rates of less than or equal to 13% (which is two thirds the stocking rates recommended in Table 3.39).

4 Enhanced understanding of grazing distribution

4.1 Key messages

- This study involved two experiments with a total of six paddock configurations with the aim of determining the effectiveness of the configurations on improving the evenness of grazing distribution. Three paddocks were of increasing size each with a single central water point and three paddocks were of increasing size but with the larger paddocks having more water points.
- Reducing paddock size was generally more effective than adding more water points to large paddocks in achieving greater grazing use of the available landscape and effectively increasing the area of pasture that is used by cattle.
- There were no differences in pasture condition amongst the paddock configurations and no systematic effect on livestock production.
- A paddock of 30-40 km^2 with two well-separated water points appears to offer a good compromise between improving grazing distribution to make most effective use of pasture resources and the cost of the infrastructure.
- In larger paddocks water points should be about 5-6 km apart.
- Reducing paddock size is not particularly effective at improving the uniformity of grazing within paddocks; other techniques should be used for this purpose.
- Vegetation condition, soil/land type and distance from water were important in explaining the location of cattle within the paddocks.
- Cattle appeared to avoid both land in the poorest condition and land in good condition with abundant 3P grasses in favour of areas that had less perennial grass and more annual grasses and forbs.
- Black soils tended to be weakly avoided during the wet season in favour of red soil and riparian areas, and red soils were also favoured in the dry season.

4.2 Introduction

Opportunities to benefit from intensification are most apparent in large enterprises that have historically had relatively poor water and fencing infrastructure development resulting in very uneven use of the available landscape by livestock. Improving water distribution may allow livestock numbers to be increased without greatly increasing effective utilisation rates across individual paddocks. Key questions that need to be answered in developing more water-points are:

- Can more even grazing distribution be achieved with additional water points in a paddock without subdividing the paddock?
- If subdivision is necessary to improve grazing distribution what paddock size and distance from water is optimal in terms of cost and evenness of use?

Reducing paddock size by fencing will be far more costly than just increasing the numbers of waters in a large paddock. However, increased sub-division will also provide better animal control, and offers a number of other opportunities including:

- Better management of grazing pressure and the use of resting strategies.
- More flexibility to use fire to manage grazing pressure and overcome uneven grazing at patch scales (Andrew 1986b).
- Potentially lower mustering costs through reducing reliance on expensive helicopter mustering.

However, intensification poses a number of risks, including:

- A loss of landscape heterogeneity. Large heterogeneous paddocks may provide some buffering against density dependent declines in animal productivity that occur with increasing stocking rate (Scoones 1995, Ash *et al*. 2004), especially in times of drought. By reducing the spatial scale of grazing through paddock subdivision it is likely that livestock diet choice will be reduced. A greater diet choice in larger paddocks may also be of benefit during the dry season when protein becomes a major limiting factor in the diet.
- Decline in land condition through overgrazing. While increased infrastructure may provide increased flexibility to better manage grazing pressure, it is likely that in intensified systems grazing pressure will, on the whole, be maintained closer to ecological thresholds.
- An intensively managed property may be more prone to fail if prices or demand fall due to market shocks, as they have a higher cost structure and less capacity to adjust.
- Potential loss of biodiversity. The increased availability of water sources opens up previously ungrazed areas that may have provided habitat for grazing-sensitive species (discussed elsewhere in this report).

Intensification will have implications for both the inputs (infrastructure costs) and outputs (animal performance and resource condition) of extensive beef grazing enterprises. The challenge for pastoral management therefore is to make the most of the opportunities intensification offers and to minimise any negative consequences. Key questions in improving our understanding of these issues are:

- do large paddocks that contain diverse landscapes and habitats but have good water distribution have advantages over smaller paddocks through better landscape-animal interactions that improve animal performance?
- does increasing the number of waters even out grazing distribution as effectively as reducing paddock size, or do animals end up favouring particular water points at the expense of animal production and land condition?
- if reducing paddock size, what is the optimum size and maximum distance to water?

The research reported in this chapter investigated these questions.

4.3 Methods

4.3.1 Experimental design

Two separate but related studies were conducted. One study involved three paddocks of increasing size, each with a single central water point. This study was designed primarily to examine the effect of paddock size, grazing radius and the number of cattle per water point on landscape use, livestock performance and range condition. The second study examined the effects of landscape diversity, water distribution and paddock size on grazing distribution, livestock performance and range condition by having a series of paddocks of increasing size and number of water points. Here we refer to grazing radius as the maximum distance cattle can reach from a water point (or from water if a paddock contains multiple waters). We specified intended (or nominal) grazing radii for paddocks in the design phase (see Table 4.1), although some variation from this occurred. Actual distances from water are presented later. Specific details of each study follow.

Experiment 1 (grazing radius study) considered the effect of paddock size, grazing radius and the number of cattle per water point on landscape use by cattle, and associated pasture and livestock production response. This study (referred to as the grazing radius study) involved three paddocks (9, 21 and 34 sq. km. in area, referred to as GR1, GR2 and GR3, respectively) each with a single watering point. Each paddock was stocked with the appropriate number of cattle to approximately achieve an annual forage utilisation rate of 20% based on standing herbage biomass available at the end of the growing (i.e. wet) season. This experiment addressed hypotheses 1 and 2:

1. There is an optimum maximum distance to water for evenness of use and land condition.
2. There is an optimum maximum distance to water for animal production.

Experiment 2 (paddock configuration study) examined the effects of landscape diversity, water distribution and paddock size on grazing distribution, livestock performance and range condition. For this study (referred to later as the grazing distribution study) it was assumed that larger paddocks encompass greater landscape diversity. Three paddocks that differed in size (9, 34 and 57 sq. km) and the availability of water, but that had similar grazing radii (2.5 km) were used. The smallest paddock contained one water point, the intermediate size paddock two water points and the 57 sq. km paddock had five water points in order to achieve approximately similar grazing radii for all water points (Table 4.1, Fig. 2.3). As with experiment 1, each paddock was stocked with the appropriate number of cattle to achieve an annual utilisation rate of 20%. This experiment addressed hypotheses 3 and 4:

3. Increasing spatial scale and landscape diversity reduces coupling between utilisation rate and animal production per head such that the usual linear decline in animal production per head with increasing utilisation rate observed at small spatial scales is dampened at large spatial scales.
4. Increasing landscape diversity will result in more uneven use and more land in poor condition (independent of distance to water).

The results of the two experiments are presented separately. However, since the two approaches (single or multiple water points) are alternative options available to a manager, the results and implications of each study will be considered together in the discussion.

Table 4.1. Treatments in the two grazing distribution studies. Experiment 1 was the Grazing Radius study, and experiment 2 was the Paddock Configuration study.

Experiment	Paddock name	Paddock size (km^2)	Number of water points	Nominal grazing radius (km)	Average distance between water points (km)	Average stocking rate (AE/km^2)	Average annual pasture utilisation rate (%)	Treatment designation
1, 2	Barra	9	1	1.0	-	13	19	GR1; One water
1	Sandstone	21	1	2.0	-	14	17	GR2
1	South Stevens Creek	34	1	3.0	-	12	15	GR3
2	North Stevens Creek	34	2	2.5	4	12	15	Two waters
2	Racecourse	57	5	3	3.5	10	16	Multiple waters

The study assessed the effect of these paddock configurations on patterns of landscape use by cattle and associated effects on the vegetation and land condition. The distribution of cattle activity within the different paddocks was monitored by fitting global positioning system (GPS) collars on cattle grazing in the paddocks. Spatial patterns of defoliation, plant species composition and pasture productivity were regularly assessed by ground-based pasture sampling. The collar and pasture data were also used together to develop a better understanding of the factors that influence cattle grazing distribution. The effects on dietary quality, liveweight gain and branding percentage were also monitored.

In addition to the main study paddocks listed in Table 4.1, GPS collars were also deployed in a large, 'undeveloped' commercial paddock to provide a comparison between grazing distribution achieved in the developed paddocks at Pigeon Hole and current commercial practice. Lochart paddock at Mt Sanford was selected as the undeveloped paddock. This paddock is on the Wave Hill land system (i.e. same as the Pigeon Hole site), covers 149 km^2 and contains three water points (Fig. 4.1). A total of five cows were fitted with collars over two periods of about 6 months (one wet and one dry season) from November 2006 to November 2007.

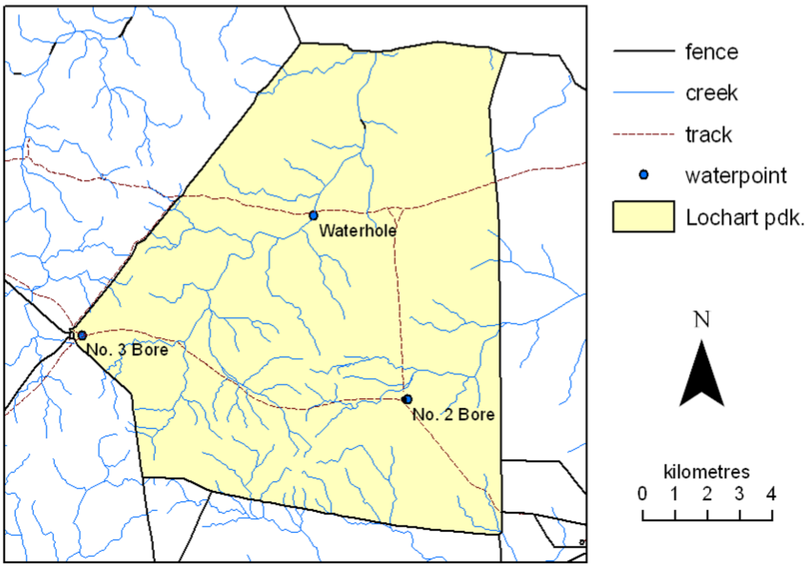


Fig. 4.1. Map of Lochart paddock (149 km^2) on Mt Sanford, which was used to provide a comparison of grazing distribution in an 'undeveloped' commercial paddock with that in the smaller developed paddocks on Pigeon Hole.

4.3.2 Paddock characteristics

The proportion of each of the study paddocks at various distances from water is shown in Fig. 4.2 and Fig. 4.3. Despite larger paddocks in the paddock configuration study having additional water points, there was a greater proportion of these paddocks distant from water.

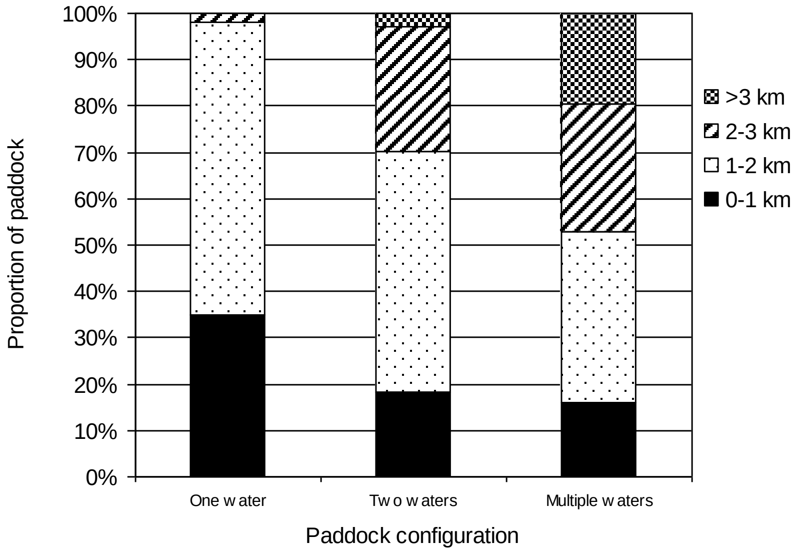


Fig. 4.2. The proportion of each of the three paddocks in the paddock configuration experiment within varying distances from water.

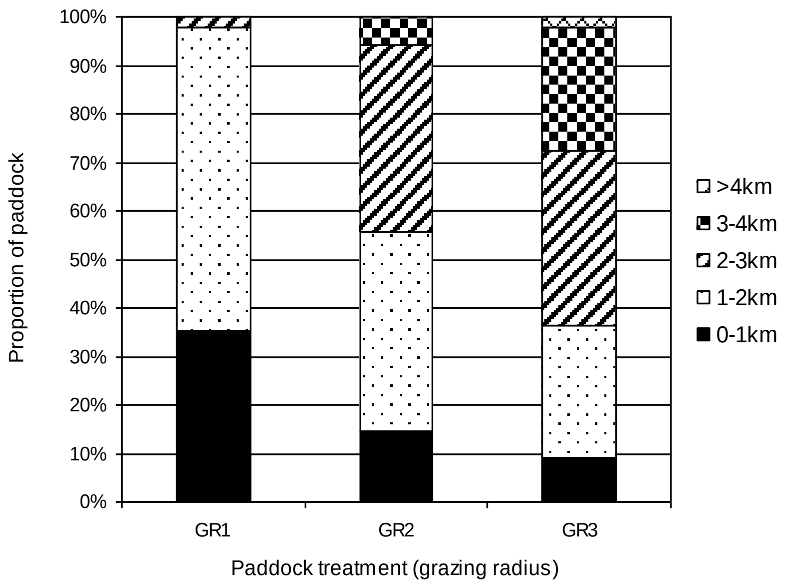


Fig. 4.3. The proportion of each of the grazing radius paddocks within varying distances from water.

Table 4.2. Mean and median distance to water in each of the treatment paddocks in the two grazing distribution studies.

	Distance from water (m)	
	Mean	Median
One water/Grazing radius 1	1152	1191
Two waters	1654	1663
Multiple waters	2053	1915
Grazing radius 2	1862	1877
Grazing radius 3	2341	2364
Large commercial paddock	3251	3212

4.3.3 Recording landscape use by cattle

Collars containing a global positioning system (GPS) were fitted to cows in the study paddocks to better understand use of the landscape by cattle and the factors influencing this. These collars log a cow's location at predefined intervals over extended periods, and under some circumstances also allow inferences to be drawn in respect of whether a cow is engaged primarily in grazing, resting and travelling activities between location fixes.

Lotek 2200LR and 3300LR collars containing two-axis activity sensors and a temperature sensor were used. For most of the study a GPS fix interval of one hour and activity sensor sampling period of 5 minutes were used. In addition to recording the location of the cow at every GPS fix the collars record the time and date of fix, an activity sensor count averaged over sub-samples during the fix interval, the temperature (approximating ambient temperature), and information relating to satellite identity and performance. This information is written to memory at each fix for later downloading.

Collars were fitted to and retrieved from cattle when each paddock was mustered as part of normal herd management. Musters occurred twice a year (usually in April and September) and the collars remained on the cattle for the entire period between musters. Upon retrieving the collars the data were downloaded, the collars fitted with charged batteries and reinitialised and fitted to different cattle. The cattle were then returned to their respective paddocks. Thus we obtained data on grazing behaviour for entire years partitioned approximately into the wet and dry seasons. Collars were fitted to cows only. These were selected randomly within the constraints of meeting the pregnancy status and body condition score expected by the station managers at that time. When possible, up to four cows per paddock were fitted with collars on each occasion. This was not always possible due to collars being damaged by the cattle and requiring servicing.

Collars were initially deployed in the three paddocks that constituted the paddock configuration study (experiment 2). Later, collars were deployed in the grazing radius paddocks that comprised experiment 1, and in a typical commercial paddock to provide an undeveloped 'control' treatment. Details of the GPS collar deployments for each of the experimental treatments are presented in Table 4.3.

Table 4.3. Details of GPS collar deployments for each of the experimental treatments in the grazing distribution studies. Dry season deployments were usually from April/May to September and wet season deployments were usually September to April/May. Experiment 1 was the Grazing Radius study, and experiment 2 was the Paddock Configuration study.

Experiment	Treatment	Paddock	Period of collar deployment	Number of seasons of deployment	Total individual collar deployments by season*
1, 2	GR1; One water	Barra	May 2004 to April 2007	3 wet and 3 dry seasons	9 dry season, 7 wet season
1	GR2	Sandstone	April 2007 to Sept 2007	1 wet and 1 dry season	3 dry season, 4 wet season
1	GR3	South Stevens Creek	April 2007 to Sept 2007	1 wet and 1 dry season	3 dry season, 4 wet season
2	Two waters	North Stevens Creek	May 2004, May 2005 to April 2007	3 dry and 2 wet seasons	10 dry season, 5 wet season
2	Multiple waters	Racecourse	May 2004 to April 2007	3 wet and 3 dry seasons	7 dry season, 8 wet season
	Large commercial paddock	Lochart	April 2007 to Nov 2007	1 wet and 1 dry season	2 dry season, 3 wet season

*from which more than two months of useful data were obtained.

4.3.4 Spatial patterns

Several measures were used to assess the effect of different paddock configurations on the evenness of grazing use within each paddock. One approach used the standard deviation of pasture defoliation across all pasture sampling quadrats in each paddock. The proportion of quadrats that were not used at all and the proportion that were heavily used were also used as indicators of the evenness of use.

A comparison of pasture defoliation rates in relation to distance to water in each treatment at the end of the study was carried out using Analysis of Covariance.

4.3.5 Cattle location data – basic analyses

Complete data sets were not always obtained from the GPS collars for several reasons. Poor satellite signal reception and battery failure were the most common reasons. The data therefore required some editing to remove spurious GPS fixes, and some data have not been included in the analysis where the period over which data was collected was relatively short. Data from the first 24 hours following the return of collared cows to the paddock and the data from the day cattle were mustered were also excluded from the analyses.

Basic statistics calculated for each data-set (i.e. one cow for one mustering) included:

- inter-fix distance (i.e. distance travelled in one hour);
- cumulative distance travelled over the deployment period, and average distance travelled per day;
- mean and maximum distance from water;
- home range (using a 95% minimum convex polygon with fixed mean);
- the proportion of the paddock used (i.e. home range relative to paddock size).

ArcView GIS 3.2 and the Home Range extension (Rogers and Carr 1998) were used for these calculations.

4.3.6 Classifying different behaviours

The two activity sensors in the GPS collars (which measure vertical and lateral movements of a cow's head) were used in combination with inter-fix distances to define when different animal activities occurred. Calibration of the activity sensors is required to define the time spent in various activities. By relating direct observations of collared cows in the paddock to activity sensor and distance data three activities were defined: grazing, travelling and resting. Using information on the various activities should allow the development of a more refined understanding of how cattle use the landscape and the factors that influence grazing distribution.

The calibration of the activity sensors was conducted in Spell horse paddock, a small (8 km^2) at Pigeon Hole during December 2006. For nine consecutive days observers recorded the activity (grazing, resting, travelling, drinking) of cows fitted with GPS collars. Observations occurred only during daylight hours, generally from dawn to dusk, as it proved impossible to observe cattle at night without night-vision equipment. During observations, the time (to the closest minute) when a cow switched from one activity to another was recorded (unless the new activity persisted for less than 30 seconds and the former activity was resumed). These data were recorded on hand-held computers. At any one time, two cattle were fitted with GPS collars. The cattle were observed (one per observer, with observers working two-hour shifts) for approximately two days before the cattle were mustered and the activity sensor data downloaded from the collars. The collars were then fitted to another two cattle in the same mob of 20 cattle and the cattle returned to the paddock for further observation. A total of 156 hours of observations were made.

Back in the laboratory the data was processed in order to determine the number of minutes per hour spent in the three primary activities of grazing, resting and travelling. A time-frame of one hour was used as this was the fix interval adopted for GPS positional fixes in the main study paddocks, and hence the period over which activity sensor counts were averaged. Regression tree analysis was used to relate the x and y activity counts and inter-fix distance with the number of minutes spent in each activity. These analyses use a combination of the three variables to estimate time spent in each activity for each hour. Each observation hour was allocated a single activity according to the activity which occupied most time during the hour. For each activity a pruned regression tree that gave a good compromise between computational complexity and accurate predictions of time in the activity was selected to calibrate the activity sensor records from the collars deployed in the experimental paddocks. Table 4.4 presents an assessment of the accuracy of the calibration regression trees when applied to the data from direct observations. It should be noted that the calibration was not validated against an independent set of observations.

Table 4.4. The accuracy of classifying three primary cattle activity types using activity sensors in the GPS collars, based on direct observations of cattle. The data are the actual number of hours in which the given activity was the dominant observed activity within the hour, the number of hours in which each activity was estimated to be the dominant activity, and the percentage of actual hours that were correctly classified.

Activity	Actual (hours)	Estimated (hours)	Percent correct
Grazing	42	41	83%
Resting	91	95	98%
Travelling	23	20	73%
(Total hours)	(156)	(156)	

4.3.7 Factors influencing patterns of use: pasture and environmental variables and cattle distribution

A number of factors were investigated as possible determinants of cattle grazing distribution within paddocks, including palatable pasture availability, total pasture availability, pasture condition or state (i.e. approximating the GLM condition classes A, B, C, D), land type and distance to water. Five land type classes were used, defined on the basis of soil type or landscape feature. These classes were black soil, red soil, intermediate soil, riparian and creek line. These land types were expected to affect grazing distribution because of variation in factors such as pasture type, quality and quantity, availability of shade and proneness to being boggy during the wet season.

Two sets of data were derived from the pasture and GPS collar data and other spatial data for use in developing an understanding of the factors that are potentially important in determining grazing distribution. Firstly, the distance of each GPS fix to the closest water point and distance to the closest creek were calculated in ARCGIS. Secondly, the proportion of fixes that occurred in different pasture communities and soil types was determined (ignoring all fixes within 250 m of water points). These data were derived by first developing separate spatial interpolations of several descriptors of the pasture data (e.g. different pasture community types, total pasture yield, palatable forage yield and perennial grass basal area). A soil data layer was also developed using a combination of the ground observations and an aerial photo interpretation of the site (K. Richardson, pers. comm). By then intersecting each GPS location fix with various data layers describing the spatial arrangement of particular land and pasture characteristics within a geographic information system secondary data was compiled on the proportion of GPS fixes in different habitat types.

The spatial interpolations were performed in ARCGIS using the inverse distance method. Each paddock was interpolated separately so that data from neighbouring paddocks did not influence the interpolation of the paddock of interest.

An initial examination of the factors most likely to influence the way cattle use the landscape within paddocks was achieved by plotting the proportion of fixes that occurred in different pasture communities and soil types. However, since these results can be influenced by the area of a paddock within a particular class, with larger classes more likely to have more fixes simply by chance, the data was adjusted by the proportion of a paddock within the particular classes of features. The data thus can be interpreted as a measure of selection for or avoidance of land or habitat of certain characteristics (or proportional habitat use).

Proportional habitat use (x) is interpreted as follows:

x = proportion of time/fixes in pasture class a/proportion of pasture class a in paddock

If x = 1 then no selection for that habitat class
If x>1 then selecting for that habitat class
If x<1 then avoiding that habitat class.

Proportional habitat use (or the selection index) was calculated excluding GPS fixes within 250 m of water points and paddock areas constituting less than 0.5 % of the paddock.

Generalised Linear Models (GLMs) were used to assess the influence of environmental and pasture attributes in determining the use of paddocks by cattle. The GLMs were implemented as step-wise regressions using a Poisson error distribution and log link and modelled the relationships between the number of GPS fixes and the classes within the environmental attributes. Models were fitted for each observation period (usually about six months) and paddock (i.e. including all collared animal). The attributes and the classes are presented in Table 4.5. The data were prepared for analysis by allocating each GPS fix to a class within each of the predictor variables, usually by spatially intersecting the GPS fixes with data layers of the environmental attributes within a geographic information system (ArcView).

Table 4.5. Predictor variables and classes used in models.

Environmental attribute	Classes	Type of variable
Distance from water	100 m intervals	continuous (linear and quadratic)
Soil type	Black, red, riparian, creek line, intermediate	categorical
Vegetation class	1-4 (reflecting combined species composition and biomass attributes)	categorical

4.4 Results

4.4.1 Experiment 1 – Grazing radius

4.4.1.1 Cattle behaviour in relation to paddock configuration

4.4.1.1.1 Paddock use by cattle

There were marked differences between paddocks in various measures of cattle distribution and behaviour. Home ranges of individual cattle tended to be larger in larger paddocks that have a larger nominal grazing radius (Table 4.6). However, there was some evidence that the proportion of each paddock used (measured as the home range as a proportion of paddock size) showed the opposite trend, decreasing with increasing grazing radius, with a higher proportion of GR1 being used than for the two larger paddocks (although the proportion used was similar for Grazing radius 2 and Grazing radius 3). The reason for a relatively smaller proportion of the GR2 paddock being used may be related to the different pasture characteristics of the paddock (i.e. a greater abundance of *Eulalia aurea*, a perennial grass of low palatability, and the distribution of this in the paddock).

Table 4.6. Average home range, proportion of paddock used and distance walked per day for individual cows grazing in three paddocks differing in nominal grazing radius (i.e. maximum distance to water) for six-month periods. Collars were deployed for two to six periods of six months (depending on the paddock) with different cows being used each period. Data for GR1 were collected in different seasons to the other paddocks (see Table 4.3). All paddocks contain one, centrally-located water point. Not all collars functioned for the entire six-month deployment period; the results include data only from collars that functioned for a minimum of two months.

Treatment	Paddock area (km^2)	Number of collared cows	Mean home range in km^2 (sd)	Mean percentage of paddock used by individual cows (%)	Mean distance walked per day in metres* (sd)
Grazing radius 1	8.9	16	7.7 (1.18)	86.5	5637 (906)
Grazing radius 2	21.3	6	13.3 (3.65)	62.4	5779 (488)
Grazing radius 3	34.5	7	22.0 (4.88)	63.6	7171 (1595)

* Treatment had a significant effect ($P < 0.01$) on mean distance walked per day.

There was no consistent trend between paddocks in the distance cows walked each day. Despite GR2 recording a larger home range, collared cows in this paddock walked a similar distance each day to those in GR1 (Table 4.6), while those in GR3 walked about 1.5 km further per day.

Home ranges provide an indication of the area of land explored by an individual animal. It is important to acknowledge that they do not necessarily provide a measure of how evenly the land is used. However, they can provide an indication of overall use of the landscape and whether the patterns of overall use are spread relatively evenly across the landscape.

Table 4.7 presents composite home ranges, core area and mean distance to water for the grazing radius paddocks. Composite home range (i.e. the amalgamation of all estimated individual home ranges within a paddock) provides a better measure of overall use of the paddock by the herd than individual home ranges. Composite home range is usually larger than individual home ranges for a paddock because different animals use different parts of a paddock. The composite home range increased with paddock size (similar to the trend in individual home ranges) but still encompassed a smaller proportion of a paddock with increasing paddock size. The overlap in the home ranges of individual cattle (termed 'core' area) is likely to represent the most heavily used part a paddock. Core area was a greater proportion of the total paddock area in the smallest paddock than the larger paddocks.

Table 4.7. Mean composite home range, core area and mean distance of cows from water in each of the grazing radius paddocks.

Treatment	Paddock area (km^2)	Mean composite home range (km^2)	Mean composite home range as percentage of paddock (%)	Mean core area (km^2)	Mean core area as percentage of paddock (%)	Mean distance of cows from water* (metres) (sd)
Grazing radius 1	8.9	8.4	94.4	6.9	77.5	941 (168)
Grazing radius 2	21.3	19.2	90.1	6.4	30.0	1265 (164)
Grazing radius 3	34.5	28.7	83.2	13.1	37.9	1534 (215)

* Treatment had a significant effect ($P < 0.001$) on mean distance of cows from water.

Home ranges tended to be smaller during the dry season in all paddocks (Table 4.8), although there was considerable variability between cows in this respect. This reduction in home range is attributed to the need for cattle to drink regularly (daily) during the dry season, so that they are not able to venture as far from the water point. In fact, cattle do tend to spend most of the daylight hours loitering near the water point during the dry season, and often leave the water late in the day to graze during the night. In comparison, the availability of water in creeks and the availability of moist green forage during the wet season would appear to allow cattle to wander further from the water point during this season. Wet season home ranges were approximately 20-30% larger than dry season home ranges. This finding contradicts the expectation that cattle would range further from water during the dry season in order to maintain forage intake as pasture availability in the vicinity of water declined. This raises two possibilities: 1) that cattle were able to maintain forage intake or 2) cattle intake declined since they did not travel further from water to seek out areas supporting more abundant forage.

Table 4.8. Home ranges and percent use of paddocks for collared cows during the dry and wet seasons. Data are means of all cows and sampling periods. Results include data only from collars that functioned for a minimum of two months during the deployment period.

Paddock	Mean home range (km^2)	Mean percentage of paddock used by individual cows (%)
	Dry season	
Grazing radius 1	6.8	75.9
Grazing radius 2	12.3	57.7
Grazing radius 3	20.9	60.4
	Wet season	
Grazing radius 1	8.5	94.7
Grazing radius 2	15.3	71.8
Grazing radius 3	23.4	67.9

Graphs of the number of GPS collar fixes per hectare in 100 m annuli surrounding the water point show that there is a greater concentration of fixes within 200 m of the water point in each of the three grazing radius paddocks (Fig. 4.4, Fig. 4.5 and Fig. 4.6). These results suggest cattle spent more time near the water than at any other distance from water. This is not unexpected given the need for cattle to drink regularly in this hot climate, and is consistent with studies elsewhere in northern Australia (e.g. Schmidt 1969). As expected the number of fixes declines rapidly within the first few hundred meters of water. However, what is surprising is that outside of the immediate vicinity of the water point the concentration of fixes is relatively constant within a broad zone away from water, before declining further. Furthermore, this occurs in each of the Grazing radius paddocks. This suggests that the cattle are exploring these areas relatively uniformly (at least with respect to distance to water).

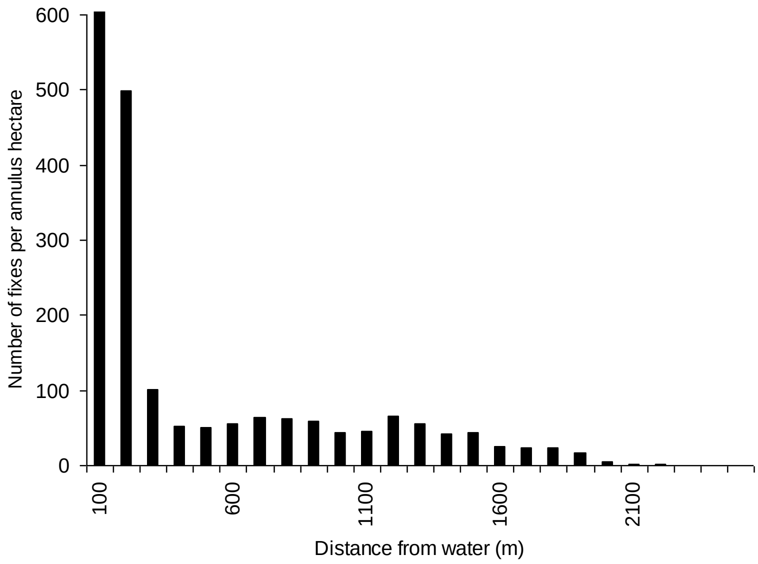


Fig. 4.4. The distribution of fixes in 100 m annuli around the water point in the Grazing radius 1 paddock. These data are for all collars for all deployment periods in this paddock. Note the Y-axis is truncated and the value for the 100 m bar is 1925 fixes per hectare.

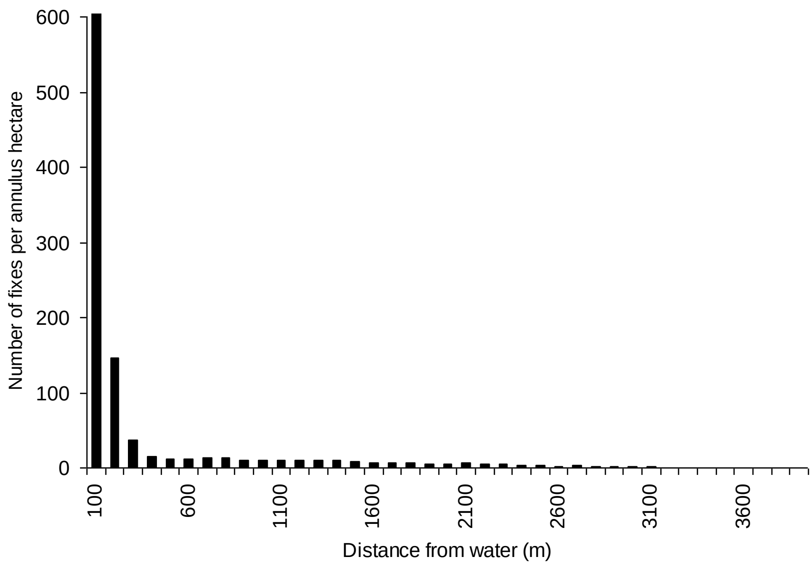


Fig. 4.5. The distribution of fixes in 100 m annuli around the water point in the Grazing radius 2 paddock. These data are for all collars for all deployment periods in this paddock. Note the Y-axis is truncated and the value for the 100 m bar is 1010 fixes per hectare.

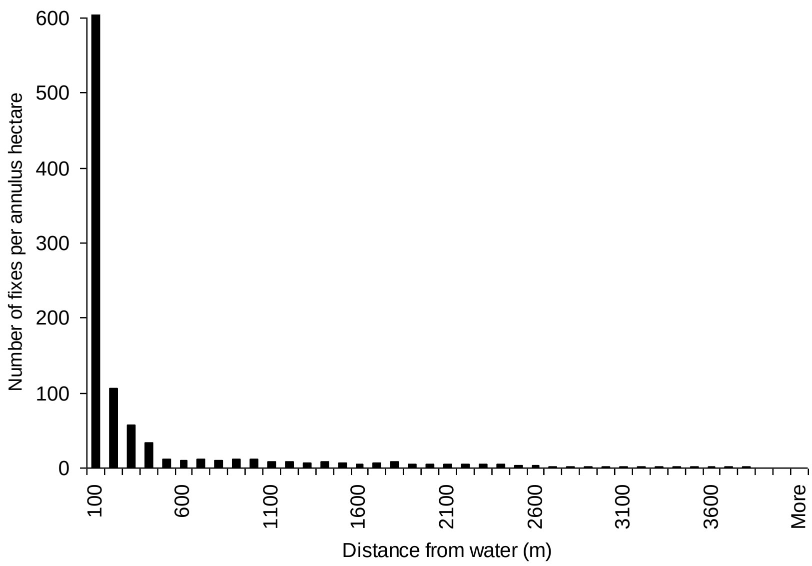


Fig. 4.6. The distribution of fixes in 100 m annuli around the water point in the Grazing radius 3 paddock. These data are for all collars for all deployment periods in this paddock. Note the Y-axis is truncated and the value for the 100 m bar is 1095 fixes per hectare.

As expected from the home range data, individual cattle tend to explore further from the water point in paddocks with a nominal larger grazing radius than in smaller paddocks. This is also apparent in terms of the distance from water which encompasses 90% of the GPS fixes for each of the paddocks (Table 4.9). In each of the paddocks cattle were venturing to the far reaches of the paddock, with fixes being recorded at close to the furthest distance from water possible in each of the paddocks. Given that these three paddocks are stocked at the same utilisation rate (and therefore there are more cattle in paddocks with a larger grazing radius) these results suggest the greater number of cattle means the animals are forced to use more of the paddock to obtain an adequate dietary intake. A surprising result however is the consistency of the ratio of the distance from water encompassing 90% of fixes and the maximum distance from water possible in a paddock. In each of the three paddocks this was around 70% (Table 4.9). The reason for this consistency is not readily apparent but it does seem to suggest that some behavioural factor may be affecting grazing distribution. Alternatively, it may be related to the comparable stocking rates within the effective grazing radius (i.e. distance with 90% of fixes) in each paddock (GR1 = 12.8, GR2 = 12.8, GR3 = 11.9 AE/km^2), suggesting the cattle did not need to venture further from water to satisfy their intake requirements.

Table 4.9. The radial distance from water which encompasses 90% of GPS fixes (i.e. hourly cattle locations) and the maximum distance from water GPS fixes occurred for the grazing radius treatments. These data were calculated from all collar data (i.e. from all cows and deployment periods) combined for each paddock. For comparison, the maximum distance from water that is possible in each paddock is also presented.

	Distance encompassing 90% of GPS fixes (m)	Maximum distance of fixes from water (m)	Maximum distance from water in paddock (m)	Distance with 90% fixes as percentage of max. distance possible (%)
GR1	1700	2398	2411	71
GR2	2700	3853	3858	70
GR3	3300	4599*	4560	72

* Maximum distance of fixes exceeds maximum distance possible because of GPS error.

4.4.1.1.2 Diurnal activity patterns

Cattle spent most of their time resting (approximately 60%), 35-40% of their time grazing, and 1-5% travelling. There were only minor differences among treatments in the proportion of time spent grazing, travelling and resting. Time spent grazing decreased marginally as paddock size and grazing radius increased, with a concomitant increase in travelling time (Fig. 4.7). For much of the year, cattle generally spent daylight hours loitering at a water point. At approximately 6 pm each day the cattle departed the water point, and did not return until about 7 am the following morning.

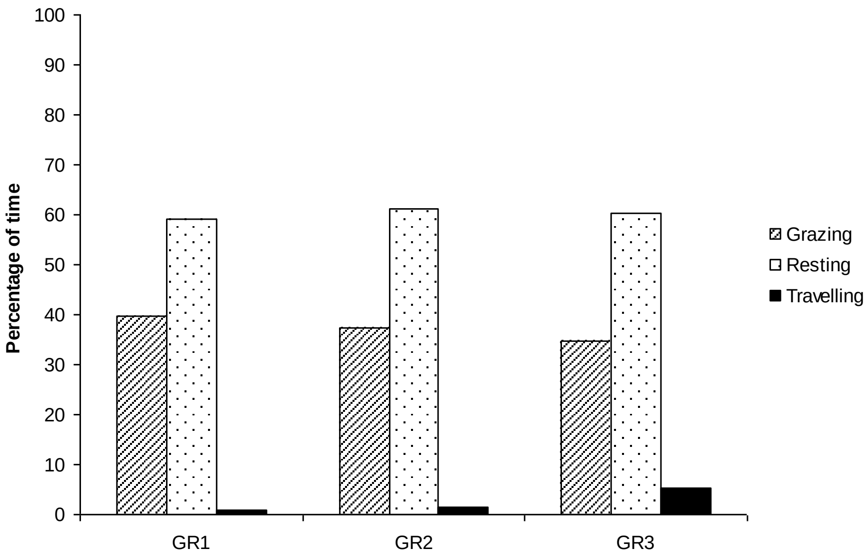


Fig. 4.7. Percentage of time cattle spent grazing, resting and travelling in the grazing radius paddocks (means for 1-3 animals per paddock over a six-month period in the 2006-2007 wet season).

4.4.1.2 Evenness of grazing use

A smaller standard deviation for overall pasture defoliation across sampling quadrats in a paddock was used as an indicator of more even use within a paddock compared with other paddocks. Paddocks with a lower proportion of quadrats that were heavily used or not used at all were also considered to show more even grazing use.

Fig. 4.8 shows there were no consistent trends in the standard deviation of overall defoliation across the three grazing radius paddocks for most years. Only in the final year (May 2007) was there a consistent (albeit marginal) increase in standard deviation with paddock size, suggesting that grazing use was more uneven with an increase in paddock size. In two years (2004 and 2006) the standard deviation for the smallest paddock was lower than the larger paddocks.

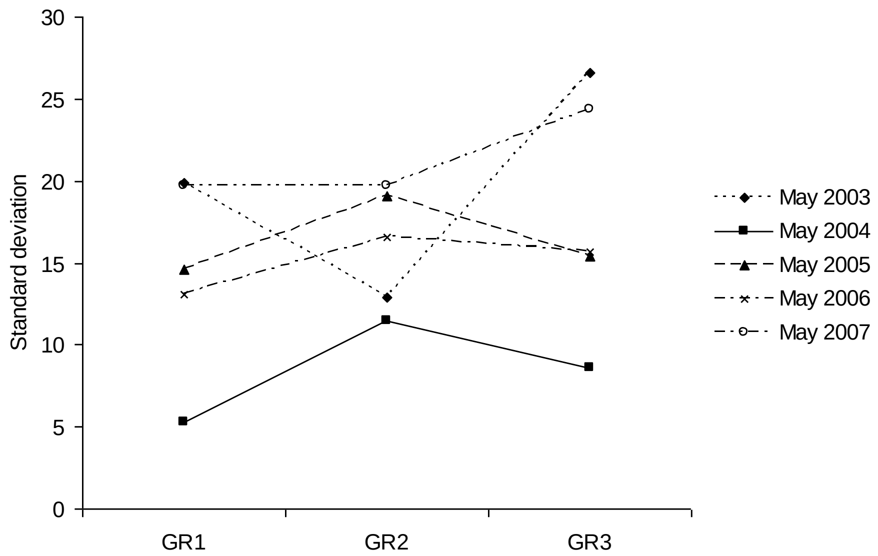


Fig. 4.8. The standard deviation of defoliation across all quadrats within the grazing radius paddocks for five years. Note that May 2003 was pre-treatment.

There were only weak trends in the proportion of quadrats that were not used by cattle (i.e. defoliation score was zero). In most years in May, GR1 had fewer quadrats (lower by about 10%) that were not used compared with the other paddocks but there was little difference between GR2 and GR3 (Fig. 4.9). There were no clear differences among paddocks in the proportion of quadrats that were heavily used (i.e. defoliation of 75-100%), although in the final year (2007) a very weak trend of increasing proportion of heavily defoliated quadrats with paddock size was apparent. However, only a small number of quadrats (less than about 5% of quadrats) were heavily utilised (Fig. 4.10). These results suggest there were only minor differences in the evenness of grazing use among the paddocks. In the smallest paddock (GR1 = 9 km^2) was there a small reduction in the proportion of the paddock that was not used, suggesting marginally more uniform grazing use.

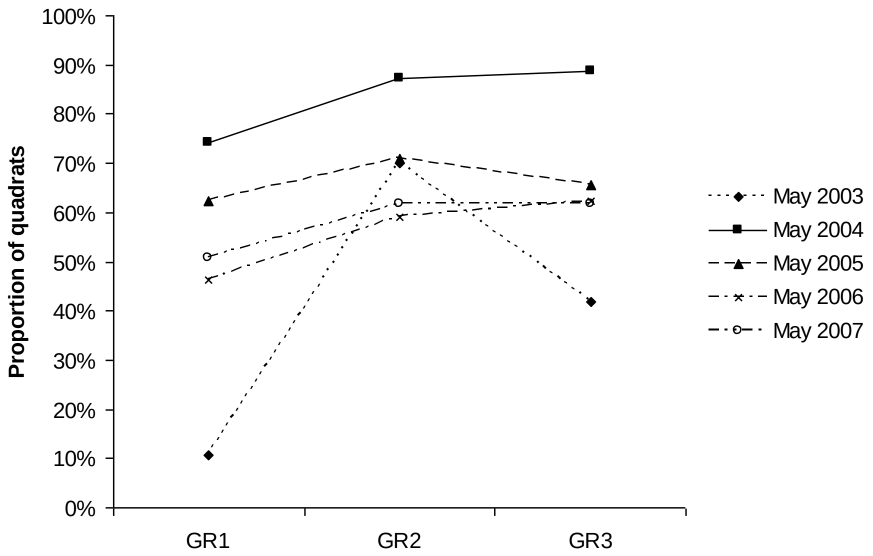


Fig. 4.9. The proportion of quadrats that were not used (defoliation score of zero) for the grazing radius paddocks. May 2003 was pre-treatment.

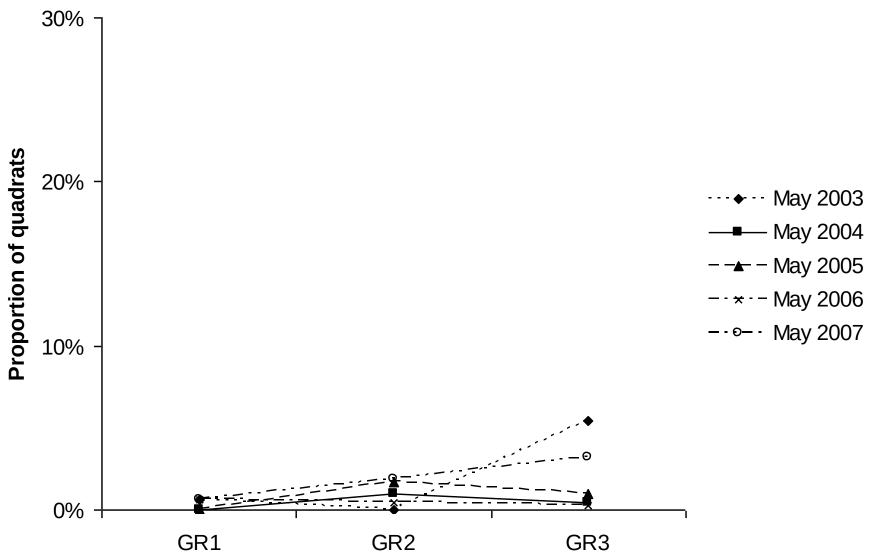


Fig. 4.10. The proportion of quadrats that were heavily used (defoliation score of 75-100%) for the grazing radius paddocks. May 2003 was pre-treatment.

The standard deviation of ground cover showed similarly variable trends between the paddocks, including showing both decreases and increases with paddock size (Fig. 4.11). The final year was the only occasion when a consistent increase in standard deviation with paddock size was recorded.

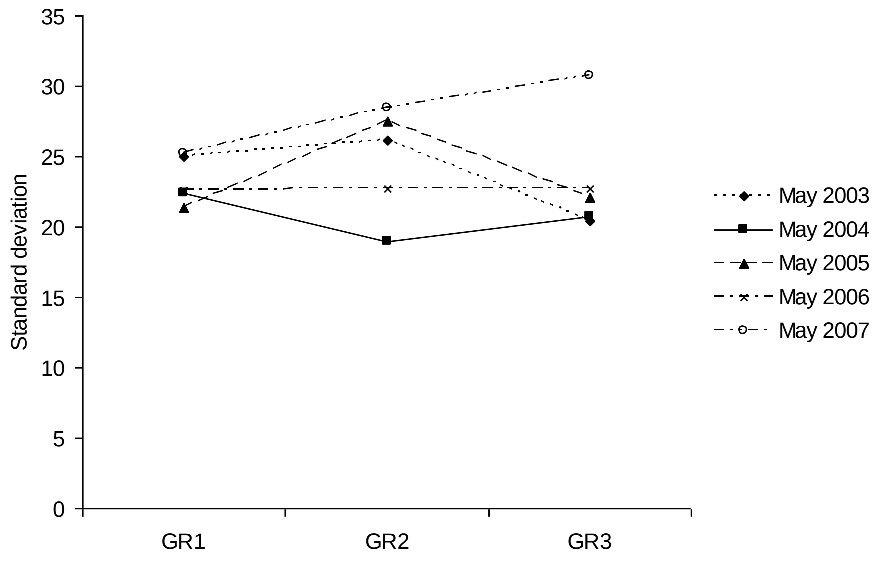


Fig. 4.11. The standard deviation of ground cover across all quadrats within the grazing radius paddocks for five years. Note that May 2003 was prior to treatments being applied.

In most years there were no differences among paddocks in the proportion of quadrats with less than 25% ground cover (Fig. 4.12). In the final year a smaller proportion of the smallest paddock (GR1) had low ground cover compared with the other paddocks. There were no trends in the proportion of paddocks with high ground cover levels in relation to paddock size (Fig. 4.13). The pattern of differences between paddocks were consistent for the first three years, suggesting that proportion of different pasture types in each paddock may have been the dominant influence on ground cover. For example, paddocks with large areas of annual sorghum are likely to have recorded a large proportion of quadrats with high cover levels regardless of paddock size or grazing use since cattle tend to avoid such areas.

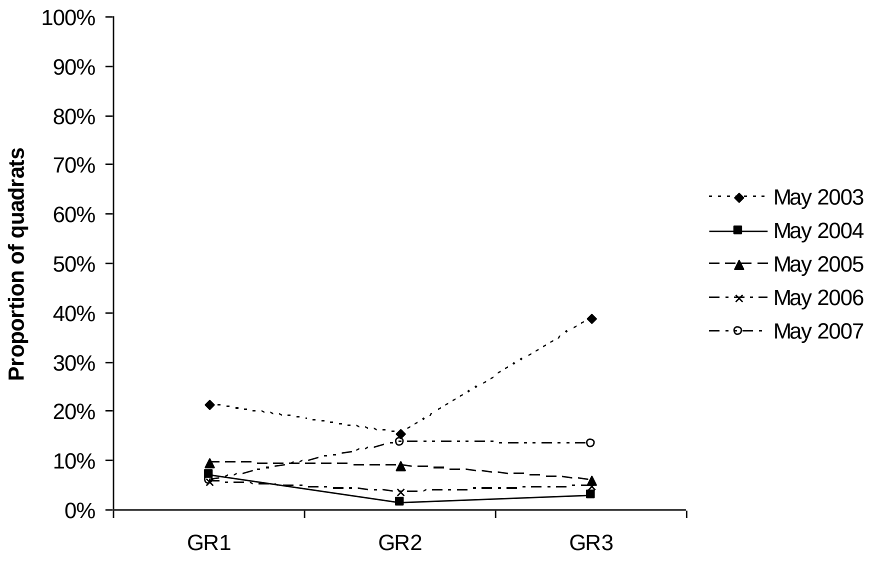


Fig. 4.12. The proportion of quadrats with less than 25% ground cover for the grazing radius paddocks over five years. May 2003 was pre-treatment.

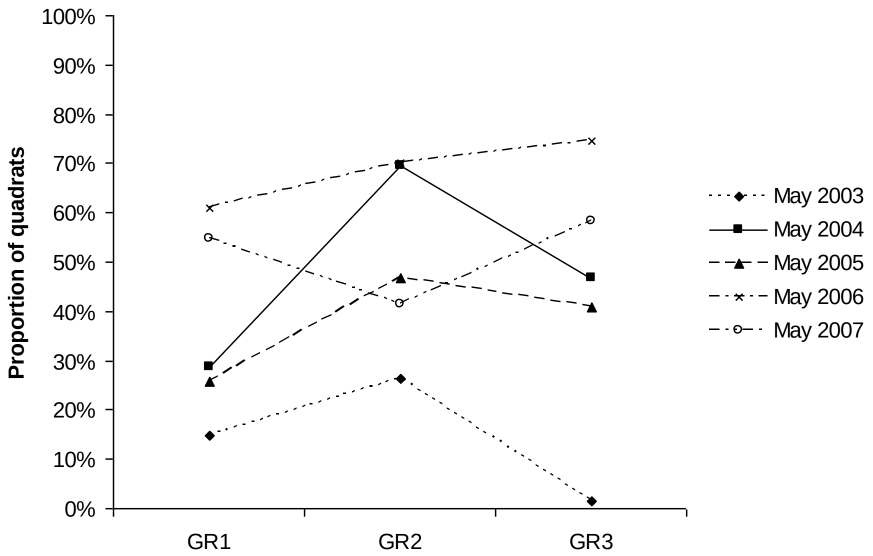


Fig. 4.13. The proportion of quadrats with 75-100% ground cover for the grazing radius paddocks over five years. May 2003 was pre-treatment.

Each of the paddocks showed similar rates of decline in overall pasture defoliation with distance from water, although the actual levels of defoliation differed (Fig. 4.14). The reason for these differences is not clear, although higher defoliation rates are expected near water in paddocks with a larger grazing radius because of the greater number of cattle using the water point. The observed trends may be confounded by historical grazing effects within each paddock (noting that the water points were newly created for this study) or peculiarities of each paddock affecting contemporary grazing distribution. These differences are not explained by differences in applied utilisation rates.

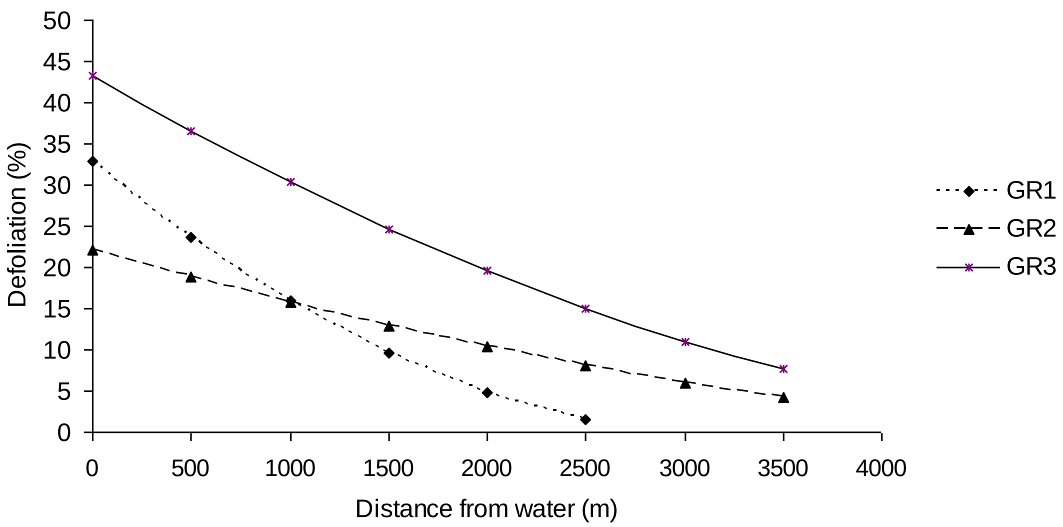


Fig. 4.14. Overall pasture defoliation rates for the dry season in three paddocks of different size at Pigeon Hole. Each paddock has a single central water point. GR1 = 9 km^2, GR2 = 21 km^2, GR3 = 34 km^2. Predicted results from an analysis of covariance of observed defoliation rates. Note that the model was significant but only accounted for <10% of the variation.

These results suggest that paddock size (or grazing radius) was not an important determinant of evenness of grazing use of a paddock by cattle. Although the home range data suggested cattle activity was more evenly distributed within smaller paddocks this did not translate to more uniform pasture utilisation. Other factors that are likely to influence patterns of pasture use include patchiness in pasture composition or pasture structure (e.g., from previous grazing), shade, riparian zones and topography. In particular, a greater incidence of less preferred vegetation within a paddock is likely to increase the unevenness of grazing, since cattle would spend less time grazing in these areas.

4.4.1.3 Effect of paddock configuration on the pasture

The analyses of variance of pasture attributes for the grazing radius treatments indicated that there was a significant treatment effect only for pasture yield, and a significant year effect and significant interaction between treatment and year for all pasture attributes (Table 4.10). However, for some attributes (e.g. yield and ground cover) there were differences between some paddocks before the treatments were imposed, which makes the treatment x year interaction especially important in assessing treatment effects. Since this effect is significant for all variables this suggests that some treatments were having differential effects on the pasture over time or, where initial differences existed between treatments, that the treatments were becoming similar with respect to the variables measured.

Table 4.10. Results of the split-plot-in-time repeated measures Analysis of Variance for the grazing radius treatments for May pasture data from 2003-2007.

Effect	Variables			
	Yield	Defoliation	Perennial Grass Basal Area	Ground Cover
Treatment	*	NS	NS	NS
Year	***	***	***	***
Treatment*Year	**	***	*	***

*** P<0.001, ** P<0.01, * P<0.05, NS = not sig.

It might be expected that over time paddocks with a larger grazing radius would have higher average forage biomass per hectare than paddocks with smaller grazing radii (despite similar imposed utilisation rates) since more of the paddock is further from water in the former case and cattle might be less likely to travel to distant areas to graze. If this is the case it would suggest that the available forage is being used to a lesser degree because it is less accessible to cattle. Although pasture yield was not significantly different amongst treatments in the last two years of the study, a weak trend of lower pasture yield in the paddock with the smallest (1 km) grazing radius did emerge over the study period (Fig. 4.15). There were marked variations amongst years in pasture yield in all treatments (as indicated by the significant year effect), associated with different rainfall amounts.

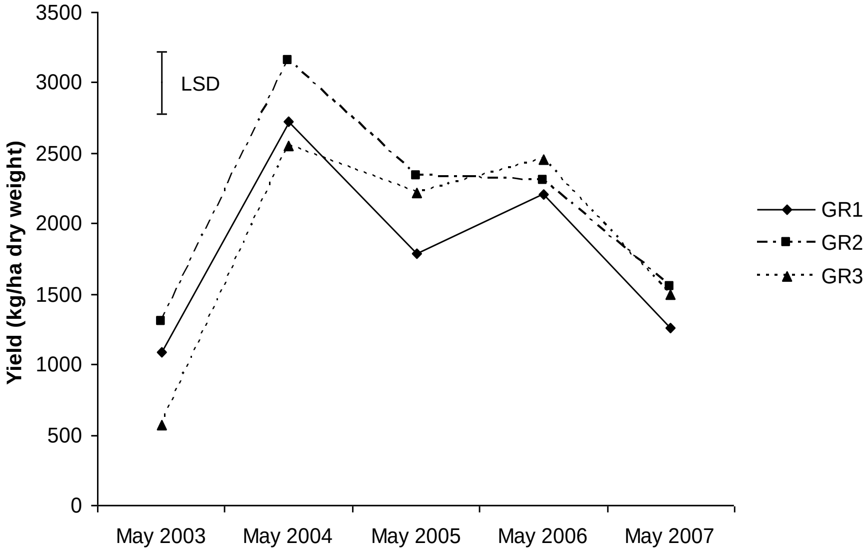


Fig. 4.15. Mean pasture yield (kg/ha dry weight) in May of each year of the study for the three grazing radius paddocks. (Fitted means from analysis of variance). May 2003 was pre-treatment. GR1, GR2 and GR3 = grazing radius of 1, 2 and 3 km, respectively. LSD, least significant difference.

However, this observation is not consistent with data on palatable yield (Fig. 4.16). Palatable yield was comprised of those pasture species usually considered to be palatable and preferred by cattle (the perennial grasses *Astrebla spp*., *Chrysopogon fallax*, *Dichanthium fecundum*, and the annual grasses *Iseilema* spp. and *Brachyachne convergens*). The yield represents the pasture remaining in the paddock at sampling, and does not include the amount already consumed by the cattle. Slightly greater palatable forage yields sometimes occurred in smallest grazing radius paddock. The yield of palatable forage in GR2 was always less than the other two paddocks. These differences are more likely to reflect inherent paddock differences rather than an effect of treatment. It is notable that in two years the yield of palatable forage in GR1 was lower at the end of the dry season than for GR3, suggesting the possibility that cattle were having a greater impact in consuming this component of the understorey in the smaller paddock – although a definitive conclusion is not possible.

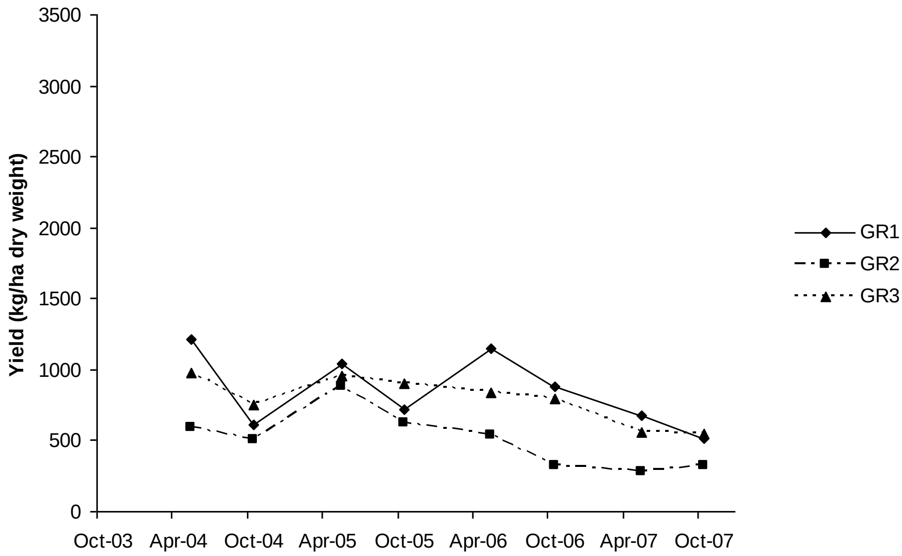


Fig. 4.16. Yield of palatable forage for the three grazing radius paddocks in May and October in each year of the study. GR1, GR2 and GR3 = grazing radius of 1, 2 and 3 km, respectively.

There were no significant differences in pasture defoliation rate amongst treatments in May of any year of the study (Fig. 4.17). Differences in defoliation in May 2003 were just prior to the study beginning. Defoliation rate generally increased over time in each treatment following the imposition of the treatments in October 2003.

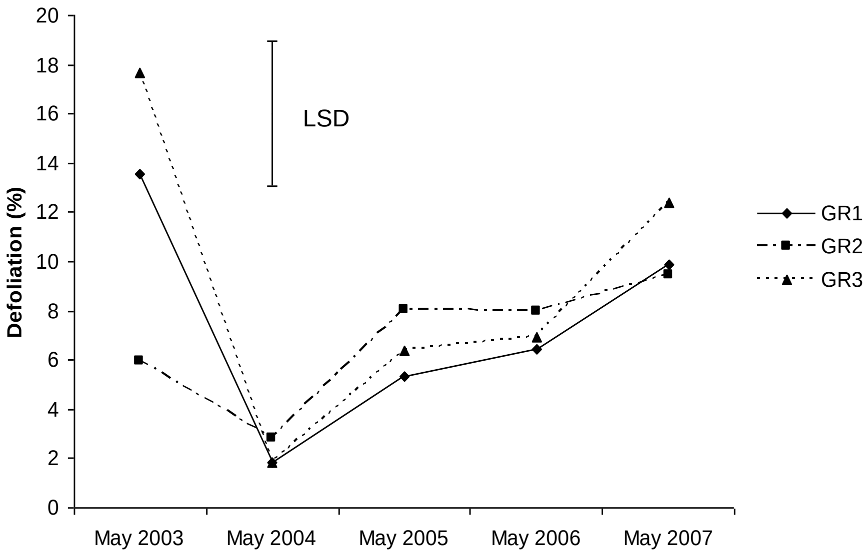


Fig. 4.17. Mean defoliation (%) in May of each year of the study for the three grazing radius paddocks. (Fitted means from analysis of variance). May 2003 was pre-treatment. GR1, GR2 and GR3 = grazing radius of 1, 2 and 3 km, respectively. LSD, least significant difference.

Perennial grass basal area (PGBA) differed amongst years but the overall treatment effect was not significant (Table 4.10), and there has been no consistent response to the treatments over time (Fig. 4.18). The year x treatment interaction was significant, reflecting the stronger fluctuations in basal area in GR3 over time. It should be noted that any changes in the basal area of desirable (or decreaser) species may have been masked by opposite changes in undesirable (or increaser) species such as *Aristida latifolia*, since basal area was estimated without regard for the identity of the perennial grass species.

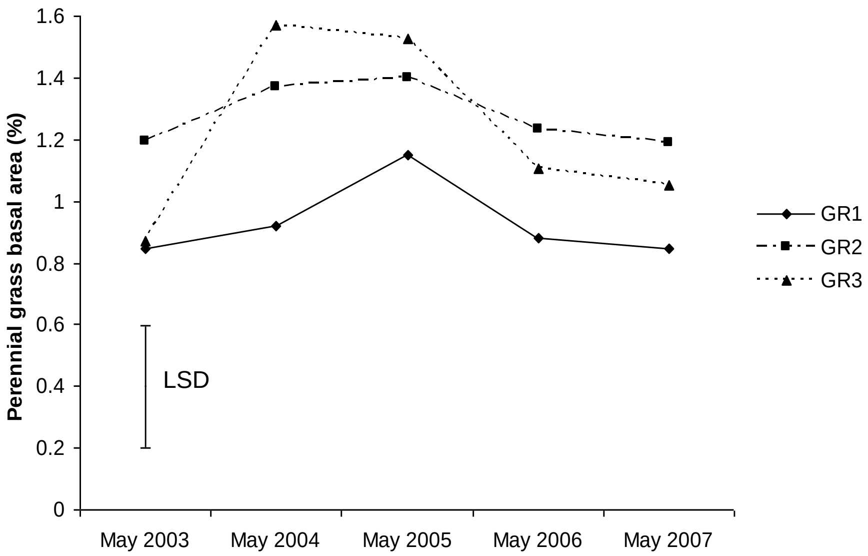


Fig. 4.18. Mean perennial grass basal area (%) in May of each year of the study for the three grazing radius paddocks for the duration of the study. (Fitted means from analysis of variance). May 2003 was pre-treatment. GR1, GR2 and GR3 = grazing radius of 1, 2 and 3 km, respectively. LSD, least significant difference.

There were initial differences amongst treatments in ground cover but as the study progressed cover levels on the treatments converged so that there were no differences at the final sampling (Fig. 4.19). There was a strong increase in cover from May 2003 (just prior to the study) to May 2004 due to the effects of fire in late 2002. Ground cover exceeded 60% in May in the final two years for all treatments.

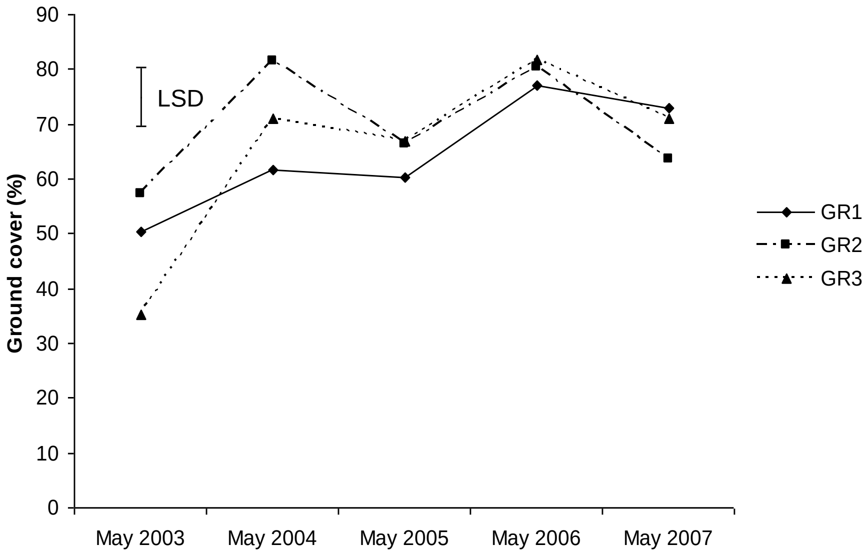


Fig. 4.19. Mean ground cover in May of each year of the study for the three grazing radius paddocks for the duration of the study. (Fitted means from analysis of variance). May 2003 was pre-treatment. GR1, GR2 and GR3 = grazing radius of 1, 2 and 3 km, respectively. LSD, least significant difference.

There was a significant overall difference in pasture species composition amongst treatments (ANOSIM R = 0.885, P = 0.001). However, ordination of species composition (based on percent composition by weight) indicated that initial composition at the start of the study differed amongst paddocks (i.e. they were well separated in the ordination) and differences remained for the duration of the study (Fig. 4.20). There were no significant differences in species composition amongst years (R = -0.188, P = 0.918). These differences in species composition amongst treatments are reflected in the contribution of different plant functional groups to pasture yield (Fig. 4.21 - Fig. 4.23).

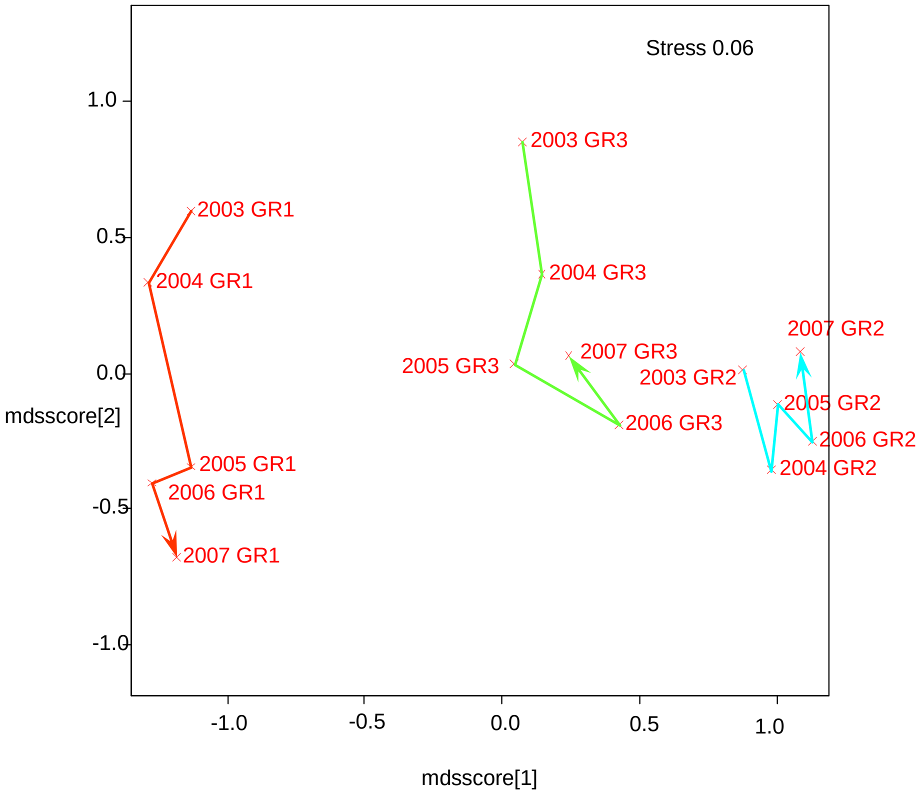


Fig. 4.20. Ordination (non-metric multidimensional scaling) of species composition for the grazing radius paddocks (GR1, GR2 and GR3) over the years of the study, based on percent species composition by weight.

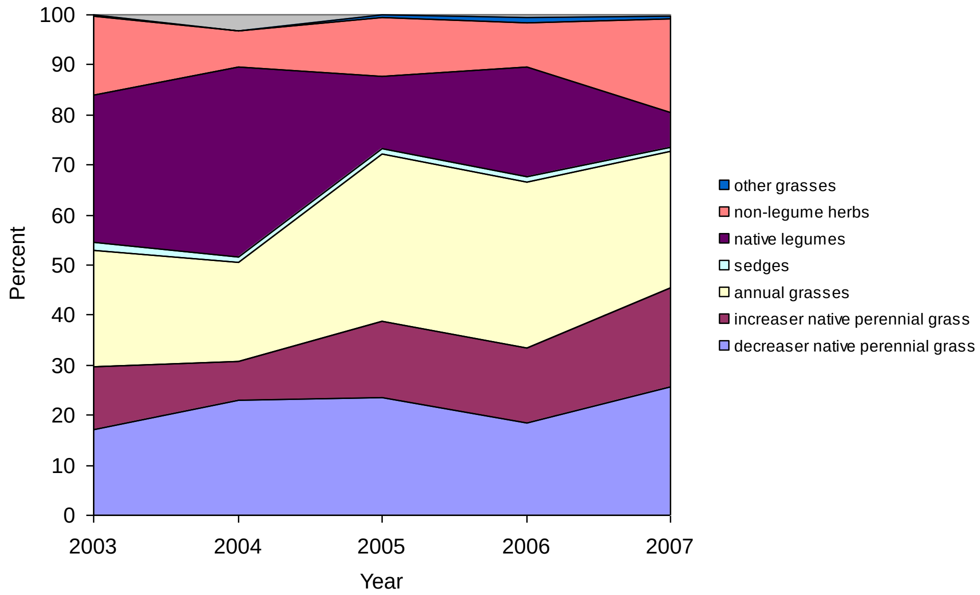


Fig. 4.21. Plant functional group contribution to pasture yield for the Grazing Radius 1 paddock (GR1) during the study. Note that the grey area at the top of the chart represents error where functional group yields do not total 100% (due to differences between observers' estimated yield and the corrected yield from calibration regression equations).

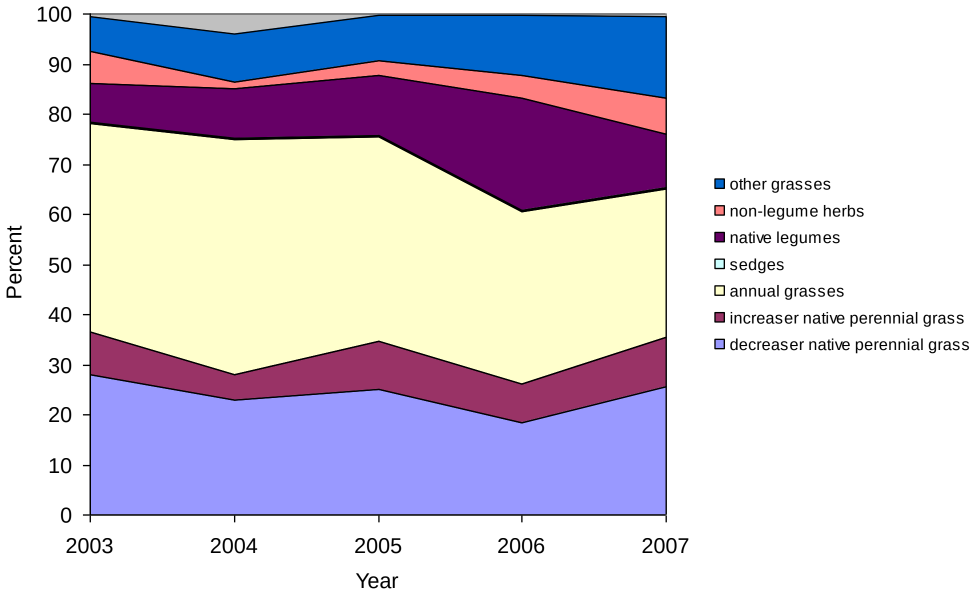


Fig. 4.22. Plant functional group contribution to pasture yield for the Grazing Radius 2 paddock (GR2) during the study.

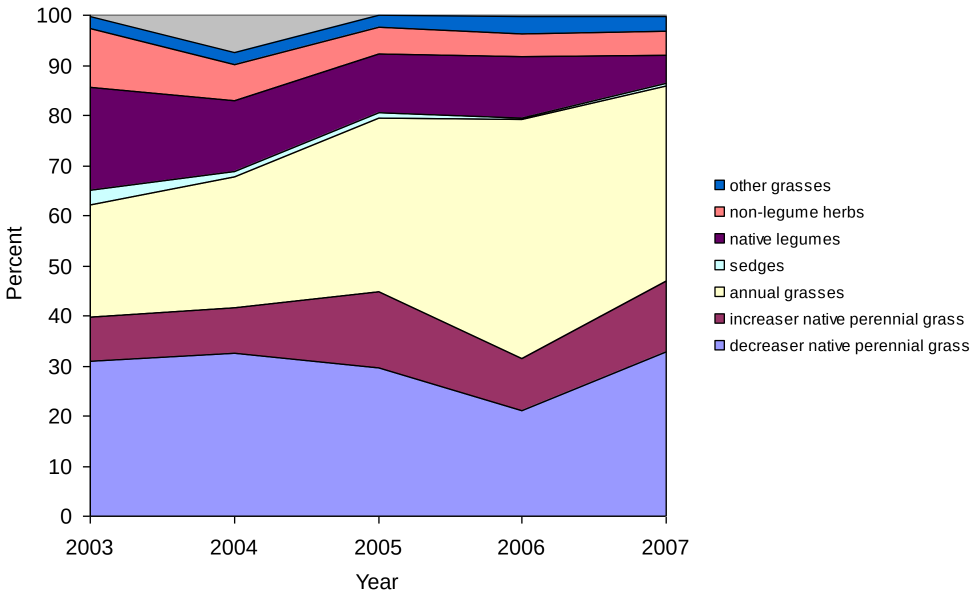


Fig. 4.23. Plant functional group contribution to pasture yield for the Grazing Radius 3 paddock (GR3) during the study.

Fig. 4.24 shows the proportion of each of the treatment paddocks within four land condition categories which approximate the A, B, C and D classes used in the GLM system, based on the percentage of quadrats in each condition class. There was little difference in land condition amongst the treatment paddocks and no apparent trends in condition during the study.

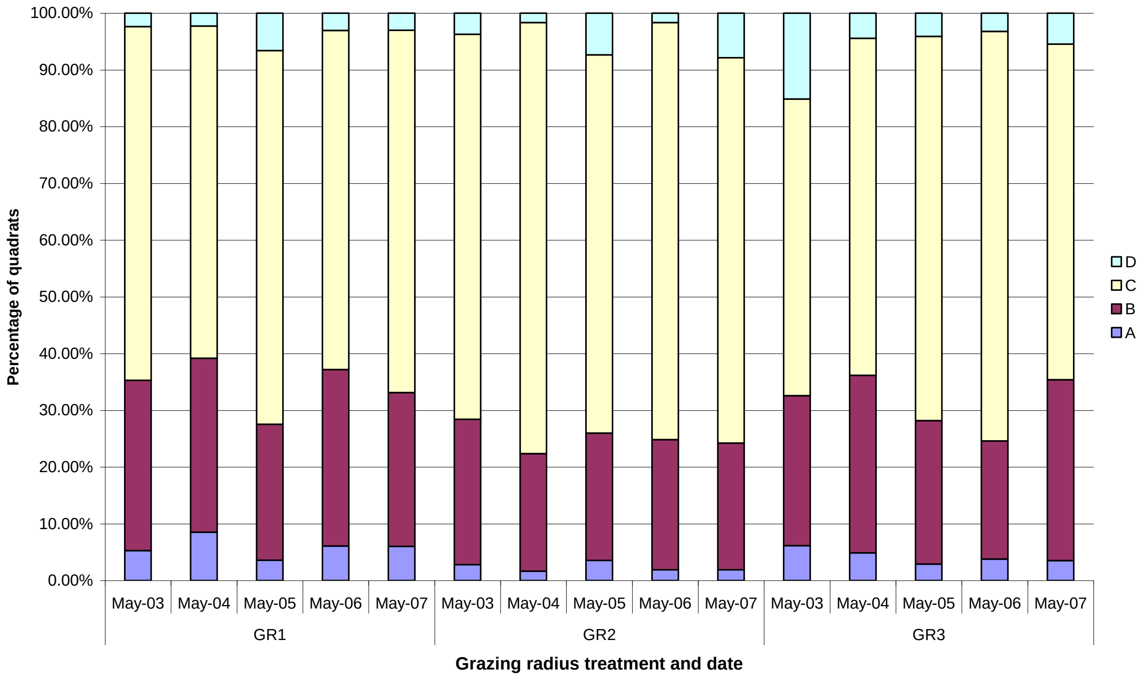


Fig. 4.24. Proportion of each paddock in four GLM land condition classes (A-D) for the duration of the study.

4.4.1.4 Conclusions relating to patterns of grazing use

The variable pasture data results and measures of evenness of use suggest that the grazing radius treatments were not having a marked effect on patterns of paddock use by cattle or the pasture. It was only in the final year that the larger standard deviation for defoliation and ground cover and the greater proportion of quadrats with high levels of cover in the larger paddocks suggest that despite similar utilisation rates in each paddock, those with a larger grazing radius might be experiencing more uneven grazing. If that is the case, some of the available forage would not be utilised, although in areas closer to water the forage is more likely to be depleted. The home range data that indicated a smaller proportion of the larger paddocks was being used by cattle suggests that in these paddocks more uneven grazing might be expected.

4.4.1.5 Livestock performance and dietary quality for different grazing radii

4.4.1.5.1 Dietary quality

There were no consistent differences in dietary quality amongst the treatments. Each treatment showed the expected seasonal trends in quality associated with the wet and dry seasons, with crude protein (Fig. 4.25) and dry matter digestibility (Fig. 4.26) both peaking during the wet, growing season. The only marked distinction between the treatments was greater dietary crude protein in GR1 during the late dry season in 2005 and 2006. This possibly reflects the generally larger proportion of palatable forage in the pasture in GR1 relative to the other paddocks (usually about 50-60% palatable compared with <45%).

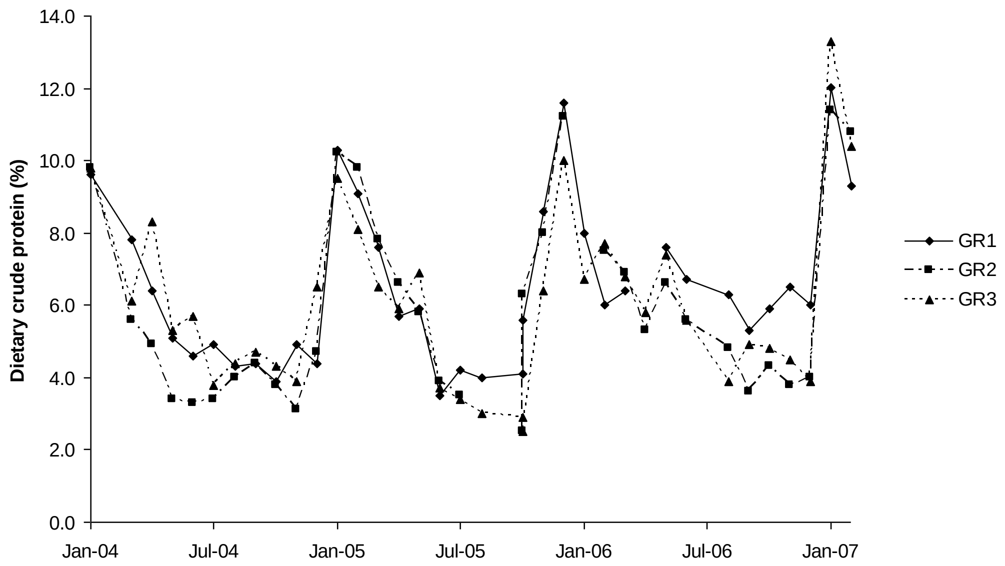


Fig. 4.25. Percent dietary crude protein for the grazing radius treatments, measured using faecal near infra-red spectroscopy.

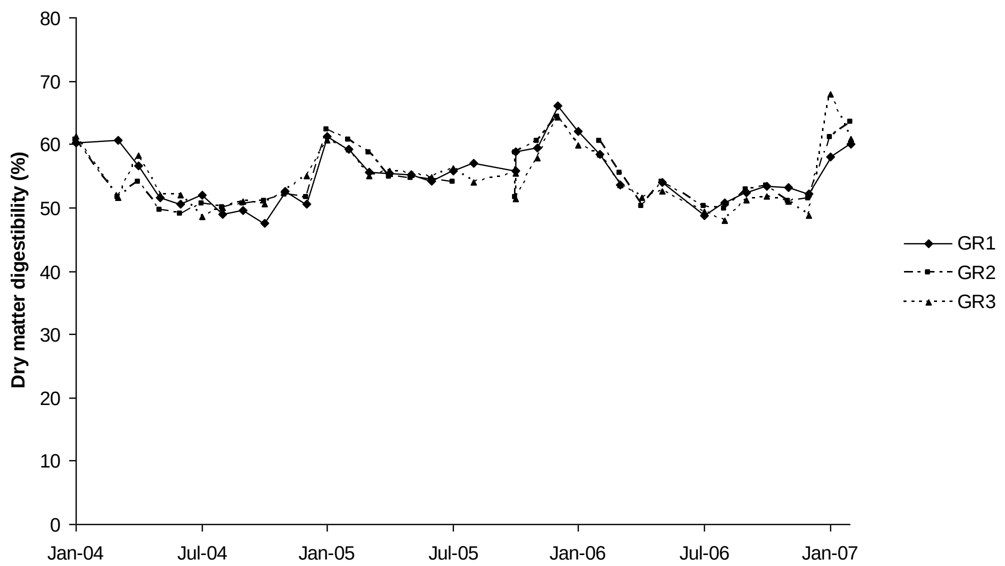


Fig. 4.26. Dry matter digestibility (%) of cattle diets for the grazing radius treatments, measured using faecal near infra-red spectroscopy.

4.4.1.5.2 Liveweight gain

Daily liveweight gain of grower steers was analysed separately for the wet and dry seasons. Analysis of Covariance was used for the statistical analysis, with liveweight at the start of each measurement season as a covariate. A primary aim of the analysis was to test whether there was a significant treatment x year interaction on liveweight gain. Because there was no replication of treatments and the pasture data indicated that there were some initial differences between treatment paddocks, testing for a treatment x year interaction was considered as the most informative way to assess the effects of the different paddock configurations on liveweight gain. If the grazing radius treatment was having an effect on liveweight gain it might be expected that the treatments would show a separation, or an emerging consistent difference, over time, as indicated by a significant treatment x year interaction.

There were no conclusive effects of the grazing radius treatments on liveweight gain for the wet season (Fig. 4.27). Both the treatment and year main effects were significant (P<0.001 for both) but the treatment by year interaction was not significant (P=0.822). Despite the significant treatment effect, significant differences between individual treatments occurred only in the final year (2006-2007) when liveweight gain in GR3 was significantly less (P<0.05) than in GR1 and GR2 (0.34 kg/day c.f. 0.41 and 0.45 kg/day, respectively). Apparent differences in liveweight gain amongst treatments in the first year were not significant due to high variability around the means.

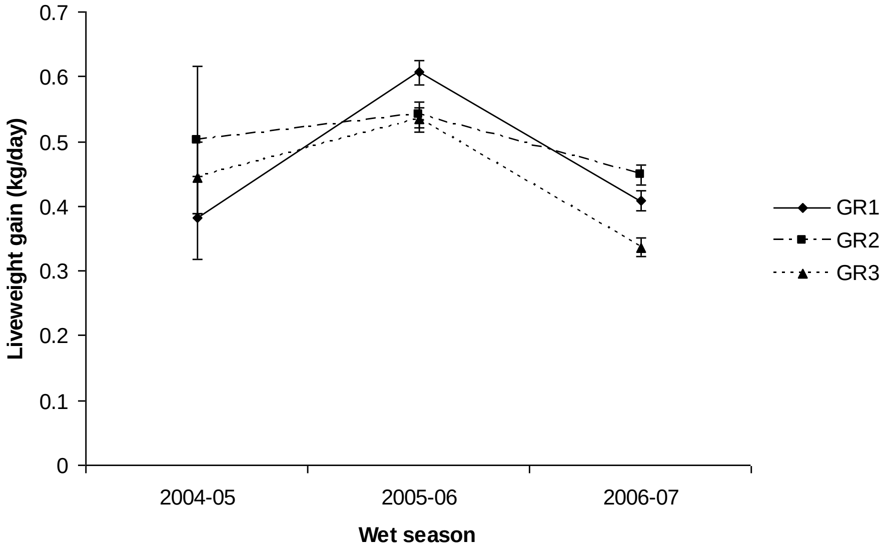


Fig. 4.27. Mean daily liveweight gain (±SE) of steers for the grazing radius treatments over three wet seasons. Fitted means from the analysis of covariance with liveweight at the start of each measurement season as the covariate.

For the dry season, there was a significant effect of grazing radius treatment and year (both P<0.001) on daily liveweight gain, and the treatment x year interaction was weakly significant (P=0.042). Liveweight gain was significantly greater (P<0.05) for GR1 than the other treatments in 2006 and 2007 (Fig. 4.28), but there were no differences between GR2 and GR3 in any year. Although liveweight gain was also markedly greater in GR1 than the other treatments in the first year, high variability around the means in this year meant that this difference was not significant. The significant treatment x year interaction reflects the smaller difference between GR1 and the other treatments after the first year.

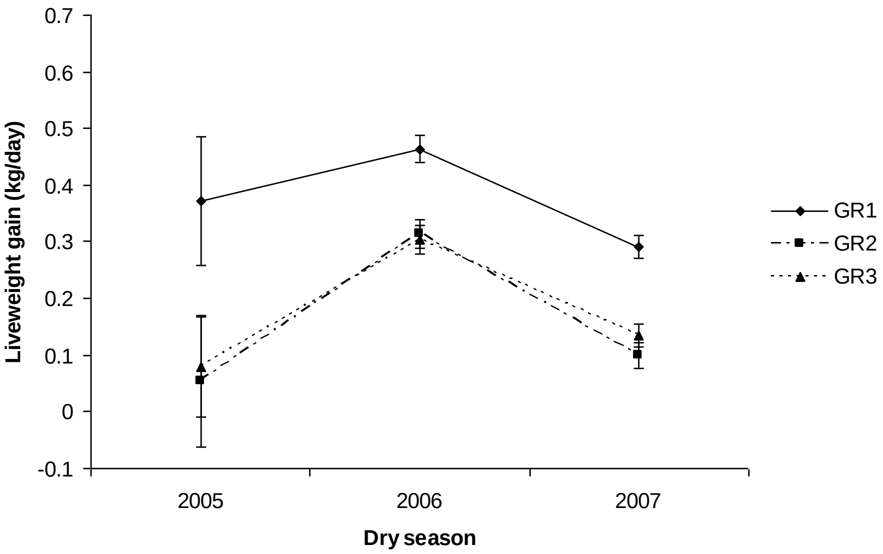


Fig. 4.28. Mean daily liveweight gain (±SE) of steers for the grazing radius treatments over three dry seasons. Fitted means from the analysis of covariance with liveweight at the start of each measurement season as the covariate.

Although there was a significant overall treatment effect for both the wet and dry season analyses, overall these results suggest that grazing radius was having little effect on liveweight gain. However, it is not possible to draw firm conclusions from the results. Uncertainty about the effects arises from the differences (and variability) in liveweight gain between treatments in the first year, variability in wet season results for the different treatments across years, and the lack of clear separation of the treatments over time. Although cattle consistently gained more weight in GR1 in the dry season, this may have been due to inherent characteristics of the pasture in this paddock compared with the others, rather than grazing radius *per se*. Because of our unreplicated experimental design we are unable to discount this possibility. Also, the lack of difference between GR2 and GR3 over the dry season in the later two years suggests grazing radius was not an important influence on liveweight gain. If grazing radius treatment was affecting liveweight gain we might have observed a separation of the treatments over time, with some consistency in the direction of the effect of different grazing radii on liveweight gain.

4.4.1.5.3 Breeder liveweight

Breeder liveweights were adjusted for pregnancy status prior to analysis. The analysis of variance of breeder liveweight showed that the main effects of grazing radius, year and the year x treatment interaction were significant for both weaning rounds ($P<0.001$ in all cases except $P=0.017$ for the year x treatment interaction in the first weaning round). Nevertheless, there were no consistent trends in liveweight in relation to grazing radius treatment or time in weaning round one, and only two pairwise comparisons were significant. These were in 2006 when liveweight was significantly ($P<0.05$) higher in GR1 than the other two treatments (Fig. 4.29).

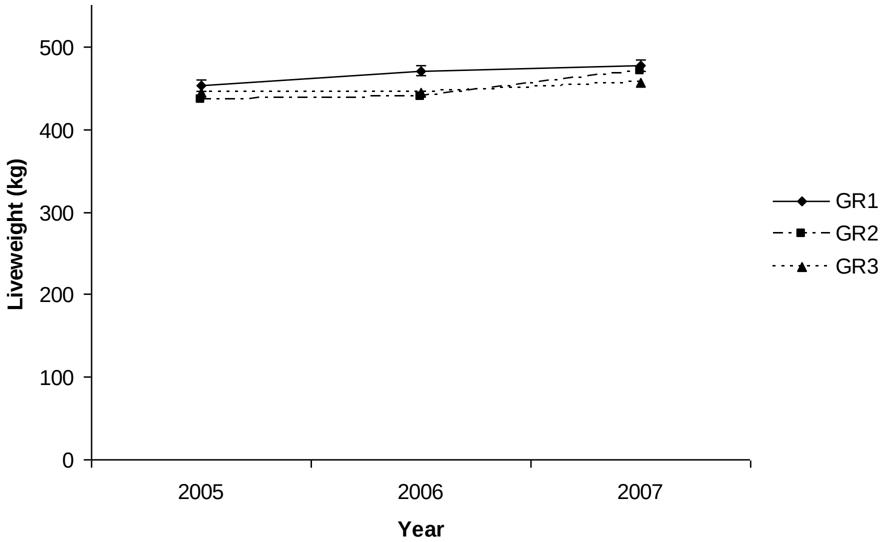


Fig. 4.29. Liveweight (mean ± standard error) of breeder cattle adjusted for pregnancy at weaning round 1 (April-May) for three years of the study.

At weaning round two, liveweight was always significantly higher in GR1 ($P<0.05$) than the other two treatments. There were no consistent differences between GR2 and GR3; on two occasions they were not significantly different, on one occasion liveweight in GR3 was higher and in the last year GR2 was higher (Fig. 4.30). These variable responses would have been the reason behind the significant year x treatment interaction.

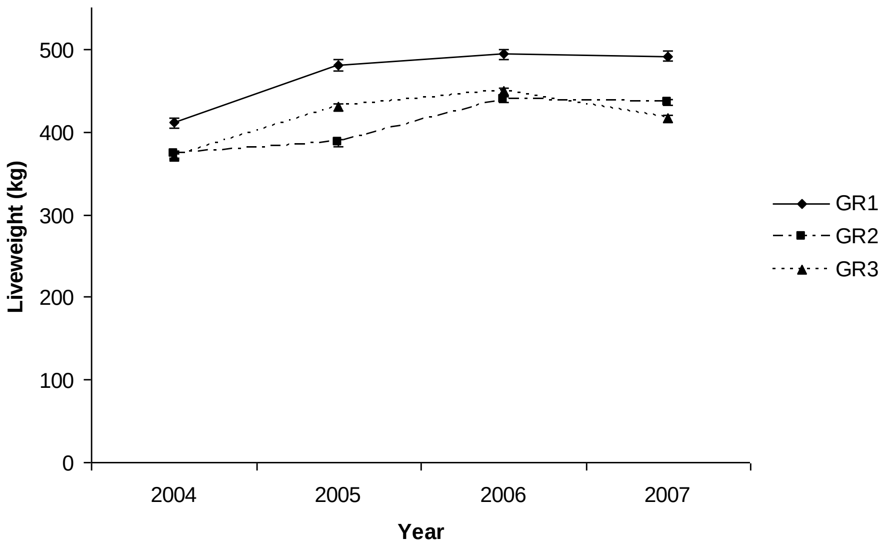


Fig. 4.30. Liveweight (mean ± standard error) of breeder cattle adjusted for pregnancy at weaning round 2 (Sep-Oct) for three years of the study.

Overall, these results indicate the grazing radius of a paddock was likely having no effect on breeder liveweights. Although liveweight was consistently higher in GR1 at weaning round two, it is possible that this effect reflected an inherent difference in the pasture or livestock in GR1 compared with the other paddocks, rather than an effect of the size of the grazing radius.

4.4.1.5.4 Body condition

Body condition scores differed significantly amongst grazing radius treatments and year, and the year x treatment interaction was also significant (P<0.001) for both mustering rounds. For mustering round 1, there was initially no difference between GR1 and both GR2 and GR3, but body condition score was significantly higher in GR3 than for GR2. By the end of the study, body condition score was significantly different (P<0.05) amongst all grazing radius treatments - highest (score of 5.7) in GR1, intermediate (4.81) in GR2 and lowest (4.33) in GR3 (Fig. 4.31).

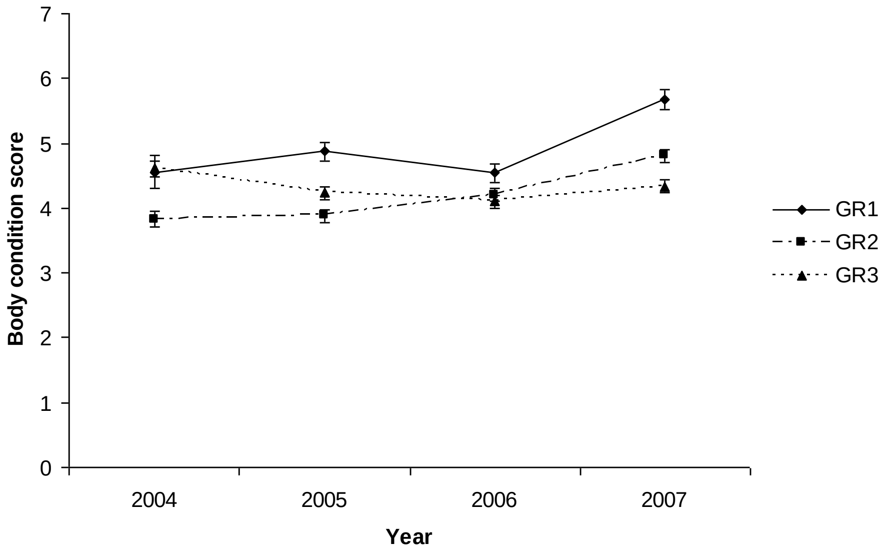


Fig. 4.31. Body condition score (mean ± standard error) for weaning round 1 (April-May) for the three grazing radius treatments over four years of the study.

For mustering round 2, there were initially no differences between grazing radius treatments, significant differences amongst some treatments in the middle years, and in the final year body condition score was significantly (P<0.05) higher in GR1 (Fig. 4.32). There were marked variations between years, particularly for GR3, although the reasons for this are not readily apparent; presumably seasonal conditions would have had some effect.

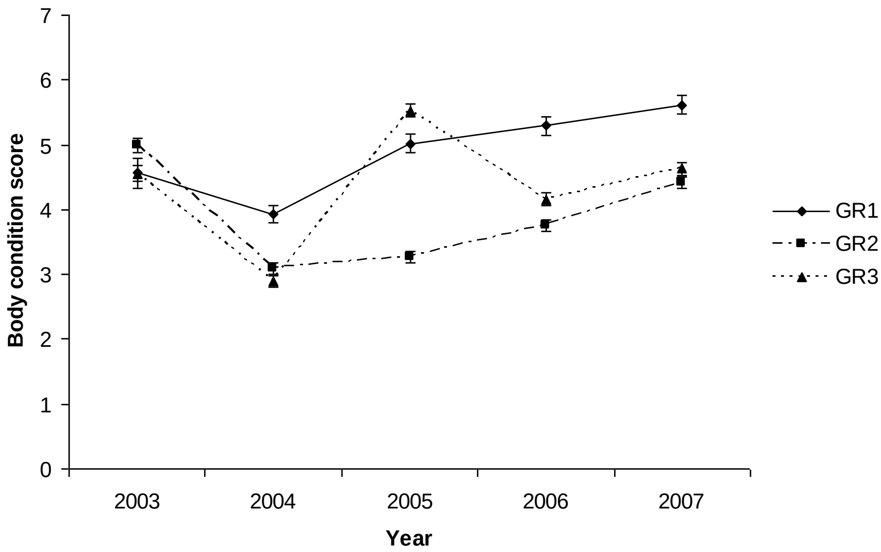


Fig. 4.32. Body condition score (mean ± standard error) for weaning round 2 (September-October) for the three grazing radius paddocks over four years of the study (note that the 2003 data are the initial scores when treatments were first applied).

These results provide weak support for the notion that body condition was poorer with increasing grazing radius, although this is certainly not conclusive. Intuitively one might expect body condition to be higher where the grazing radius (and in this case paddock size) is smaller, since cattle would expend less energy walking between water and forage. A more pronounced effect of grazing radius on body condition might have been apparent had the treatments been in place for longer so the effects on the pasture (e.g. depletion of biomass) of higher numbers of cattle around the water point in the larger grazing radius treatments had become more apparent.

4.4.1.5.5 Inter-calving interval

The inter-calving interval data were analysed using a generalised linear model with Poisson distribution to test for an effect of grazing radius treatment overall years. Overall, there was a significant ($P<0.001$) effect of grazing radius treatment on inter-calving interval. Grazing radius 2 recorded the longest mean inter-calving interval of 15.7 months, while GR1 recorded the shortest (Table 4.11). The difference between these two treatments was significant ($P<0.001$), but there was no significant difference ($P=0.241$) between GR1 and GR3. The lack of systematic effect of grazing radius on inter-calving interval suggests some caution is needed in interpreting these results, and that these differences may be a reflection of other variation between the treatment paddocks rather than grazing radius per se. It should also be noted that the median inter-calving interval was the same for each treatment.

Table 4.11. Mean and median inter-calving interval (months) for the three grazing radius treatments calculated over the four years of the study.

	GR1	GR2	GR3
Mean	14.3	15.7	14.7
Median	14.0	14.0	14.0

4.4.1.5.6 Fertility (re-conception rate)

Fertility was measured as the number of cows that were pregnant and lactating divided by the number that were lactating. Overall, these proportions were relatively low (Fig. 4.33), with the highest being 0.41 (for GR1 in the third year). A series of binomial tests was used to compare the proportions between treatments within each year. There was no significant difference ($P>0.05$) in fertility between GR1 and GR3 in any year, but in 2004 and 2006 fertility in GR2 was significantly lower than in GR1 and GR3 (all *P*<0.05), and significantly (*P*=0.002) lower than GR3 in 2005. There were no significant differences between treatments in the final year (2007). These results suggest that, overall, grazing radius was having no effect on the fertility of the cows.

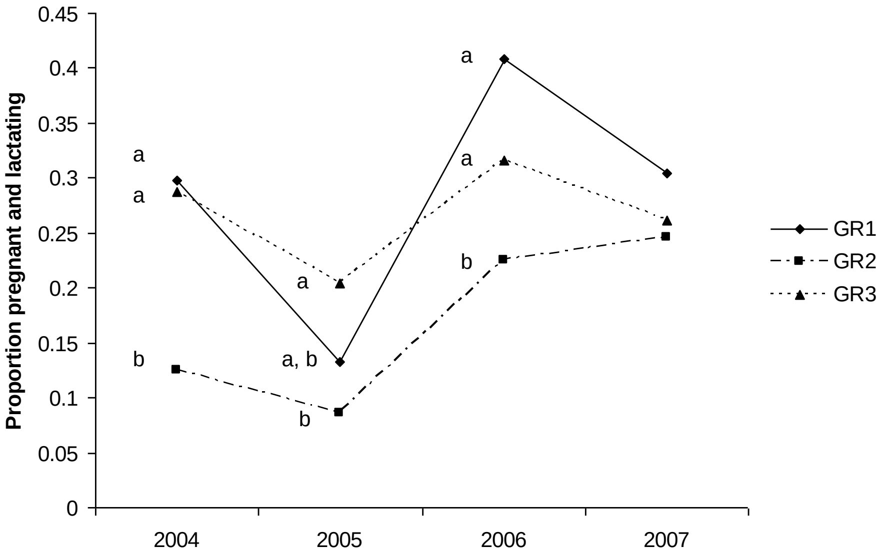


Fig. 4.33. Fertility of cows (measured as the proportion of lactating cows that were pregnant) for the grazing radius treatments during the study. Points with the same letter within years are not significantly different at *P*=0.05.

4.4.1.5.7 Branding and weaning rates

There was a significant overall effect of grazing radius treatment on branding and weaning rates (*P*<0.001 and *P*<0.01 respectively) over all years. Branding rate was significantly greater in GR1 compared with the other treatments (Table 4.12), while branding rate in GR3 was higher than for GR2. Weaning rate was significantly greater in GR1 than GR2 but there was no significant difference between GR1 and GR3. Weaning rate was similar in GR2 and GR3. To some extent these results reflect differences in fertility amongst the treatment paddocks.

Table 4.12. Mean branding and weaning rates over all years for the grazing radius treatments. These are fitted means from a binomial model.

	GR1	GR2	GR3
Branding Rate (%)	84.7	71.7	78.0
Weaning Rate (%)	77.7	67.8	71.8

Although the performance of GR1 was better than the other treatments, the fact that the middle treatment (GR2) performed worst suggest that these differences were more likely related to inherent paddock differences than the size of the grazing radius (i.e. paddock) per se.

4.4.1.5.8 Weaner production

Grazing radius 2 performed better in terms of average annual weight weaned (7.5 kg per hectare and 52 kg per breeder animal equivalent) than the other two treatments (Fig. 4.34 and Fig. 4.35). No statistical analysis of these data was possible because of the lack of replication. However, the differences in terms of weight weaned per breeder were generally small. Grazing radius 3 was the worst performer on an area basis, producing 4.7 kilograms weight weaned per hectare. Differences in stocking rates amongst the treatment paddocks would have contributed to differences in weight weaned per hectare. Given that there was not a consistent trend in weight weaned with increasing (or decreasing) grazing radius, it is reasonable to conclude that grazing radius was not an important influence on weight weaned.

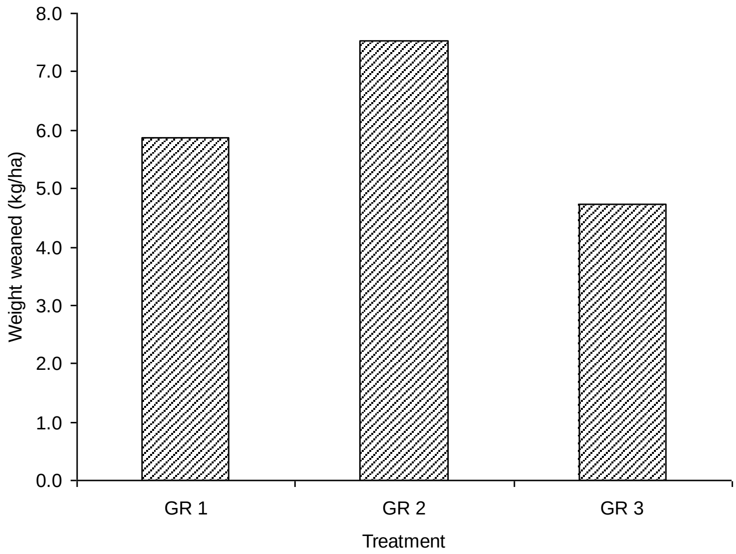


Fig. 4.34. Average annual weight weaned (kilograms per hectare) for the grazing radius treatments. Data averaged over 2004 and 2005.

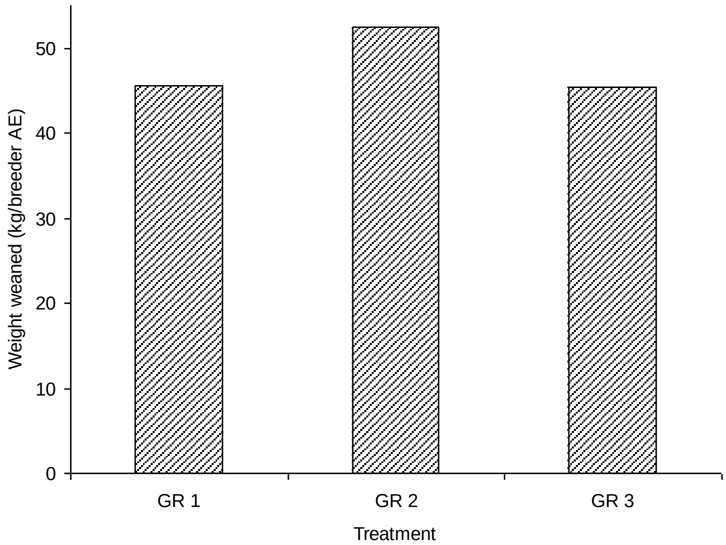


Fig. 4.35. Average annual weight weaned (kilograms per breeder animal equivalent) for the grazing radius treatments. Data averaged over 2004 and 2005.

4.4.1.5.9 Calf loss

Calf loss was analysed as the proportion of calves lost per treatment (paddock), using a Generalised Linear Model (Binomial error with logit link). The analysis was conducted over the entire study using different years as replicates.

There were no significant differences in calf loss amongst the grazing radius treatments (Fig. 4.36).

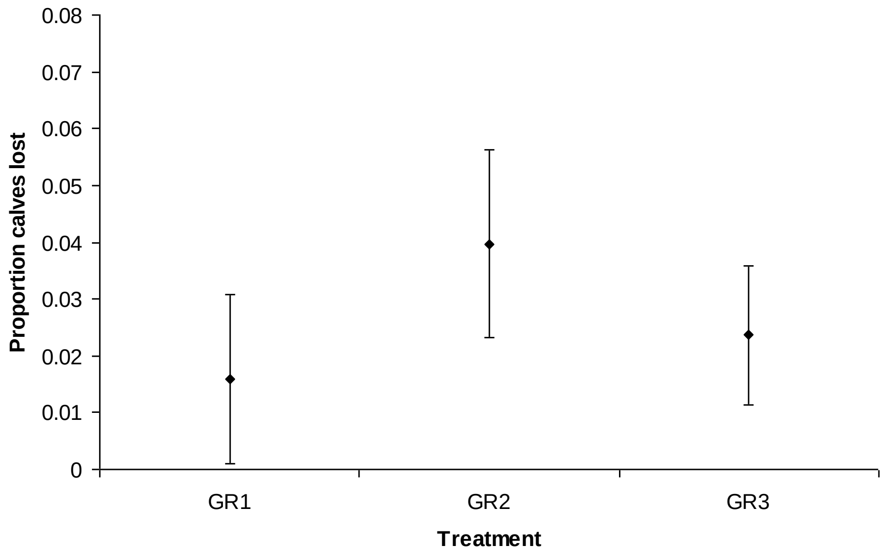


Fig. 4.36. The mean proportion (± 95% confidence interval) of calves lost over the study period for each of the grazing radius treatments.

4.4.1.6 Conclusions from grazing radius experiment

Taken together, these results suggest that there was little effect of the size of the grazing radius (and hence the number of cattle per water point) on land and pasture condition and livestock production for the duration of the study. However, the differences in patterns of use indicated by the GPS data suggest that in the longer term some differences might emerge. For example, the combination of a larger number of cattle and the smaller proportion of the larger paddocks used by the cattle, would mean the areas actually used would have experienced a higher pasture utilisation rate than the overall intended rate of 20%. In the longer term this may result in the more heavily used areas becoming degraded, with potentially adverse effects on livestock production.

4.4.2 Experiment 2 – Paddock configuration

4.4.2.1 Cattle behaviour in relation to paddock configuration

4.4.2.1.1 Paddock use by cattle

The cattle location data from the GPS collars indicated there were marked differences between different paddock configurations (i.e. paddocks differing in size and water point number) in various measures of cattle distribution and behaviour. Home ranges of individual cattle tended to be larger in larger paddocks but the proportion of a paddock used by individual cattle decreased with increasing paddock size (Table 4.13). The large undeveloped commercial paddock recorded the largest mean home range and smallest proportion of the paddock used by individual cattle.

Table 4.13. Average home range, proportion of paddock used and distance walked per day for individual cows grazing in three developed paddocks for six, six-month periods (different cows used each time), and for cows in a typical commercial paddock (Lochart paddock, Mt Sanford) for two six-month periods. Not all collars functioned for the entire six-month deployment period; home range results include data only from collars that functioned for a minimum of two months.

Paddock	Paddock area (sq. km)	Number of water points	Number of collared cows	Mean home range in sq. km (sd)	Mean percentage of paddock used by individual cows (%)	Mean distance walked per day in metres* (sd)
Developed paddocks						
One water	8.9	1	16	7.7 (1.18)	86.5	5637 (906)
Two waters	34.3	2	15	25.1 (7.78)	73.3	5797 (1074)
Multiple waters	56.9	5	15	31.3 (7.61)	54.9	5378 (587)
'Typical' commercial paddock	148.6	3	4	72.7 (31.41)	48.9	7533 (1267)

* There was no significant difference ($P > 0.05$) amongst treatments in distance walked per day.

The composite home range (home ranges from all tracked cattle within a paddock combined) also increased with larger paddock size while the proportion of a paddock used decreased (Table 4.14). Because the composite home range incorporates differences between individual cattle in the areas used (due to individual preferences for certain water points and certain habitats) they provide a better estimate of overall paddock use. The composite home range suggests that a greater proportion of large paddocks is used than indicated by the individual home ranges since individual patterns of use can often be complementary (see Fig. 4.37 for an example from the Multiple waters paddock). Nevertheless, the actual area that was not used regularly (i.e. the area not encompassed by the composite home range) was greater in the larger paddocks. For example, the area not used in the largest developed paddock (Multiple waters) was approximately 14 km^2 while in the large commercial paddock approximately 35 km^2 was not used. It should be noted that the small sample size for the large commercial paddock (only four collared cows) is likely to have been inadequate to obtain a robust estimate of use for this paddock.

The 'core' area (the area of overlap of all estimated home ranges in a paddock and hence likely to be the most heavily used part a paddock) was smallest in the smallest paddock, but surprisingly was a similar size in the Two waters, Multiple waters and commercial paddock (Table 4.14).

Table 4.14. Mean composite home range, core area and mean distance of cows from water in each of the grazing configuration paddocks.

Paddock	Paddock area (sq. km)	Mean composite home range (sq. km)	Mean composite home range as percentage of paddock (%)	Mean core area (sq. km)	Mean core area as percentage of paddock (%)	Mean distance of cows from water (metres)* (sd)
Developed paddocks						
One water	8.9	8.4	94.4	6.9	77.5	941 (168)
Two waters	34.3	27.6	80.5	19.3	56.3	1546 (218)
Multiple waters	56.9	43.3	76.1	20.5	36.3	1394 (298)
'Typical' undeveloped commercial paddock	148.6	113.7	76.5	19.3	12.9	2945 (831)

* Treatment had a significant effect ($P < 0.001$) on mean distance of cows from water for the three developed paddocks.

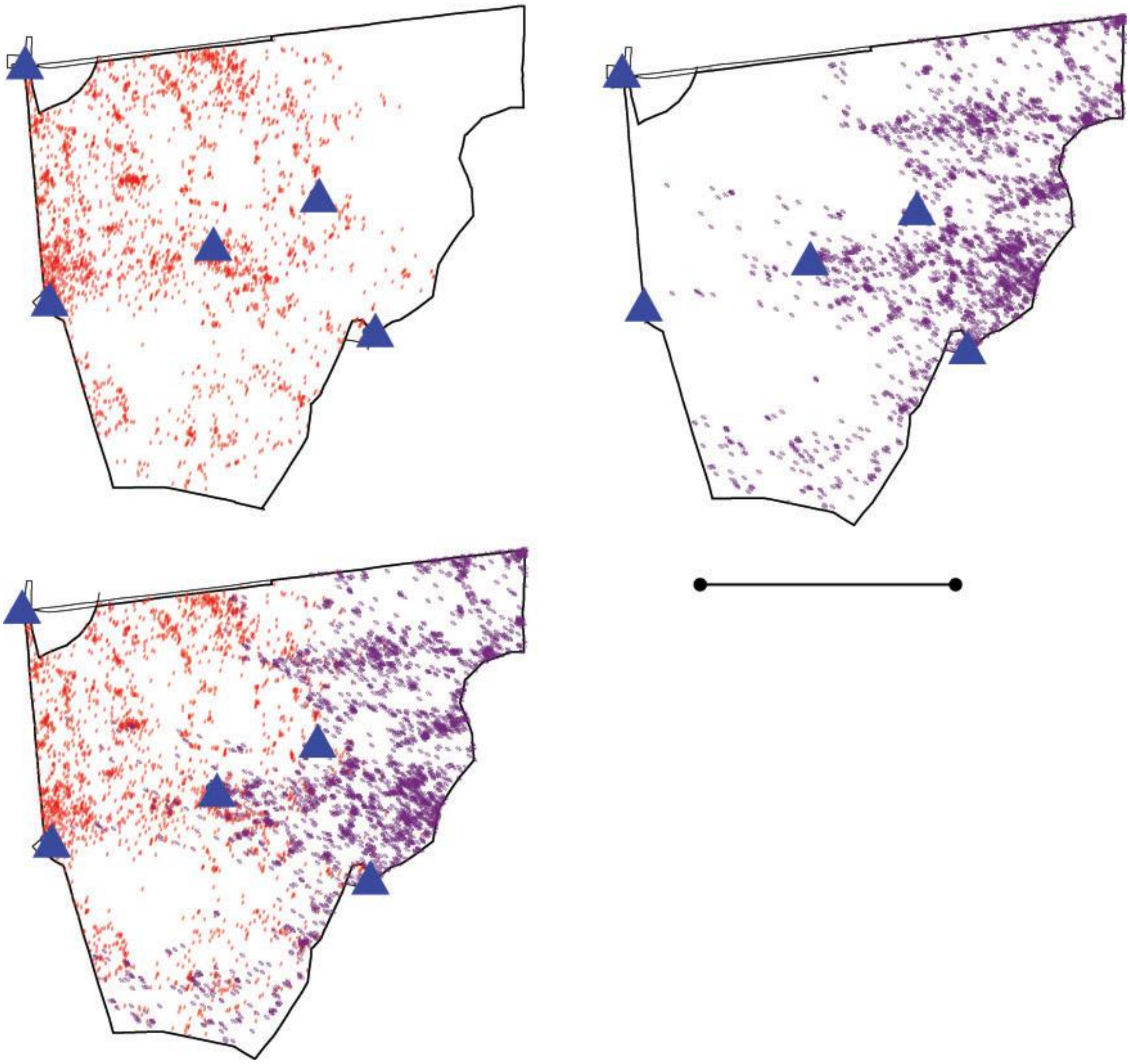


Fig. 4.37. Example of complementary distributions of two cattle (top panels) and combined use (lower panel) in the Multiple Waters paddock (57 km^2 with five water points). Each dot is an hourly GPS fix; triangles indicate water points. The distance bar represents 5 km. (from Hunt *et al.* 2007).

As mentioned, cattle in the large, undeveloped commercial paddock generally had considerably larger home ranges and used a smaller proportion of the paddock than in any of the developed experimental paddocks (Table 4.13. While there was some variation amongst individual cattle in the commercial paddock with respect to home range size and distance walked per day, these results seem to be a reasonable assessment for this paddock despite the small sample size. As with the Multiple water paddock, individual cattle favoured a particular water point and associated areas of the paddock for most of the observation period.

Cattle walked a similar distance (approx. 5.5 km) per day in each of the developed paddocks. Cattle In the commercial paddock walked about 2 km further each day than in the developed paddocks (Table 4.13).

Assuming the size of cattle home ranges (individual and composite) relative to the size of a paddock is a good measure of the effectiveness of paddock use, there is a clear effect of reducing paddock size in improving the effectiveness of use of the landscape by both individual cattle and the herd as a whole. Paddock use was most effective in the smallest paddock (One water), since home range was close to paddock size. As paddock size increased, paddocks were used less effectively by cattle despite the larger paddocks having additional water points (and generally similar grazing radii). However, without the additional water points being established in the larger paddocks, much less of these paddocks would have been used by the cattle.

Although the overall effectiveness of landscape use is improved by reducing paddock size, the data from the GPS collars suggest that it is much less effective at producing more even use within paddocks. While a close correspondence between home range and paddock size in small paddocks might suggest more even use of a paddock, it is perhaps not surprising to see that use within the smaller paddocks remained uneven to some degree. Cattle continued to heavily use certain areas at particular times. In this study these areas were often riparian areas (despite the creeks usually being dry) and areas of red soil (depending on the season and seasonal conditions; see Section 4.4.3). Other areas that were favoured appeared to be associated with past grazing use.

As was the case in the grazing radius experiment, cattle home ranges tended to be larger during the wet season in all paddocks (Table 4.15), although there was considerable variability between cows in this respect. These larger home ranges presumably reflect a reduced reliance on artificial waters during the wet season because of the availability of surface water in creeks and waterholes scattered over the paddock.

Table 4.15. Home ranges and percent use of paddocks for collared cows during the dry and wet seasons. Data are means of all cows and sampling periods. Results include data from all collars that functioned for a minimum of two months during the deployment period.

Paddock	Mean home range (km^2)	Mean percentage of paddock used by individual cows (%)
	Dry season	
One water	6.8	75.9
Two waters	17.4	50.8
Multiple waters	27.0	47.4
Commercial paddock	85.9	57.8
	Wet season	
One water	8.5	94.7
Two waters	29.0	84.5
Multiple waters	36.2	63.5
Commercial paddock	52.8	35.5

The distance from water that encompassed 90% of the GPS collar fixes for each paddock is presented in Table 4.16. In the two developed paddocks that had more than one water (i.e. Two waters and Multiple waters) 90% of fixes were within 2600-2700 m of water, while cattle activity began to decline at 2.2 - 2.6 km from water. To some extent these results are an artefact of the location and distance between the waters in each of these paddocks. However, given that cattle were free to venture further than the distance encompassing 90% of the fixes, these data suggest that grazing radii should not exceed about 2.5 km (i.e. no more than 5 km between water points) to maximise grazing use of the landscape.

Table 4.16. The radial distance from water which encompasses 90% of GPS fixes (i.e. hourly cattle locations) and the maximum distance from water GPS fixes occurred for the grazing distribution treatments. These data were calculated from all collar data (i.e. from all cows and deployment periods) combined for each paddock. For comparison, the maximum distance from water that is possible in each paddock is also presented.

	Distance encompassing 90% of GPS fixes (m)	Maximum distance of fixes from water (m)	Maximum distance from water in paddock (m)
One water	1700	2398	2411
Two waters	2600	3484	3489
Multiple waters	2700	5330*	5313
Commercial paddock	5300	7757	7772

* Maximum distance of fixes exceeds maximum distance possible because of GPS error.

4.4.2.1.2 Diurnal activity patterns

There were no consistent trends amongst treatments in the proportion of time cattle spent grazing, travelling and resting. Cattle spent approximately 28-40% of their time grazing, 60-70% resting and 1-3% travelling (Fig. 4.38). There was a marginal increase in travelling time with increasing paddock size (probably related to the increased proportion of the paddocks at greater distances from water (see Fig. 4.2). As with the grazing radius treatments, cattle generally spent daylight hours loitering at a water point during much of the year. At approximately 6 pm each day the cattle departed the water point, and did not return until about 7 am the following morning.

Surprisingly the single cow with activity data in the large undeveloped paddock recorded broadly similar amounts of time occupied in grazing, resting and travelling as in the developed paddocks. This is despite cows in this paddock having substantially larger home ranges.

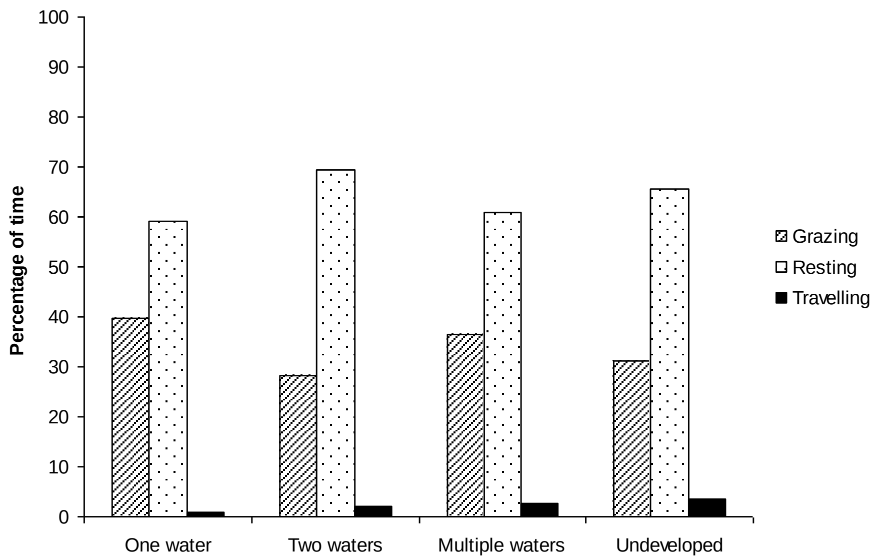


Fig. 4.38. Percentage of time cattle spent grazing, resting and travelling in the grazing distribution paddocks (means for 1-3 animals per paddock over a six-month period in the 2005 dry season). The activity budget for an undeveloped commercial paddock (Lochart paddock, Mt Sanford) is shown for comparison.

4.4.2.2 Evenness of grazing use

Fig. 4.39 shows there were no consistent trends in the standard deviation of overall defoliation across the three grazing distribution paddocks. In May 2004 and May 2006 standard deviation increased marginally with paddock size, suggesting that grazing use was more uneven in the larger paddocks, but in other years no trend or, in the case of the final year, a reverse trend was observed.

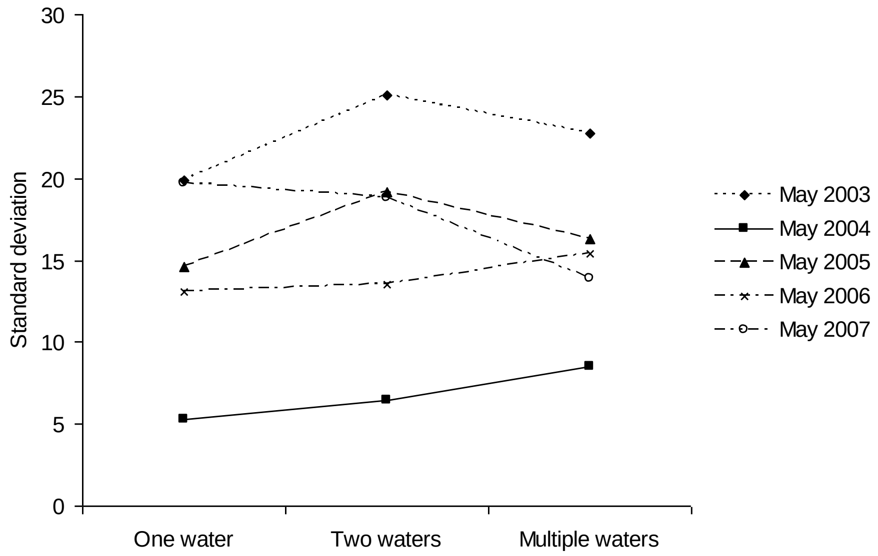


Fig. 4.39. The standard deviation of defoliation across all quadrats within the grazing distribution paddocks for five years. Note that May 2003 was prior to treatments being applied.

The proportion of quadrats that were not used at all (i.e. defoliation was zero) was consistently lower for the one water point paddock (Fig. 4.40). There was little difference between the other two paddock configurations. However, this trend was apparent in 2003 before the treatments were applied, suggesting the results were a function of the pasture resources rather than the paddock configuration. Only a small proportion of quadrats (<5%) in each paddock were heavily used (defoliation 75-100%), and there were no consistent effects of paddock configuration (Fig. 4.41).

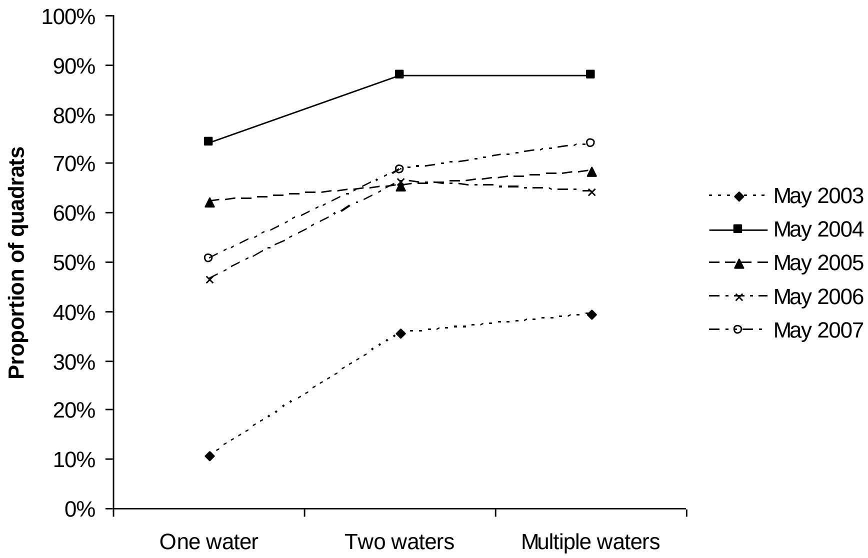


Fig. 4.40. The proportion of quadrats that were not used (defoliation score of zero) for the grazing distribution paddocks. May 2003 was pre-treatment.

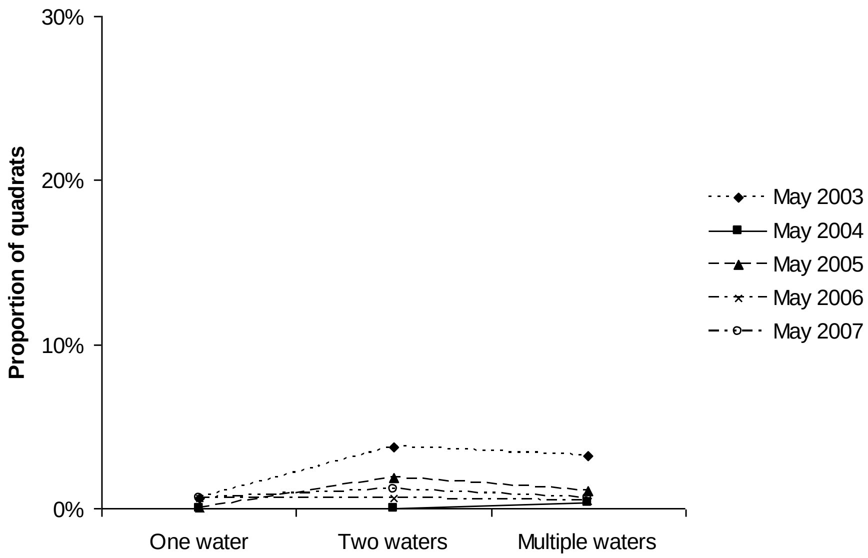


Fig. 4.41. The proportion of quadrats that were heavily used (defoliation score 75-100) for the grazing distribution paddocks. May 2003 was pre-treatment.

Fig. 4.42 presents a spatial interpolation of pasture defoliation during one dry season (i.e. October data) as an example of the unevenness of grazing use across the paddocks.

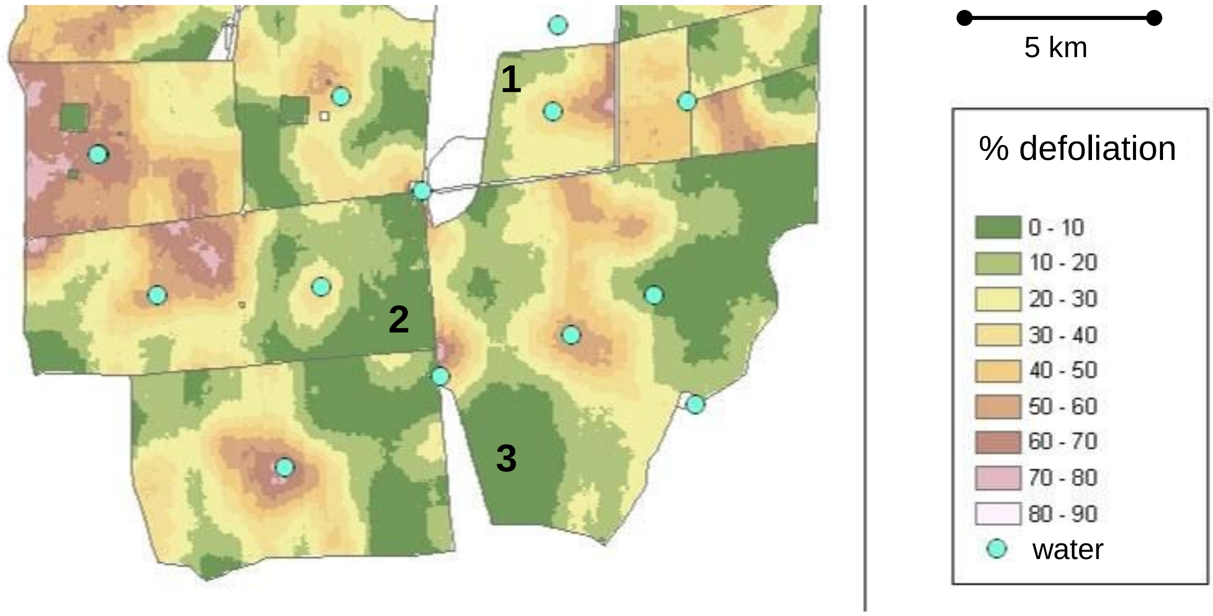


Fig. 4.42. Spatial interpolation of pasture defoliation rate (%) for the three paddock configuration treatments over the 2005 dry season. 1 = One water paddock, 2 = Two waters paddock, 3 = Multiple waters paddock.

Paddock configuration appeared to have no influence on the patchiness of ground cover, as indicated by the absence of consistent trends in the standard deviation of ground cover across treatments (Fig. 4.43). As with the grazing radius paddocks, the nature of the paddocks (including vegetation, topography etc) appeared as though it was the dominant influence on the patchiness of use.

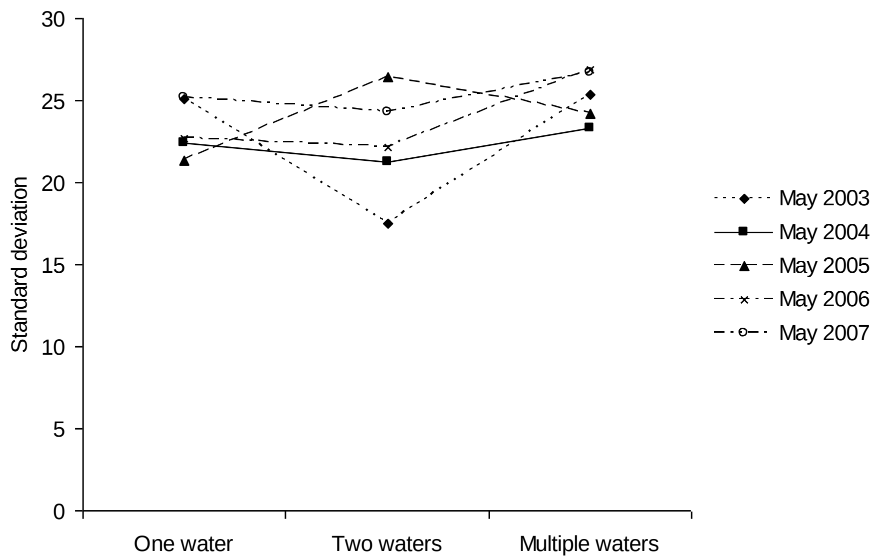


Fig. 4.43. The standard deviation of ground cover across all quadrats within the grazing distribution paddocks for five years. Note that May 2003 was prior to treatments being applied.

Neither the proportion of quadrats with less than 25% ground cover nor the proportion with ground cover of 75-100% showed consistent effects of paddock configuration (Fig. 4.44 and Fig. 4.45), suggesting that there were no consistent differences in uniformity of use within paddocks.

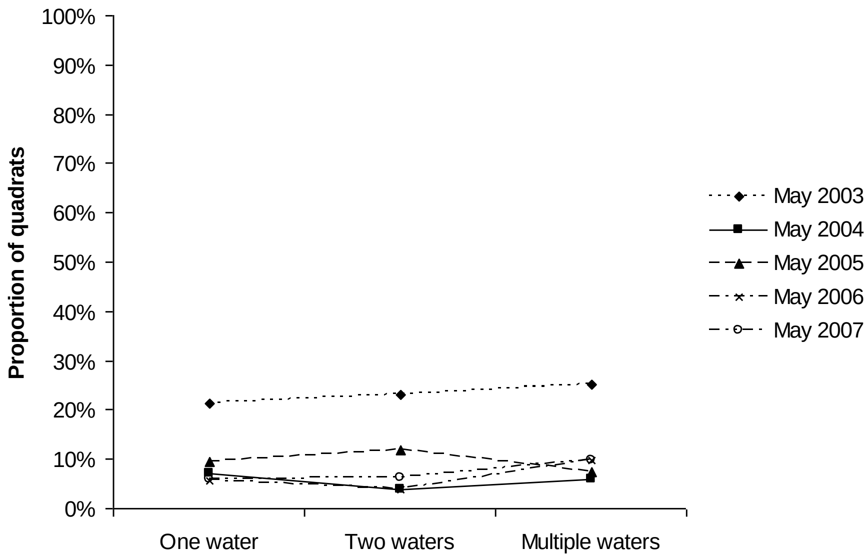


Fig. 4.44. The proportion of quadrats with less than 25% ground cover for the grazing distribution paddocks over five years. May 2003 was pre-treatment.

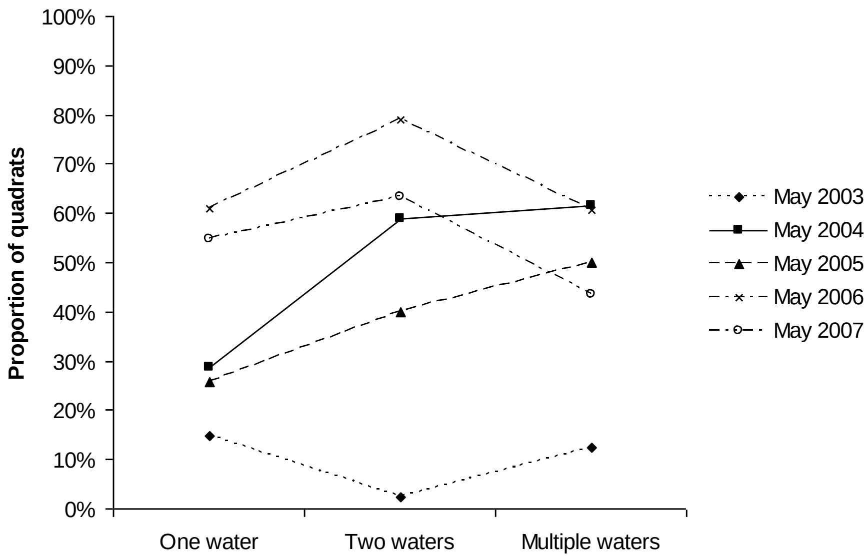


Fig. 4.45. The proportion of quadrats with 75-100% ground cover for the grazing distribution paddocks over five years. May 2003 was pre-treatment.

In contrast to the effect on evenness of use over the entire paddocks, adding additional waters did appear to improve the evenness of use in relation to distance to water (Fig. 4.46), although there is some confounding of paddock size with this effect. Also note that the One water paddock had a slightly higher annual average utilisation rate applied (19%) than the other paddocks (15-16%).

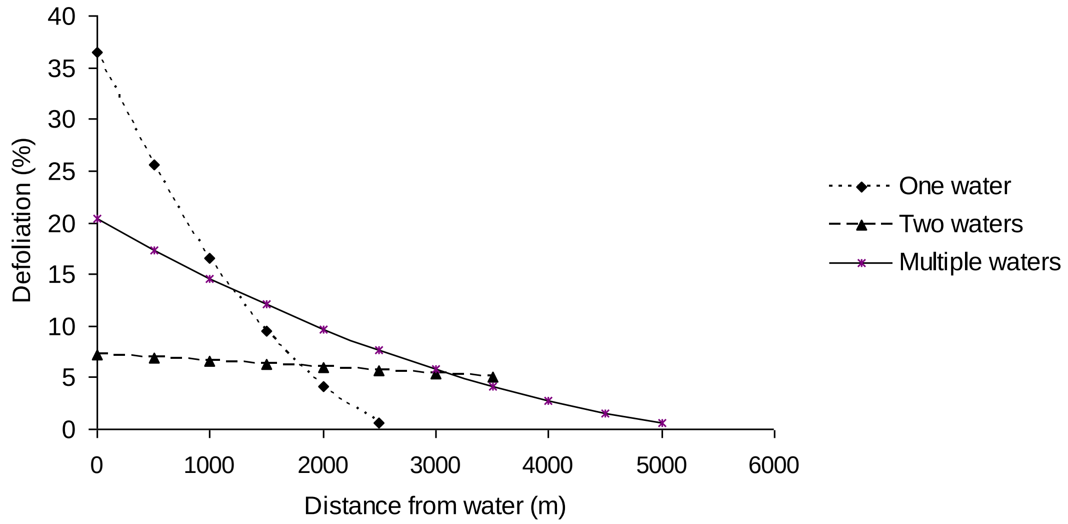


Fig. 4.46. Overall pasture defoliation rates for the dry season in three paddocks of different size and number of water points at Pigeon Hole. One water = 9 km^2, Two waters = 21 km^2, Multiple (5) waters = 57 km^2. Predicted results from an analysis of covariance of observed defoliation rates. Note that the model was significant but only accounted for <10% of the variation.

4.4.2.3 Effect of paddock configuration on the pasture

The analyses of variance conducted on the pasture data indicated that there was a significant treatment effect only for pasture yield, a significant year effect for all four tested variables and a significant year x treatment interaction for yield, perennial grass basal area and ground cover (Table 4.17). However, because the values for some of these variables initially differed between paddocks, significant effects do not necessarily indicate an effect of the applied paddock configuration treatments.

Table 4.17. Results of the split-plot-in-time repeated measures Analysis of Variance for the grazing distribution treatments for May pasture data from 2003-2007.

Effect	Variables			
	Yield	Defoliation	Perennial Grass Basal Area	Ground Cover
Treatment	***	NS	NS	NS
Year	***	***	***	***
Treatment*Year	***	NS	**	***

*** = P<0.001, ** = P<0.01, * = P<0.05, NS = not sig.

Pasture yield fluctuated markedly from year to year but generally showed similar annual variation in each of the treatments (Fig. 4.47). Initial yield in the One water paddock was significantly (P<0.05) higher than in the other treatments. In the final year the mean yield of 1603 kg/ha in the Two water paddock was significantly higher (P<0.05) than either of the other treatments, which themselves were not significantly different (1258 and 1055 kg/ha for One water and Multiple waters, respectively).

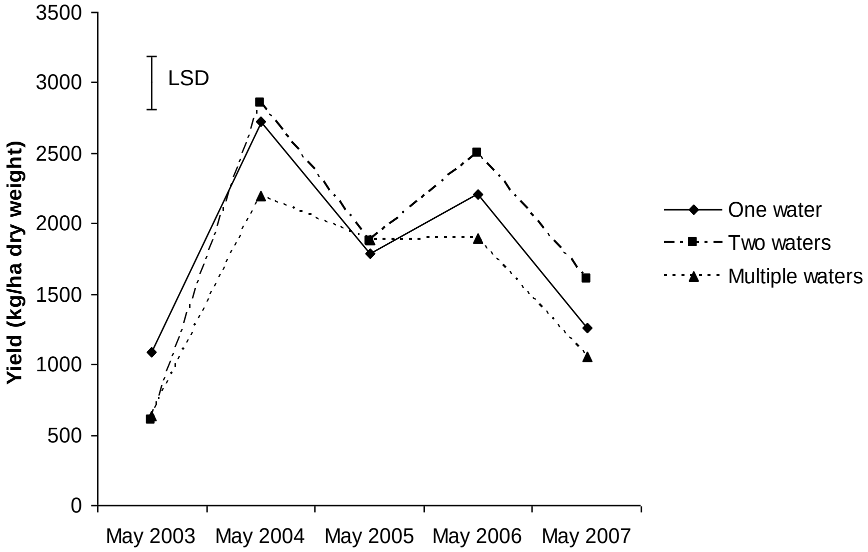


Fig. 4.47. Mean pasture yield (kg/ha dry weight) in May of each year of the study for the three paddock configuration treatments . (Fitted means from analysis of variance). May 2003 was pre-treatment. LSD, least significant difference.

There were no markedly different trends between the treatments in terms of yield of palatable forage over the life of the study, although there appeared to be a weak trend of declining palatable yield in all treatments towards the end of the study (Fig. 4.48).

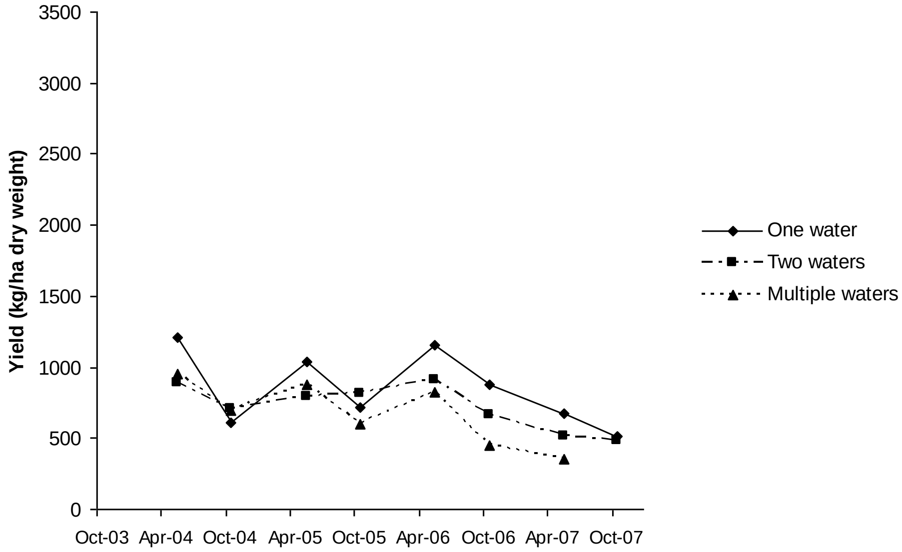


Fig. 4.48. Yield of palatable forage for the three paddock configuration treatments for the duration of the study.

There were no differences in pasture defoliation amongst the treatments in most years (Fig. 4.49). In the final year (2007) defoliation in the treatments was ordered One water (mean 9.9) > Two waters (8.4) > Multiple waters (4.5), but only the difference between One water and Multiple waters was significant (marginally) at $P<0.05$.

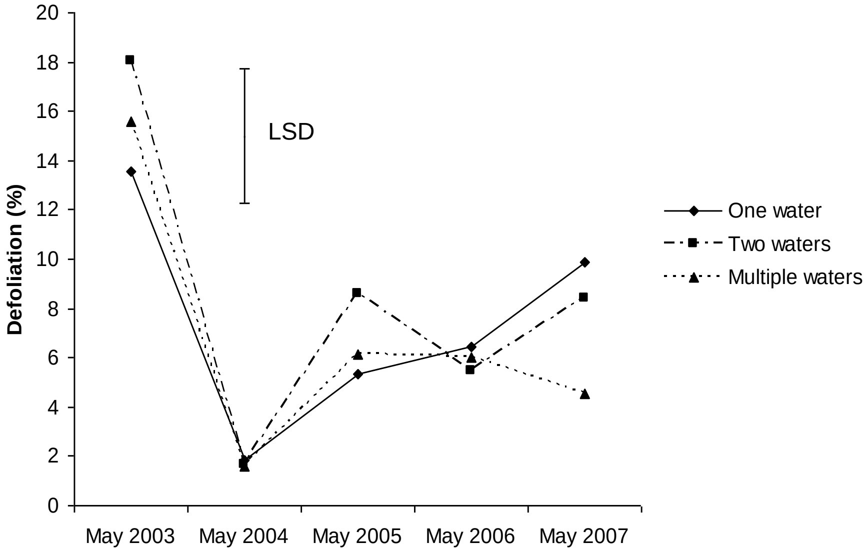


Fig. 4.49. Mean defoliation (%) in May of each year of the study for the three paddock configuration treatments. (Fitted means from analysis of variance). May 2003 was pre-treatment. LSD, least significant difference.

There was no consistent effect on paddock configuration on perennial grass basal area. Although basal area was significantly higher in the Two waters paddock in 2004, there were no differences in any other years (Fig. 4.50).

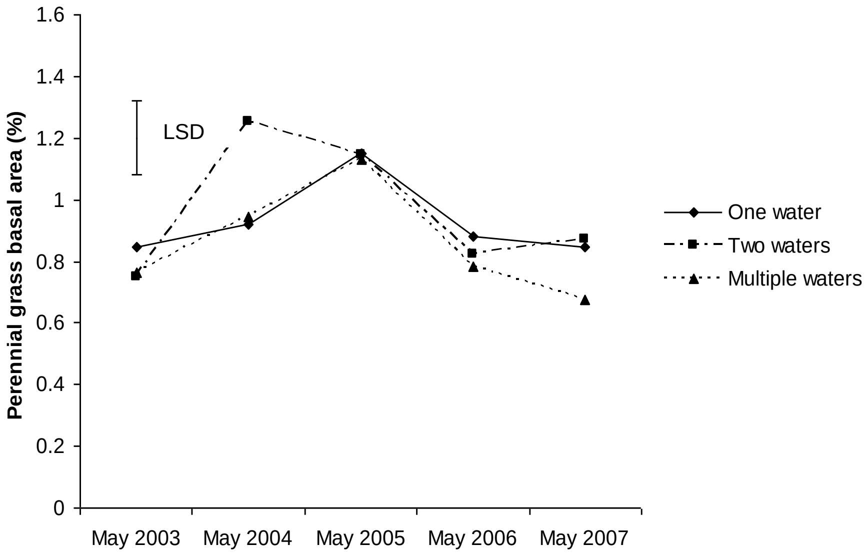


Fig. 4.50. Mean perennial grass basal area (%) in May of each year of the study for the three paddock configuration treatments for the duration of the study. (Fitted means from analysis of variance). May 2003 was pre-treatment. LSD, least significant difference.

Ground cover (Fig. 4.51) showed a general increase in all paddocks over time. However the differences in cover levels between treatments varied amongst years, with no consistent pattern emerging.

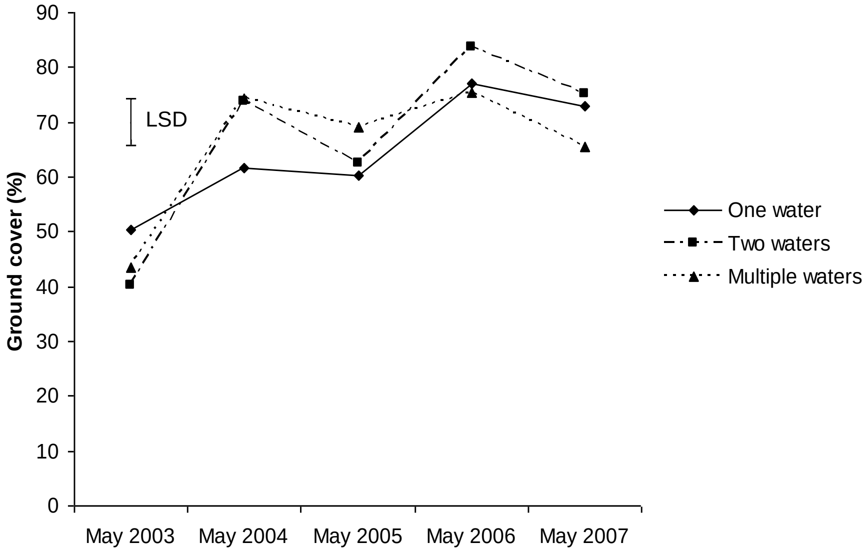


Fig. 4.51. Mean ground cover in May of each year of the study for the three paddock configuration treatments for the duration of the study. (Fitted means from analysis of variance). May 2003 was pre-treatment. LSD, least significant difference.

Fig. 4.52 shows the proportion of each of the treatment paddocks within the different land condition categories, based on the percentage of quadrats in each condition class. There was little difference in land condition amongst the treatment paddocks and no apparent trends in condition during the study.

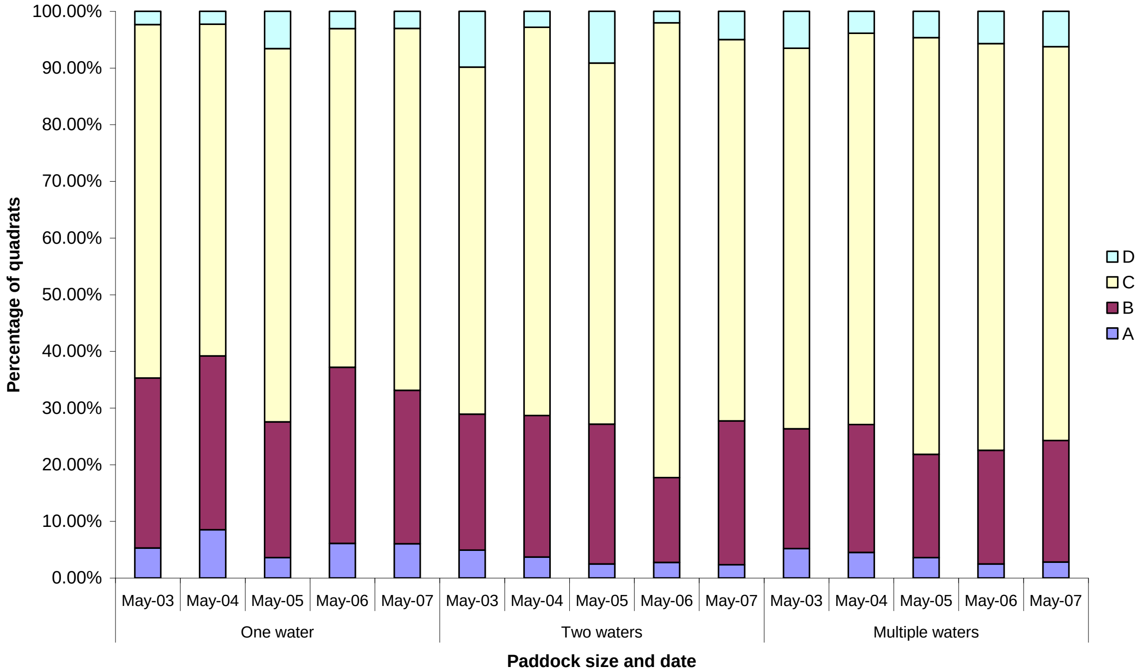


Fig. 4.52. Proportion of each paddock in four GLM land condition classes (A-D) for the duration of the study.

It might be expected that little difference would emerge between the three paddock configuration treatments in the effect on pasture variables because the overall target utilisation rate was the same for each paddock, and since larger paddocks had more water points grazing radii were broadly similar in each paddock. Grazing pressure is therefore expected to be more evenly distributed over each paddock, potentially leading to similar overall impacts on the vegetation. These expectations are borne out by the pasture results.

While the lack of differential treatment effects for most variables might be attributed to the effectiveness of more even water distribution across each paddock in spreading out grazing, this is unlikely the case. A failure to detect clear effects is more likely due to hysteresis in the ecological system, the relatively short time treatments have been in place and/or the lack of extreme seasonal conditions rather than the absence of any effect. Indeed, the cattle distribution data from the GPS collars suggest that grazing was not necessarily evenly distributed within the paddocks (in particular, in the larger ones).

The GPS collar data suggested that the smaller paddock with a single watering point achieved more effective grazing use of the landscape as a whole than the larger paddocks despite these paddocks having multiple water points. While this may have been partly a result of water points being unevenly spaced within the paddocks, other factors were also likely at play. Firstly, there is much less control over where cattle can go in larger paddocks with several water points than in a smaller paddock. Additional water points provide no guarantee that cattle will distribute themselves evenly amongst water points and different habitats. Secondly, because some sites within paddocks often support abundant biomass of undesirable pasture species they tend to be avoided even if they occur close to water. This was the case with areas of dense annual sorghum in this study.

As with the grazing radius study, there was a significant overall difference in pasture species composition amongst treatments (ANOSIM R = 0.897, *P* = 0.001) but no significant differences in species composition amongst years (R = -0.121, *P* = 0.793). Ordination of species composition (based on percent composition by weight) indicated that initial composition at the start of the study differed amongst paddocks and differences remained for the duration of the study (Fig. 4.53). Differences in species composition amongst treatments are also reflected in the contribution of different plant functional groups to pasture yield (Fig. 4.54 - Fig. 4.56).

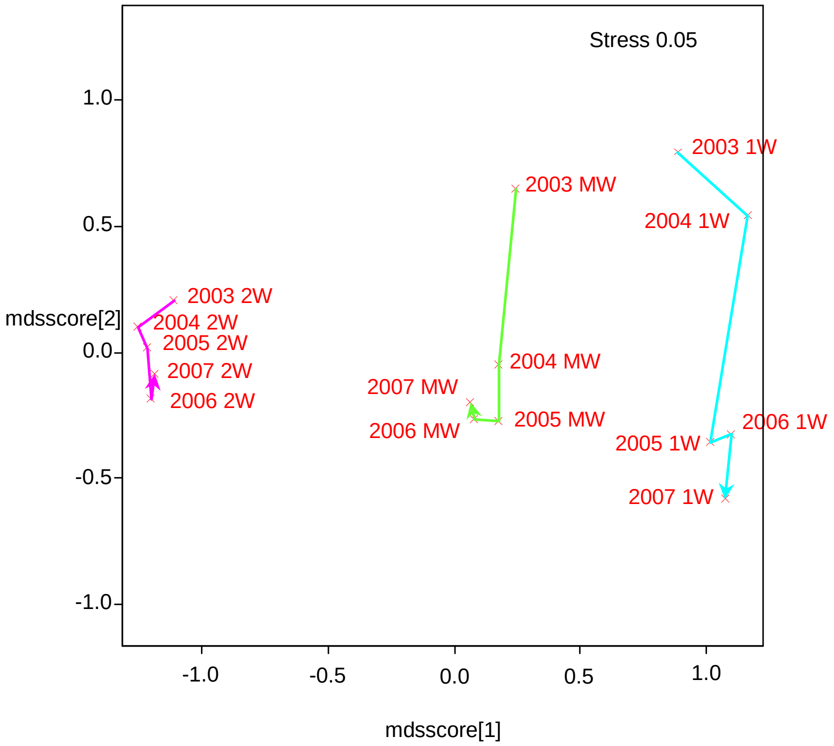


Fig. 4.53. Ordination (non-metric multidimensional scaling) of species composition for the paddock configuration treatments (1W = one water, 2W= two waters and MW = multiple waters) over the years of the study, based on percent species composition by weight.

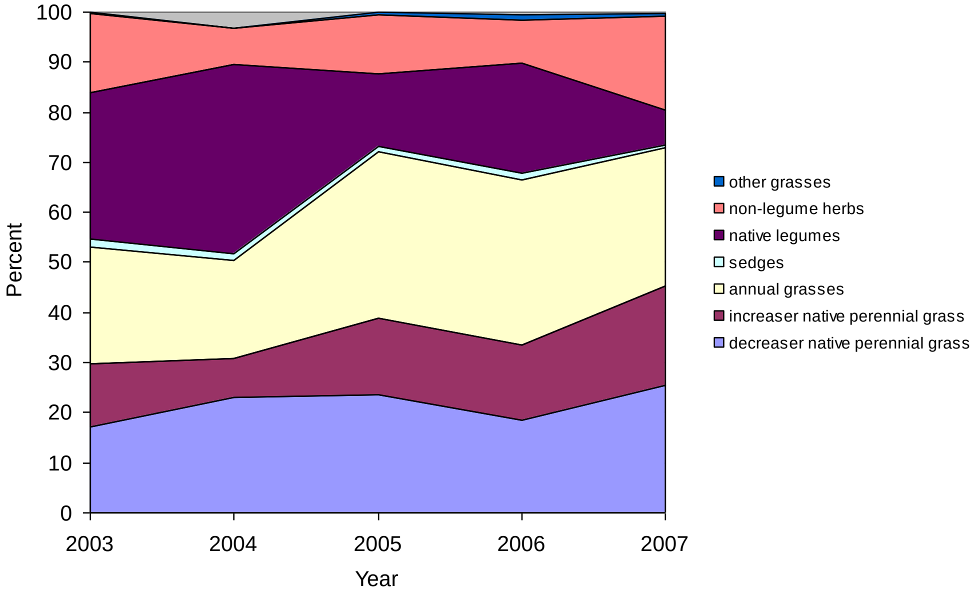


Fig. 4.54. Plant functional group contribution to pasture yield for the One water paddock during the study.

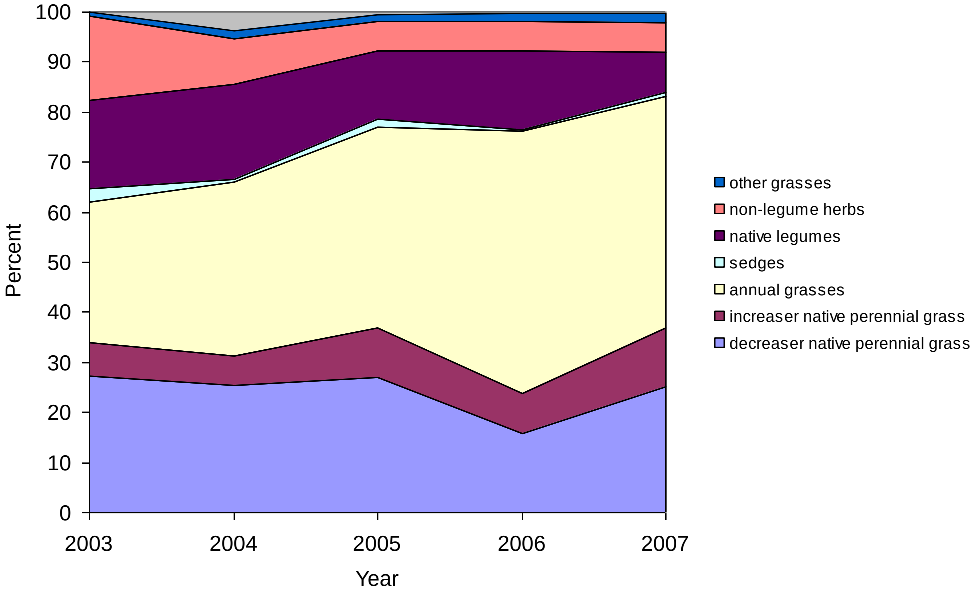


Fig. 4.55. Plant functional group contribution to pasture yield for the Two waters paddock during the study.

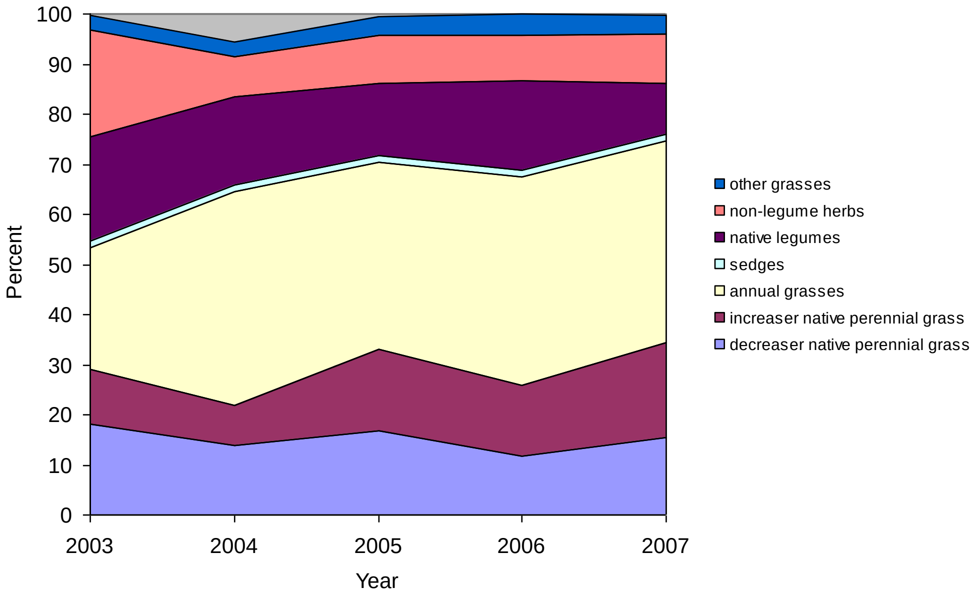


Fig. 4.56. Plant functional group contribution to pasture yield for the Multiple waters paddock during the study.

4.4.2.4 Livestock performance and dietary quality for different paddock configurations

4.4.2.4.1 Dietary quality

There were no consistent differences in dietary quality amongst the treatments. The data showed the expected seasonal trends of higher protein and digestibility associated with the wet (growing) season and declines during the dry dormant seasons (Fig. 4.57 and Fig. 4.58). The only marked distinction between the treatments was greater dietary crude protein in the One water paddock during the mid-dry season in 2004, late dry season in 2005, and for most of the dry season in 2006. This may reflect the generally larger proportion of palatable forage in the pasture in the One water paddock (which doubled up as the GR1 treatment) relative to the other paddocks (usually 50-60% palatable compared with approximately 45%).

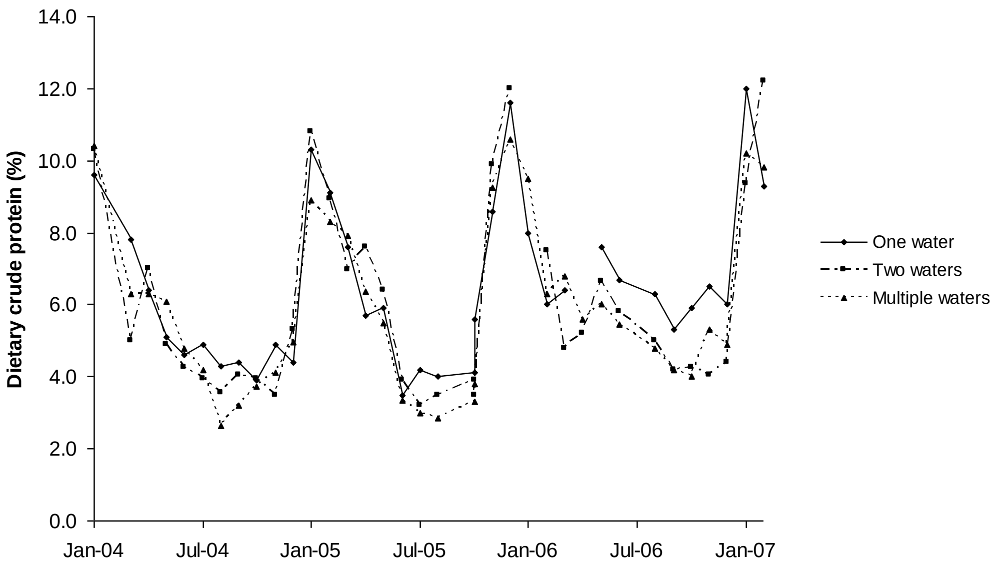


Fig. 4.57. Percent dietary crude protein for the paddock configuration treatments, measured using faecal near infra-red spectroscopy.

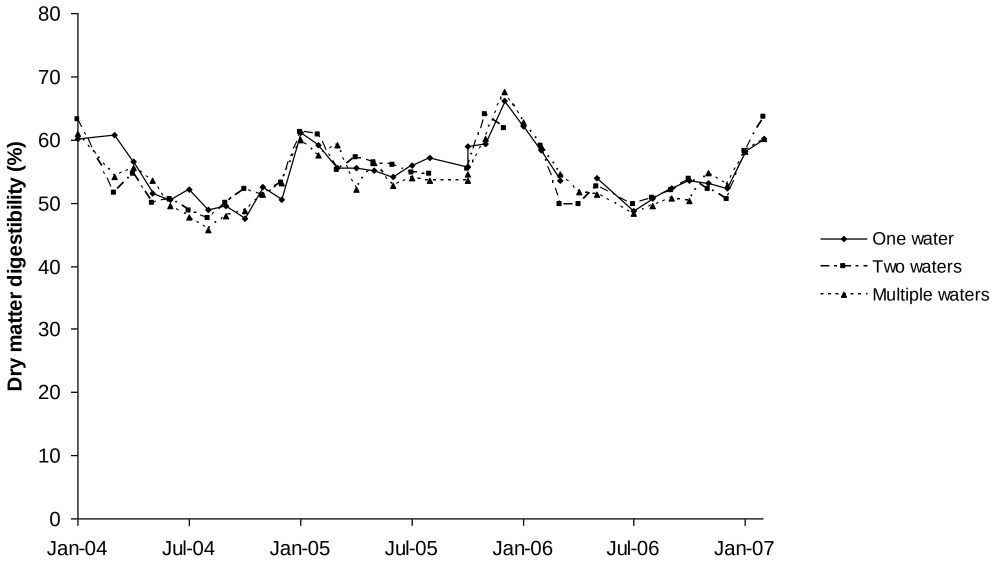


Fig. 4.58. Dry matter digestibility (%) of cattle diets for the paddock configuration treatments, measured using faecal near infra-red spectroscopy.

To assess potential variability in diet quality at different locations in larger paddocks, faecal samples were collected from the vicinity of several water points in the Multiple water and Two water paddocks and analysed separately. Although only a single bulked sample was collected from each water point on each occasion and statistical analysis of the data was not possible, these data suggested there were no differences in crude protein or dry matter digestibility amongst locations (data not presented).

4.4.2.4.2 Liveweight gain

The effect of paddock configuration on daily liveweight gain of grower steers was assessed as for the grazing radius experiment using analysis of covariance. Separate analyses were conducted for liveweight gain over the wet and dry seasons, with liveweight at the start of each measurement season (i.e. at the previous muster) as a covariate.

The analysis of covariance for the wet season indicated the treatment and treatment x year interactions were not significant (P=0.300 and P=0.165, respectively), but there was a significant effect of year (P<0.001) on liveweight gain. A noticeable feature of liveweight gain was the greater variability around the means in the first year, the inconsistent pattern of differences between treatments in the first two years, and the lack of differences between the treatments in the final year (Fig. 4.59). In the first year liveweight gain was significantly greater (P<0.05) for the Two waters treatment than the other paddock configurations, while in the second year the Multiple waters configuration recorded significantly greater (P<0.05) liveweight gain than either of the other treatments. In the final year (2006-07) all pairwise comparisons between treatments were not significant (P>0.05). The markedly different result for Two waters in the first year is not readily explained and perhaps suggests an error in data collection.

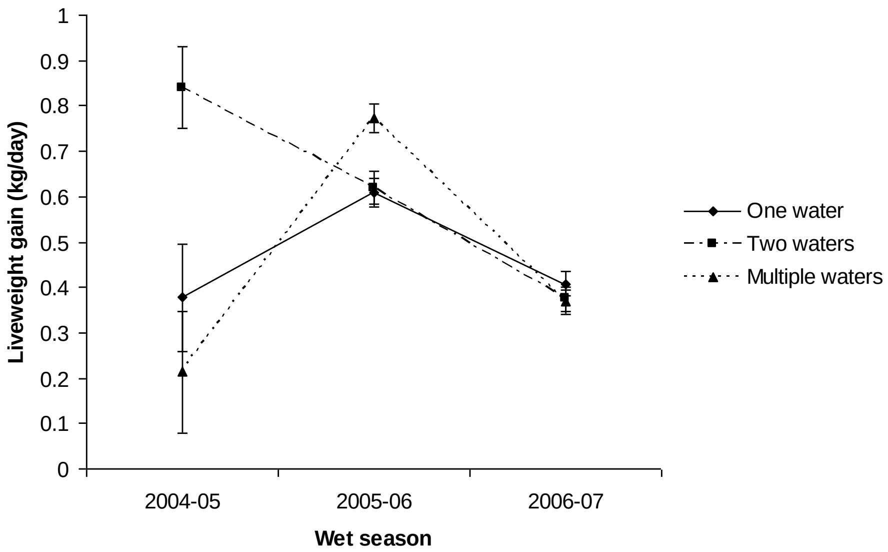


Fig. 4.59. Mean daily liveweight gain (±SE) of grower steers for the paddock configuration treatments over three wet seasons. Fitted means from the analysis of covariance with liveweight at the start of each measurement season (i.e. at the previous muster) as the covariate.

For dry season liveweight gain, the overall treatment (i.e. paddock configuration) effect was significant (P<0.001), but year and the treatment x year interaction were not significant (P=0.237 and P=0.317, respectively). However, the data showed erratic responses in the first two years and high variability around the mean, especially for Multiple waters in the first year (Fig. 4.60). Again, the erratic responses may suggest a problem with data collection. Despite apparent differences between treatments in the first year, the high sample variability meant that none of the differences were significant (i.e. P>0.05). Cattle in Multiple waters lost weight in the dry season of 2006 (liveweight gain of -0.009 kg/day), compared to gains of 0.46 and 0.32 kg/day for the One water and Two water treatments, respectively. These differences were significant at P<0.05. There were no significant differences (P>0.05) in liveweight gain between One water and Two waters in 2006 and 2007. No data are available for the Multiple water treatment in 2007 as this was terminated prior to the dry season.

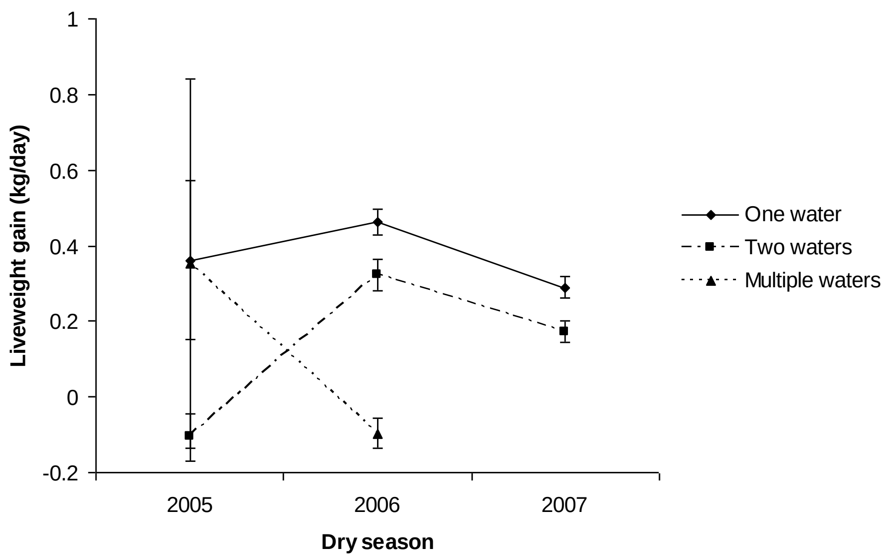


Fig. 4.60. Mean daily liveweight gain (±SE) of steers for the paddock configuration treatments over three dry seasons. Fitted means from the analysis of covariance with liveweight at the start of each measurement season (i.e. at the previous muster) as the covariate.

The results do not provide any evidence of a consistent effect of paddock configuration on liveweight gain, and it is reasonable to conclude that paddock configuration did not affect liveweight gain in either the wet or dry season during the study. In the case of the significant overall treatment effect for the dry season, variability in the results and the lack of replication cloud the interpretation, so that it is not possible to attribute this effect to paddock configuration rather than possible inherent differences between the treatment paddocks. Nevertheless, the lack of both a significant treatment x year interaction and a consistent divergence of the treatments over time (for both seasons) provide further support for the conclusion that paddock configuration was not affecting liveweight gain.

The absence of an effect of paddock configuration on liveweight gain is contrary to expectations that larger paddocks with good water distribution (i.e. multiple waters) might allow higher liveweight gain than smaller paddocks, especially during the dry season, because of the potentially greater diversity of habitats and pasture resources available to the cattle. Instead, it seems likely that cattle simply do not explore much of the area in larger paddocks, and generally graze the same areas repeatedly. This conclusion is supported by the GPS collar data from the paddocks with multiple waters.

On the other hand, the results suggest that liveweight gain is not adversely affected by either small paddocks or large paddocks with multiple waters.

4.4.2.4.3 Breeder liveweight

The main effects of grazing distribution treatment and year, and the year x treatment interaction were all highly significant (P<0.001) for both mustering rounds. For mustering round 1, there was a consistent trend of liveweight in the One water treatment being lower than for the Two water treatment (although the difference was not always significant; Fig. 4.61). Breeder liveweight varied most over time in the Multiple water paddock, being lowest of all the paddocks in the first and last years (440 kg and 467 kg in 2005 and 2007, respectively) and highest (536 kg) in 2006 (although the latter result appears anomalous). Overall, however, there did not appear to be a consistent effect of paddock configuration.

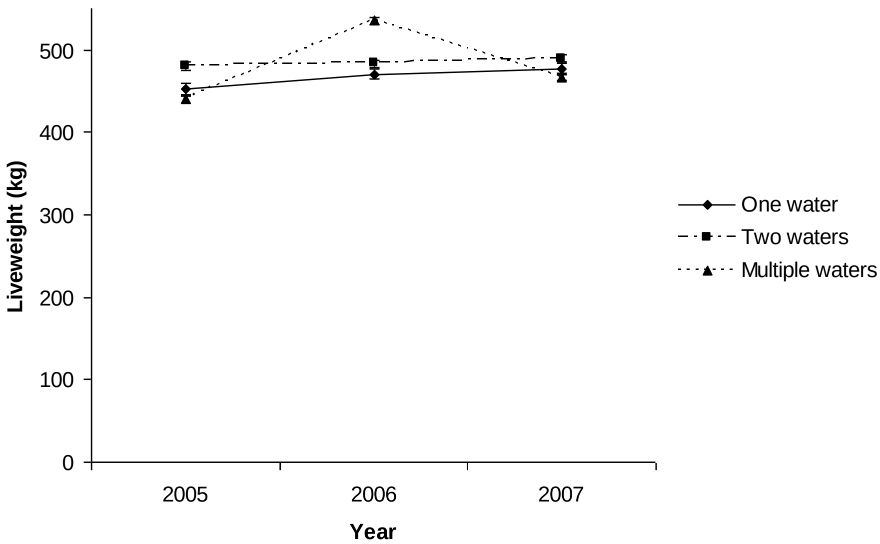


Fig. 4.61. Liveweight (mean ± standard error) of breeder cattle adjusted for pregnancy at weaning round 1 (April-May) for three years of the paddock configuration study.

In contrast to the first mustering round, breeder liveweight was generally higher in the One water paddock compared to the other paddocks at the second mustering round (Fig. 4.62). There were no differences amongst treatments at the initial sampling date in 2004. The One water treatment was significantly higher (P<0.05) than the other paddocks in 2005 and 2007, but in 2006 was only significantly higher than the Multiple water paddock. The data did suggest that the treatments were beginning to separate out towards the end of the study, with liveweight in the One water paddock the highest, Two waters an intermediate liveweight and Multiple waters the lowest, although the latter treatment was not continued through the final year of the project.

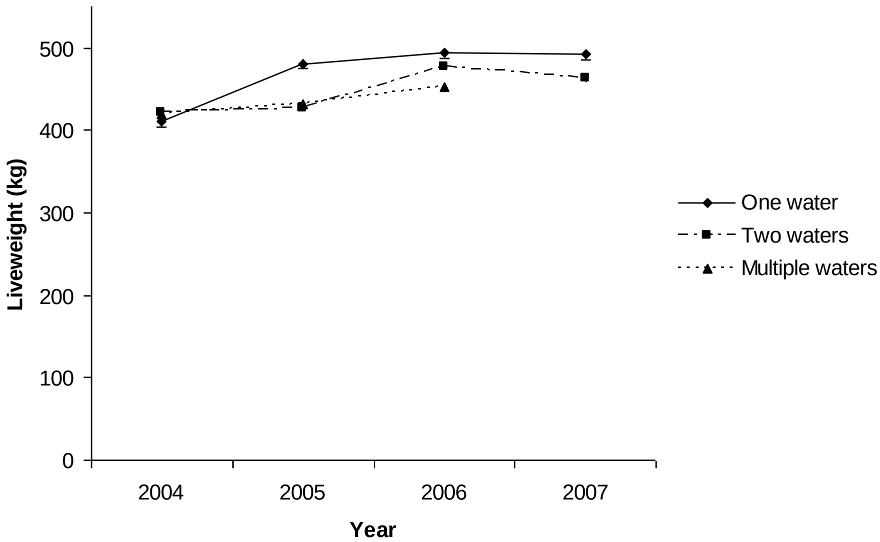


Fig. 4.62. Liveweight (mean ± standard error) of breeder cattle adjusted for pregnancy at weaning round 2 (Sep-Oct) for three years of the grazing distribution/paddock configuration study.

It might be expected that the effect of paddock configuration on liveweight would be strongest during the dry season when forage availability near water might be limiting intake, rather than in the wet season when fresh pasture growth is available. Our data support this notion to some extent, in that there was not a consistent separation of the treatments in the first mustering round (i.e. post wet) but there was at the second round (post dry). However, contrary to expectations, liveweight was greater in the smaller paddock. This suggests that there was no effect of spatial buffering in the larger paddock in helping to maintain cattle liveweight during the dry season, as has been proposed (Ash and Stafford Smith 2003). As discussed in the previous section, this may reflect the concentrations of animals in heavily grazed preferred areas during the dry season, as suggested by the smaller home ranges at this time of year (Table 4.15). This represents one of the potential problems with multiple water paddocks; there is little control of grazing distribution in such paddocks, and given the larger number of animals there is greater potential for heavy concentrations of animals to occur.

4.4.2.4.4 Body condition

Body condition differed amongst treatments and years (P<0.001) and the year x treatment interaction was significant (P<0.001) for both mustering rounds, but there were no clear-cut effects of paddock configuration on body condition. Initial body condition for round one was similar amongst paddocks but by the end of the study body condition was significantly (P<0.05) higher in the One water treatment (5.7) than the other treatments (approx 4.7; Fig. 4.63).

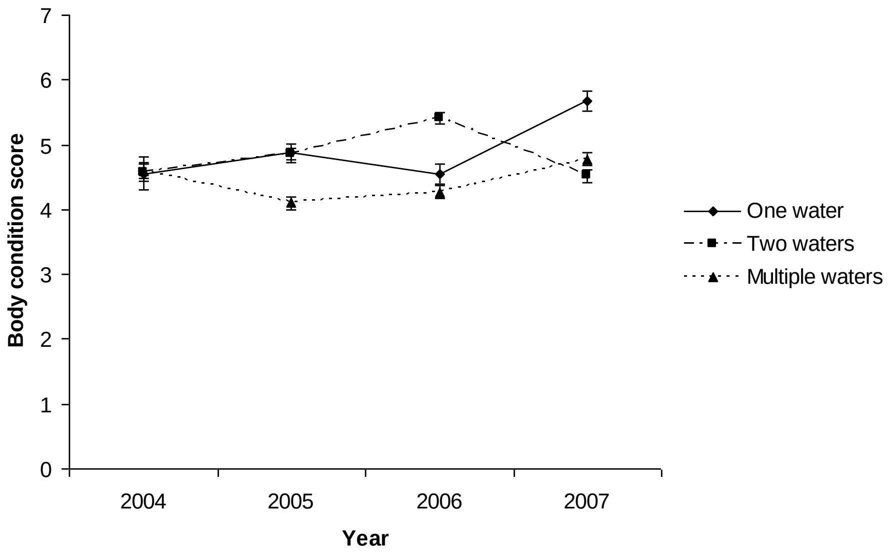


Fig. 4.63. Body condition score (mean ± standard error) for weaning round 1 (April-May) for the three paddock configuration treatments over four years of the study.

For mustering round two, there appeared to be a systematic separation amongst treatments over the last two years, so that body condition was highest in the One water treatment and lowest in the Multiple water treatment late in the study (although, once again the Multiple water treatment was not included in the final year). Body condition was significantly ($P<0.05$) lower for the Multiple water paddock in 2006 (4.12 c.f. 5.29 and 4.83 for the One and Two water treatments respectively), and One water was significantly higher than Two waters in the final year (5.16 cf 4.93; Fig. 4.64). However, given the variability in the data in the earlier years, it is not possible to conclude that this apparent effect of paddock configuration on body condition was a lasting effect.

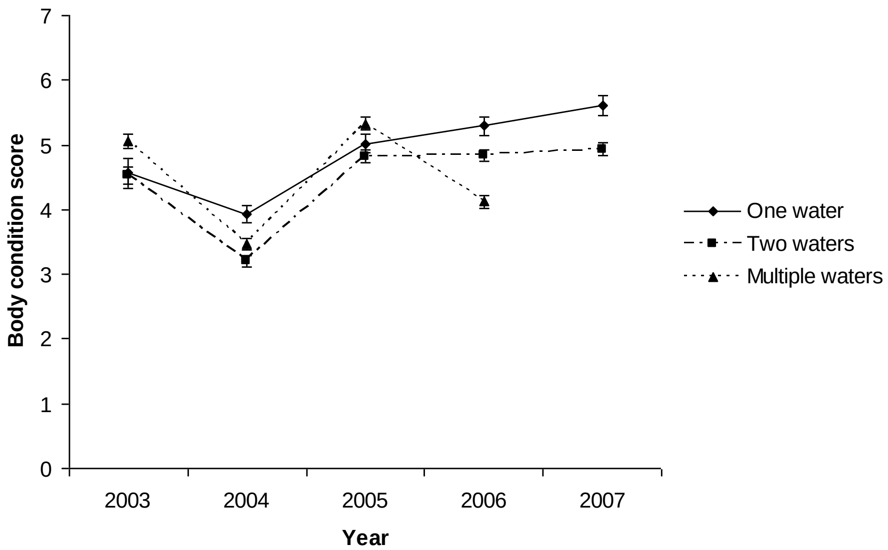


Fig. 4.64. Body condition score (mean ± standard error) for weaning round 2 (September-October) for the three paddock configuration treatments over four years of the study (note that the 2003 data are the initial scores when treatments were first applied).

The separation in body condition scores in accordance with paddock configuration for mustering round two later in the study is consistent with the breeder liveweight data. This does suggest that paddock configuration was influencing the performance of the cattle in these paddocks over the dry season. Again, this might be related to the larger concentrations of cattle in paddocks with more than one water (and the lack of control over where cattle graze and water in these paddocks) which results in areas near the preferred waters being depleted of forage early in the dry season even though the overall paddock utilisation rate was the same as in the One water paddock. In comparison, in the One water paddock, the lower number of cattle in the paddock means large concentrations of cattle are not possible, and cattle can easily reach all parts of the paddock to graze should some areas become depleted of forage.

4.4.2.4.5 Inter-calving interval

The inter-calving interval data were analysed using a generalised linear model with Poisson distribution to test for an effect of grazing distribution treatment overall years. The analysis showed that inter-calving interval did not differ amongst grazing distribution treatments (P=0.618). The individual pairwise comparisons between treatments also did not differ. Mean inter-calving interval was around 14.4 months, although the median was slightly less at around 13.5 (reflecting skewness in the data with a long tail of greater inter-calving interval (Table 4.18).

Table 4.18. Mean and median inter-calving interval (months) for the three paddock configuration treatments calculated over the four years of the study.

	One water	Two waters	Multiple waters
Mean	14.3	14.5	14.3
Median	14.0	13.0	13.0

4.4.2.4.6 Fertility (re-conception rate)

As for the grazing radius experiment, the fertility of cows (the proportion of lactating cows that were pregnant) was relatively low, varying between 0.13 and 0.41 (Fig. 4.65). Binomial tests showed that there were no differences in fertility between grazing distribution treatments within each year except for in the final year (2007). In this year, fertility was significantly (P<0.01) lower in the Multiple waters treatment. These results suggest that, overall, paddock configuration (i.e. grazing distribution treatment) was having no effect on the fertility of the cows.

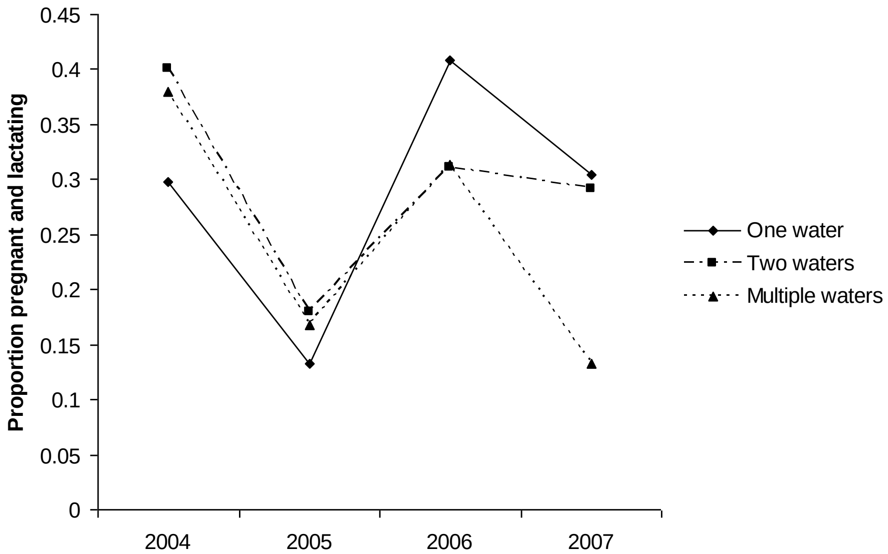


Fig. 4.65. Fertility of cows (measured as the proportion of lactating cows that were pregnant) for the paddock configuration treatments during the study.

4.4.2.4.7 Branding and weaning rates

There was a significant overall effect of grazing radius treatment on branding and weaning rates (both $P<0.0001$) over all years. Branding rate was significantly greater in One water compared with the Multiple waters paddock (Table 4.19), but not compared to the Two water treatment. Branding rate in the latter treatment was also higher than in Multiple waters. For weaning rate there was no significant difference between One water and the Two water treatments, but weaning was significantly lower ($P<0.01$) in Multiple waters than the other treatments.

Table 4.19. Mean branding and weaning rates over all years for the paddock configuration treatments. These are fitted means from a binomial model.

	One water	Two waters	Multiple waters
Branding Rate (%)	84.7	81.6	73.8
Weaning Rate (%)	77.7	78.1	68.4

Clearly, branding and weaning performance was poorer in the Multiple waters paddock. While there is some suggestion that branding and weaning performance was favoured by smaller paddocks with fewer water points, whether the observed effects are in fact due to paddock configuration is not certain. The similarity in performance between One and Two waters suggests that paddock configuration is either not important, or that once paddocks exceed a certain size branding and weaning performance is adversely affected.

4.4.2.4.8 Weaner production

There were only small differences in average annual weight weaned (per hectare and per breeder animal equivalent) amongst the grazing distribution treatments (Fig. 4.66 and Fig. 4.67). There was a weak trend of increasing weight weaned per breeder with increasing paddock size and number of waters, but this is unlikely to be significant. It was not possible to statistically test the significance of this trend because of the lack of replication. The data suggest that paddock configuration was not an important influence on weight weaned.

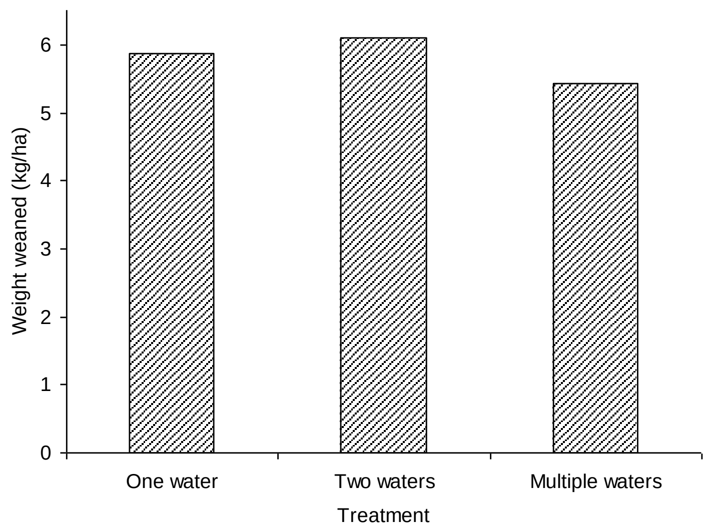


Fig. 4.66. Average annual weight weaned (kilograms per hectare) for the paddock configuration treatments. Data averaged over 2004 and 2005.

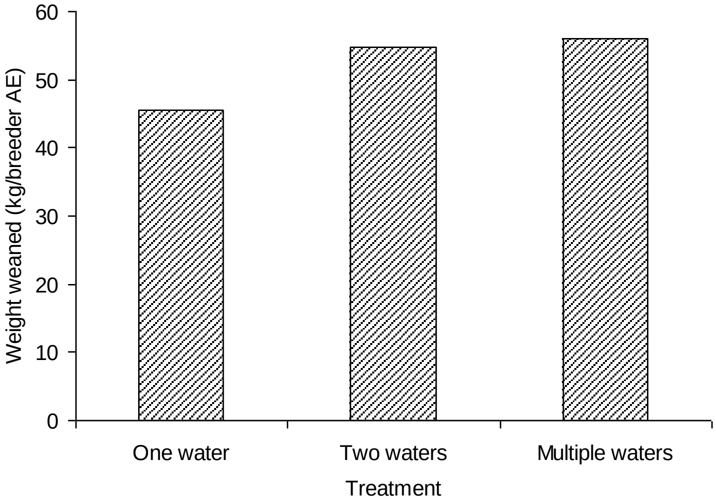


Fig. 4.67. Average annual weight weaned (kilograms per breeder animal equivalent) for the paddock configuration treatments. Data averaged over 2004 and 2005.

4.4.2.4.9 Calf loss

As for the grazing radius experiment, calf loss was analysed over the entire study using different years as replicates.

There were no significant differences in calf loss amongst the grazing radius treatments (Fig. 4.68).

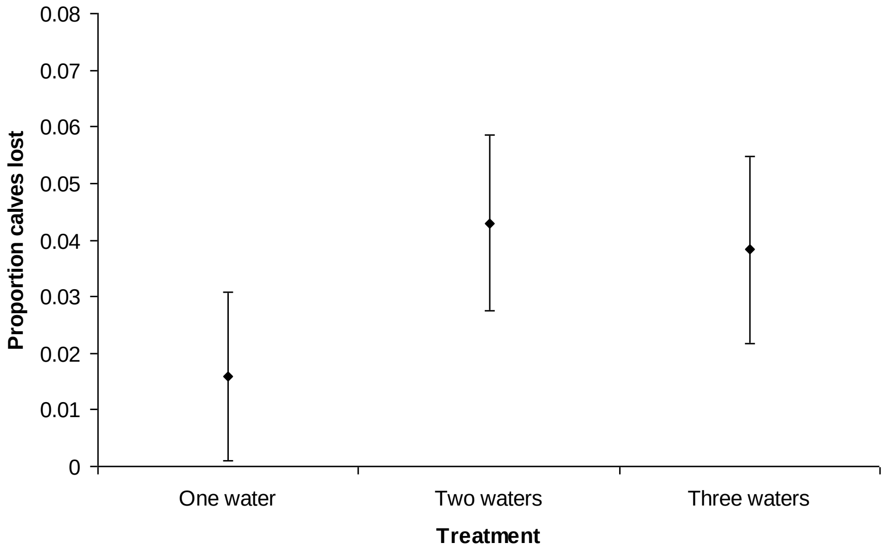


Fig. 4.68. The mean proportion (± 95% confidence interval) of calves lost over the study period for each of the paddock configuration treatments.

4.4.2.5 Conclusions from paddock configuration experiment

Despite the obvious differences in patterns of cattle distribution amongst the three paddock configurations, there were no strong effects on pasture condition or livestock production during the course of the study. However, in the longer term differences in pasture condition might be expected to occur, particularly in certain sections of the paddocks with multiple waters because of the relative ineffectiveness of water points in creating uniform grazing distribution across the paddocks. These effects may then flow through to livestock production. The poor control achieved over cattle distribution in combination with higher stock numbers creates the potential for preferred areas to be heavily utilised and degraded (i.e. loss of 3P grasses and soil structure and health).

It has been suggested that larger paddocks may benefit livestock production by spatially buffering declines in the quantity and quality of forage during the dry season or below average wet seasons. There was no evidence of such a benefit occurring in this study, with little difference in livestock production amongst the treatments. Conversely, the relatively uneven use in the larger paddocks with multiple waters might have been expected to reduce livestock production during the study because cattle spent a lot of time in heavily grazed areas, rather than venturing to rarely frequented sites with more abundant forage. However, since heavily utilised areas can often produce higher quality regrowth pasture, this may have compensated for lower pasture availability (and generally favourable seasonal conditions during the study probably also helped to minimise any adverse effects). Cattle (and other herbivores) have been shown to trade off forage quantity for quality. It remains to be seen whether livestock production will be adversely affected in the long term in larger paddocks due to poor grazing distribution or whether such trading off can maintain livestock production.

4.4.3 Cattle distribution - factors influencing patterns of use

Understanding what factors determine the way cattle use the landscape within paddocks will facilitate the development of improved techniques for managing grazing distribution. In this study, the influence of key pasture and landscape characteristics on patterns of use by cattle were examined using generalised linear models and by calculating preference indices.

The generalised linear models (GLMs) examined the relationship between counts of GPS collar fixes and the different levels of the environmental attributes where GPS fixes occurred within the experimental paddocks. The environmental attributes considered to be of most importance were distance to water, pasture class and soil type. Pasture class comprised four pasture condition classes based on species composition (by dry weight) of the herbaceous understorey estimated in the Botanal process. The four classes (see Table 4.20) approximated the A, B, C, D land condition framework from the Grazing Land Management package (although there were some differences in that pasture species considered of no pastoral value such as *Triodia* species were allocated to class 4, considered equivalent to class D). As such, these pasture classes represent different grazing histories and the consequent changes in pasture composition and productivity. The land types were black soil (Vertisol, the dominant cracking clay soil of the Wave Hill land system), red soil (Kandosol, a minority soil type found in restricted areas), intermediate (usually a stony, chocolate-brown soil found as a transition between areas with black and red soils, but also including any other soil not conforming to the black and red types) and riparian (in creeks or closely associated with creeks).

To provide the data necessary for the models, data layers of the different levels of the pasture and soil attributes across the study paddocks were generated by interpolating the Botanal pasture estimates and soil attributes within ArcView. The soil type map was generated using a combination of quadrat-based data collected in during the Botanal process and an aerial photo-interpretation by NT Department of Natural Resources, Environment and the Arts (K. Richardson, pers. comm). The photo-interpretation provided spatial information on creeks and riparian areas, while the quadrat observations provided information on soil type outside of the riparian zones. The pasture and soil layers were intersected with the GPS collar data for each cow to allocate each location fix to a class within each of the pasture attribute and soil types. Because of the relative coarseness of the field pasture surveys the interpolations may not necessarily represent true pasture conditions at a site, thus being a potential source of error in the analyses. Distance to the nearest water was also calculated for each GPS fix within Arcview.

Preference indices provide a measure of the strength of selection (or avoidance) for particular landscape attributes. Strictly speaking, these indices measure selection by cattle rather than preference (the latter interacts with the availability of resources to determine selection). Preference indices (PI) for a level of an environmental attribute (e.g. soil type, pasture class) were calculated as the percentage of GPS fixes occurring within that level of the environmental attribute as a proportion of the percentage of the paddock with that level of the attribute, i.e.

$$PI = \frac{\%\, fixes}{\%\, paddockarea}$$

This approach corrects for the different proportions of each attribute class in each paddock, thus reducing the effect of chance in determining the apparent importance of a particular land or pasture attribute (i.e. avoiding the possibility that the dominant class of a particular environmental attribute will show the highest use by virtue of its dominance). Preference indices were calculated for pasture class, soil type (both as used in the GLMs), total forage biomass and palatable forage biomass. Total forage biomass was the dry weight of all plant species in the herbaceous understorey. Palatable forage biomass included the dry weight of those species in the herbaceous understorey considered to be most commonly selected and grazed by cattle. These data were spatially interpolated and intersected with the GPS fix data within Arcview as described for the GLMs. The limitations associated with interpolating pasture characteristics across a paddock based on a relatively small number of samples should be acknowledged when interpreting these results.

Table 4.20. Pasture species included in each pasture class. These are mostly black soil species, since these soils strongly dominated the study site.

Pasture class			
Class 1 (palatable perennial grasses)	Class 2 (less preferred perennial grasses, palatable annual grasses)	Class 3 (forbs, increaser perennial grasses)	Class 4 (unpalatable perennial and annual grasses)
Astrebla spp.	*Chrysopogon fallax*	*Aristida latifolia*	*Eriachne obtusa*
Dichanthium fecundum	*Dichanthium sericeum*	*Brachyachne convergens*	*Eulalia aurea*
Panicum decompositum	*Iseilema* spp.	*Cyperus* spp.	*Sehima nervosum*
		Other Annual Grasses	*Sorghum timorense*
		Alysicarpus muelleri	*Triodia* spp.
		Flemingia pauciflora	Other Grasses
		Jacquemontia browniana	Other Perennial Grasses
		Phyllanthus maderaspatensis	
		Rhynchosia minima	
		Sesbania spp.	
		Tephrosia rosea	
		Trichodesma zeylanicum	
		Wedelia asperrima	
		Other Herbs	
		Other Native Legumes	

The GLMs and preference indices excluded all GPS fixes within the first 24 hours of the cattle being returned to the paddock, those fixes on the day of mustering, and those located within 200 m of a water point (250 m for preference indices). Fixes near water points were omitted since cattle tended to spend many hours each day loitering near the water point, and the aim of the modelling was to establish what factors affected broader patterns of use across the study paddocks. Allocating a dominant activity (i.e. grazing, travelling or resting) to each GPS fix (based on activity sensors in the collars) for the hour preceding each fix and using only the ‘grazing’ sub-set of GPS fixes in these analyses failed to improve the relationships between patterns of use and environmental attributes. Consequently, all valid GPS fixes for each cow were included in the analyses where the collar functioned continuously for a minimum of 1000 fixes (i.e. approximately six weeks). The results of these analyses are summarised without regard for the experimental treatment (i.e. paddock configuration), or year of data collection.

4.4.3.1 Generalised linear models of cattle distribution

The generalised linear models used a Poisson distribution with a log link function. Independent (i.e. predictor) variables tested in the models were pasture class, soil/land type, distance to water and a quadratic function of distance to water (i.e. $(\text{distance-mean(distance)})^2$), fitted in that order. Distance to water was included as a linear variable in classes of 100 m. The quadratic distance function tests for a humped distribution of collar fixes with distance from water, which might be expected given that the area in various distance classes increases with distance from water so GPS fix counts are likely to increase, but then as distance increases further and cattle use declines GPS fix counts decline. Factors were fitted individually to test whether including each new factor improved the model over the previous model. For analyses of cow distribution data collected over each wet season pasture class was based on the pasture data collected during the preceding October, and for cow distribution data from the dry season vegetation data collected during the preceding May was used. Vegetation data collected at the end of the wet season in May was not used in the analyses of wet season cattle distribution presented here for two reasons: firstly, it generally accounted for less of the deviance in models than the data from the preceding October, and secondly, because there was a risk that the data in May was simply a reflection of patterns of use during the wet season (so a significant relationship between cattle location and pasture class would be expected by default). Vegetation class one (broadly equivalent to A condition land in the Grazing Land Management framework) and black soils were the reference groups used in comparisons of the different levels within each of these predictor factors.

Separate models were run for each collared animal for each of the paddocks and sampling periods. The number of GPS fixes in each combination of pasture class, soil type, distance from water and quadratic distance was the response modelled.

In all cases, regardless of the treatment or season, the full model which included all predictors was highly significant ($P<0.001$). Vegetation class usually accounted for the largest share of the deviance (indicating it was the factor most influencing cattle distribution), while soil type was the second most important factor. The quadratic distance function usually accounted for more of the model deviance than linear distance, suggesting a humped distribution of GPS fix counts with distance from water, as described above. Table 4.21 summarises the results, showing the number of models in which each predictor variable was significant at $P<0.05$.

Table 4.21. Summary of the percentage of models in which each predictor variable was significant ($P<0.05$) in generalised linear models of cattle locations (based on counts of GPS fixes from cattle collars in different levels of each predictor variable). Individual models were developed for each collared cow. n = number of collared cattle in each paddock (and therefore the total number of models for that paddock and season). Data for each paddock are aggregated over several seasons. Quadratic distance = (distance-mean(distance))^2.

Season and treatment	n	Predictor variables in models			
		Vegetation class	Soil/land type	Distance from water (100 m intervals)	Quadratic distance from water
		Paddock configuration treatments			
Wet season					
One water	9	100	100	89	100
Two waters	10	100	100	60	100
Multiple waters	7	100	100	100	100
Dry season					
One water	7	100	100	100	100
Two water	5	100	100	80	100
Multiple waters	8	100	100	100	100
		Grazing radius treatments			
Wet season					
GR1	9	100	100	89	100
GR2	3	100	100	100	100
GR3	3	100	100	100	67
Dry season					
GR1	7	100	100	100	100
GR2	4	100	100	100	100
GR3	4	100	100	75	100

The results clearly show that vegetation class, soil/land type, distance from water and the quadratic distance effect were important in explaining the location of cattle within the paddocks. Only on a few occasions were distance to water and the quadratic distance effect not significant; the other predictors were significant on all occasions, regardless of paddock configuration, paddock size, or season. Vegetation class and soil type usually accounted for more of the deviance than distance to water (either linear or quadratic). On more than half the sampling occasions soil type accounted for more of the model deviance than vegetation class, indicating that soil type had a stronger effect on patterns of use than vegetation. However, there was no seasonal difference in when this occurred.

The effects of different levels of the predictor variables were usually significant ($P<0.001$) in the models, indicating that certain vegetation states and soil types recorded higher counts of GPS fixes. Parameter estimates for the different vegetation suggested that in most cases the different vegetation classes were ranked from greatest to lowest number of GPS fixes as class 3>class 4>class 2>class 1 (i.e. collared cattle tended to occur more often in areas of vegetation class three). Notably, areas of vegetation class one (i.e. land in the best condition) usually recorded the fewest GPS fixes. The ranking for soil types was black soils>red soils>riparian>intermediate soils, reflecting the strong dominance of black soils across the study area. These trends were generally consistent across all paddock configurations.

Although the models did not test interaction terms, an interaction between distance from water and vegetation and soil factors would be expected to contribute to observed cattle distributions. Thus, while vegetation class and soil type influenced cattle distribution this would have occurred within the constraints of cattle needing to remain within reasonable walking distance of water.

Because the models were calculated using all GPS fix data, it does not necessarily follow that the factors that are significant in the models are important in influencing grazing use of the landscape (as opposed to non-grazing activity).

4.4.3.2 Wet season preference indices

Since pasture attributes (especially biomass) are expected to change as pastures grow during the wet season, the cattle location data for the wet season were examined in relation to pasture attributes at the time of deployment of the collars (usually October) and also for pasture attributes when the collars were recovered (usually May).

Preference indices are presented on a log scale to provide a more balanced representation of avoidance relative to preference due to the avoidance scale being limited (because values below zero are not possible), which tends to compress avoidance values relative to preference values.. Thus, a preference index of one indicates neither selection nor avoidance, greater than one indicates selection for that class, and less than one indicates avoidance.

There was an apparent preference for areas with lower quantities of pasture, and avoidance of areas with higher pasture biomass in relation to pasture availability in both October and May (Fig. 4.69). This trend was strongest in relation to pasture attributes in May (i.e. at the end of the GPS deployment period). However, in May this might be a consequence of preference for these locations for other reasons, so that by May recent grazing has reduced biomass at these locations rather than there being a preference for sites with lower pasture biomass per se.

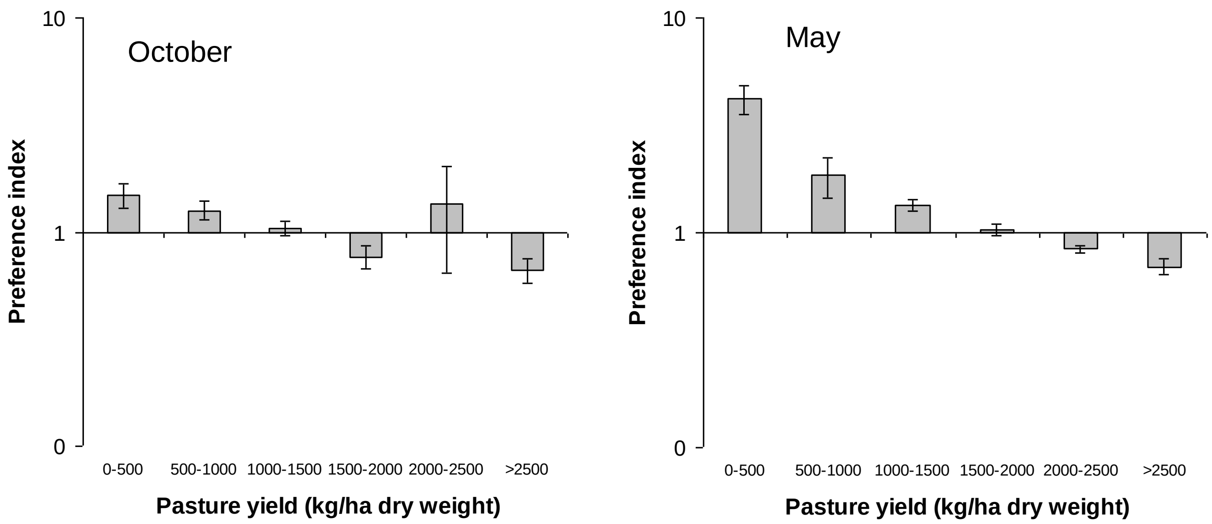


Fig. 4.69. Preference by cows (± se) during the wet season for areas supporting different total pasture biomass. October graph is preference in relation to pasture biomass at the beginning of the collar deployment period, and May is in relation to pasture biomass at the end of the deployment period. These data include all collared cattle for all paddock configurations over all wet season observation periods, except for collars with less than 1000 position fixes for the observation period. A preference index > 1

indicates preferential use, <1 indicates avoidance. Note the log scale for the y axis (used to scale the strength of preference and avoidance equally).

A slightly different picture emerges in relation to palatable pasture biomass. There was a strong preference for sites where palatable pasture biomass was high in October when the collars were deployed, but a weak preference for low palatable pasture biomass in relation to the May pasture data at the end of the deployment period (Fig. 4.70). This might reflect a more uniform availability of palatable pasture species across paddocks during the growing season. A comparison of Fig. 4.69 and Fig. 4.70 also suggests that low palatable pasture biomass is not necessarily associated with low total biomass, but that factors such as the species or rankness of the pasture at locations of high biomass are deterring cattle from those sites.

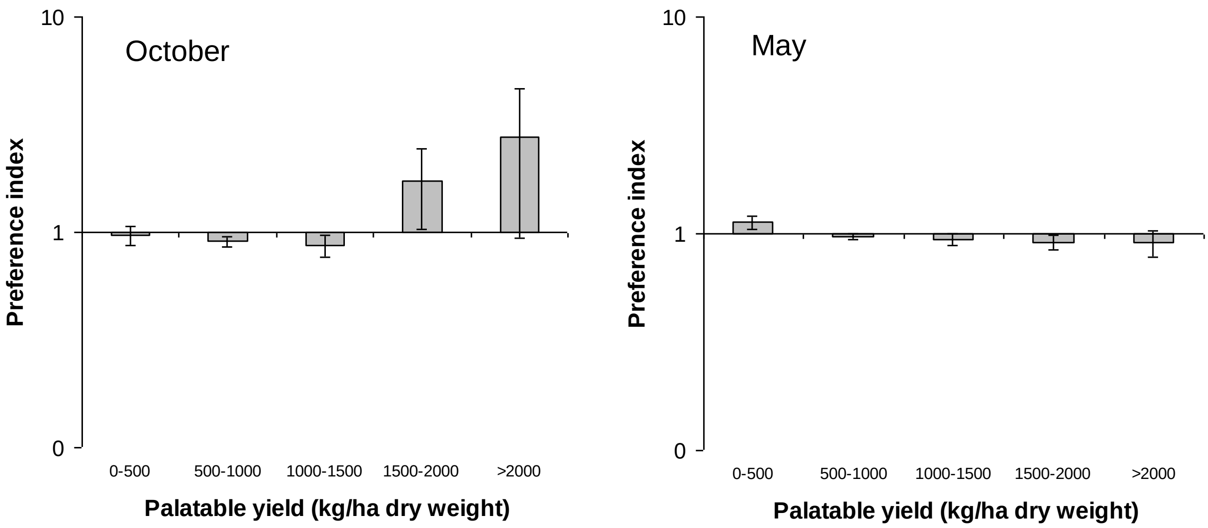


Fig. 4.70. Preference by cows (± se) during the wet season for areas supporting different palatable pasture biomass. October graph is preference in relation to palatable pasture biomass at the beginning of the collar deployment period, and May is in relation to palatable pasture biomass at the end of the deployment period. These data include all collared cattle for all paddock configurations over all wet season observation periods. A preference index > 1 indicates preferential use, <1 indicates avoidance. Note the log scale for the y axis (used to scale the strength of preference and avoidance equally).

Fig. 4.71 shows an example of the pattern of use of one cow during the 2004-2005 wet season in relation to palatable pasture yield at the end of the deployment period (i.e. May 2005). This cow spent much of its time in areas of higher palatable pasture biomass, but did not favour these areas exclusively.

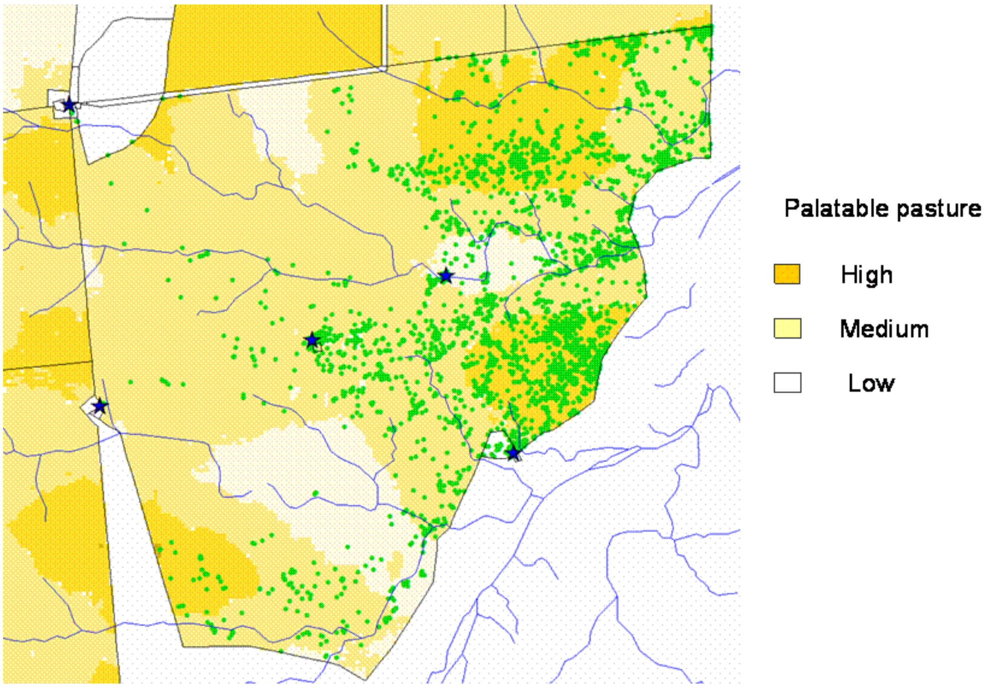


Fig. 4.71. Example of cattle distribution plot overlaid on spatial pasture interpolations for the Multiple waters paddock during the 2004-2005 wet season. Pasture data is for the end of the collar deployment period (May 2005). Water points shown as blue stars.

No strong trends were apparent between patterns of use by cattle and pasture class (similar to land condition classes A-D), although there was a weak indication that pasture state 4 (equivalent to class D) was avoided by cattle (Fig. 4.72).

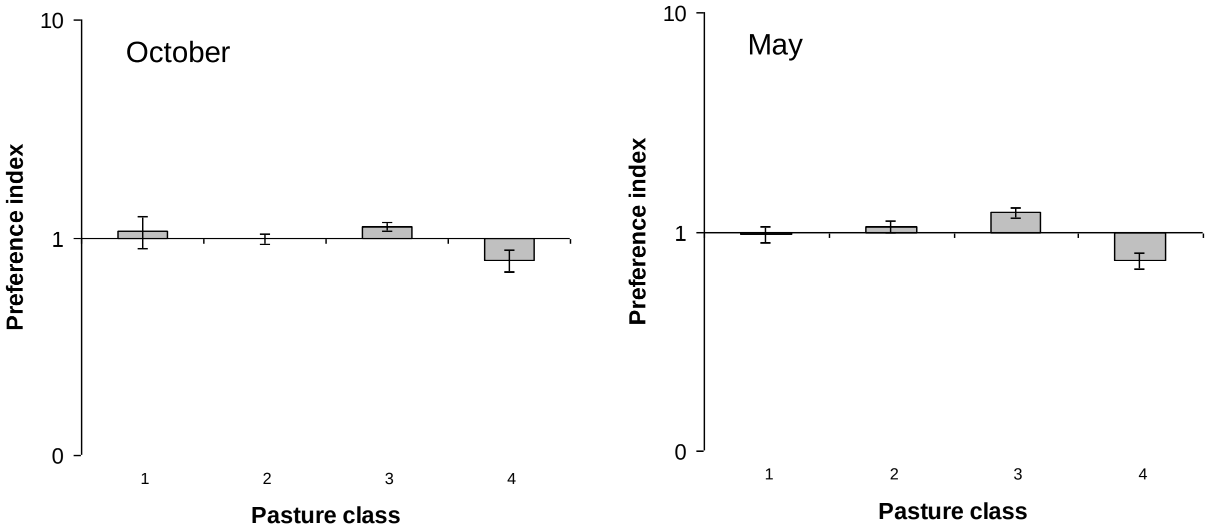


Fig. 4.72. Preference by cows (± se) during the wet season for different pasture classes (similar to land condition class). October graph is preference in relation to pasture class at the beginning of the collar deployment period, and May is in relation to pasture class at the end of the deployment period. These data include all collared cattle for all paddock configurations over all wet season observation periods. A preference index > 1 indicates preferential use, <1 indicates avoidance. Note the log scale for the y axis (used to scale the strength of preference and avoidance equally).

Some care is needed in interpreting the importance of pasture characteristics in determining patterns of cattle activity. The pasture data was collected only at the start and end of the GPS collar deployment periods. The combined effects of pasture growth and grazing use during the season may cloud the situation in relation to the factors driving the spatial distribution of cattle activity. In particular, a strong association might be expected between low pasture biomass at the end of a collar deployment and cattle distribution. Thus, the observed association may simply reflect recent grazing activity rather than demonstrate a preference for areas of low biomass per se. In the case of the wet season, comparing cattle activity during the season with pasture characteristics at the start of the deployment period may mean the results are more a function of cattle preference rather than a consequence of recent grazing activity, than comparing with pasture results at the end of the period. However, pasture growth during the season may also be important in determining spatial patterns of activity, so comparison with pasture data at the end of the season might be informative.

There was a weak avoidance of black soils and preference for red soils and riparian areas during the wet season (Fig. 4.73), although closer examination of the results suggested this was not consistent between paddocks. In the One Water paddock there was a preference for intermediate soil, but this was not as strong in the other paddocks. A strong preference for riparian areas was evident in the Two Waters paddock. The ambiguous nature of these results might reflect the location of different soil types in relation to the water points and whether certain types were close enough to water that cattle were able to exhibit a preference for soil type. Some soil types were also a very minor part of certain paddocks.

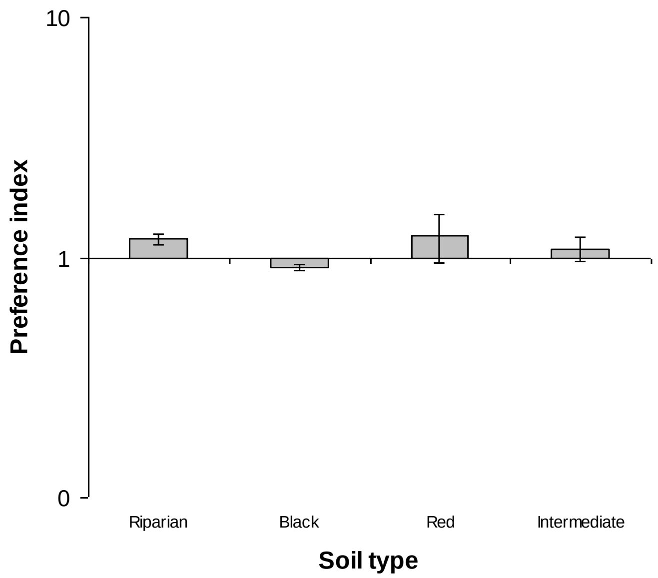


Fig. 4.73. Preference by cows (± se) during the wet season for different soil/land types. These data include all collared cattle for all paddock configurations over all wet season observation periods. A preference index > 1 indicates preferential use, <1 indicates avoidance. Note the log scale for the y axis (used to scale the strength of preference and avoidance equally).

4.4.3.3 Dry season preference indices

Cattle distribution patterns during the dry season were examined in relation to pasture attributes at the beginning of the dry season. There was an almost linear trend between the cattle's preference for different areas and total pasture biomass. Cattle showed a strong preference for locations with lower levels of total pasture biomass. As biomass increased preference weakened, and sites with the highest biomass levels were avoided (Fig. 4.74).

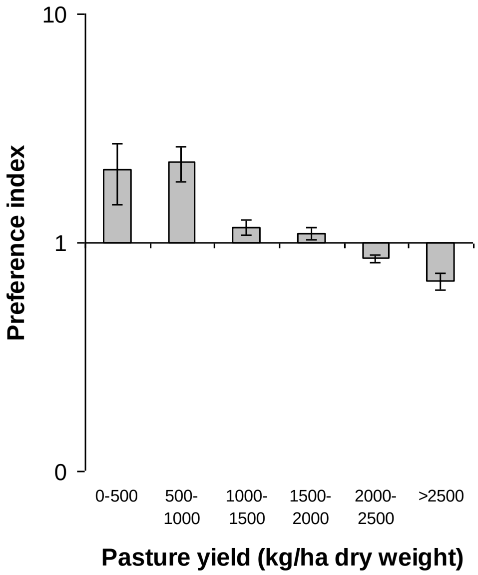


Fig. 4.74. Preference by cows (± se) during the dry season for areas supporting different total pasture biomass. These data include all collared cattle for all paddock configurations over all dry season observation periods. A preference index > 1 indicates preferential use, <1 indicates avoidance.

Cattle did not showed a strong preference for, or avoidance of, areas with differing quantities of palatable biomass during the dry season (Fig. 4.75). However, there was a weak trend of lower use in areas with higher palatable biomass, although the results were variable (indicated by the standard errors).

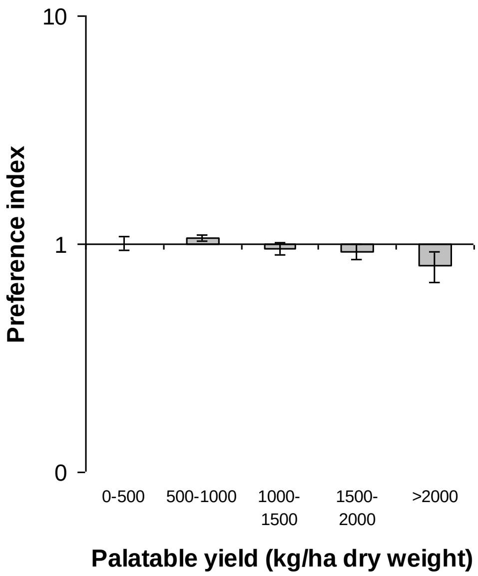


Fig. 4.75. Preference by cows (± se) during the dry season for areas with different palatable pasture biomass. These data include all collared cattle for all paddock configurations over all dry season observation periods. A preference index > 1 indicates preferential use, <1 indicates avoidance.

Cattle tended to avoid areas in pasture class four (Fig. 4.76). A similar response was observed during wet season, suggesting this behaviour was consistent throughout the year. However, these areas were more strongly avoided during the dry season than in the wet. No differences in selection for the other land conditions states were apparent.

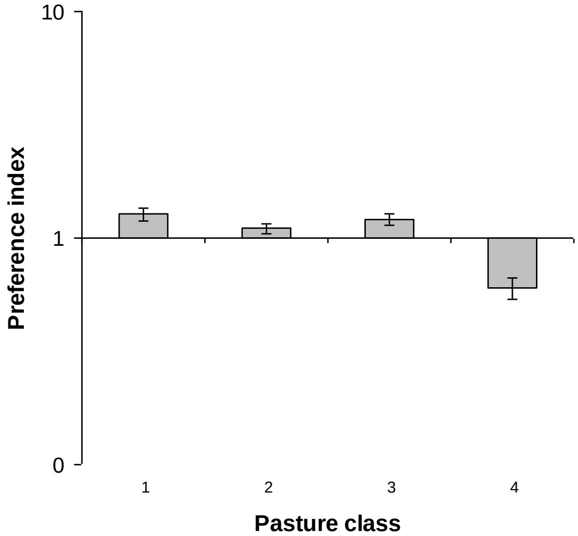


Fig. 4.76. Preference by cows (± se) during the dry season for different pasture classes (similar to land condition class). These data include all collared cattle for all paddock configurations over all dry season observation periods. A preference index > 1 indicates preferential use, <1 indicates avoidance.

Red soils appeared to be slightly more preferred by cattle during the dry season, and intermediate soils were avoided (Fig. 4.77). Cattle showed neither preference nor avoidance of black soils and riparian areas at this time. These results contrast with the wet season when riparian, red soil and intermediate soil areas were weakly preferred and black soils tended to be avoided. Again, there was some variation between individual animals, paddocks and observation periods in preference for different soil types.

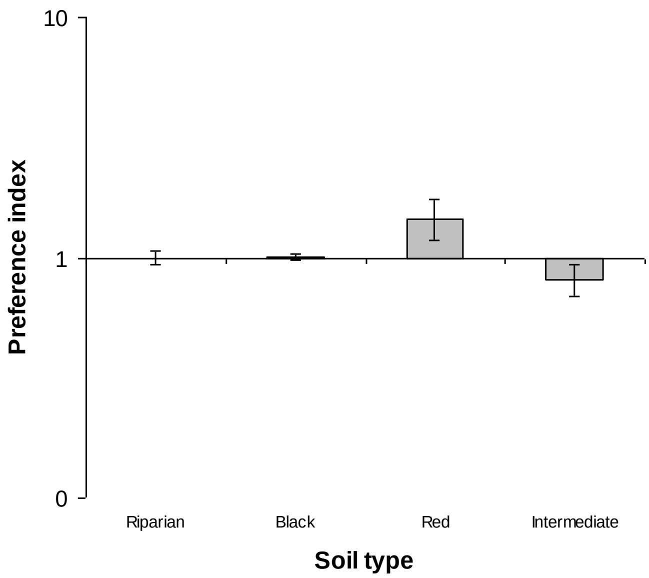


Fig. 4.77. Preference by cows (± se) during the dry season for different soil/land types. These data include all collared cattle for all paddock configurations over all dry season observation periods. A preference index > 1 indicates preferential use, <1 indicates avoidance.

Red soils are thought to be preferred by cattle in this region for two reasons. Firstly, they support a different suite of pasture species that cattle appear to prefer (e.g. an array of nutritious forbs and short-lived perennial grasses such as *Enneapogon* spp.). Secondly, during the wet season the black cracking clays that are a feature of the Wave Hill land system and dominate the study site become boggy following heavy rain. This makes walking difficult for cattle, whereas the red soils tend to remain firmer and easier walking. Paradoxically, the preference for riparian areas during the wet season is also attributed to ease of walking, owing to the higher gravel and rock content of riparian soils. An unexpected result was that riparian areas were not preferred during the dry season. Riparian areas were expected to be favoured by cattle during the dry season because creeks sometimes hold water (especially early in the season), these areas can support more nutritious forage that stays greener for longer than in non-riparian areas, and because of the shade provide by the denser tree cover.

4.4.3.4 Conclusions relating to factors affecting patterns of use

Pasture class, soil type and distance to water were consistently important factors driving the distribution of cattle activity within the study paddocks, being significant in the majority of the GLMs. It is important to recognise however, that occupancy of a site does not necessarily mean cattle were grazing at that site. This issue is discussed in more detail later.

The GLMs indicated that pasture classes two and three were used more than classes one and four, and the preference indices (which, unlike the GLMs, adjust for the area of each class in the paddock) showed a consistent avoidance of pasture class four throughout the year. There was also a tendency for cattle to avoid areas supporting high pasture biomass. Thus, cattle appeared to be avoiding land in the poorest condition but did not necessarily show a strong preference for land in good condition with abundant 3P grasses. Instead they appeared to favour areas that had more annual grasses and forbs.

The GLMs indicated that black soils were used the most (i.e. more GPS fixes occurred on these soils), but this is simply a reflection of the dominance of black soils at the study site. The preference indices suggested black soils tended to be weakly avoided during the wet season in favour of red soil and riparian areas, and red soils were also favoured in the dry season. As suggested earlier, the bogginess of black soils during the wet is the most probable cause of this avoidance, and preferred plant species (i.e. short-lived grasses and forbs) attract cattle to the red soils. Unexpectedly, riparian areas were not favoured during the dry season, but there is no obvious explanation for this. It might reflect the practice of cattle loafing near the water point during daylight hours in the dry season whereas they may spend more time loafing in the shade of riparian zones during the wet season when water may be available in nearby creeks.

Although distance to water was an important influence on cattle distribution, GPS fixes were not necessary concentrated near water; the significant quadratic distance term in the GLMs indicated that the number of fixes initially increased with distance from water and then declined (in accordance with the increase in area within each concentric zone away from water) . Nevertheless, cattle frequently loitered near water from soon after sunrise until late afternoon, particularly during hot weather, but these fixes were removed from the GLMs and preference index calculations.

Cattle might have used areas with lower pasture biomass simply because they were within easy walking distance of water, or because the nutritional quality of fresh regrowth in frequently grazed areas can be higher. This is the mechanism behind the widely recognised issue of patch grazing. The effects of grazing in keeping the pasture short and stimulating nutritious regrowth may be perpetuating a preference for these areas despite lower forage (total and palatable) availability. An abundance of old standing plant material in areas with high pasture biomass is also likely to deter cattle from grazing because new growth is hard to select without also ingesting old plant material.

Although no data has been presented to illustrate the point, there was often considerable variation between individual cows, seasons and paddocks in patterns of use and in preferences for land and pasture classes.

One aim in examining the relationships between grazing distribution and pasture and landscape variables was to identify those factors that are likely to be useful in models and decision support tools designed to explain and/or predict the use of the landscape by cattle. It is not clear how useful the variables considered here are likely to be for this purpose, given the relatively weak preferences recorded for factors such as soil type. However, the results have highlighted some important issues associated with understanding the drivers of grazing distribution. For example, higher biomass of palatable forage was expected to be strongly preferred and positively related to cattle activity, but this was not always the case (e.g. in the dry season). Proximity to water and the re-use of previously grazed areas appear to be strong determinants of grazing distribution.

The combination of cattle activity distribution data and pasture defoliation patterns suggest that none of the different paddock configurations were entirely effective at increasing the use of all areas within paddocks and achieving relatively uniform grazing distribution. Some areas of most paddocks were heavily used while others were grazed lightly or were largely avoided. Reducing paddock size appeared to be more effective in achieving relatively uniform use across a paddock than installing additional waters in large paddocks. Also, the cattle distribution results from the GPS collars in the grazing radius paddocks suggested that the paddock with the smallest nominal grazing radius (i.e. the GR1 paddock, approximate paddock area of 9 km^2) achieved more even use than paddocks with larger grazing radii. Surprisingly, individual cattle use in the GR2 treatment (a very small paddock by regional standards with an area of 21 km^2) was relatively uneven, but this is likely a consequence of the specific nature of this paddock and the relatively large areas of the less preferred *Eulalia aurea* it contained. Although the smallest paddock appeared to be most effective at increasing the uniformity of cattle activity across the paddock uneven use still occurred, with riparian areas, red and intermediate soil areas and the area near the water point all receiving the heaviest grazing use.

4.4.4 Economics of development

The financial cost of subdividing large paddocks and installing more waters on a property to improve grazing distribution and forage utilisation across the property can be substantial, as can be the additional maintenance costs once the infrastructure is operational. Where overall stocking rates (i.e. pasture utilisation rates) on a property are presently low, there may be the capacity to increase overall stock numbers following the improved distribution of livestock that is possible with more, smaller paddocks. This increase in stocking rates may offset the capital cost of the new infrastructure. The calculated financial returns for the different infrastructure developments used in the grazing radius and paddock configuration experiments at Pigeon Hole are presented in Table 4.22.

There was no apparent systematic variation in financial performance amongst paddock configurations related to the level or types of development. Variation in the actual stocking rates used and the performance of the cattle (e.g. branding percentage) amongst paddocks contributed to the differences in financial performance. Surprisingly, the most intensive development (the smallest paddock with a single water point) generated the best overall return on invested capital (ROIC) of 8.3%, apparently due in part to the higher stocking rate and branding percentage. Despite the lower costs associated with simply adding more waters to a large paddock (i.e. the Multiple waters treatment), this provided the lowest ROIC of 6.2% (largely due to the lower stocking rate). The results suggest that differences in performance were related to the characteristics of particular paddocks or the stocking rates used.

However, in comparison, a typical commercial paddock stocked at 10 AE/km^2 returned earnings before interest and tax (EBIT) of $72 per AE and $721 per km^2 and an ROIC of 5.4% (see Table 5.6). Thus, all of the development configurations used in this study were more financially rewarding than a traditional commercial system, despite the additional costs associated with reducing paddock size and establishing additional water points. This was because of the additional livestock that could be carried following property development.

Table 4.22. Calculated financial returns for the different infrastructure developments used in the grazing radius and paddock configuration experiments. These are calculated using actual livestock performance data from the experimental paddocks where possible (e.g. stocking rate and branding percentage), but are calculated on a whole-property basis (i.e. assumes the entire property is developed to the extent of each of the experimental configurations). See Table 5.6 for data for a typical undeveloped commercial paddock.

		Paddock configuration				
		GR1 & One water	GR2	GR3	Two waters	Multiple waters
Herd data	Stocking rate (AE/km^2)	13.2	13.7	12.1	11.9	10.2
	Branding percentage	84%	73%	82%	83%	85%
	Herd mortality	1%	1%	1%	1%	1%
	Breeders	6,449	6,866	6,043	5,943	5,094
	Total herd (AE)	17,999	17,759	16,640	16,475	14,311
	Sale cows	806	858	755	743	637
	Sale steers	2,577	2,384	2,357	2,347	2,060
	Sale heifers	1,658	1,406	1,496	1,500	1,334
	Total sale kg	1,795,058	1,660,224	1,641,791	1,634,394	1,434,749
Financial data	Replacement capital	$64,629	$64,629	$64,629	$64,629	$64,629
	Fixed costs	$250,634	$250,634	$250,634	$250,634	$250,634
	Direct costs	$547,775	$556,706	$528,560	$524,955	$489,265
	Total operating	$863,038	$871,969	$843,823	$840,218	$804,529
	Livestock revenue	$2,781,487	$2,546,691	$2,539,856	$2,530,498	$2,224,924
	Total revenue	$2,801,077	$2,566,281	$2,559,446	$2,550,088	$2,244,514
	EBIT (total)	$1,753,185	$1,523,979	$1,546,654	$1,541,611	$1,292,193
	EBIT (per AE)	$97	$86	$93	$94	$90
	EBIT (per km^2)	$1286	$1176	$1125	$1114	$921
	Capital value	$21,057,264	$21,099,510	$20,742,158	$20,766,961	$20,960,777
	ROIC	8.3%	7.2%	7.5%	7.4%	6.2%

Development of a property will require careful planning and assessment of the costs and likely benefits to achieve a cost-effective improvement in grazing distribution. In most cases, this assessment will involve a trade-off between the cost of development (i.e. size of paddocks and number of waters) and the expected improvement in grazing distribution and capacity to carry more cattle. The extent to which a property should be developed, the type of development (i.e. subdivision, more waters or both) and the effectiveness in improving grazing distribution and forage use will be influenced by the particular characteristics and circumstances of the property (e.g. land and pasture type, variability in land systems). The cost is also likely to be determined by the nature of the terrain, availability of water, and the degree of infrastructure already in place. While the costs of a proposed development can be readily estimated, quantifying the benefits is less clear cut. Benefits will depend on the extent to which there is ineffective use of the landscape, and current stocking rates. If there is no capacity for increasing stocking rates following property development there may be little apparent financial incentive to use infrastructure to achieve more uniform grazing use across the landscape. However, in this situation some development should be considered to improve or maintain land condition, which may have financial value if it arrests any current decline in productivity.

While actual development costs will be specific to a particular property and site, a hypothetical example of development can be useful for assessing the extent of development that is reasonable financially. Combining these insights with the results from this project about the effect of paddock size and additional water points on grazing distribution provides some broad guidelines for property development to improve grazing distribution.

4.4.4.1 Hypothetical example

In this section a hypothetical example of development is considered, where a 144 km^2 paddock without any artificial water points is taken as the 'undeveloped' state and is then developed to varying degrees. The example shows the cost of progressively smaller subdivision of this paddock and addition of water points, to the point where there are 16 paddocks each of 9 sq. km and with one central water point. A number of assumptions relating to the position of bores, troughs and paddock shape have been made to develop this example, but costs are based on actual 2007 prices for the required infrastructure. Note that ongoing maintenance and running costs are not included.

Assumptions for development scenarios

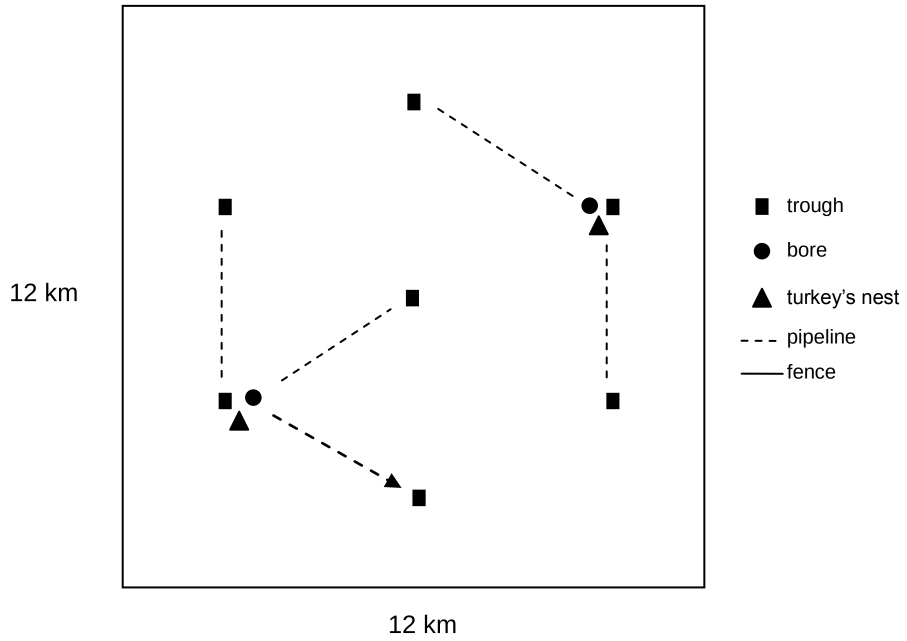
- 144 sq. km at 15 head/sq. km (= 2160 hd)
- approximately 1000 head per turkeys nest maximum
- two turkeys nests per bore maximum
- up to four troughs per turkeys nest
- up to four troughs per medicator (unless blocks used instead)
- already a perimeter fence around the paddock
- there are no waters in paddock to start with (although in many cases there will be at least one bore and turkey's nest already present)
- cost of clearing fence lines not included.

1. *Install seven waters only*

Requirements:

- 7 troughs @ $2000 each ($14,000)
- 2 turkeys nests @ $16,000 each ($32,000)
- 2 medicators @ $4000 each ($8,000)
- 2 equipped bores @ $25,000 each ($50,000)
- No fencing
- 21 km poly pipe at $1600/km (to troughs) ($33,600)

Total: $137,600

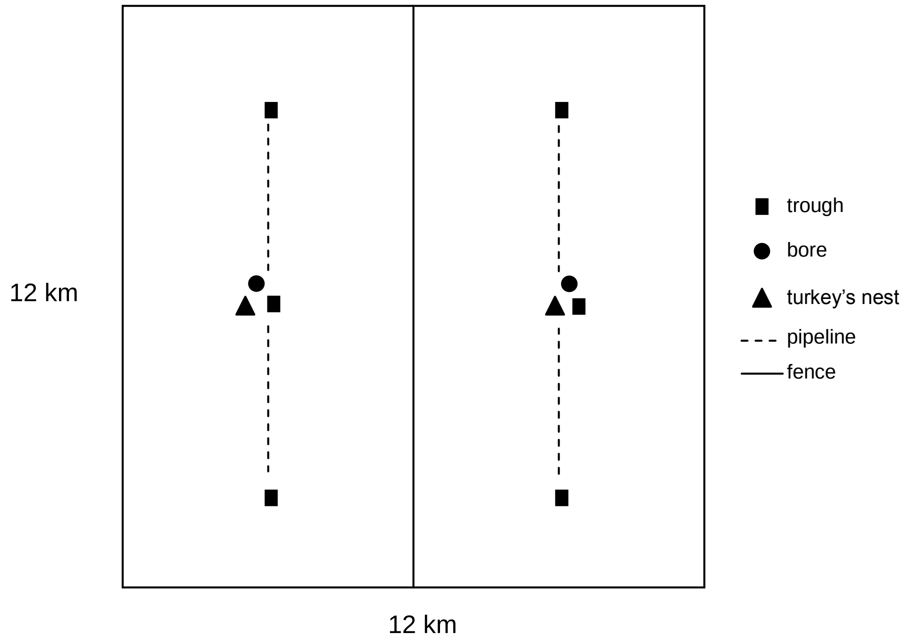


2. Subdivide into two 72 km² paddocks

Requirements:

- 6 troughs @ $2000 each (three per paddock) ($12,000)
- 2 turkeys nests @ $16,000 ($32,000)
- 2 medicators @ $4000 each ($8,000)
- 2 equipped bores @ $25,000 each ($50,000)
- 12 km fencing @ $2200/km ($26,400)
- 16 km poly pipe at $1600/km (to troughs) ($25,600)

Total: $154,000

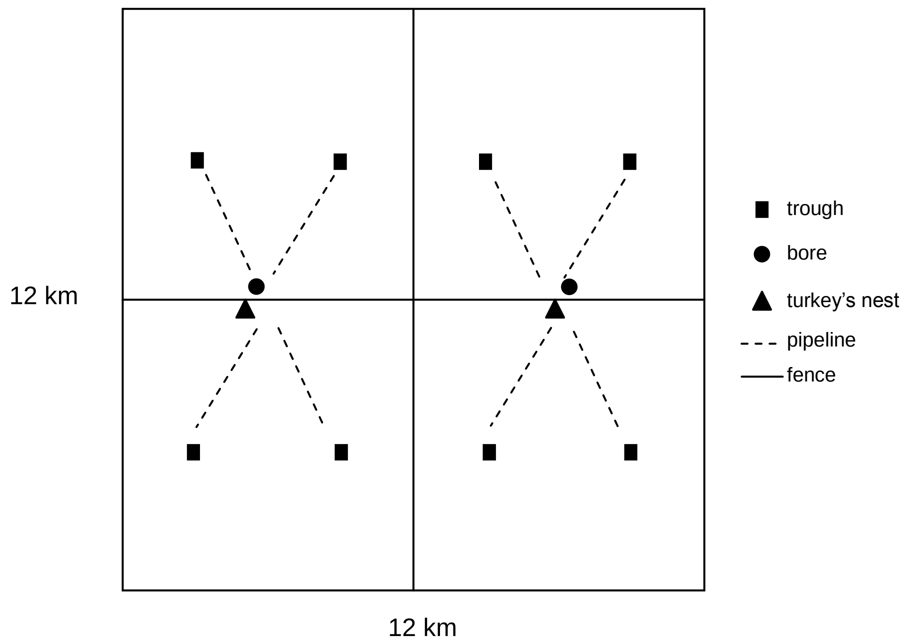


3. Subdivide into four 36 km^2 paddocks

Requirements:

- 8 troughs @ $2000 each (two per paddock) ($16,000)
- 2 turkeys nests @ $16,000 ($32,000)
- 2 medicators @ $4000 each ($8,000)
- 2 equipped bores @ $25,000 each ($50,000)
- 24 km fencing @ $2200/km ($52,800)
- 27 km poly pipe at $1600/km (to troughs) ($43,200)

Total: $202,000

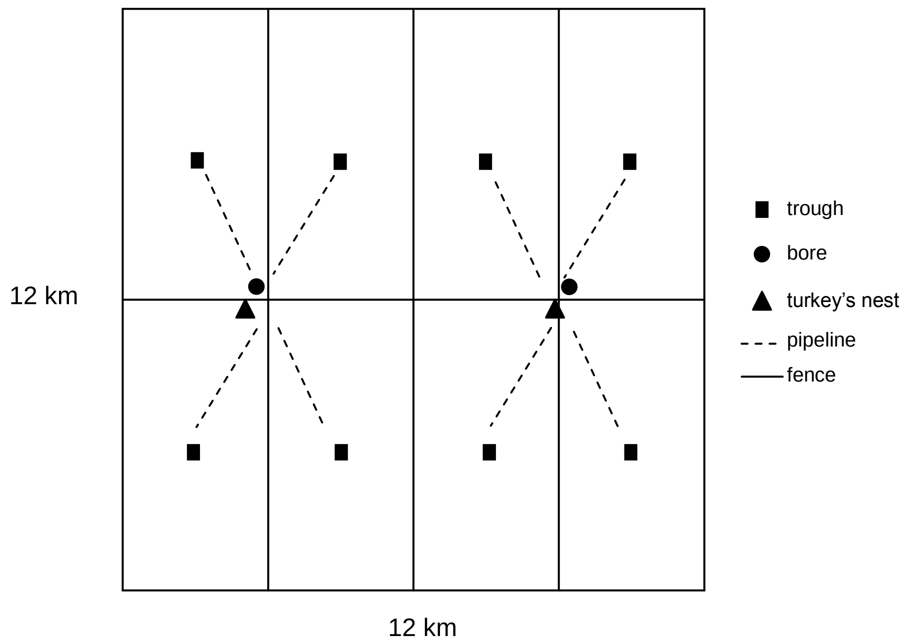


4. Subdivide into eight 18 km^2 paddocks

Requirements:

- 8 troughs @ $2000 each ($16,000)
- 2 turkeys nests @ $16,000 each ($32,000)
- 2 medicators @ $4000 each ($8,000)
- 2 equipped bores @ $25,000 each ($50,000)
- 48 km fencing @ $2200/km ($105,600)
- 27 km poly pipe at $1600/km (to troughs) ($43,200)

Total: $254,800

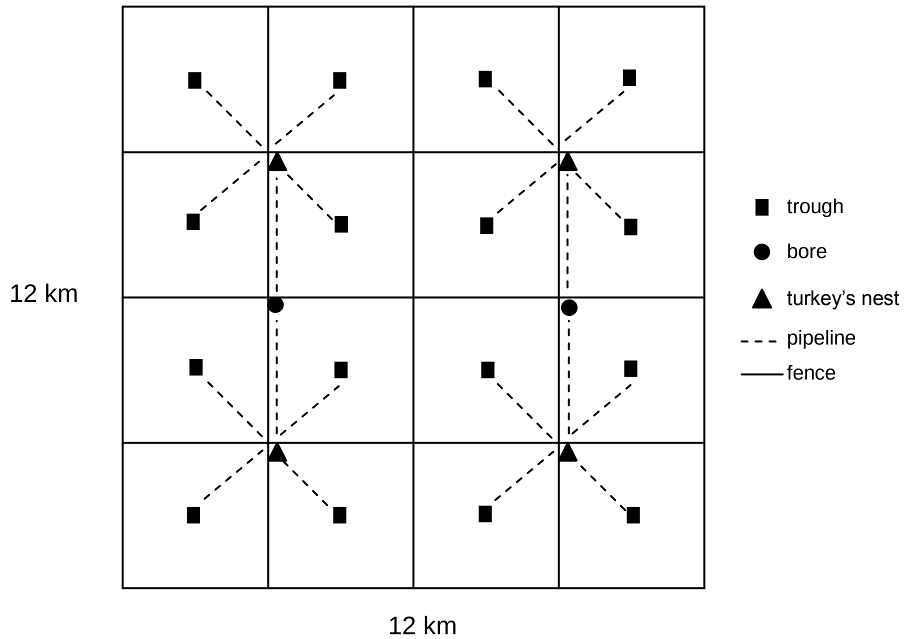


5. Subdivide into sixteen 9 km² paddocks

Requirements:

- 16 troughs @ $2000 each ($32,000)
- 4 turkeys nests @ $16,000 each ($64,000)
- 4 medicators @ $4000 ($16,000)
- 2 equipped bores @ $25,000 each ($50,000)
- 72 km fencing @ $2200/km ($158,400)
- 34 km poly pipe at $1600/km (to troughs) ($54,400)
- 12 km poly pipe at $3500/km (bore to turkeys nests) ($42,000)

Total: $416,800



The costs for fencing into smaller paddocks and installing more waters associated with these scenarios are presented in Fig. 4.78 and Fig. 4.79. These highlight the disproportionate cost of fencing for paddocks below about 40 km^2. In comparison, the cost for providing additional water points remains relatively constant for all development scenarios because of the need to make water accessible to most areas regardless of paddock size. Interestingly, the home range data from Pigeon Hole suggests that a paddock size of 30-40 km^2 with two well-spaced water points provides relatively widespread use of a paddock. Although more even grazing use is achieved as paddock size is reduced further (as shown by the 9 sq. km paddock), the cost of the infrastructure becomes prohibitive. Consequently a paddock size of 30-40 km^2 with two well-spaced water points is recommended for the study region as a compromise between achieving more uniform grazing use and the cost.

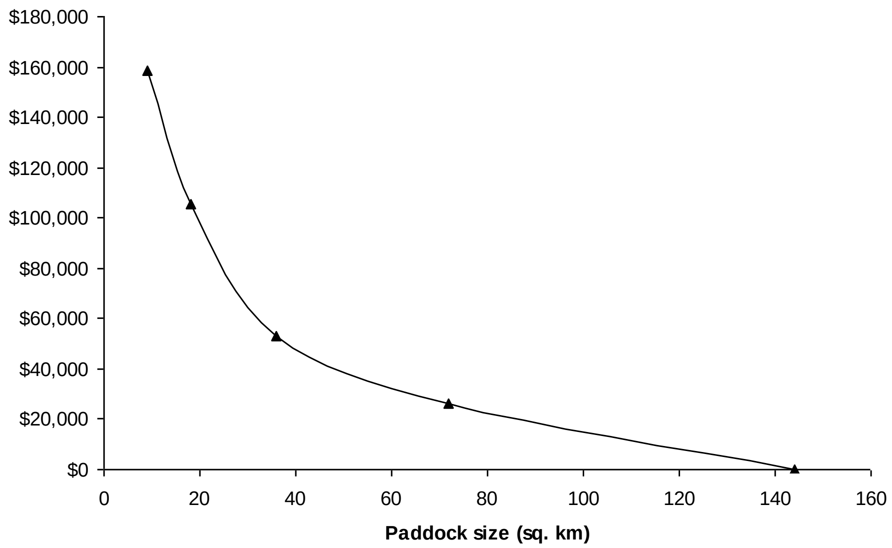


Fig. 4.78. The cost of fencing for subdividing a 144 km^2 paddock in the hypothetical development scenarios.

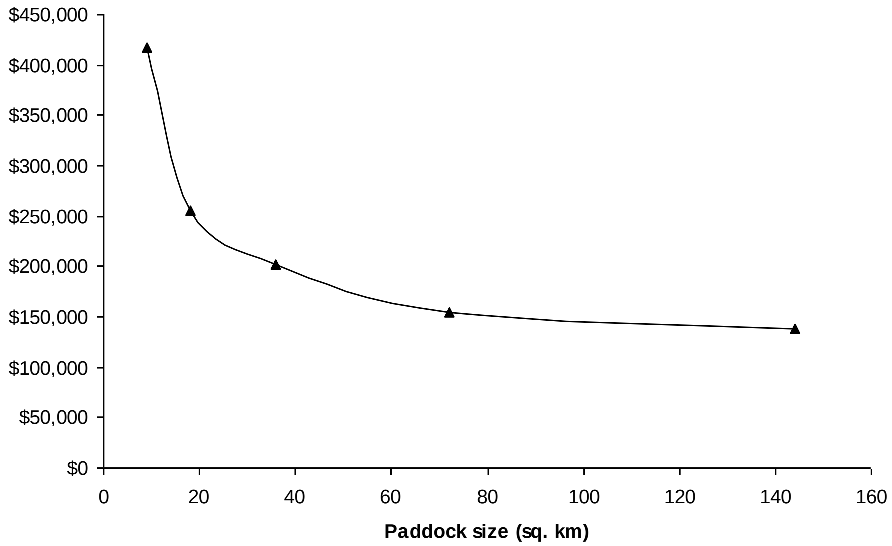


Fig. 4.79. The indicative total cost including fences and water points of hypothetical development scenarios for a 144 km^2 paddock.

4.5 Discussion

4.5.1.1 Uniformity of grazing

The grazing distribution component of this project had the aim of testing different infrastructure developments in achieving more effective (and more uniform) use of the pasture by grazing cattle. More uniform grazing use was expected to improve the sustainability of grazing and potentially allow increase in stocking rates. A key hypothesis in the study was that smaller paddocks result in more even grazing across paddocks, potentially reducing the development of heavily grazed areas. However, in view of the high cost of fencing for subdividing large paddocks, we were also interested in whether installing additional water points in large paddocks is as effective as reducing paddock size in improving the uniformity of grazing.

Our results suggest that reducing paddock size is more effective in achieving relatively uniform use across a paddock than installing additional waters in large paddocks (based on the GPS collar data). Overall, we had only limited success in increasing the effectiveness of pasture utilisation by cattle in large paddocks by simply adding additional water points. We found no marked or consistent effect (either positive or negative) of the different paddock configurations on the pasture, livestock production or financial performance. However, all of the paddock configurations used in the study were more financially rewarding than a traditional commercial system because of the additional livestock that could be carried following development (current commercial stocking rate of 10 AE/km^2 compared with developed stocking rate of 13-14 AE/km^2 - see Table 4.22 and Section 3.4.5.13).

While smaller paddocks were effective in achieving more effective use of the landscape overall, uneven grazing continued to occur at the patch scale in the smallest paddock. This finding highlights the importance of using management tools that operate at the correct scale of impact to alter grazing behaviour. In our case, we attempted to alter the uniformity of grazing at the patch scale using infrastructure developments, which largely operate at the landscape scale. Additional management techniques such as the strategic use of fire and lick blocks should be considered to further improve grazing distribution in subdivided paddocks.

It is also important to consider what degree of uniformity of grazing within paddocks can realistically be expected. Some pasture types, such as dense stands of annual sorghum (*Sarga timorense*), have very little forage value for livestock and are largely avoided by cattle. There would seem little point in expecting these areas to be utilised to the same extent as more preferred pasture types. A realistic aim in managing grazing distribution therefore should be for relatively even use of preferred pasture types (at sustainable utilisation rates) within a paddock. To do this effectively will require an assessment of the area of a paddock supporting useful pasture types and for stocking rates to be set on that basis rather than on the total paddock area.

At the outset of the project we assumed that by making areas that had been remote from water more easily accessible cattle would use those areas because of the virtually untouched forage available in those areas. This occurred to some extent but less than expected. The cattle tended to concentrate on the areas closer to water and once the structure of the pasture was modified (reducing the amount of rank, stemmy material) it appeared they continued to use these areas repeatedly. This was despite these areas now having lower pasture yields and there being areas supporting higher palatable pasture biomass within grazing range. The cattle appeared to use areas with higher levels of palatable pasture biomass only sporadically, presumably selecting only the most palatable and nutritious species available (annual forbs and grasses). Manipulating the structure of the pasture sward therefore seems to be an important element of improving grazing distribution. Burning long ungrazed pasture to remove the build-up of rank, stemmy material (followed by rest to allow some pasture recovery) should help in improving grazing distribution in newly watered areas.

The study provided some insights in relation to the four hypotheses it was intended to address.

Hypothesis 1: There is an optimum maximum distance to water for evenness of use and land condition.

This hypothesis confuses two separate issues – evenness of use within paddocks and effectiveness of use of the landscape. The study suggested that if considering evenness of use on its own, there was no optimum distance to water. Evenness of use appears to continue to improve as paddock size decreases, although entirely even use is never likely. This conclusion is based on the GPS collar data, since the pasture suggested no difference amongst paddocks over the relatively short term and favourable seasons of this study. However, we were able to recommend an optimum distance between water points (~5 km) and optimum paddock size (30-

40 km^2) based on considerations of effectiveness of use of the landscape and the cost of infrastructure (see section 4.5.1.4 below). An important aspect to maintain good land condition appears to be limiting the number of head per water point to no more than 300 (which has implications for the number of waters and paddock size at a given stocking rate).

Hypothesis 2: There is an optimum maximum distance to water for animal production.

Our data suggested there was no effect of distance to water on livestock production. However, an optimum maximum distance to water may exist where higher levels of utilisation than those in this study are used.

Hypothesis 3: Increasing spatial scale and landscape diversity reduces coupling between utilisation rate and animal production per head such that the usual linear decline in animal production per head with increasing utilisation rate observed at small spatial scales is dampened at large spatial scales.

The study failed to demonstrate that there was a 'spatial buffering' benefit for livestock production from using larger paddocks. No consistent difference in livestock production was apparent amongst the different treatments (paddock configurations). The study design did not allow us to explicitly assess the effect of increasing spatial scale on the relationship between individual livestock production and pasture utilisation rates.

Hypothesis 4: Increasing landscape diversity will result in more uneven use and more land in poor condition (independent of distance to water).

We were unable to provide a definitive answer to this question. However, the Multiple waters paddocks (which was the largest and most diverse of the developed paddocks) showed the most uneven distribution of cattle activity of all of the paddocks.

A word of caution is warranted in relation to the long-term relevance of the findings. Although there were no strong effects of the different paddock configurations in altering the variability (evenness) of defoliation (and other pasture variables) within paddocks, these effects may be slow to emerge and are difficult to measure at coarse scales. Thus, our findings might reflect the lag in grazing effects flowing through to the pasture that can be a feature of these ecosystems, particularly given the relatively favourable seasons we experienced, rather than the ineffectiveness of the treatments. The inherent variability between the paddocks may also confound this effect and mask treatment effects.

4.5.1.2 Understanding and predicting grazing distribution

Pasture class, soil type and distance to water all influenced the distribution of cattle activity within the study paddocks. Areas dominated by palatable perennial grasses or with high yields of palatable pasture species were not necessarily strongly favoured by cattle. Instead areas in intermediate condition with lower biomasses of total and palatable pasture were favoured. Similar results have been reported elsewhere (Houliston *et al*. 1996, Post *et al*. 2006). Land in good and poor condition tended to be avoided. While soil type was apparently important according to the results of the modelling, the preference indices suggest it is not necessarily a strong determinant of landscape use by cattle. However, black soils were avoided to some extent during the wet season. Differences between the study paddocks in the proportion and location of different soil types and their location relative to the water points potentially affected the apparent preferences for different soil types. It can also affect the degree to which preferred soils are subjected to heavy grazing. For example, small areas of red soil in a paddock with large areas of black soils are likely to experience utilisation rates well in excess of the intended utilisation rate for the paddock during the wet season.

Overall, the results suggest that proximity to water and the re-use of previously grazed areas were important determinants of grazing distribution in the study paddocks. As discussed earlier, cattle often prefer areas with a history of grazing because the quality of regrowing pasture can be higher in these areas. Cattle select for pastures that have a higher leaf:stem ratio, and also trade-off pasture quantity for quality (Wallis de Vries and Daleboudt 1994). Consequently, they tend to avoid areas with high pasture biomass (where pasture quality is often lower) and ungrazed perennial grasses that have become stemmy. This behaviour appeared to be a key factor in limiting the success of smaller paddocks and (especially) additional water points in improving the distribution of grazing. The self-sustaining nature of cattle grazing patterns, whereby livestock repeatedly use the same areas, is widely recognised (Ganskopp and Bohnert 2006). A key to altering grazing distribution is to break these feedback mechanisms.

These findings are in contrast to the situation with sheep in the southern chenopod rangelands where the animals spend less time in areas that have been grazed out (Stafford Smith 1990). This response probably reflects the more arid conditions and poor regrowth response of heavily grazed pasture in more arid areas. In the tropics, regrowth of perennial grasses and, over the longer term, an increase in forb species following the loss of perennial grasses, are thought to contribute to the attractiveness of previously grazed areas. Forb species can be a more nutritious component of cattle diets than grasses, especially during the dry season Ash *et al*. (1995), and this may lead to cattle seeking out these species.

Structure of the pasture is a key factor in the attractiveness of certain areas to large herbivores (Owen-Smith 2002). The structure of the vegetation can affect bite size, which is a primary determinant of intake rate (Allden and Whittaker 1970, Stobbs 1973, Owen-Smith 2002) and therefore can affect choice of grazing site. Pastures that are too short or too tall are expected to reduce intake rate. In this study we did not assess pasture structure, although it can be inferred to some extent (i.e. the shorter, more open swards associated with grazed patches compared to the stemmy perennials in areas that are rarely grazed). Future studies of grazing distribution should consider assessing pasture structure. Including structure as a predictor variable in models of grazing distribution might also improve the explanatory power of the models. Manipulating the structure of pasture is also likely to be a powerful way of altering grazing distribution, as this operates at the appropriate scale of impact. Fire, for example, can quickly change the pasture from a tall stemmy pasture to a short pasture with a higher leaf:stem ratio.

The finding that cattle home ranges are larger in the wet season than the dry season supports the conclusion that distance to water is an important determinant of grazing distribution. Increased availability of water in creeks and puddles during the wet season would appear to decrease reliance on artificial water sources. This is contrary to the expectation that home ranges would be larger during the dry season as cattle venture further from heavily grazed areas near water in search of more abundant and nutritious forage. Spatial buffering of declines in forage quality whereby cattle graze areas not usually utilised has been suggested as an important mechanism in maintaining intake and livestock production during the dry season. However, smaller home ranges during the dry season suggest that cattle are not venturing further into areas that are usually not grazed. The possibility remains that the area in which grazing activity is focused might change in the dry season, although there was no evidence of this occurring.

Developing a computer-based decision support tool that can be used to model grazing distribution and the effect of different management techniques would be a useful tool to aid pastoralists. This study identified a number of factors that are important in determining grazing patterns, and might be of potential use in predictive models of grazing distribution for this region. However, the wider application of these models across northern Australia might be limited. Attempts elsewhere to develop general predictive models of grazing distribution and apply them in other grazing systems and areas have shown that the models are usually highly location specific. Although they can reliably predict grazing distribution at the sites from which the original data arises, the models usually perform poorly in other locations.

The likelihood of developing good predictive models of grazing distribution might be enhanced if the location of grazing activity within paddocks could be better discriminated from other activities such as resting and travelling. The activity calibration for the GPS fix data at Pigeon Hole suggested a reasonable ability to correctly identify the dominant activity associated with each GPS fix (approximately 70% correct). However, given that GPS fixes were recorded hourly, and the activity sensors are averaged over five minute periods and then for the hour, it is possible much information on activity budgets was ‘lost’. Better discrimination might be possible with shorter fix intervals, but this would require collars to be retrieved more frequently than the six monthly intervals in this study.

4.5.1.3 Diurnal activity patterns of cattle

Daily activity budgets of cattle were broadly similar to those reported in central Australia (Low *et al*. 1981), although cattle at Pigeon Hole generally spent slightly less time grazing and travelling and about 10% more of each day resting compared to Shorthorn cattle in central Australia. There was a surprising similarity between paddocks in the distance cattle walked each day despite the mean distance to water differing. Increasing the number of waters in large paddocks appeared to marginally reduce the distance cattle travelled compared with larger paddocks without additional water points. For example the distance walked in Two waters and Multiple waters was approximately 5500 m per day compared with about 7000 m per day in GR3 (only one water).

Cattle spend most of the daylight hours loitering near a water-point regardless of paddock size. Late in the day they rapidly move to areas some distance from water to graze during hours of darkness. Early the following day they return to the water point in a quite directed fashion, with little grazing apparently occurring on the way. Often their night-time grazing is confined to a small area, with cattle returning to the same general area on successive nights. However, there is usually some point when this pattern of use changes, at least to the extent that other parts of a paddock become preferred grazing areas.

4.5.1.4 Recommended paddock configuration

Some broad recommendations for the use of infrastructure to improve grazing distribution are possible from this study. The study failed to demonstrate that there was a ‘spatial buffering’ benefit for livestock production from using larger paddocks. It also demonstrated that although smaller paddocks improved over-all grazing use of the landscape, uneven use still occurred within smaller paddocks. The cost of fencing also escalates rapidly when subdividing into paddocks below about 40 km^2. Recommendations for the optimum paddock configuration are therefore made on the basis of a compromise between the cost of development and the effectiveness of improving grazing distribution. However, some adaptation of these recommendations to suit local circumstances and individual properties will be needed, and pastoralists are best-placed to do this.

The recommended paddock configuration for improving grazing distribution on extensive northern beef properties is:

1) Paddock size of 30-40 sq. km.
2) If possible, paddocks of this size should contain two evenly-spaced water points.
3) When positioning fences and water points consideration should be given to the location of land and pasture characteristics. In particular, to maximise the use of a paddock water points should be located away from areas that have a history of grazing (and thus have altered plant species composition).

This configuration would mean there are about 250-300 head per water point at a pasture utilisation rate of 20% in the VRD (assuming a stocking rate of 15 AE/km^2). This setup should provide the added benefit of ease of mustering. At recommended stocking rates, the number of cattle in these paddocks would also be a convenient number for processing through the yards in a single day at mustering rounds.

To further improve grazing distribution within these paddocks, additional techniques such as the strategic placement of lick blocks and the use of fire should be employed.

Because of the high cost for fences and water points, it is probable that many producers will opt for installing additional waters in large paddocks rather than subdividing them. While adding more waters does improve the use of the landscape, cattle still have considerable freedom to choose where they graze, and heavy use of preferred areas will continue. Again, incorporating other tools (as described above) should be considered to further improve grazing distribution.

Where additional waters are installed in larger paddocks, water points should be approximately 5 km apart and should not exceed 6 km (i.e. grazing radii should not exceed about 3 km). Grazing radii that exceed this appear to result in a considerable area of a paddock not being grazed to any extent. GPS collar data from this study suggested the mean distance cattle ventured from water in the large paddocks was approximately 1.4 km (although nominal grazing radii were about 2-4.5 km). As an approximate rule of thumb, there should be one water point for each 20-25 sq. km of a paddock. Ideally, to minimise the rate of growth of the sacrifice area around water points the number of head per water point should not exceed 300.

As well as improving grazing distribution, the other benefits of using smaller paddocks should be considered when deciding between the two options of subdividing or only adding more waters in larger paddocks. Smaller paddocks offer better control and segregation of cattle which offers the potential for significant improvements to reproduction and genetics (e.g. controlled mating, targeted management of first-calf heifers, targeted management of cows in poor condition) and supplementation efficiency (e.g. targeted feeding of certain classes of animal).

4.5.1.5 Issues requiring further research

To further enhance our ability to manage grazing distribution future research should investigate the strategic use of fire and feed supplements. An important part of this is the development of recommendations for practical systems of managing cattle and paddocks on a property to allow improvement in grazing distribution and the effective use of forage. Incorporating such strategies with the need for wet season spelling may be a profitable avenue to explore.

As mentioned above, the development of generic, widely applicable predictive models of grazing distribution has been unsuccessful. Most models prove to be very location specific. However, such a tool would greatly benefit producers and their advisers in devising strategies for managing grazing distribution. The most useful approach to this would appear to be an ‘expert-knowledge’ based model (perhaps using a Bayesian framework), rather than a detailed mechanistic model. This reflects the inexact nature of the science of grazing distribution and the objective of broad improvements in the management of grazing distribution, rather than expecting a precise outcome. A knowledge based approach would incorporate general relationships describing foraging behaviour with local knowledge provided by managers and extension agents from the region of interest. Incorporating local knowledge of grazing behaviour and the idiosyncrasies of particular grazing systems and locations should provide a more useful tool to aid the management of grazing distribution. These tools should allow the testing of different scenarios involving alternative paddock configurations and the use of other tools such as fire.

Further work might also be warranted in some rangeland types to better define the characteristics of the areas that cattle appear to graze preferentially in order to develop decision support models. In future work, pasture structure variables should be measured as this can be a primary driver of grazing distribution.

5 Grazing systems

5.1 Key messages

- In this experiment four grazing systems were compared. These were set stocking, set utilisation at 20% (annual), wet season spelling and cell grazing.
- All grazing management systems averaged around 20% utilisation. There were no marked differences in pasture condition and livestock performance between the systems indicating 20% utilisation is a suitable utilisation rate in the short-term.
- Set pasture utilisation at an annual rate of 20% was the best performing system in economic terms and appeared to have no adverse effects on land condition during the study.
- Despite greater total production, cell grazing was the least profitable system due to the additional capital and operational costs.
- Despite wet season spelling showing potential to marginally improve livestock production above that of set stocking due to better weight gains, the improvement in livestock performance did not flow through to improved economic performance because of the greater capital and management costs associated with the system (as implemented in this study).
- Wet season spelling did not produce any significant improvement in pasture condition against expectations.

5.2 Introduction

Set stocking is the standard grazing practice in extensive grazing areas across northern Australia and is used on one-third of the properties in the Katherine region (Oxley 2004). However, as mentioned in section 1.4.3, there are a number of problems associated with set stocking. These include uneven grazing distribution, patch grazing (Mott 1987) and localised overgrazing due to the large paddocks and heterogeneous landscapes typical of northern Australia, and over-grazing in poor seasons if stock numbers are unaltered.

The overall aim of the grazing systems study was to assess whether some systems can generate higher levels of livestock production whilst maintaining good land condition. Improvements in livestock production might be expected if a grazing system results in more spatially uniform grazing use than occurs under conventional continuous grazing and this allows the use of higher pasture utilisation rates and hence stocking rates. Alternatively, a system could improve pasture condition by encouraging palatable perennial grasses, thereby enhancing the productivity and sustainability of the pasture. Four grazing systems were compared in this study. In two systems paddocks were grazed year-round, and two systems incorporated pasture spelling with livestock rotation through multiple paddocks. The systems were:

- set stocking (continuous grazing at a set stocking rate);
- set utilisation (continuous grazing at a set pasture utilisation rate);
- wet season spelling (pastures being spelled for part of the wet season);
- cell grazing (high stocking density with rapid rotation of the herd around a series of very small paddocks).

Set stocking was included in the study to provide a basis for comparing the other systems since it is standard industry practice in the VRD. The other systems were selected because they were considered to have potential to improve livestock production and pasture condition, they are generally simple systems and their adoption requires minimal changes to infrastructure (with the exception of cell grazing where management and infrastructure requirements are much greater).

Set utilisation aims to maximise the likelihood of palatable perennial grass persistence by maintaining a safe level of pasture utilisation in all years, and thus minimise the risk of overgrazing in poor seasons (Hunt 2008).

Wet season spelling is expected to benefit the pasture during the periods without grazing. Early wet season spelling is reported to encourage vigorous growth and reduce the death of perennial grass plants and tillers from overgrazing when they are especially sensitive to defoliation soon after the recommencement of growth following dry season dormancy (Ash *et al.* 1997). Late wet season spelling is reported to further encourage perennial grass vigour and benefit reproductive capacity through improved flowering and seed set. Possible increases in carrying capacity have also been reported for northern Queensland pastures using wet season spelling (Ash *et al.* 2001) and pasture condition was maintained without necessarily requiring significant capital investment in infrastructure.

5.3 Methods

5.3.1 Description and management of the grazing systems

Details of the four systems studied are as follows. Each system was applied to a single paddock or group of paddocks (i.e. systems were not replicated).

<u>Set stocking</u>: The set stocking (SS) system involved continuous grazing with a set target stocking rate. The intended stocking rate and annual pasture utilisation rate were 18 AE/km^2 and 20% respectively. These are approximately double current industry averages but grazing at these rates was shown to be sustainable in the first phase of the Mt Sanford study (Cowley *et al.* 2007). However, in this study set stocking was implemented in a smaller paddock (21 km^2) than is customary in the region (average 130 km^2; Oxley 2004), although of a similar size to paddocks used for the other grazing systems in the study (see Fig. 2.2 for allocation of grazing systems to paddocks). Calves born during the year were not included in stocking rate calculations, and calves were weaned after attaining weaning weight. Breeders were culled and numbers were re-adjusted usually at the first round muster (April). As the study progressed, stocking rates in this treatment varied more than originally anticipated as the station managers responded to poor and above-average seasons by decreasing and increasing stocking rates, respectively.

<u>Set utilisation</u> *(of standing feed)*: This system (referred to as U20%) aimed for 20% utilisation of wet season pasture production over the 12-month period following each wet season. This was achieved by adjusting livestock numbers often at the first round muster each year, but also during the dry season, according to estimated pasture production during the preceding wet season. The U20% paddock was 21 km^2.

<u>Wet season spelling</u>: The wet season spelling (WSS) system used a group of three paddocks (each 5 km^2) and rotated a single herd of cattle through them. Access to each paddock was through a gate in a fenced central watering area, which allowed individual paddocks to be closed for spelling (see Fig. 2.2). The spelling regime proceeded as follows. During year one, paddock A was spelled for the early wet season, paddock B for the late wet season and all paddocks were grazed during the dry season. During year two, paddock B was spelled for the early wet season, paddock C for the late wet season and all paddocks were grazed during the dry. In the third year, paddock C was spelled for the early wet season, paddock A for the late wet season and all paddocks were grazed during the dry. Thus, over three years, each paddock received both an early and late wet season spelling (Table 5.1). Removal of cattle from the paddock to be spelled late and opening up of the early spelled paddock to grazing was determined by levels of pasture growth in both paddocks. This decision was based on the intention to achieve an average annual pasture utilisation rate over the study of 25% (calculated on the basis of standing forage at the end of the wet season).

Table 5.1. Wet season spelling details: dates of early and late spelling periods, paddocks spelled (A, B, C), duration of the spelling period, rainfall during the spelling period, and rainfall during the spelling period as a percentage of the wet season total.

	2003-04	2004-05	2005-06	2006-07
Early spelling start (and paddock)	Dec 10 (**A**)	Nov 4 (**B**)	Sep 25 (**C**)	Nov 25 (**A**)
Early spelling finish	Mar 23	Mar 24	Feb 3	Feb 21
Duration (days)	104	140	132	89
Rainfall (mm) (% of rainy season total)	768 (95%)	619 (100%)	724 (69%)	324 (60%)
Late spelling start (and paddock)	Mar 23 (**B**)	Mar 24 (**C**)	Feb 3 (**A**)	Feb 21 (**B**)
Late spelling finish	May 14	Apr 29	Apr 13	Apr 14
Duration (days)	52	36	69	53
Rainfall (mm) (% of rainy season total)	43 (5%)	0 (0%)	164 (16%)	234 (43%)

Cell grazing: Cell grazing (CG) used a time control grazing system with high stock densities for short durations. The short grazing periods were interspersed with longer spelling times, and both were reduced in the wet season (Table 5.2). Based on recommendations from Resource Consulting Services, a keen advocate of cell grazing, a single herd of cattle was rotated through 25 small paddocks (70 to 168 ha) in a wagon-wheel arrangement around five watering points (see Fig. 2.3). The total cell grazing area was 31 km^2. All paddocks around a water point were grazed before cattle were moved to the next group of paddocks. Rotations were based on estimates of pasture biomass and growth stage in both the paddocks the cattle were being moved from and to. Intended average annual utilisation rate over the study was 50%. The cell grazing system was discontinued in November 2006, one year before the other systems.

Table 5.2. The average number of times the paddocks in the cell grazing system were grazed in each wet and dry season, and the average length of the grazing and spelling periods (in days).

	Dry season 2004	Wet season 2004-05	Dry season 2005	Wet season 2005-06	Dry season 2006
Number of times grazed	0.7	2.6	1.1	2.4	1.8
Grazing period (days)	9	3	5	4	5
Spelling period (days)	123	37	102	46	125

A ‘control’ paddock for the cell grazing system (referred to as cell grazing control or CGC) was also included in the study. This was a 1.9 km^2 paddock managed as a set-stocked system with a similar stocking rate to the cell grazing system.

Each grazing system was run as a commercial operation with the managers of Pigeon Hole station making the decisions on stocking rates and times for grazing, spelling and rotation. These decisions were made within a broad framework for each system decided by the project technical advisory team.

5.3.2 Actual stocking and pasture utilisation rates

The achieved stocking and pasture utilisation rates were quite variable and differed from those originally proposed, in part because data on standing pasture biomass were not available until after the first round muster when cattle numbers were usually adjusted. As mentioned earlier, stock numbers were instead based on a pasture production prediction from the GRASP pasture growth model (Littleboy and McKeon 1997). To ensure desired utilisation rates were not exceeded, cattle numbers returned were generally the same as that removed or fewer. Field pasture biomass estimates were subsequently used to adjust cattle numbers before the end of the dry season muster according to the desired annual pasture utilisation rate. Fig. 5.1 and Table 5.3 present actual stocking rates and utilisation rates for the different grazing systems.

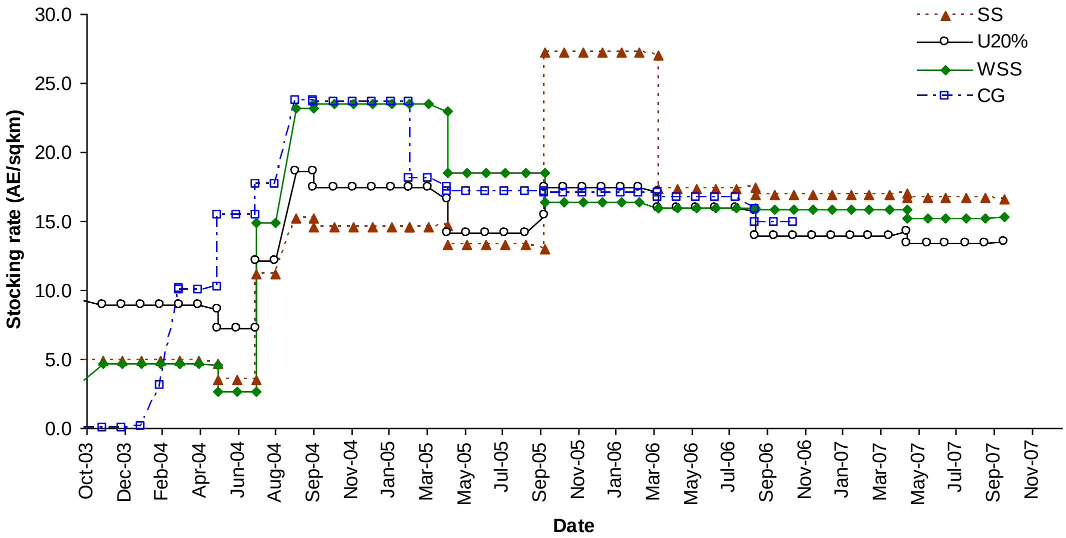


Fig. 5.1. Monthly stocking rates (AE/km^2) in the set stocking (SS), 20% set utilisation (U20%), wet season spelling (WSS) and cell grazing (CG) systems.

Table 5.3. Stocking rates (AE/km^2) between October to April musters (wet season) and May to October musters (dry season) and annual utilisation rates* (%) for the wet season year (from the start of one wet season to the start of the next wet season) for the grazing systems set stocking (SS), 20% set utilisation (U20%), wet season spelling (WSS) and cell grazing (CG).

		Stocking rate (AE/km^2)					Utilisation rate (%)				
Grazing system	Period	2004	2005	2006	2007	Ave	2004	2005	2006	2007	Ave
SS	Oct-Apr	4.9	14.6	27.2	16.9						
	May-Oct	9.0	13.2	17.3	16.7						
	Year	8.2	14.9	20.4	16.3	14.7	9	16	31	29	21
U20%	Oct-Apr	8.9	17.3	17.4	14.0						
	May-Oct	11.9	14.4	15.9	13.4						
	Year	11.3	15.7	15.7	13.6	13.9	11	15	22	20	17
WSS	Oct-Apr	4.6	23.5	16.3	15.9						
	May-Sep	12.0	18.5	15.9	15.2						
	Year	10.5	19.3	15.4	14.8	14.5	14	22	24	30	22
CG	Oct-Apr	4.8	21.7	17.0	11.6						
	May-Sep	18.5	17.2	16.1							
	Year	19.5	18.8	16.1		18.1	15	21	21	#21	20

*Note: Utilisation rate takes account of DMD (from NIRS), and a 15% increase in intake due to dietary supplementation.
#Utilisation rate adjusted for the time the study animals were in the paddock only.

5.3.3 Land type

On-ground assessments during the pasture surveys indicated black soil was the dominant land type (67% to 87% of each paddock), and creek lines were least represented (2% to 7%; Fig. 5.2) in the grazing system paddocks. The cell grazing and set stocking paddocks were the most alike of the grazing systems, but there was a significant difference between the set utilisation and wet season spelling paddocks in the proportion of different land types (χ^2 homogeneity test, χ^2=840.3, d.f.=12, P<0.001).

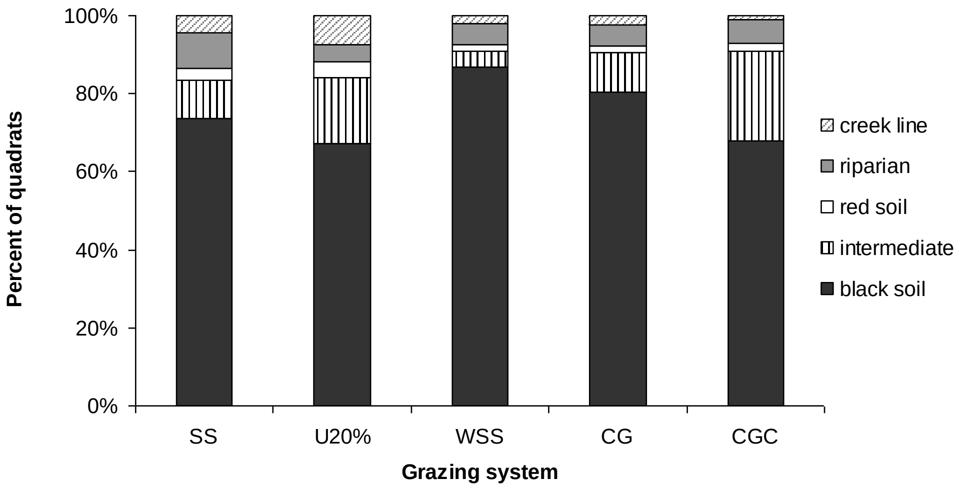


Fig. 5.2. Percentage of each land type present in the set stocking (SS), 20% set utilisation (U20%), wet season spelling (WSS), cell grazing (CG) paddocks and in the cell grazing control (CGC).

5.3.4 Fire

Fires started by lightning burnt substantial portions of the paddocks prior to or during the study. Fire can have a marked effect on the pasture and hence animal production, and have the potential to confound the results of the study. Table 5.4 presents the details of fires recorded before or during the study and the percentage of sampling quadrats burnt in the grazing system paddocks.

Table 5.4. Wildfire occurrence and the percentage of quadrats burnt in the set stocking (SS), 20% set utilisation (U20%), wet season spelling (WSS) and cell grazing (CG) paddocks.

Date	Season	Grazing system			
		SS	U20%	WSS	CG
Oct 2001	Dry	42%	100%		70%
Nov 2002	Dry	66%	28%	99%	7%
Nov 2004	Dry				21%
Dec 2004	Wet		9%		
Dec 2006	Dry		19%		

5.3.5 Data collection and analysis

The effects of grazing system on livestock performance, pasture attributes and productivity, and dietary quality were statistically analysed according to the methods described in Chapter 2.

In addition, repeated measures ANOVAs (often with transformed data) were used to test differences between species and functional groups and analysis of co-variance tested distance from water trends using SS as the comparative reference and distance to water as the covariate.

5.4 Results

5.4.1 Pastures

5.4.1.1 Yield

May pasture yields differed significantly amongst grazing systems and years (both $P<0.001$). However all systems showed very similar trends between years (Fig. 5.3) and the year x grazing system effect was not significant ($P=0.067$). This suggests there were inherent differences in pasture yield amongst the grazing system paddocks, but that grazing system (and the stocking rates imposed on each) was having no effect on pasture yield.

The annual variation in yield appeared to be positively related to rainfall (see Table 2.1 for rainfall). However, the 2005-06 wet season was long (193 days, which exceeds the 70 to 102 days required for good pasture growth; Cobiac 2001) and received well above average rainfall. Nevertheless, yields in U20%, WSS and SS were similar to the previous year, and CG was the only system showing an increase suggesting plants were possibly able to take advantage of the extended wet season.

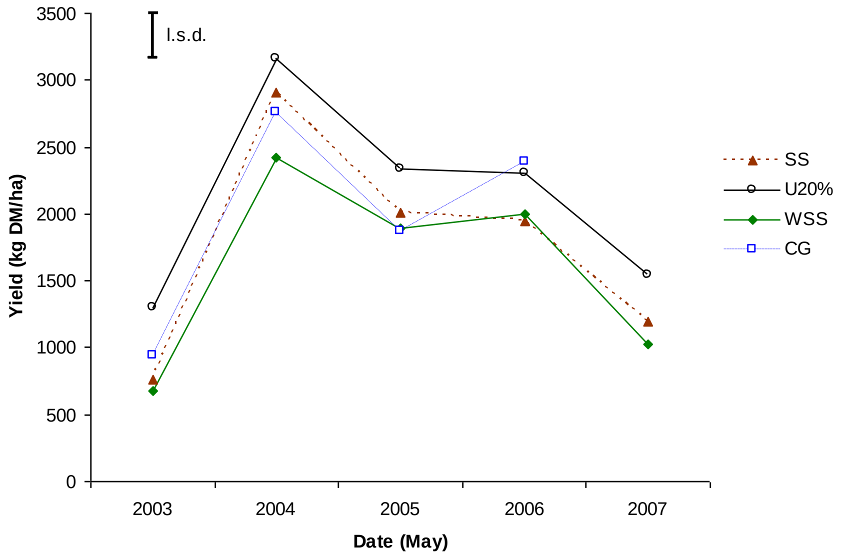


Fig. 5.3. May pasture yields (kg DM/ha), (mean with average least significant difference, l.s.d; *P*<0.05) for the grazing systems set stocking (SS), 20% set utilisation (U20%), wet season spelling (WSS) and cell grazing (CG).

5.4.1.2 Ground cover

Cover in May was significantly different for grazing treatments, years and year x treatment (all P<0.001). The results suggest that although there were initial differences amongst grazing system paddocks, an effect of grazing system (or other factors such as fire or differential grazing pressure) emerged during the study (Fig. 5.4). The significant interaction term can largely be attributed to WSS, where cover increased 32%, from the lowest in 2003 to the highest in 2007. Also, cover in U20% decreased from the greatest at the start to near the lowest in 2007, due to wildfire (Fig. 5.4). The increased cover observed in WSS agrees with the findings of Jacobo *et al.* (2006) that the amount of bare soil decreases in rotational systems, but the initial low cover in May 2003 due to wildfire (Table 5.4) might have exaggerated the perceived benefit of WSS.

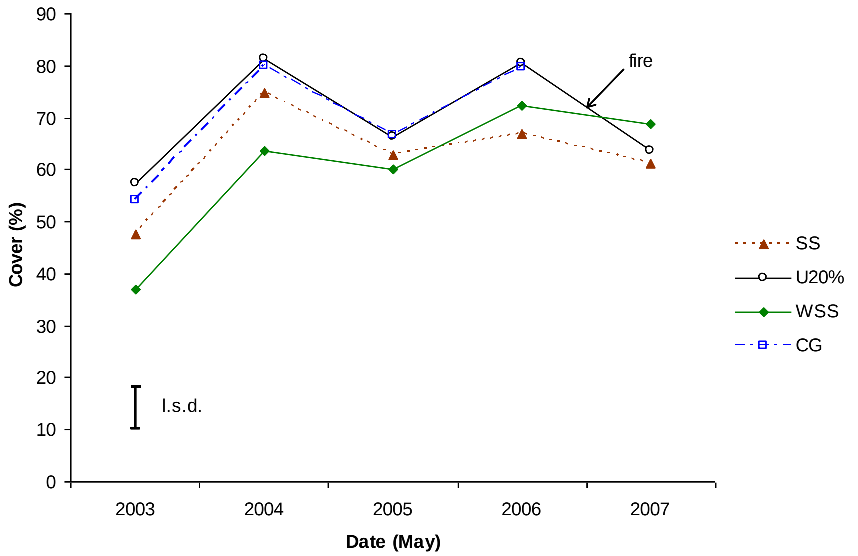


Fig. 5.4. May cover (%) (mean with average least significant difference, l.s.d: P<0.05) for the grazing systems set stocking (SS), 20% set utilisation (U20%), wet season spelling (WSS) and cell grazing (CG). Note that approximately 19% of the U20% paddock was burnt in December 2006.

5.4.1.3 Perennial grass basal area

There was no significant year x treatment effect (*P*=0.290) on perennial grass basal area (PGBA) amongst the grazing systems (Fig. 5.5), indicating that grazing system had no effect on PGBA. PGBA was generally low (maximum of 1.40%) compared to a mean of 2.57% reported for the VRD (Cobiac 2001). There appeared to be a weak trend of declining PGBA over the study. There was a significant difference amongst the grazing treatments (*P* <0.001) and years (*P*=0.003). PGBA was significantly higher in U20% than WSS at the start of the study and higher than all other systems at the end study. Change in PGBA is acknowledged as a sensitive indicator of pasture sustainability and vigour under grazing (Briske and Hendrickson 1998, Fuhlendorf *et al.* 2001, McIvor 2007).

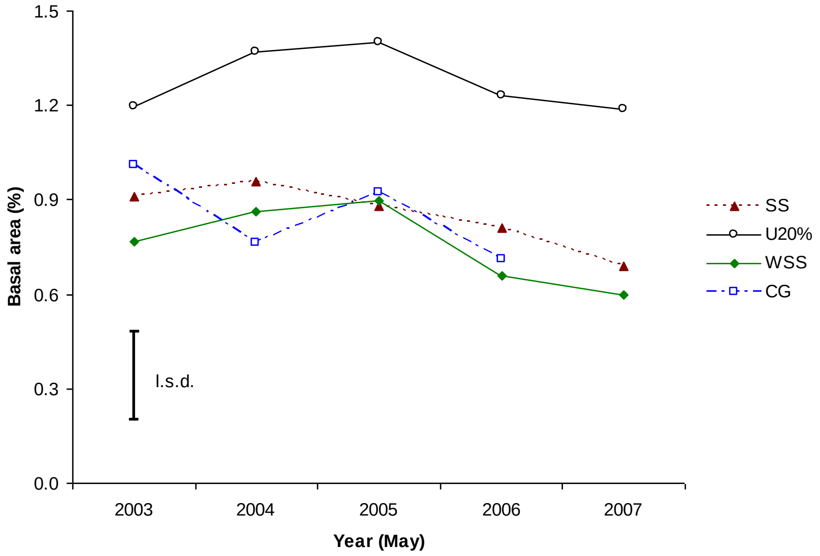


Fig. 5.5. Perennial grass basal areas (%) for May (mean with average least significant difference, l.s.d: P<0.05) for the grazing systems set stocking (SS), 20% set utilisation (U20%), wet season spelling (WSS) and cell grazing (CG).

5.4.1.4 Defoliation

There was a general trend of increasing defoliation over the years of the study. Defoliation levels were not significantly different amongst grazing systems in the first two years and the final year, but defoliation was lower in cell grazing in 2006 than in set stocking. There was a significant year x grazing system interaction (*P*=0.001) (Fig. 5.6). This can be attributed to the increase in defoliation in WSS in each year and the decrease in cell grazing relative to the other treatments in 2006. The result for U20% in the final year was likely influenced by the December 2006 fire which burnt 19% of the paddock.

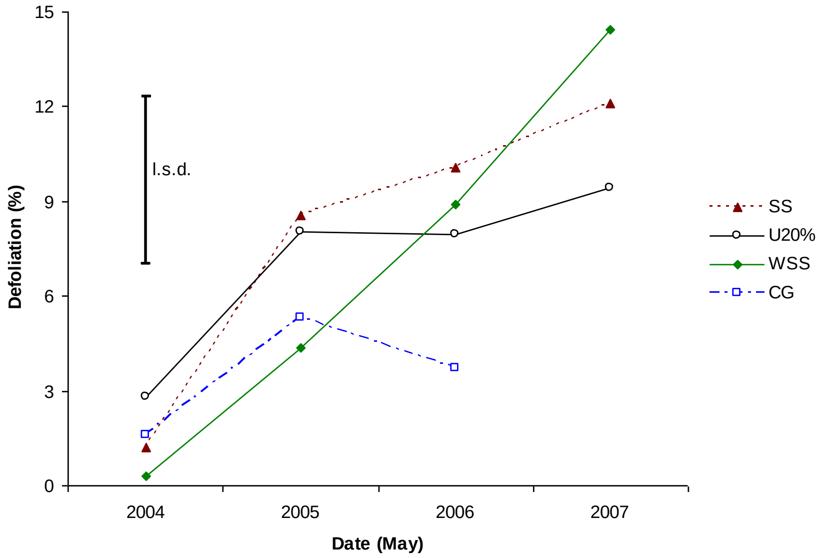


Fig. 5.6. Defoliation rates (%) for May (mean with average least significant difference, l.s.d: $P<0.05$) for the grazing systems set stocking (SS), 20% set utilisation (U20%), wet season spelling (WSS) and cell grazing (CG).

5.4.1.5 Species composition

Comparison of species composition showed marked initial differences amongst some of the treatments (evident by separation of paddocks in the ordination; Fig. 5.7). There was greater variation in composition among treatments (ANOSIM R = 0.541, P = 0.001) than amongst years (ANOSIM R = 0.191, P = 0.036). There was no marked divergence of treatments over time, although cell grazing appeared to show a more consistent directional shift over time that was not apparent for the other treatments. While the initial differences in species composition amongst treatments complicate the interpretation, these results suggest there was little effect of grazing system on species composition during the study, except perhaps for cell grazing, but this was likely due to paddock differences.

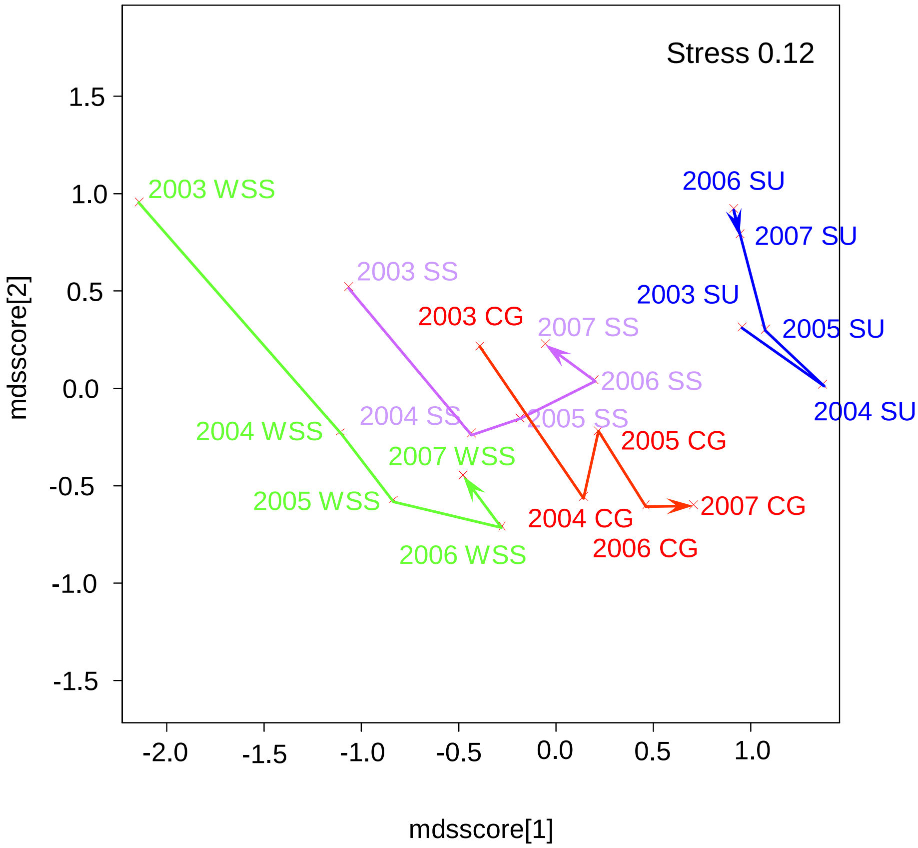


Fig. 5.7. Ordination (non-metric Multidimensional scaling) of species composition over time based on percent composition by weight for the grazing system treatments. WSS = wet season spelling, SS = set stocking, CG = cell grazing, SU = 20% set utilisation.

5.4.1.6 Summary

Total yield, ground cover, perennial grass basal area, species composition and defoliation did not exhibit any definitive trends which could be attributed to the different grazing systems. While significant year x grazing system differences were observed for cover and defoliation, interpretation was confounded mainly by wildfire, with initial paddock differences and management issues (discussed later) adding further complexity. Nevertheless, the lack of significant change implies that the different grazing systems were not producing marked effects on the pasture in the short term. The initial differences between the paddocks and annual variation in rainfall appeared to have a larger effect on some of the pasture attributes than the grazing systems.

5.4.2 Livestock production

5.4.2.1 Diet quality

There were no significant differences in mean annual dietary CP% (*P*=0.560) (Fig. 5.8), dietary non-grass material (*P*=0.286) and IVDMD (*P*=0.890) for the different grazing systems. Overall CP% means were CG 5.4%, U20% 5.9%, SS 6.0%, WSS 6.1%, with maxima occurring early in the wet seasons. Peaks ranged from 12.8% for U20% to 10.7% for WSS in Jan/Feb 2007, and for CG a relatively low peak, 7.6% in Mar 2006. Dietary non-grass means for the different grazing systems ranged from 26.5% for WSS to 22% for U20%. Between-year variations were large, from lows of around 4% to highs of 50%. The proportion of non-grass material was higher in dry seasons (26.5%) than wet seasons (19.5% mean). All grazing systems showed similar temporal trends in IVDMD, with the lowest values in the early dry season (e.g. 40% for U20% in April 2006) and highest in the early wet season (e.g. around 60% in 2006-07).

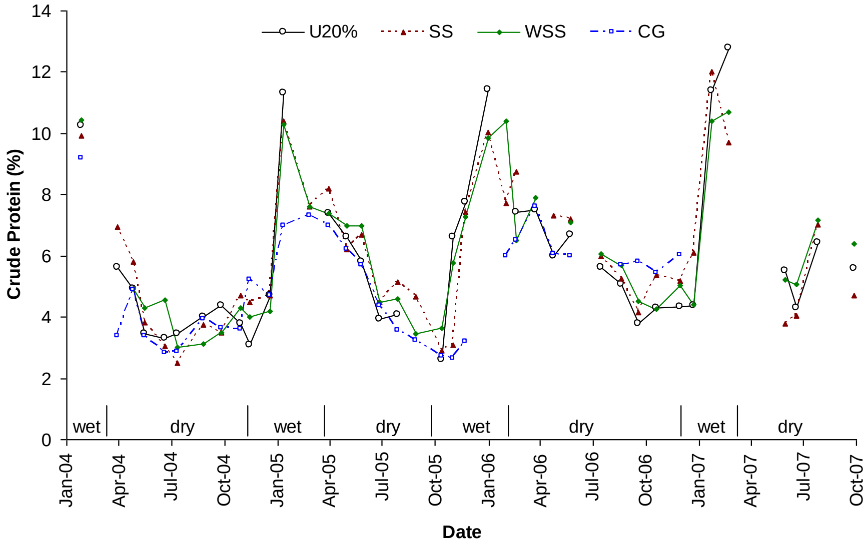


Fig. 5.8. Faecal NIRS predictions of dietary crude protein (CP%) for cattle in set stocking (SS), 20% set utilisation (U20%), wet season spelling (WSS) and cell grazing (CG) grazing systems.

5.4.2.2 Mortalities

Grazing system had no effect on annual mortality rates averaged over the trial. Annual breeder mortality rates for all grazing systems were around 1%, much lower than the averages of 2.1% to 3.0% reported for the VRD (Cobiac 2006b, Oxley 2004).

5.4.2.3 Grower liveweights

There was a significant year x grazing systems effect (*P*<0.001) for daily liveweight gains of grower cattle (Fig. 5.9), but there was no consistent trend amongst the systems. Instead all systems were variable over time. For example, in October 2005 CG had significantly larger weight gains (than SS and U20%), while in October 2006 CG had significantly smaller gains than other systems. WSS recorded the greatest October liveweight gain in 2007, which was significantly greater (*P*<0.05) than SS and U20%.

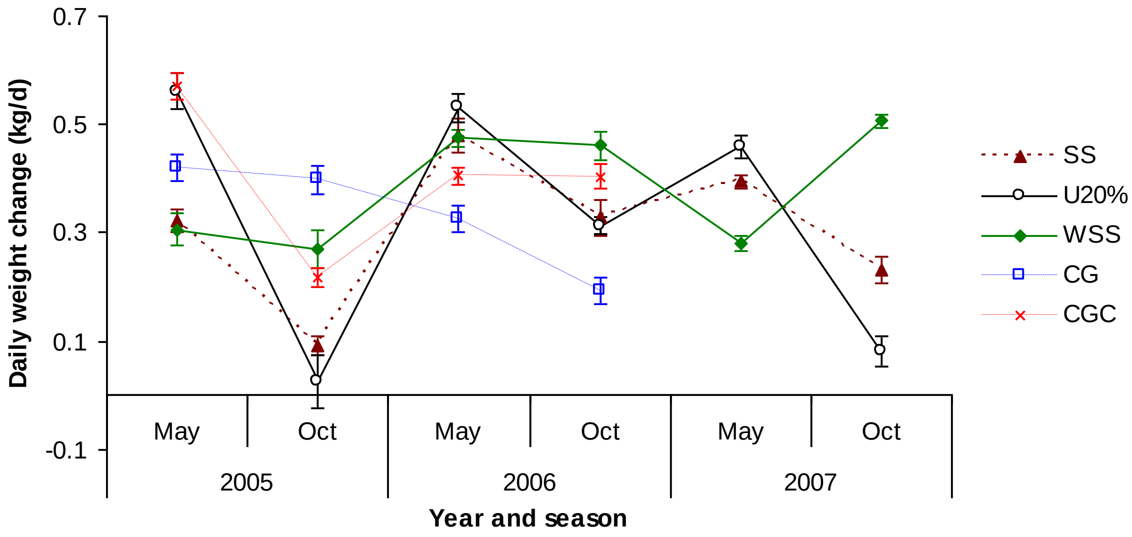


Fig. 5.9. Daily liveweight changes (kg/d) (means ± S.E) for steers and spayed heifers in set stocking (SS), 20% set utilisation (U20%), wet season spelling (WSS), cell grazing (CG) and cell grazing control (CGC) for the wet season (May) and dry season (Oct).

Mean annual weight gain per animal was greatest (142 kg) in WSS, compared with 130 kg for SS, 126 kg for U20% and 112 kg for CG (the latter averaged over two years only). These weight gains compare favourably with other northern Australian pasture communities, e.g. 111 kg/annum for Mitchell grass and 114 kg/annum for annual sorghum (Bortolussi *et al.* 2005b), but the differences could relate to paddock differences. Weight gains in WSS and CG (i.e. the systems that included spelling) were more uniform between seasons (Fig. 5.10), and the dry season contributions (57 and 43% of the annual totals) were significantly greater (P<0.001) than for SS and U20%. WSS had the highest annual daily weight gains, and dry season gains appeared to be increasing as the study progressed (Fig. 5.9). This occurred despite pasture yields in the WSS paddocks in May each year being generally the lowest of all the treatments, and there being little apparent difference in dietary quality amongst the grazing systems.

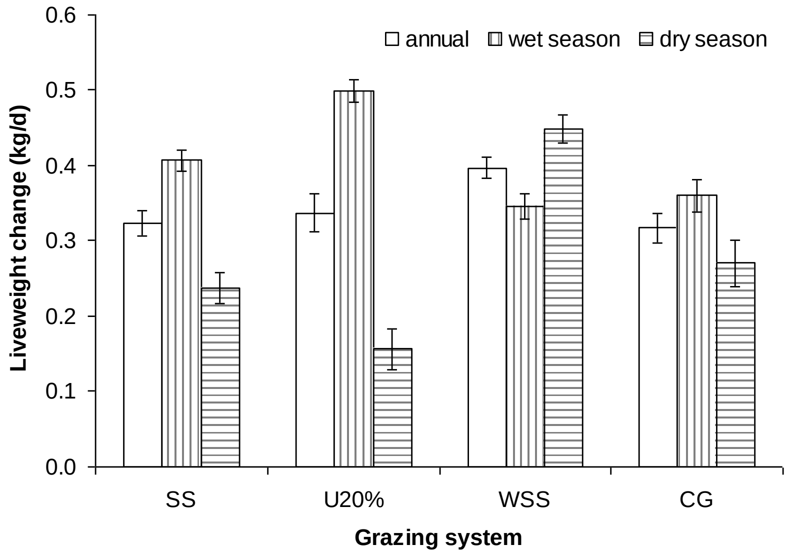


Fig. 5.10. Annual, wet season and dry season daily liveweight changes (kg/day) (means ± S.E.) for grower cattle in set stocking (SS), 20% set utilisation (U20%), wet season spelling (WSS) and cell grazing (CG).

5.4.2.4 Breeder liveweights

Analysis of variance of the May and October breeder liveweights (corrected for pregnancy status; O'Rourke *et al.* 1991) showed significant differences (*P*<0.001) for year, treatment and year x treatment. Cell grazing recorded the highest annual weight gain (Fig. 5.11). Liveweight in SS and U20% showed the typical seasonal pattern of wet season gain and dry season loss (Cobiac 2006b). In contrast, weight gains were recorded in both the dry season and the wet season for WSS and CG (67% of the annual mean for WSS and 56% for CG). For WSS the dry season weight gains of the breeders appeared to be increasing during the study (Fig. 5.12), as it did for the growers. Trends in CG were more difficult to determine due to the early termination, but the greater annual and dry season weight gains were probably a consequence of the lower reproductive performance.

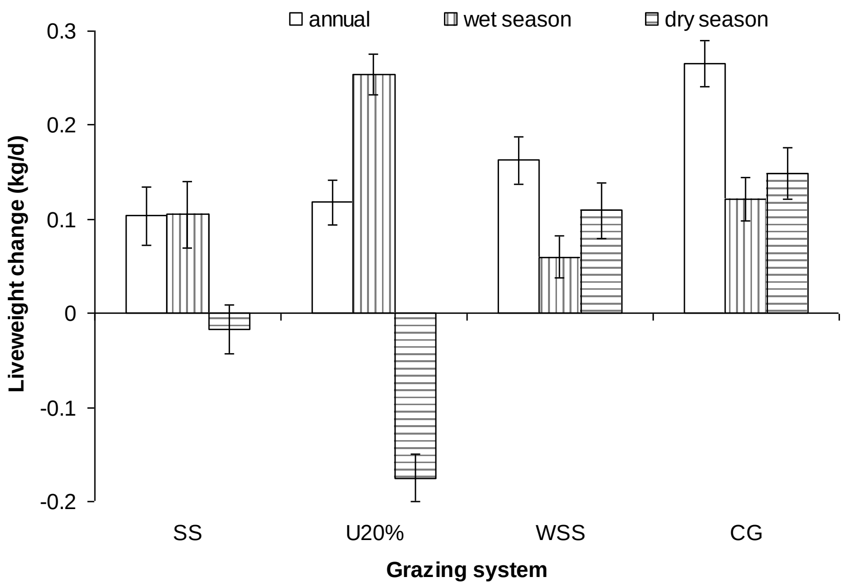


Fig. 5.11. Annual, wet season and dry season daily liveweight changes (kg/day) (means ± S.E.) for breeder cattle in the grazing systems set stocking (SS), 20% set utilisation (U20%), wet season spelling (WSS) and cell grazing (CG).

Breeder liveweights increased in all grazing systems over the study (Fig. 5.12). From October 2004 to October 2007 liveweights in WSS increased by 22%, 17% for U20% and 14% for SS. CG was terminated in October 2006 with liveweights increasing by 26% over only two years. The reduced numbers of wet and pregnant cows and increased numbers of dry and empty cows (Table 5.5) may have promoted the increased liveweight gains in CG.

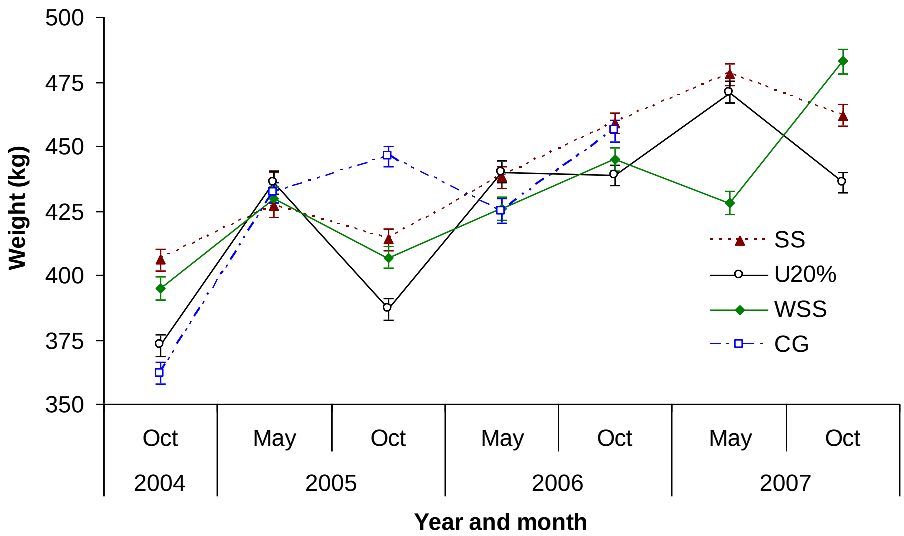


Fig. 5.12. Breeder liveweights (kg) (means ± S.E.) of cattle in the grazing systems set stocking (SS), 20% set utilisation (U20%), wet season spelling (WSS) and cell grazing (CG).

5.4.2.5 Weaner weights

The average weight of weaners in SS (calculated annually, per hectare and corrected for breeder numbers) appeared lower than the other systems (Fig. 5.13), with similar overall trends displayed when calculated on a per animal basis. However, as assessments were based on variable sample sizes (8 to 84) from only 2004 and 2005, the results do not provide a good basis for comparing the grazing systems. In addition, as the grazing systems were not control mated, weaner weights will be strongly influenced by calving patterns which were highly variable between the different systems.

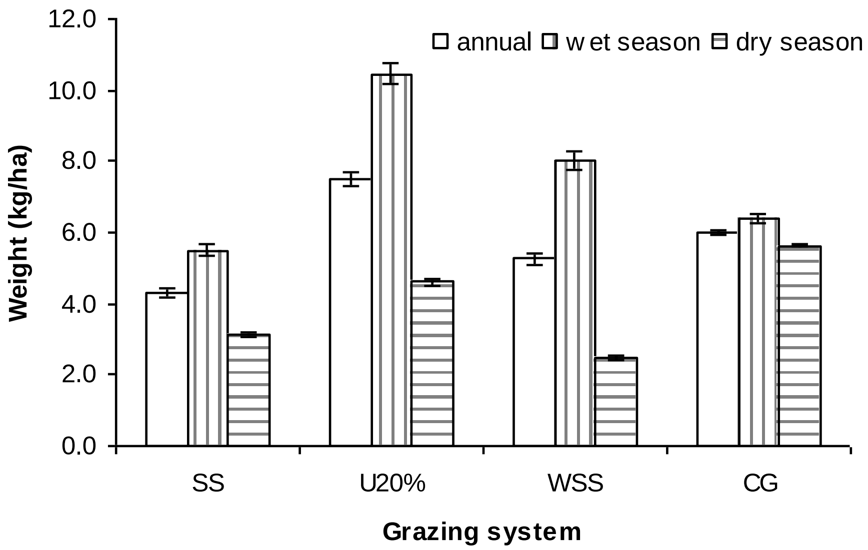


Fig. 5.13. Seasonal and annual weaner weights (kg/ha) (means ± S.E.) standardised for breeder numbers, produced from the grazing systems set stocking (SS), 20% set utilisation (U20%), wet season spelling (WSS) and cell grazing (CG).

5.4.2.6 Body condition score

Body condition score (BCS) is considered to be a more reliable indicator of nutritional status than liveweight (Eversole *et al.* 2000). BCS for May and October showed significant year x treatment difference (both *P*<0.001), which was largely due to differences in CG (Fig. 5.14). Condition scores were significantly higher for CG in May 2005 than for the other systems (which were not different) and significantly lower in May 2006. CG was significantly lower than the other systems in October, 2003, 2004 and 2006, and significantly higher than the other systems, except WSS, in 2005.

Means for the grazing systems were 4.23 for WSS, 4.20 for SS, 4.02 for U20% and 3.67 for CG. These were generally consistent with district trends, but values were lower than for Kidman Springs (median of 5; Cobiac 2006b) and for an unpublished trial in the district (mean 5.3; Golding pers. comm.).

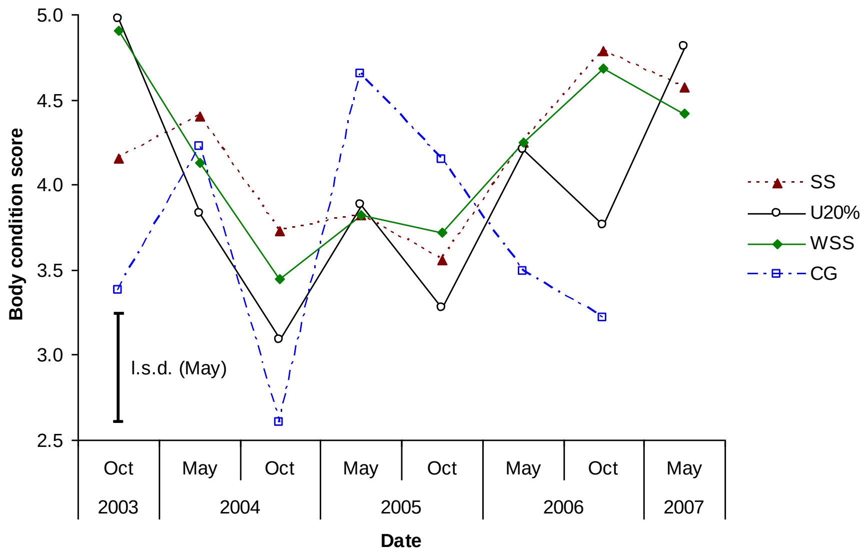


Fig. 5.14. Cattle body condition score for May (mean with average least significant difference, l.s.d. P<0.05) and October for set stocking (SS), 20% set utilisation (U20%), wet season spelling (WSS) and cell grazing (CG).

5.4.2.7 Reproduction

A number of reproduction indicators were calculated for the different grazing systems; means over the study are presented in Table 5.5.

Table 5.5. Mean reproduction indicators for the grazing systems set stocking (SS), 20% set utilisation (U20%), wet season spelling (WSS) and cell grazing (CG).

	SS	U20%	WSS	CG
Branding %	78	72	76	71
Weaning %	72	68	65	71
Inter-calving interval (ICI)	15	16	15	17
Wet and pregnant %	17	17	21	8
Dry and empty %	15	11	14	27

<u>Branding and weaning percentages</u>

Due to incomplete data sets, only the 2004 and 2005 branding and weaning percentages were analysed, with the data appearing inconsistent. Mean branding rates (Table 5.5) were all greater than the 62% average for cattle herds in the NT (Bortolussi *et al*. 2005a). Generalised linear model analyses of the branding data identified SS and WSS as being significantly greater

(*P*=0.010 and *P*=0.044) than CG and U20% which were similar (*P*=0.745). Weaning rates ranged from 72% for SS to 65% for WSS (Table 5.5) and were lower than the district average of 74% (Oxley 2004). For weaning, in contrast to branding, WSS was significantly lower than the other systems (*P*=0.047) which were not significantly different. WSS displayed an 11% reduction from branding to weaning. This has no obvious explanation. Likewise, in U20% the branding percentage decreased from 85% in 2004 to 63% in 2006, while weaning increased from 65% in 2004 to 70% in 2006. The inconsistencies reflect the difficulties associated with obtaining accurate data within a commercial operation.

<u>Inter-calving interval</u>
Mean inter-calving interval (ICI) for CG (17.5 months) was significantly greater than the other grazing systems; U20% recorded 15.7 months, and SS and WSS were both 15.1 months (Table 5.5). These values seem high for northern Australia, where 10 months is possible but not common (MacDonald *et al.* 1997). Mean ICI of around 13.3 months (Cobiac 2006b), between 14.2 and 16.5 months (Cowley *et al.* 2007) and 13.5 to 14.8 months (R. Golding pers. comm.) are more common.

The higher ICIs were probably a consequence of the low body condition (Fig. 5.14), producing increased levels of nutritional stress and prolonged periods of anoestrus (Jolly *et al.* 1996). Wright *et al*. (1992) reported that for cows with a BCS of 4, an increase to 5 represented a reduction of 27 days in time for conception, with conception rates reaching a maximum at a BCS of 5. Such levels were only observed at Pigeon Hole at the beginning and end of the study (Fig. 5.14).

Higher ICIs are also consistent with the observed low fertility rates and the highly variable calf birth patterns over any 12 month period. Management of post partum anoestrus should aim to maintain body condition, by reducing liveweight losses during the dry season, and utilise early weaning (around 3 months) to maintain dam nutrition levels (Jolly *et al.* 1996). Due to their enhanced weights during the dry season and occasionally higher BCS, whether because of paddock difference or grazing system, it would be expected that WSS and CG would have better ICI and fertility levels. This appeared to be the case for WSS, with greater fertility in 2004 and 2006, but was not apparent for cell grazing.

<u>Fertility</u>
Breeder fertility (the proportion of lactating cows that were also pregnant) did not differ among the grazing systems in 2005, but in 2006 the fertility level of 33% in WSS was significantly greater ($P<0.05$) than for the other systems. In 2004 breeder fertility in WSS (27%) was also significantly greater than CG and U20%. Fertility was generally low compared to district figures. For example, Cobiac (2006b) reported a mean of 47% for April/May musters at Kidman Springs. In 2004 CG (8%) was significantly lower than SS and in 2006 (12%), lower than U20%.

5.4.2.8 Summary

Whilst there were few apparent differences in livestock performance amongst the grazing systems, it was noted that the grazing systems that involved spelling (i.e. WSS and CG) at times recorded higher weight gains per animal. For grower cattle, weight gains were greater in WSS and CG in the dry season, with a small apparent annual advantage for WSS. For breeder cattle dry season and annual weight gains were greater for both WSS and CG. The extent to which this is simply due to paddock differences or some element of the grazing system is uncertain. Further the causal mechanism for these effects, if due to grazing system, are unclear. The only other attributes to show statistically significant differences were BCS (due to the very variable and generally lower CG values), ICI (which was significantly greater in CG) and fertility (significantly higher in WSS in 2006 and in 2004 higher than CG and U20%).

5.4.3 Cell grazing control paddock

The cell grazing control (CGC) paddock was managed as a set stocked system with similar stocking rates to CG but in a single paddock of 1.9 km^2. A number of issues were identified which brought into question the value of this as a 'control' treatment for comparison with cell grazing. The proportion of soil/land types in the CGC paddock was quite different to CG (Fig. 5.2). Because of the small paddock size, pasture heterogeneity was markedly lower and there was little similarity in species composition, functional groups and seasonal response between CG and CGC. In addition, CGC was stocked with bullocks with an average weight of 336 kg, compared with 245 kg for the cows in CG, so the only livestock production contrast that was possible was between weight gains from different sized animals. Although mean weight gain was 0.399 kg/day for CGC and 0.285 kg/day for CG, the inherent differences between the paddocks and livestock limit the value of this comparison.

5.4.4 Economics

Since the pasture utilisation rate in the U20% treatment averaged 17% over the study and the 25% utilisation treatment averaged 19% (see Chapter 3), the latter is closer to the other systems. Consequently, U25% is used in the economic analysis as the set utilisation comparison.

The economic comparison was based on the total costs and returns from actual stocking rates and branding rates from the study and the assumptions used in the economic model and other background information are presented in Appendix E.

CG was the least profitable grazing system with a return on invested capital (ROIC) of 5.3% (Table 5.6). It had very similar returns to the commercial herd (5.4%). U25% produced the best ROIC of 8.7%, followed by SS (8.1%), U20% (6.9%) and WSS (6.8%). Inherent differences amongst the paddocks will have contributed to the apparent differences in the parameters used in the economic analysis, so the calculated differences in economic performance should be interpreted cautiously.

From a number of perspectives CG could be considered the grazing system least similar to the other systems. From an economic perspective, this is reflected in the lowest ROIC of the systems studied. The stocking rate, 18.1 AE/km^2, was the highest of all the grazing systems, but it also had the greatest costs. These included capital costs mainly for the additional fencing and waters for the smaller more numerous paddocks, and higher operating costs for the increased management and staff needed, especially for the frequent rotations of livestock through the paddocks. The economic analysis indicated that CG was the least profitable of the systems studied. No pasture improvements were evident, agreeing with similar findings of Joseph *et al.* (2002) and with the potential for increased stocking rates being questioned, as for Holechek *et al.* (2000), it appears to have least potential for adoption.

Stocking rates were similar in the other systems. SS and U25% were both 14.7 AE/km^2 and WSS was slightly lower at 14.5 AE/km^2. Operating costs were also similar, but with U25% being greater due to the potential issues concerning adjusting livestock numbers to maintain a constant utilisation rate in a variable rainfall environment (Appendix E). WSS had the greatest earnings before interest and tax (EBIT) of all the systems, but the main factor that reduced ROIC for WSS was the capital value. WSS used smaller paddocks that required additional fencing, and had capital values around 12%, or \$2,000/km^2 in excess of those for SS and U20% (Table 5.6). Also contributing to the low ROIC for WSS, was the fact that WSS had a lower branding percentage than U25% and SS (78%, 86% and 80%, respectively).

All systems except CG produced a better ROIC than the commercial herd (which represented current management practices using lower stocking rates and larger paddocks than those in the study).

Table 5.6. Economic comparison of a commercial operation, set stocking (SS), set utilisation of 25% (U25%) and 20% (U20%), wet season spelling (WSS) and cell grazing (CG). Data above the middle line are actual data from Pigeon Hole; below the line are modelled results. EBIT = earnings before interest and tax. ROIC = return on invested capital. Background herd and financial data are presented in Appendix E.

	Commercial	SS	U20%	U25%	WSS	CG
Total capital costs ($/km^2)	$13,433	$15,915	$14,846	$16,014	$18,038	$25,681
Stocking rate (AE/km^2)	10.0	14.7	13.9	14.7	14.5	18.1
Operating costs ($/AE)	$68	$49	$54	$51	$49	$65
Gross returns ($/AE)	$150	$152	$145	$158	$158	$147
EBIT ($/AE)	$72	$93	$79	$95	$97	$71
EBIT ($/km^2)	$721	$1,375	$1,090	$1,394	$1,413	$1,287
ROIC (%)*	5.4%	8.1%	6.9%	8.7%	6.8%	5.3%

* Before interest, replacement capital and tax

5.5 Discussion

There were few apparent differences in pasture or livestock performance amongst the different grazing systems. However, there was a suggestion that dry season weight gains per animal were enhanced in WSS and CG, the two systems that used spelling periods. While this may reflect paddock variations rather than grazing system, the apparent difference is contrary to other grazing studies that concluded that livestock production in grazing systems with a spelling period is either equal to, or lower than, that from continuous grazing (Briske *et al.* 2008, Howery *et al*. 2000, O'Reagain and Turner 1992, Norton 1998). Despite the better weight gains in WSS and CG paddocks, set utilisation at about 20% and set stocking were the most profitable systems.

The ease of management is an important consideration in the choice of grazing system on a property. Set utilisation and set stocking, as well as being the most profitable, were the easiest systems to manage. The management issues and challenges associated with implementing each system in this study are discussed in the following section.

5.5.1 Management issues associated with the grazing systems

The on-ground management of the systems in this study was a compromise between the needs of a commercial operation and those of a scientific experiment with appropriate rigour. This in itself presented a number of challenges, and meant that on occasions actions were taken that may not have been ideal from a commercial, or alternatively a scientific, perspective. Nevertheless, the study has provided a sound basis for comparing the performance of the grazing systems at a commercial scale and identifying a range of issues associated with the use of each system.

5.5.1.1 Set stocking

SS was considered the baseline grazing system for comparison with the other systems as it most closely represents common industry practice in the VRD. The target SR and pasture utilisation rates were 18 AEs/km^2 and 20%, with averages of 14.7 AE/km^2 and 21% achieved. The performance of SS was similar to the other grazing systems in terms of livestock production attributes, but body condition score was lower than district benchmarks and dry season weight losses were evident for breeder cattle. An economic analysis showed return on invested capital for SS was better than for CG and WSS, but not as good as a set utilisation system with a similar stocking rate (Table 5.6).

An important management issue in the SS system was the variable stocking rates achieved (Fig. 5.1), which are contrary to the concept of set stocking. These ranged from an average in 2004 of 8.2 AE/km^2 (reflecting management's response to the poor pasture response from the 2003-04 wet season) to 20.4 AE/km^2 in 2006 (Table 5.3). The decision to substantially increase the stocking rate over the 2005-06 wet season (Fig. 5.1) was in response to high pasture growth and light stocking rates in the 2004-05 wet season. This variation in stocking rate is of importance in comparing the grazing systems, especially given that stocking rate is considered the most influential management factor for both pasture condition and animal production (Briske *et al.* 2008). However, the average stocking rates for all grazing systems were generally similar (Table 5.3), and did not show the range anticipated at the start of the study. As such, observed differences are more likely to be due to grazing system differences (or differences in paddocks) than differences in stocking rates. It is acknowledged however, that this interpretation does not consider the important influence of timing of stocking rates adjustments.

Set stocking is the simplest grazing system. However, even at low utilisation rates patch grazing can occur and result in pasture degradation, the risk exacerbated with higher utilisation rates and poor seasons.

5.5.1.2 Set utilisation

In the U20% system, the annual pasture utilisation rate over the study averaged 17%, ranging from 11% in 2004 to 22% in 2006 (Table 5.3). The performance of U20% was generally similar to SS. However, seasonal variation in breeder and grower weight gains was greatest in U20%, recording the largest liveweight increases over the wet and greatest losses (for breeders) or smallest gains (for growers) over the dry. The economic performance (i.e. return on invested capital) of a system using a set annual utilisation rate of approximately 20% was better than the other grazing system studied (Table 5.6).

The advantage of a set utilisation rate system is that it should maximise the sustainable level of pasture use. The system does not necessarily require additional infrastructure to implement, but estimates of pasture biomass are required and additional management effort is needed to alter cattle numbers to maintain the desired utilisation rate as annual pasture production varies. To be able to alter cattle numbers also requires having extra cattle available to increase stocking rates when needed and somewhere to send excess cattle when stocking rates need to be reduced, which can presents difficulties on many properties (see below).

Adjusting stocking rates to achieve the target utilisation rate proved difficult in this study, as indicated by the range of annual rates achieved (Table 5.3). If wet season pasture response was good and, as often happened, cattle numbers were not changed significantly until the muster in September-October, cattle numbers had to be increased substantially for the subsequent wet season for the desired 12-month utilisation rate to be attained. This created the risk that if rainfall and pasture response over this wet season was poor, then grazing pressure on the new season's growth would be excessive. Conversely, after a poor pasture response from the initial wet season, if numbers were not reduced until September-October and a good wet season followed, then grazing pressure over that wet season would be relatively low. This may have allowed some pasture recovery and increased individual animal production, although it is likely overall livestock production would have declined. This may allow some pasture recovery and increased animal production as occurred in May 2004 when pasture yield in all grazing systems was greatest (Fig. 5.3) following the lowest stocking rates.

Both of these scenarios are contrary to what set utilisation is intended to achieve, as neither matched stocking rates to current pasture levels to achieve desired utilisation levels. Ideally, changes should have been made to stock numbers at both musters based on standing pasture biomass at the time. To set grazing numbers during the wet season, consideration could also be given to using seasonal forecasts (O'Reagain *et al.* 2007), especially if their reliability for the VRD improves (Lo *et al.* 2008).

To achieve consistent utilisation rates in variable seasonal conditions may require substantial changes in stock numbers in any year. For example, in the U20% paddock pasture yield was 3,122 kg/ha in 2004 and 1,505 kg/ha in 2007. To achieve 20% pasture utilisation in this paddock of 20 km^2, 370 AEs were needed in 2004 and 179 AEs in 2007. The required 50% reduction in livestock numbers would create significant logistical difficulties and added costs for either moving or buying/selling animals. Larger corporate operations are likely to have more flexibility to adjust numbers than smaller individual properties by moving cattle between properties, although there will be costs associated with transportation. Using a variable stocking rate strategy therefore shows potential for improving economic performance, but the environmental and economic risks are increased (O'Reagain *et al.* 2007). Keeping a proportion of the paddocks on a property ungrazed at any time will provide greater management flexibility to adjust livestock numbers in stocked paddocks, but may come at the cost of lower overall financial returns.

5.5.1.3 Wet Season Spelling

Wet season spelling appeared to produce the best overall animal production outcomes. Mortalities were equal to that in SS, while breeder and grower liveweight gains were greater (the latter only slightly better). Body condition was also highest in wet season spelling. This occurred despite paddock yields and perennial grass basal area frequently being the lowest, and ground cover increasing most over the study. However, the increased capital required for the system as implemented in this study reduced the return on capital invested to between 1.3 to 1.9% below that of set utilisation (U25%) and set stocking (Table 5.6).

The targeted annual pasture utilisation rate for wet season spelling was 25%, and the average achieved was 22%, slightly greater than for SS (Table 5.3). In another wet season spelling study that involved spelling early in the wet season, annual utilisation levels up to 50% were apparently sustainable and business profitability increased significantly (Ash *et al*. 2001). However, spelling of the plots in this latter study occurred every year and the impact of having higher-than-normal cattle numbers in unspelled areas during the wet was not evaluated or considered (Ash *et al*. 2001).

In the current study, cattle were removed from the early spelled paddock before rain or just after the first minor falls. The decision to end the early spelling period and start late spelling was based on estimates of pasture growth. However, when October and November rain was minimal, poor pasture growth resulted and moves were delayed. To maximise pasture response from both the early and late spelling periods, it is proposed that the rotation should be as close as possible to the midpoint of the wet season (based on rainfall received). This was best achieved in 2006-07 when the early spelling period (duration of 89 days) had 60% of the total rainfall (Table 5.1). The benefits of wet season spelling appeared to increase as the study progressed (e.g. improved cover levels, dry season weight gains and fertility), so it is possible that further improvements might be expected over the longer term.

If early and late spelling periods are to be used, the rotation should be guided by rainfall history. At Pigeon Hole, early spelling should commence December 7 (Table 2.1), and rotation timing should be based on average wet season duration of 114 days with rainfall of 753 mm. Alternatively, spelling for the entire wet season may be simpler and provide greater benefits. Kernot *et al.* (2001) demonstrated increased pasture yield, proportion of perennial grasses, carrying capacity and liveweight gains with full wet season spelling compared to continuous grazing and O'Reagain *et al.* (2007) reported better pasture condition and composition with full wet season spelling. A 100-year simulation suggested that a three-paddock, full wet season spelling system with a 35% pasture utilisation rate, was more profitable than continuous stocking at 25% utilisation, with no additional environmental impacts (Ash *et al* 2001).

A significant management issue in the wet season spelling study at Pigeon Hole was controlling cattle distribution to achieve a more uniform spread between grazed paddocks. At the end of a spelling period the gate to the spelled paddock was simply opened so livestock had access to that paddock as well as the other/s. No action was taken to move cattle into the newly opened paddock, and observations indicated they often continued grazing in the other paddock/s. This may be because the pasture in the rested paddock would have been taller, more mature and with a higher ratio of stem to leaf, conditions which cattle often avoid (Hunt *et al.* 2007). This would have increased the grazing pressure in the already grazed paddock/s. Managing access to the grazed paddock/s by cattle would seem necessary in this systems. This could be achieved by:

- running the cattle as two herds as proposed in the ECOGRAZE system (Ash *et al.* 2001), either for the entire year or only separating them during the wet season (rather than as a single herd as occurred here), and restricting access to individual paddocks;
- restricting cattle to one paddock at a time, rather than two, and rotating them around the three paddocks.

The wet season spelling system implemented in this study needed additional fencing to create the smaller paddocks and an additional muster to remove cattle when a paddock was due to be rested. However, there is potential to use current paddocks and adjust stock numbers to ensure overgrazing did not occur in the grazed paddocks. Installing spear gates in the central watered area could also avoid the need for additional stock handling to achieve the required wet season stock moves.

The potential impacts and benefits of either early/late or full wet season spelling should be investigated. During the wet season the two spelled paddocks in our study received potential benefits and the increased grazing pressure in the grazed paddocks was distributed across all non-spelled paddocks but at different times during the wet season. Entire WSS is considered simpler, more practical and more cost effective than the split system (Kirkman and Moore 1995), but only the single spelled paddock receives benefits and the increased grazing pressure occurs in both grazed paddocks for the entire wet season. The frequency of spelling also needs to be determined to optimise benefits.

5.5.1.4 Cell grazing

From economic, livestock production, management and biophysical perspectives, cell grazing was the system with least potential for adoption in the tropical savannas. May pasture yields and perennial grass basal area were most variable in the CG paddocks, and cover was frequently the highest. While liveweight appeared to improve in the dry season, this was not matched by improved livestock nutrition (via NIRS) as was also reported by Pitts and Bryant (1987) in a similar comparison of continuous grazing and cell grazing. Due to logistical issues the average utilisation rate for CG was 20%, a lot lower than the intended 50% and slightly lower than for SS (Table 5.3). CG was the least profitable grazing system in the study (Table 5.6).

Management of the CG system was complex, time consuming and logistically difficult. It required skill to constantly monitor prevailing weather, pasture and livestock conditions, and to evaluate grazing days, stocking rates and carrying capacities. Even after the training recommended prior to implementing the system (McCosker 2000), problems were still encountered. None of the claimed benefits of CG, such as better financial returns from increased cattle numbers facilitated by the improved health of the natural water and nutrient cycling systems and more robust pastures (McCosker 2000), were substantiated. The study was not intended to change station operations to suit the grazing system but to test the applicability of the grazing system for this production operation. The CG system had more problems than the other systems, was the most expensive to run, apparently had the worst overall reproductive performance and was therefore the most risky in this environment.

Running a breeding operation within a CG system on black vertisol type soils in the tropical savannas during the wet season also presented a number of issues. In the wet season, black soils become extremely boggy, so cattle avoid them. To avoid this problem, managers attempted to use the paddocks with the smallest area of black soil during the wettest times. However, vehicle access to paddocks was sometimes difficult in the boggy conditions so cattle were often confined to the red soil paddocks for extended periods, effectively limiting their spelling and potential wet season growth. This may have led to a decline in range condition in the red soil paddocks in the longer term, especially given the high stocking density.

Wet season rotations needed to be more frequent due to the rate of pasture growth. Being some distance from the homestead, vehicle access to the CG paddocks in the wet was a big issue. Moving cows and young calves from source paddock to destination paddock caused cow-calf separations similar to those reported by Howery *et al.* (2000). Mustering attempted to minimise animal production impacts by reducing the stress on cows and calves, but required experienced stockmen.

Other problems also arose:

- At the start of the study, especially in the dry season, cattle would cease grazing after a few days in a paddock and congregate around the watering point waiting to be moved to the next paddock. This behaviour was possibly associated with overestimating the pasture available in the early stages of the study due to inexperience.
- Mortalities due to wildfire occurred as cattle in the small paddocks could not avoid fires as easily as in larger paddocks.
- From December 2004 to January 2005, eight months into the CG system, all cattle were removed for four weeks and placed in an adjacent paddock where they were fed whole cotton seed. This decision was made due to the extremely poor pasture and animal condition, and fire burning out a number of paddocks that were due for grazing.
- To be consistent with the other study paddocks, cattle numbers were not adjusted at the times pasture calculations indicated a move was due. Issues associated with the required stocking rate adjustments included cattle availability when additional numbers were needed, and the availability of a site to run extra cattle when calculations indicated reductions were needed in the cell grazing system.

These issues, and the paucity of suitable skilled staff, meant that the CG system was discontinued in November 2006.

In any grazing operation, irrespective of the grazing system, adaptive management usually addresses problems such as changing seasonal conditions, invasive or unproductive plants, feral animals and fires. In this project, management decisions were made to reflect the commercial situation as much as possible. However, because the CG system was part of a research project, adaptive management was tempered to avoid compromising project results. Examples where adaptive management was used included gates frequently being left open when cows were shifted in case a calf was left behind. If cows were left behind then a follow up muster would occur the next day and the gate shut. Whenever possible, cattle were not moved through the central water point area, but this was sometimes difficult in the ‘wagon wheel’ layout. Based on the experience gained from this project, the paddock design could be improved, with more gates positioned away from the central waters, or fence designs that enabled cattle to be shifted over or under the fence. Notably, Resource Consulting Services no longer recommends the wagon wheel design.

Other changes could include removing the cows and calves from the cell system during the wet season to avoid stress from mustering. Controlled mating could avoid young calves during the wet season, although peak nutritional levels at this time would counter this suggestion. Alternatively, cattle could be given access to the whole system during the wet season and locked out of favoured paddocks when they were identified, to avoid over-grazing. Again, this is not ideal as pasture spelling would be minimised in the wet season at the time when it is most important.

5.5.2 Conclusions in relation to key hypotheses

Our findings in relation to the key hypotheses for the grazing systems experiment are as follows.

1. ***Hypothesis:*** *Grazing systems that involve regular rotation of livestock around a series of paddocks allow the use of higher pasture utilisation rates and hence generate higher livestock production than set stocking.*
   Findings: We were not able to test this hypothesis since pasture utilisation rates in the two systems that involved spelling (WSS and CG) were only marginally higher than continuously stocked systems. These systems recorded higher dry season weight gains but whether this was due to the grazing system or inherent paddock variations was unclear.

   There was no evidence that utilisation rates in WSS could be increased. Annual LWG per head appeared to be higher than other systems but whether this was an effect of grazing system is uncertain. For CG the animal production system was incompatible with the grazing system. The hypothesis is therefore not supported for either WSS or CG.

2. ***Hypothesis:*** *Grazing systems that involve periods of rest result in better pasture condition than set stocking and enable higher levels of livestock production*.
   Findings: There were few differences in pasture condition amongst systems, and spelling appeared to offer little improvement in pasture condition. Ground cover was greater for wet season spelling but this difference is confounded by wildfire which occurred in the other systems. WSS and CG appeared to produce higher dry season liveweight gains per animal, although the reasons for this are unclear. The hypothesis is rejected.

3. ***Hypothesis:*** *Higher costs associated with developing and managing more intensive rotational grazing systems are offset by higher livestock production so that these systems are more profitable than set stocking.*
   Findings: Cell grazing was the most intensive but the least profitable system, with generally lower reproduction values and lower weight gains for grower cattle. The hypothesis is rejected.

4. ***Hypothesis:*** *Grazing systems that adjust stocking rates to match annual pasture production result in better pasture condition than set stocking with no reduction in livestock production.*
   Findings: U20% was the grazing system studied that involved stocking rate adjustments to match annual pasture production. Few significant differences were observed in pasture attributes, but animal production appeared to be a little lower in U20% compared with set stocking. The hypothesis is rejected.

5.6 Conclusions

Apart from poorer economic performance of cell grazing, there were few consistent impacts of grazing system on pasture or animal productivity. As a result, set utilisation at an annual rate of 20% (consistent with safe utilisation recommendations), was the best performing system in economic terms during the study and appeared to have no short-term adverse effects on land condition. This confirms many studies that show stocking rate to be the major driver of pasture and animal performance rather than grazing system per se, but does not infer that stocking rate should not be managed carefully over time to cater for below-average seasons.

Cell grazing was the least profitable system due to the added capital and operational costs, and also placed additional demands (workload and skill requirements) on management. It produced no pasture or livestock production benefits.

The longer-term effects of the different grazing systems remain uncertain due to the short duration of this study and the lack of significant variability in rainfall over the 4 years. Set utilisation, with no pasture spelling periods, may degrade pasture as evidenced with set stocking, and economic outcomes may decline with more variable seasons and the need to adjust cattle numbers. This study suggested that wet season spelling might have the potential to improve livestock production above that of set stocking, without adverse effects on land condition. However, this improvement in livestock performance did not flow through to improved economic performance because of the greater capital costs involved.

It has been suggested that grazing systems research in rangelands often fails to reveal ecosystem changes because the duration of the research is insufficient for ecosystems to adjust to management changes (Briske *et al.* 2008), resulting in minimal changes to animal production (Jones *et al.* 1995). It is possible that a lag in the response of ecological processes to the grazing systems had a bearing on the results we obtained since data collection occurred only for five years. A lack of replication of grazing treatments also limited the capacity of the study to detect differences between the systems. For these reasons the results should be taken as indicative of possible trends.

6 Biodiversity

6.1 Key messages

- Comprehensive biodiversity studies were carried out twice yearly to examine the effects of the various grazing treatments in this study on native flora and fauna and to examine the value for biodiversity conservation of small, ungrazed areas within the grazed paddocks of the intensified system.
- There was no obvious effect of different utilisation levels, or different grazing systems on the biodiversity within the paddocks.
- These black-soil grasslands are one of the ecosystems in northern Australia most resilient to the impacts of grazing on biodiversity.
- Nevertheless, impacts on biodiversity are likely to become more pronounced if a high proportion of the land-type is subject to intensification, particularly over longer (decades) time scales and following a period of poor seasons.
- After five years there was some evidence that plant and animal composition in the exclosures was diverging from that in grazed lands and, in particular, the abundance of some grazing-sensitive species was starting to increase within the exclosures.
- It was not possible to determine a suitable size for ungrazed ‘conservation areas’, although these will most likely need to be relatively large (square kilometres) to maintain viable populations of larger organisms such as birds.
- Recommendations to protect biodiversity values in the context of broad-scale intensification are presented.

6.2 Introduction

Pastoralism is one of the predominant land uses throughout northern Australia; indeed for many regions and land types the overwhelmingly dominant. Much of the biodiversity of northern Australian occurs on, and in some cases is restricted to, land under pastoral management. For example, c. 50% of the land area of the Northern Territory is used for pastoralism, and for some of the more productive broad vegetation types (such as tussock grasslands) this proportion is as high as 84% (Woinarski *et al.* 1996). Conversely, only 9% of the NT is under conservation management and many productive land types are severely under-represented in this reserve system (the vegetation map unit on which the Pigeon Hole trial occurs has 2.7% of its total extent within reserves). It is therefore clearly important that we understand the real or potential impacts of pastoral landuse on biodiversity, and recognise the opportunities to ensure that grazing land management encompasses the protection of biodiversity values (e.g. Biograze 2000). This imperative becomes stronger where the intensity of pastoral use is increasing, along with the potential for negative biodiversity impacts.

The spread of pastoralism throughout Australian rangelands has been implicated as a factor in the decline of many native species (Woinarski & Fisher 2003), most notably the extinction of arid-zone mammals. Some of this impact represents the “shock of the new” (including very high localised stocking rates around sparse natural water sources) and likely a complex interaction with the spread of feral grazers and predators, and changes in fire regime (Morton 1990); but there is also evidence that impacts on biodiversity associated with pastoralism have been sustained and are likely ongoing (Franklin 1999, Woinarski & Catterall 2004, Franklin *et al* 2005). Studies along gradients of grazing intensity (typically piosphere gradients) in a number of rangeland ecosystems throughout Australia (Landsberg *et al.* 1997, Fisher 2001, Landsberg *et al*. 2003) have consistently demonstrated that, while many native species are apparently unaffected by prevailing grazing regimes, a significant proportion of the biota shows a “decreaser” response, i.e. are more abundant at lower grazing pressure and/or more distant from waterpoints. This response is seen in many groups that have been studied (e.g. plants, birds, reptiles, mammals, ants, beetles, spiders) and represents 10-25% of the total fauna in each group. In the most extreme scenario, some species are so grazing-sensitive that they can be found only in areas that have been historically subject to virtually no grazing pressure (Landsberg *et al.* 2002).

Pastoral use may affect various aspects of biodiversity through a variety of mechanisms (Fleischner 1994, James *et al* 1999). Grazing *per se*, and particularly selective grazing, can influence the local abundance or persistence of many plant species, but the effects of grazing-induced changes in vegetation composition and structure – and hence habitat quality - flow on to many other groups. Other impacts associated with grazing and trampling include changes in soil structure, nutrient levels and cycles, and water infiltration rates – potentially resulting in landscape-scale changes in ecosystem function (van de Koppel *et al* 1997). Pastoral development, through the proliferation of permanent waters, may additionally affect local fauna by providing a focus for predators (such as cats) and facilitating the spread of cosmopolitan “weedy” native species that displace other species that may be locally restricted or rare. This “water-spreading” has been one of the most dramatic changes in the Australian rangelands associated with the introduction and development of pastoral use, meaning that most of almost all environments in almost all regions are accessible to stock (and feral grazers) (Landsberg *et al.* 1997, Fensham & Fairfax 2008). Consequently, the area of “water-remote” land – which potentially acts as a refuge for grazing-sensitive species – has greatly diminished and fragmented. Future pastoral intensification will generally entail increasing water point density, so that water-remote area reduces further – eventually to the point where the refuge value vanishes. Similarly, a sustained increase in grazing intensity (e.g. through higher stocking rates) at paddock or property scale may exceed a threshold above which some decreaser species cannot persist.

There have been only a small number of detailed studies (e.g. Woinarski & Ash 2002, Woinarski *et al.* 2002, Fisher & Kutt 2007, Kutt & Woinarski 2007) of the impacts of pastoral use on biodiversity in the Australian tropical savanna rangelands - which have also shown that grazing disadvantages some native species, from a variety of taxa. In the most pronounced case, destocking of a large area on Mornington Station in the Kimberley resulted in a rapid increase in the richness and abundance of small mammals, in several habitats (S. Legge pers. comm.). By contrast, sampling of piosphere gradients in Mitchell grasslands (Fisher 2001) suggested a relative resilience to grazing impacts; while decreaser species could be identified, the magnitude of this response was less pronounced than documented for other ecosystems. Fisher (2001) sampled grasslands in the Victoria River District (VRD), including on Mt Sanford Station (immediately to the south of Pigeon Hole) and identified some of the most common vertebrate species (*Planigale ingrami*, *Ctenotus rimacola*, *Proablepharus kinghorni* (now *P. naranjicaudus*)) as showing a decreaser response to grazing. Other studies in the VRD have also shown that grazing intensity influences the diversity of plants and grasshoppers (Ludwig *et al* 1999) and composition of ants (Hoffmann 2000), although these effects were pronounced only relatively close to water points.

The Pigeon Hole Project was perhaps unique amongst large-scale grazing trials in integrating a detailed consideration of biodiversity effects from the planning stages. The goal of this component was to track the effects on biodiversity of the imposed grazing management strategies, through sampling as broad a range of biota as practical. A particular focus was given to the utilisation treatment, in order to determine whether there was a threshold level of utilisation above which impacts on biodiversity became pronounced (and therefore at a broader scale whether production benefits may be outweighed by environmental cost). In the context of pastoral intensification, the option of retaining a significant area of water-remote land within the grazed matrix (cf. Biograze 2000) may become unavailable, and an alternative on-property conservation strategy may be to allocate areas where grazing is deliberately excluded (or kept low) by fencing. Biodiversity was therefore also monitored within a number of exclosures established within the grazed paddocks, with a range of exclosure sizes used to test what minimum area was required to retain populations of sampled taxa.

6.3 Methods

6.3.1 Experimental design

There were two separate, related studies within the biodiversity component:
1. examining the effects of the various grazing treatments implemented in the trial;
2. examining the value for biodiversity conservation of small, ungrazed areas within the grazed paddocks.

The general approach was repeated sampling of biodiversity at a large number of fixed sites within most of the grazing treatments, and within a set of exclosures of varying size. Sampling at fixed sites was used because of the logistical requirement to establish permanent pit-traps (for sampling reptiles and small mammals), and the difficulty of sampling (for all biota) a number of random sites adequate to separate local variation from treatment effects.

The total number of sites sampled, and the allocation of sites to treatments, had a trade-off between the need for adequate replication and constraints on time and effort of sampling. A maximum of 100 sites could be sampled (requiring c. 160 person-days of fieldwork annually). Consequently, the “multiple-watering point” and “set-stocked” paddocks within the project were not sampled, and the biodiversity studies concentrated on the “utilisation”, “grazing radius” and “grazing system” treatments (as well as the “conservation areas”).

The aim was also to sample as broad a range of biota as practicable, including vascular plants, ants, birds, reptiles and small mammals. Key attributes of biodiversity for this study are species richness, species composition (particularly the balance between increaser and decreaser species), the relative abundance of individual species (particularly decreaser species and species useful as indicators) and vegetation structure (including attributes related to landscape function).

The distribution of sample sites amongst treatments is shown in Table 6.1 and Fig. 6.1. There were between 6 and 10 sites within each level of each treatment. Two sites were placed on drainage lines in each paddock within the utilisation experiment (and one in the largest exclosure) because these riparian zones have a distinct flora and fauna, and are also likely to experience a different pattern of grazing effects. Within the utilisation, grazing radius and wet-season spelling paddocks, 2 sites were placed within 500 m of the new watering point and the remainder were placed c. 1.5 km from the waterpoint. Sites within cells were 0.5-1 km from the troughs. Within the limitations of the paddock layout, all sites were placed to avoid unusual vegetation patches or landscape features, or areas that were in obviously poor prior condition.

The distance of all sites from current and previous waterpoints was quantified as one indicator of prior and current grazing pressure.

A total of 16 exclosures were established within the 5 paddocks of the utilisation experiment (Table 6.1, Fig. 6.2). Exclosures were of 4 sizes – 0.4 ha, 4 ha, 40 ha, 400 ha – with 6, 6, 3 and 1 representatives, respectively, of each size class. Exclosures of the three smaller sizes were all placed within 500m of waterpoints, in an attempt to ensure they were surrounded by an area of at least moderate grazing pressure. The location of the largest exclosure was chosen to minimise disruption to pastoral management while containing a comparable landscape to the utilisation paddocks. There were between 1 and 6 biodiversity sampling sites within each exclosure, depending on size. The adjacent Gregory National Park also contains thousands of hectares of country comparable to that within the grazing treatments, which have been fenced from the pastoral lease since c. 1990 (although this area is still grazed by variable numbers of wild and/or fugitive cattle, as well as donkeys). Five biodiversity sampling sites were located within Gregory National Park adjacent to North Stevens Ck paddock.

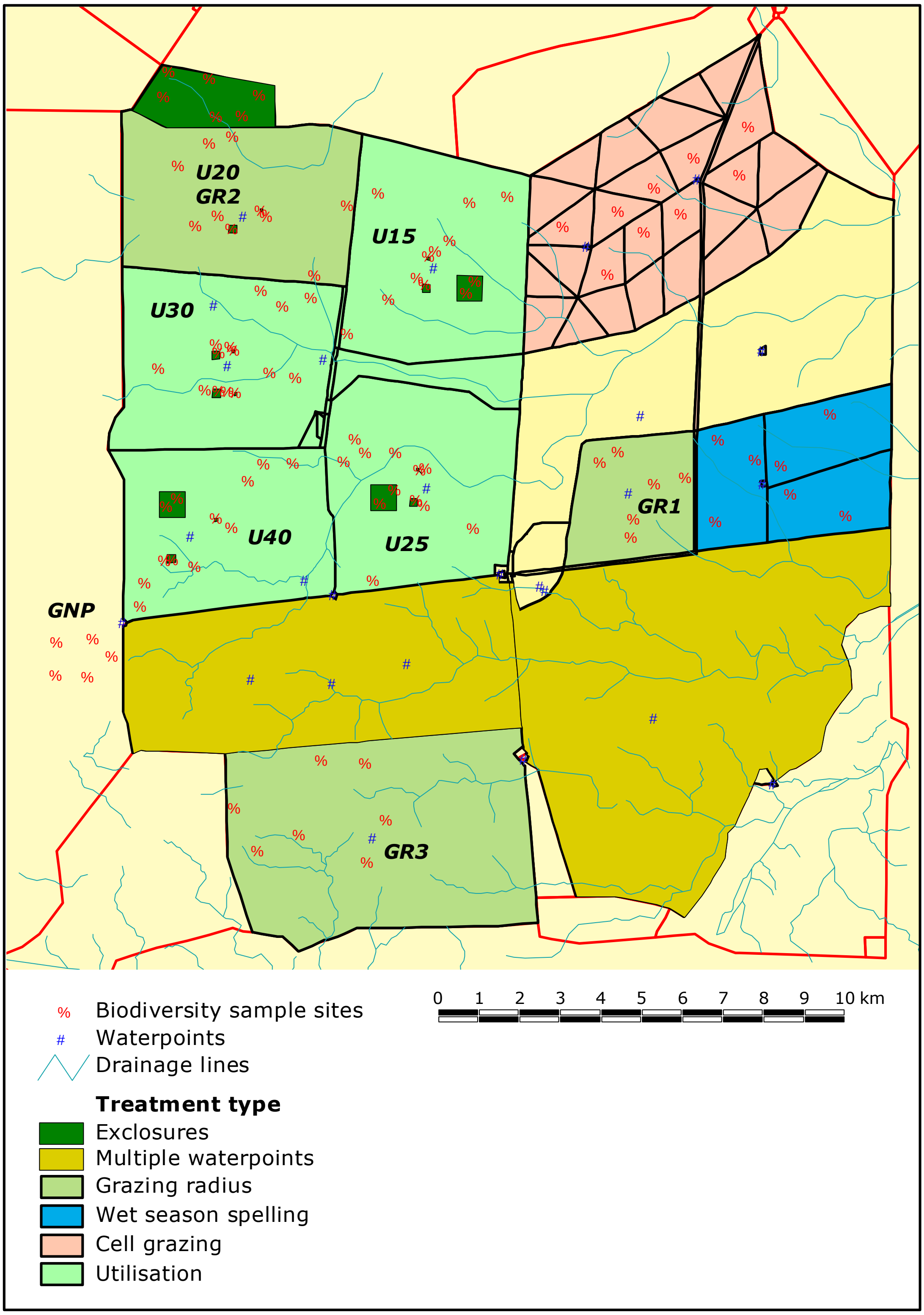


Fig. 6.1. Layout of the Pigeon Hole Project area, showing location of biodiversity sample sites. The intended levels of the utilisation (U15-40) and grazing radius (GR1-3) treatments are labelled, as well as Gregory National Park (GNP).

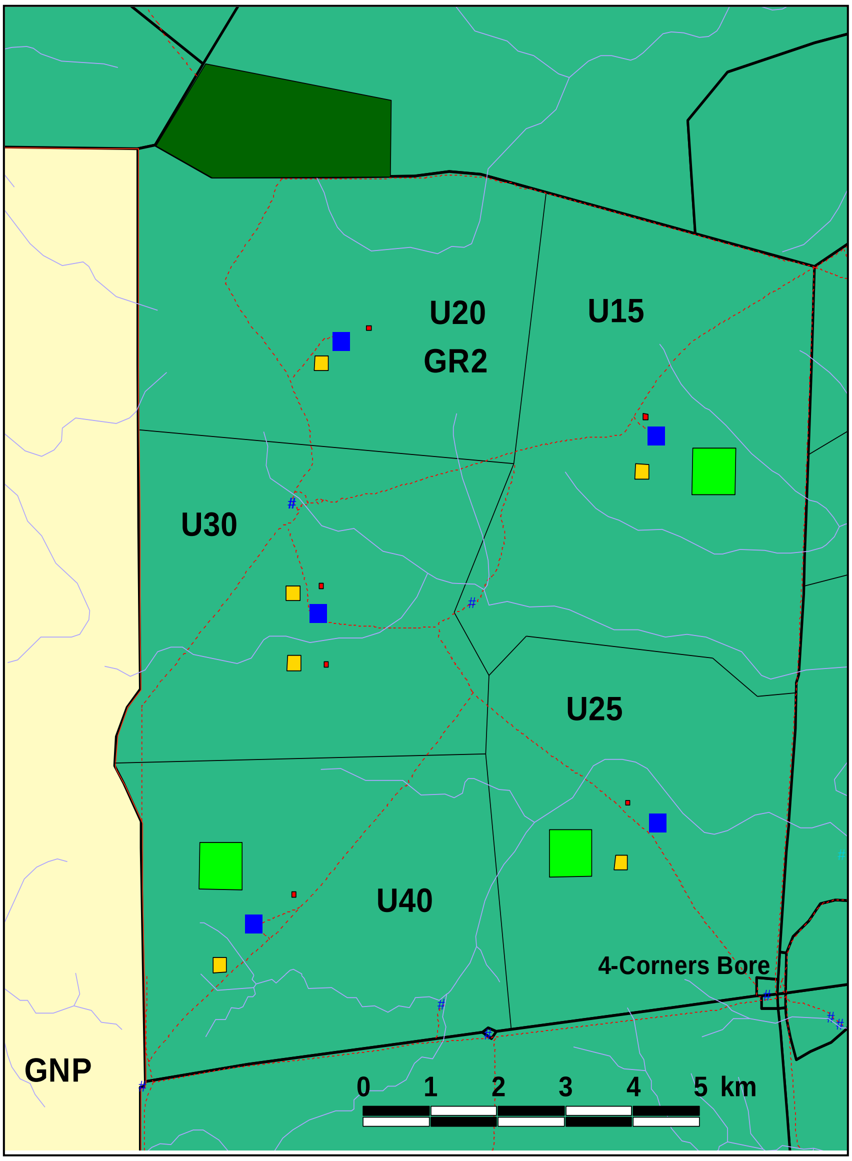


Fig. 6.2 Layout of exclosures within the utilisation paddocks. Red=0.4 ha, yellow=4 ha, light green=40 ha, dark green=400 ha. Cattle watering points are blue squares.

Table 6.1. Distribution of biodiversity sampling sites between treatments. Sites on drainage lines are indicated separately.

Treatments	Level	Paddock	Normal sites	Riparian sites
Utilisation	13%	*Brolga*	6	2
	17%[a]	*Sandstone*	6	2
	19%	*Bauhinia*	6	2
	24%	*Villiers*	8	2
	32%	*Dead Cat*	6	2
Grazing Radius	1km	*Barra*	6	
	2km[a]	*Sandstone*	6	2
	3km	*South Stevens*	7	
Wet-season Spelling	-	*Bullock*	7	
Cell-Grazing	-	26 cells	9	
Conservation	0.4ha	6 exclosures	6	
	4ha	6 exclosures	6	
	40ha	3 exclosures	6	
	400ha	1 exclosure	5	1
	Gregory National Park		5	

[a] these levels are shared between the two experiments, so these 8 sites are duplicates

6.3.2 Data collection

Sites were established in 2003, although only 62 sites were located in time for sampling in May 2003 (due to delays in finalising the layout of cell grazing and wet-season spelling paddocks, and selecting exclosure locations). There were two periods of sampling in each year. Plants, birds and ants were sampled early in the dry season (April-May). Birds, reptiles & small mammals, understorey yield & cover and grazing impact were sampled late in the dry season (Sept-Oct). The sampling methods for various taxa / attributes are summarised in Table 6.2. Most sites were sampled until late 2007. The cell-grazing treatment was abandoned in 2006 – the 9 sites in this treatment were sampled for plants in 2007, but not for vertebrates or ants. Pit-trapping was not undertaken in the wet-season spelling treatment in late 2007 because of the lack of useful data from this method.

All data were stored in purpose-built Access databases. Separate databases were maintained for vegetation/groundcover and fauna from each sample period, although these were combined across sample periods as required for analysis. Site photographs were labelled with site name and date and stored in directories by sample period. A library of other photographs (plants and animals, researchers, activities) was also maintained.

Table 6.2. Summary sampling methods for biota and habitat attributes.

Taxon / Attribute	Methods	Timing
General habitat attributes	Standard NRETA habitat description (including location, landscape position, slope, aspect, soil type, land unit, rockiness, distance to water)	Once only
Vegetation – overstorey structure & composition	Canopy height, cover, basal area and size class distribution of trees and shrubs using Bitterlich variable-radius technique from 4 corners of 0.25 ha quadrat	Once only
Vegetation - floristics and structure	0.25 ha quadrat: composition and groundlayer structure subsampled in 20 x $0.5m^2$ plots + timed search in quadrat for additional spp.	Annually: early dry season
Groundcover	Cover of bare ground, rocks, litter, groundlayer vegetation (by functional group) and perennial grass basal area, in 0.25ha quadrat as per floristic sampling	Annually: early dry season
"Pasture assessment"	Yield, cover, dominant species composition, perennial grass basal area and fire recorded in 5 x $4m^2$ plots within each 0.25ha quadrat using modified Botanal procedure	2003 and 2007 Late dry season
Birds	4 x instantaneous counts within 1ha quadrat + 2 x 1km walked transect adjacent to quadrat	Twice annually: early & late dry season
Reptiles & small mammals	4 x 20m drift fences in 1ha quadrat, each fence with 2 x 20l buckets. Open for 4 days.	Annually: late dry season
Ants	15 x 7cm diam pits in 20x40m array. Open for 3 days.	Bi-annually (2003, 2005, 2007): early dry season

6.3.3 Data Analysis

The raw data from the biodiversity study were essentially the presence and relative abundance of each plant and animal species at each site in each year, plus a number of 'habitat attributes' (understorey cover by lifeform, bare ground, etc). Relative abundance of plant species in a site was represented by both mean cover and frequency. In addition to the abundance of individual species, a set of *summary variables* were derived for each site, including:

- total species richness, broken down by taxonomic and functional groups;
- total relative abundance, broken down by taxonomic and functional groups;
- diversity indices (e.g. Shannon-Wiener), broken down by taxonomic and functional groups;
- perennial grass frequency, broken down by cover class.

While some functional groups are well defined (eg. bird foraging guilds; ant functional groups; palatable perennial grasses), other synthetic variables appropriate to this context were developed through exploratory analyses.

In addition to univariate analyses of these single response variables, multivariate analyses - ordination and ANOSIM (Clarke & Gorley 2001) - were used to compare species composition between sites and over time. In general, a square-root transformation of abundance data was used (which downweights the influence of abundant species, while retaining some information about relative abundance as well as presence). Frequency (rather than cover) of plant species was used unless otherwise specified.

The primary treatments within the grazing trial are unreplicated and there is inevitably substantial within-treatment variability. Initial analyses using ordination and ANOSIM demonstrated that, for all major taxonomic groups, there was significant pre-treatment difference in composition between paddocks. Additionally, the relative abundance of many species varies substantially between years independently of grazing effects. Consequently, simple comparisons between paddocks (e.g. of mean site richness) are relatively uninformative. The general analytical approach was therefore to examine whether trends over time (in composition, summary variables or abundance of individual species) differ significantly between treatments.

For composition this involves testing whether changes over time in the similarity of sites within a treatment differs between treatments (using the ANOSIM procedure in PRIMER); and comparison of the trajectories of sites in different treatments through ordination space.

For individual variables this involved comparison between treatments using a repeated-measures ANOVA design within the generalised linear model (GLM) module in Statistica. In particular, a significant *year*treatment* interaction may indicate an effect due to the imposed grazing treatment.

Comparison of composition and simple response variables between sites within conservation areas and those in grazed paddocks is a special case of the comparison between treatments described above. Similarly, comparisons between conservation areas of different size were made by considering size as a treatment with 5 levels. In this case, the question is whether the trajectories of sites in ordination space are dependent on exclosure size, i.e. whether there is a significant *year*size* interaction for simple response variables.

6.4 Results

6.4.1 Description of biota

6.4.1.1 Plants

A total of 223 plant species were recorded from the biodiversity sampling sites; after problematic species were removed or combined (Appendix F) this was reduced to 215 taxa used in the analyses (Table 6.3, Appendix E).

Table 6.3. Total number of species recorded for each taxon from biodiversity sites in 2003-2007. Data are from 100 sites, except where indicated (a-62; b-99; c-91; d-84; e-71 sites). Numbers in bracket in the final column are means across years.

	2003	2004	2005	2006	2007	Total
Plants	166 [a]	181	175	176	183	215 (176.2)
Birds – early	59 [a]	-	70	75	68 [c]	101 (71.0)
Birds – late	54 [b]	60	53	53	59 [d]	84 (55.8)
Birds - all						116
Ants	51 [a]		60		62 [c]	76
Reptiles	21 [b]	17	19	18	18 [e]	30
Small mammals	3 (+1) [b]	3	2	2	3 [e]	4
Macropods						4

Table 6.4. Mean site richness for each taxon in 2003-2007. Numbers in bracket are ranges.

	2003	2004	2005	2006	2007	Total (mean across years)
Plants	41.0 (21-75)	41.3 (19-83)	35.8 (17-69)	37.4 (18-76)	36.5 (22-70)	38.1 (21-75)
Plants – all years combined						59.7 (31-118)
Site and adjacent						
Birds – early	11.4 (2-25)	-	14.4 (4-26)	10.0 (2-25)	10.4 (2-22)	11.6 (2-26)
Birds – late	7.8 (1-18)	10.3 (2-24)	8.1 (0-20)	8.8 (2-22)	10.3 (2-22)	9.0 (0-24)
Site only						
Birds – early	6.2 (1-16)	-	12.3 (2-24)	8.6 (1-25)	9.5 (2-22)	9.5 (1-25)
Birds – late	6.0 (1-17)	7.7 (1-17)	7.6 (0-16)	7.9 (2-21)	9.6 (2-20)	7.7 (0-21)
Ants	12.7 (5-21)	-	14.7 (6-26)		13.0 (6-23)	13.6 (5-26)
Reptiles	2.4 (0-6)	2.4 (0-8)	2.3 (0-6)	2.7 (0-7)	2.3 (0-5)	2.4 (0-8)
Small mammals	0.6 (0-2)	0.6 (0-1)	0.3 (0-2)	0.6 (0-2)	0.5 (0-1)	0.5 (0-2)

Mean site richness of plants (across all sites and years) was 38.1 (Table 6.4), and site richness ranged from 21 to 75; the highest richness values were associated with riparian sites. This represents a moderate to high local richness of plants, but relatively low beta-diversity (species turnover between sites). There is a significant component of plant species restricted to, or with a strong preference for, black-soil grassland habitats (Fisher 2001), and a number of species rare or poorly recorded in the NT were found (including *Iseilema trichopus*).

For all years combined, 34 (6.3%) plant species were recorded from only a single site and 80 (37.2%) from five or fewer sites. Four taxa were recorded from all sites, and 19 taxa from at least 90% of sites.

6.4.1.1.1 Variation between years

There was substantial inter-annual variation in floristic composition, which cannot be attributed solely to grazing effects. While this presumably relates to seasonal conditions, particularly the amount and timing of rainfall and subsequent response of vegetation (Fig. 6.3), patterns are not necessarily consistent between taxa.

The total number of plant species recorded did not vary greatly between years (Table 6.3), but was slightly higher in 2004 and 2007. The mean site richness of plants was highest in 2003 and 2004 (Table 6.4). Interestingly, mean site richness was relatively low in 2007, despite total richness being relatively high – this probably reflects very spatially patchy rainfall in this wet season.

Only 77-85% of the 215 plant taxa used in analyses were recorded in each individual year. At the site level, mean annual site richness (38.1 species) was considerably lower than mean total sites richness over 4-5 years (59.7 species). Thus, only 64% of the total species complement of a site (as measured over 5 years) was likely to be encountered in any one year.

16 plant species were recorded in only a single year (out of 5), and another 22 species in only 2 years. These “rare” records were fairly evenly distributed amongst years, with the largest number in 2007.

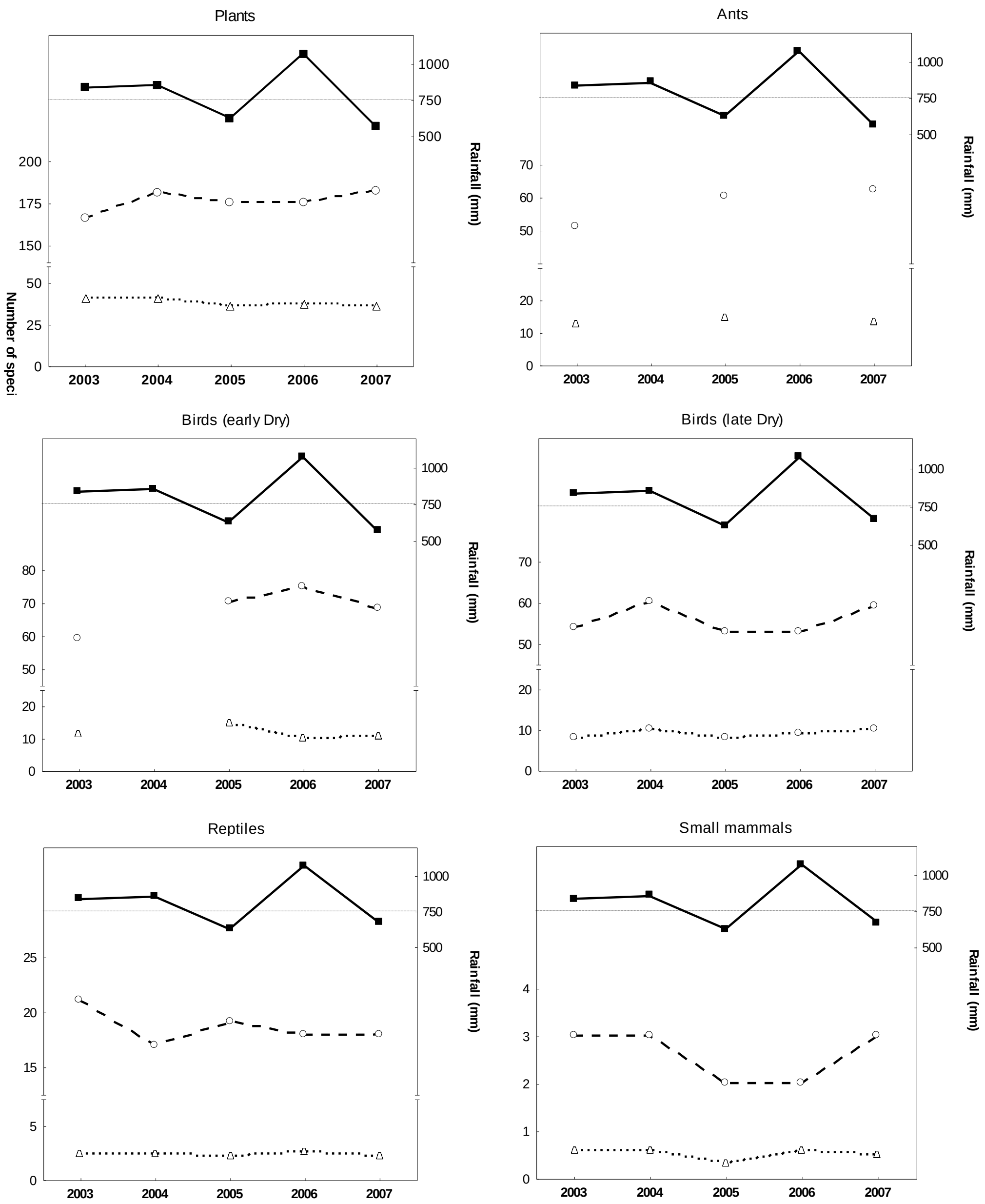


Fig. 6.3. Variation in total richness (open circles) and mean site richness (open triangles) for each group over 5 sampling years, and comparison to annual rainfall (closed squares). Annual rainfall is July-June (e.g. 2002/03 for 2003); dashed line is mean rainfall at Pigeon Hole station for 1994-2007. Rainfall in 2007 excludes large fall in June 2007 for plants, ants and birds (early dry) and includes it for other groups sampled late in 2007. Note that fewer sites were sampled for some groups in 2003 and 2007, which potentially influences total richness (but not mean site richness).

6.4.1.2 Birds

A total of 119 bird species were recorded from the biodiversity sampling sites; after three species-pairs were combined this was reduced to 116 taxa used in the analyses (Table 6.3, Appendix G).

Mean site richness of birds was 11.6 in the early dry and 9.0 in the late dry season (Table 6.4). This site richness of birds is low compared to many other ecosystems, but typical of blacksoil grassland sites with low structural diversity of vegetation. There was a very wide range of site richness in individual years (0 to 26), with the highest richness generally associated with riparian sites.

ANOSIM analysis of bird composition showed that riparian sites are significantly dissimilar to other sites, although this difference is not as pronounced as for plants (2003 late dry season data: R=0.172, p=0.039).

6.4.1.2.1 Variation between seasons and years

A larger number of bird species were generally present in early dry season than late dry (Table 6.3), and the mean site richness of birds was similarly slightly higher in the early dry season (Table 6.4). A number of bird species were markedly more frequent (i.e. recorded from more sites) in the early dry than the late dry season (Fig. 6.4) – notably most raptor species, but also some honeyeaters, bar-shouldered dove, brown songlark, rufous songlark, magpie-lark, and white-winged triller. A smaller number of species were more frequent in the late dry season (including brown quail and diamond dove).

The total number of bird species recorded was fairly constant between years, particularly for the late dry season samples. Bird site richness was notably high in the early dry season of 2005 (Fig. 6.3).

Of the 119 species recorded during the 5 years (9 periods) of sampling, 23 were recorded from only a single site in a single year, and 49 in 5 of fewer site-year combinations. These “rarer” species included waterbirds (recorded occasionally on temporary pools in riparian sites), species characteristic of other habitats in the local region (and occasionally straying in the sample area), species that are relatively rare in this part of the VRD but appeared to be responding to wetter conditions in some years (e.g. Star Finch), and some migratory species. Only 30 species were present during all 9 samples. The total number of bird species recorded in any one sample period was, on average only 53% of the total species complement.

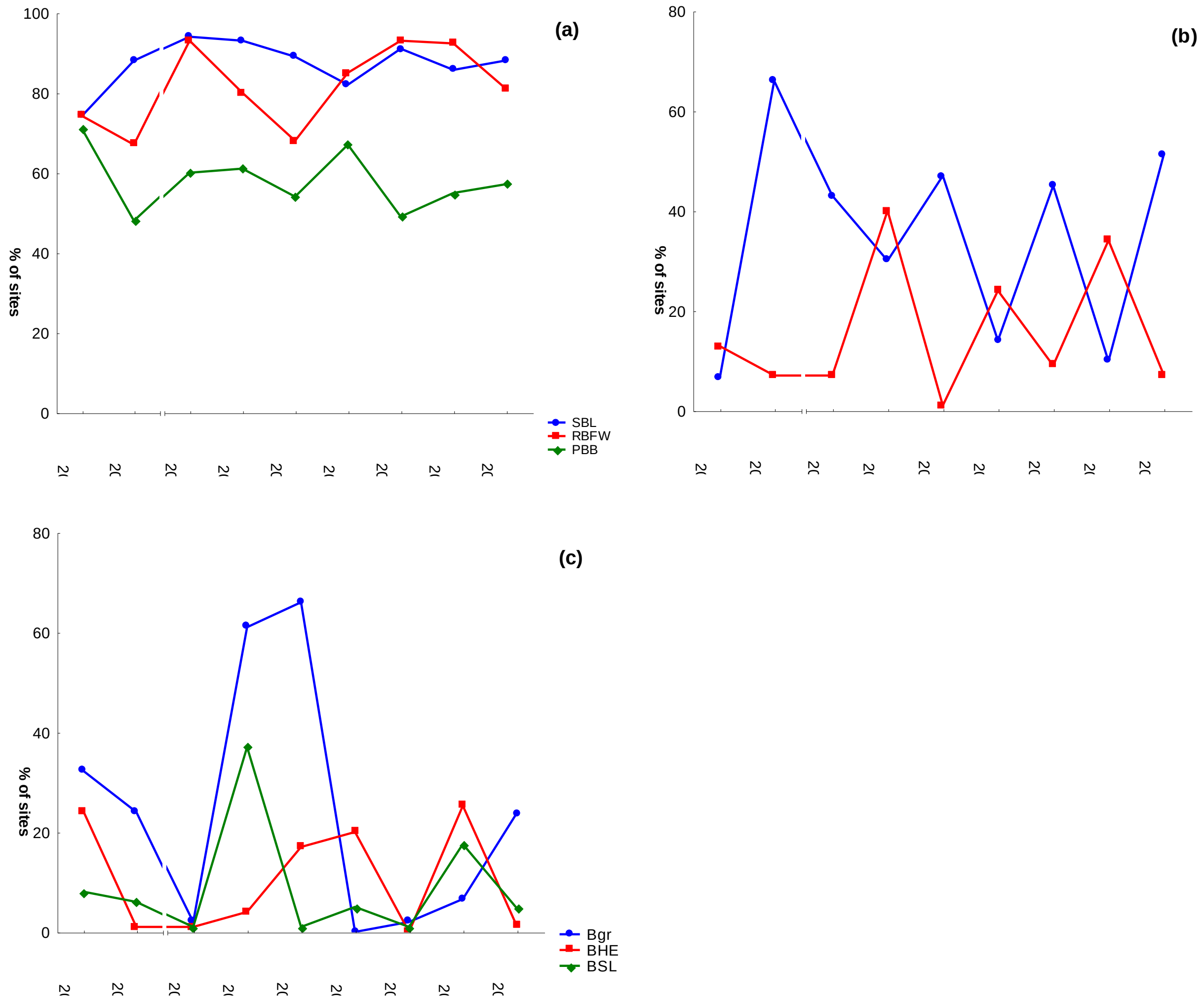


Fig. 6.4. Variation between samples in the frequency (proportion of all sites at which the species was recorded) of selected bird species; (a) common species with relative constant frequency – singing bushlark (SBL), red-backed fairy-wren (RBFW), pied butcherbird (PBB); (b) species consistently more common in the early dry season – pictorella mannikin (PM), or late dry season – diamond dove (DD); (c) species very variably common across samples – budgerigar (Bgr), brown honeyeater(BHE), brown songlark (BSL). 'E' indicates early and 'L' late dry season samples; note that there was no 2004E sample.

6.4.1.3 Reptiles and small mammals

30 reptile, 4 small mammal and 4 macropod species were recorded from the biodiversity sites during the study (Table 6.3, Appendix H).

Mean annual site richness was low for both small mammals (0.5) and reptiles (2.4). The number of reptiles recorded per site varied from 0 to 8 – the richest sites varied between years and were not identifiable by any obvious environmental characteristics.

The long-haired rat *Rattus villosissimus* was recorded only in 2003 (from 4 sites) using Elliott traps, but was never observed or captured (in pit traps) in other years. The long-tailed planigale was recorded in 92% of sites and 48.5% of site-year combinations, but the two other small mammal species were recorded in 10 or fewer sites, and never in more than one year at these sites. A low site richness of small mammals is also found in other inland blacksoil grasslands (Fisher 2001, Woinarski *et al.* 1999) in northern Australia.

Fauna sampling was not designed to systematically census macropods, although these were recorded when present during site visits and bird transects. The nailtail wallaby was recorded in 36% of sites and the euro in 17%, while antilopine wallaroo and red kangaroo were seen only infrequently.

Nine of the 30 reptile species were recorded from only a single site in a single year, and a further 8 species were seen in 6 or fewer sites (and also only a single year in each site). Only four reptile species were recorded on more than 100 site-year combinations (out of a total 470); these species also occurred in over two-thirds of all sites. Blacksoil grasslands in northern Australia generally have a low reptile richness (Fisher 2001), although the VRD lacks a number of species characteristic of Mitchell grasslands in the Barkly Tableland (*Pseudonaja guttata, P. ingrami, Acanthophis antarticus, Varanus spenceri, Pogona vitticeps, Diplodactylus tessellatus*). One very poorly known species (*Tympanocryptis uniformis*) was found at a single site, and the identity of one of the gecko species recorded (*Gehyra* cf *nana*; also from a single site) is uncertain.

Frogs were not deliberately sampled during this study, although two species (*Uperoleia* sp., *Cyclorana australis*) were occasionally captured in pit traps following late dry season storms. A number of other species (e.g. *Litoria caerulea, L. inermis*) were present around turkey nest dams and intermittent waterholes.

6.4.1.3.1 Variation between years

Small mammal richness and abundance were very low throughout the study. In each annual sample, between 38% and 68% of sites had no small mammals – the poorest result was in 2005, when site richness and abundance were about half of the other years.

The total number of reptiles recorded each year was generally consistent across years (Fig. 6.3), although it represented on average only 62% of the total reptile complement. Site richness of reptiles was also consistent across years, with a slight peak in 2006.

6.4.1.4 Ants

A total of 76 ant taxa were recorded from the 3 sample years (Table 6.3, Appendix I).

Mean site richness of ants was just under 14 species, and ranged from 5 to 26 species per site. Riparian sites did not have a higher richness (13.3 spp) than non-riparian sites, and there were no obvious environmental features distinguishing sites with the highest ant richness, which were scattered throughout the trial area.

Site richness is comparable to that previously recorded in Mitchell grasslands in the VRD and Barkly Tableland (Hoffmann 2000, Fisher 2001), but is considerably low than found in most other ecosystems in the tropical savanna and arid zone of Australia (for example, Hoffmann (2001) reported site richness of up to 75 species in eucalypt open woodlands on loam soils at Kalkarinji, c. 50km to the south of Pigeon Hole).

Riparian sites did have a significantly different composition to other sites (ANOSIM R=0.292, p=0.002), although this is not as pronounced as for plants.

6.4.1.4.1 Variation between years

23 taxa were recorded in only a single year, while 44 taxa were recorded in all 3 sample years. 9 taxa were recorded in a single site in a single year, and 31 taxa in 5 or fewer site/year combinations (of a total of 253). Four species were consistently very common, occurring in more than 80% of site/year combinations.

Site richness was slightly higher in 2005 than 2003 and 2007, although the largest total number of species was found in 2007 (Fig. 6.3).

6.4.2 Pre-treatment differences between paddocks

Comparison of the plant composition in sites from all sampled paddocks for early 2004 (Fig. 6.5) shows that, although there is substantial overlap of paddocks in the ordination, overall within-paddock similarity is significantly greater than between-paddock (ANOSIM R=0.33, p<0.0001). Of all pairwise comparisons between paddocks, 52 of 55 were significant, 36 of these at a high significance level (p<0.01). The pattern of similarity between paddocks generally reflects their geographic relationship (Fig. 6.6).

Similarly, comparison of bird composition in sites sampled in late 2003 showed a significant “paddock” effect (ANOSIM R=0.123, p=0.0009). In this case, 24 of 55 pairwise comparisons were similar. The similarity between paddocks is not so clearly related to geographic position as it is for plants (Fig. 6.7). A similar result holds for bird data from early 2003 (R=0.167, p=0.0004; 17 of 28 pairwise comparisons significant) although there were fewer samples from only 8 paddocks.

Sites in 8 paddocks were sampled for ants in 2003 (utilisation paddocks, Barra, South Stevens Ck, Gregory NP). ANOSIM analysis of ant composition also showed a significant difference in composition between paddocks (R=0.318, p<0.0001), with 21 of 28 pairwise comparisons between paddocks significant (Fig. 6.8).

Some other pre-treatment differences between sites in individual paddocks are highlighted in the analyses of richness variables, and the relative abundance of individual species, in sections below.

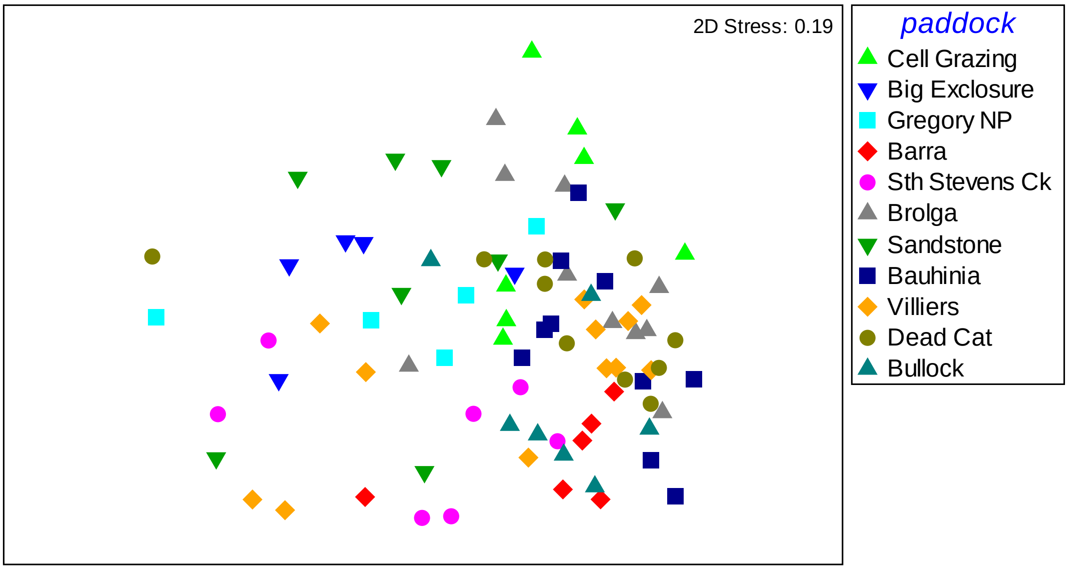


Fig. 6.5. Ordination of sites by **plant composition** (square-root transformation of frequency data) in 2004. Riparian and two 'abnormal' Cell sites are excluded; sites symbols show paddocks.

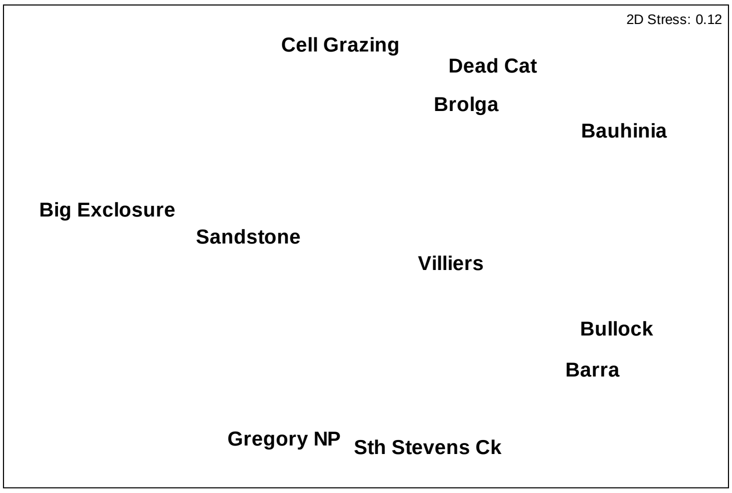
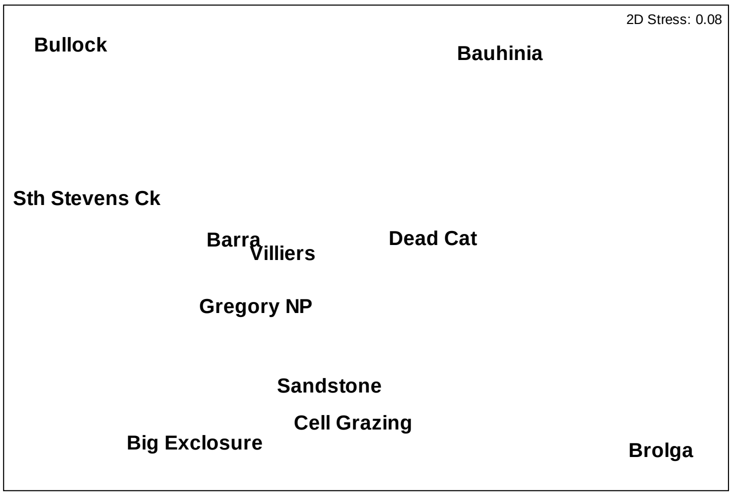


Fig. 6.6. Relationship between paddocks based on the **plant composition** ordination shown in Fig. 6.5 (labels are at the centroid for sites in that paddock), demonstrating spatial pattern of similarity in composition.

Fig. 6.7. Relationship between paddocks (as for Fig. 6.6) based on **bird composition** in late 2003.



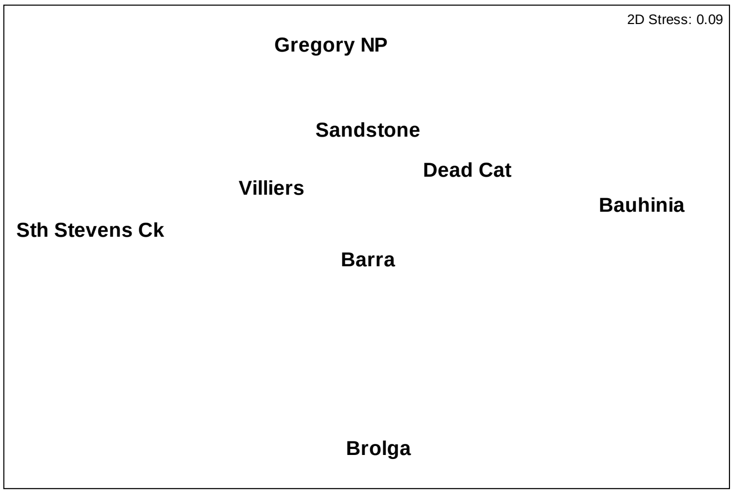


Fig. 6.8. Relationship between paddocks (as for Fig. 6.6) based on **ant composition** in early 2003 (Bullock, Cell Grazing and Big Exclosure paddocks were not sampled at this time).

6.4.3 Utilisation treatment

6.4.3.1 Plants

6.4.3.1.1 Composition

The variation in plant composition between sites in the 5 utilisation paddocks was portrayed using ordination (Fig. 6.9) and the differences between paddocks analysed using ANOSIM (Table 6.5). ANOSIM showed a significant "paddock" effect in 2003, which was maintained in 2004 (which is before there would any expectation of significant treatment effects). However compositional similarity between paddocks gradually increased in 2005 to 2007, and there was no significant overall paddock effect in 2006 and 2007.

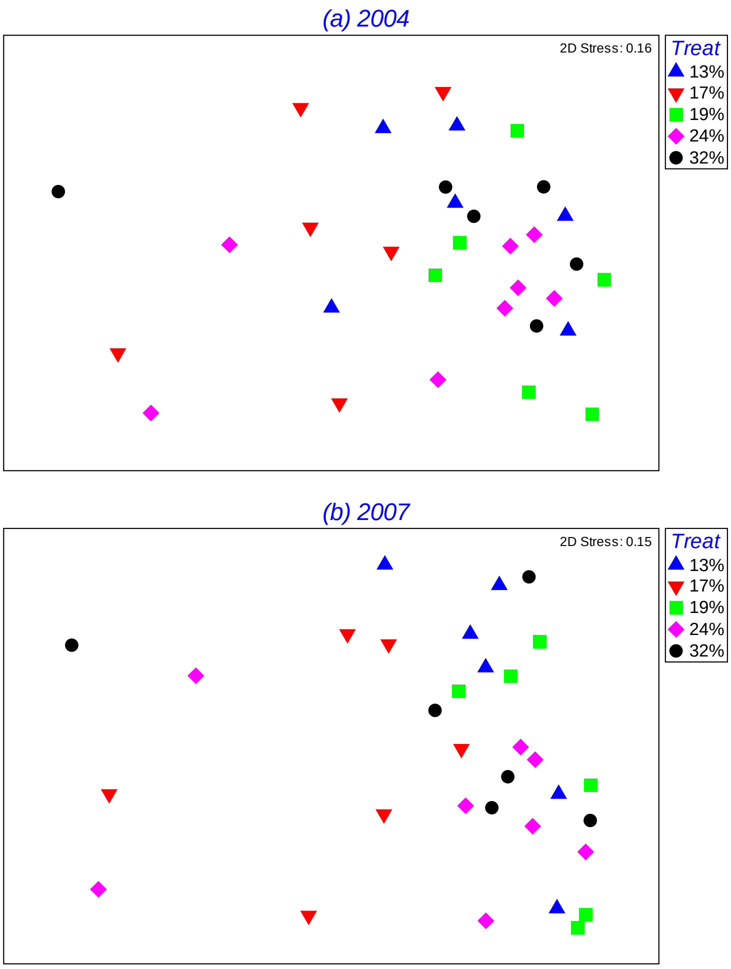


Fig. 6.9. Ordination of sites in utilisation paddocks by **plant composition** in (a) 2004 and (b) 2007.

Table 6.5 also shows pairwise comparisons between individual paddocks for each year. In 2004, all but one pairwise comparisons were significant (there were fewer significant pairwise comparisons in 2003, but this may be partly due to the smaller number of sites sampled in most paddocks). After 2004, there is a clear trend of increase in the similarity of vegetation composition across the sites within the utilisation paddocks, so that there were no significant pairwise comparisons by 2007.

A very similar result is obtained using plant cover, rather than frequency, data.

Table 6.5. ANOSIM analyses comparing **plant composition** of sites in the 5 utilisation paddocks, for 2003-2007. Global R and pairwise comparisons are reported; significant R values (p<0.1) are bolded. Riparian and exclosure sites were excluded.

a) frequency data

	2003		2004		2005		2006		2007	
Overall R	**0.205**		**0.182**		**0.100**		0.062		0.040	
Overall P	0.002		0.002		0.037		0.127		0.213	
Groups	*R*	*P*	*R*	*P*	*R*	*P*	*R*	*P*	*R*	*P*
13%, 17%	**0.33**	0.008	**0.21**	0.045	0.06	0.242	0.08	0.212	0.08	0.225
13%, 19%	-0.04	0.543	**0.20**	0.069	0.03	0.316	0.04	0.305	-0.12	0.890
13%, 24%	0.11	0.139	**0.20**	0.056	0.03	0.343	0.07	0.221	0.09	0.174
13%, 32%	0.10	0.156	**0.19**	0.045	**0.19**	0.048	0.06	0.229	0.09	0.184
17%, 19%	**0.41**	0.002	**0.38**	0.002	**0.18**	0.067	0.14	0.113	0.10	0.175
17%, 24%	**0.47**	0.017	**0.17**	0.079	0.13	0.125	0.12	0.133	0.06	0.220
17%, 32%	**0.34**	0.017	**0.31**	0.022	**0.17**	0.065	0.12	0.171	0.06	0.242
19%, 24%	**0.19**	0.076	0.08	0.195	0.03	0.340	-0.01	0.438	0.02	0.357
19%, 32%	**0.19**	0.043	**0.14**	0.089	**0.23**	0.019	**0.12**	0.089	-0.00	0.409
24%, 32%	0.07	0.184	**0.13**	0.086	0.06	0.203	-0.09	0.854	0.00	0.403

b) cover data

	2003		2004		2005		2006		2007	
Overall R	**0.276**		**0.182**		**0.107**		0.057		0.048	
Overall P	0.001		0.005		0.038		0.147		0.180	
Groups	*R*	*P*	*R*	*P*	*R*	*P*	*R*	*P*	*R*	*P*
13%, 17%	**0.23**	0.063	0.07	0.223	0.04	0.310	0.05	0.279	0.00	0.444
13%, 19%	**0.21**	0.095	**0.20**	0.074	0.05	0.297	-0.04	0.517	-0.05	0.558
13%, 24%	0.12	0.156	**0.26**	0.036	0.08	0.211	0.04	0.297	0.10	0.166
13%, 32%	**0.21**	0.089	**0.25**	0.054	**0.20**	0.035	0.04	0.253	0.01	0.383
17%, 19%	**0.60**	0.002	**0.25**	0.015	**0.19**	0.063	0.13	0.143	**0.13**	0.087
17%, 24%	**0.47**	0.019	**0.21**	0.047	**0.17**	0.086	**0.19**	0.060	0.14	0.101
17%, 32%	**0.31**	0.037	**0.29**	0.028	**0.18**	0.063	0.12	0.162	0.09	0.208
19%, 24%	**0.24**	0.052	0.11	0.165	0.04	0.323	-0.00	0.445	0.03	0.317
19%, 32%	**0.37**	0.004	**0.19**	0.067	**0.22**	0.022	0.15	0.106	0.05	0.268
24%, 32%	0.07	0.236	0.10	0.158	0.08	0.196	-0.11	0.922	-0.04	0.608

This is the reverse of the pattern that would be predicted if the achieved differences in utilisation had an immediate effect on plant composition throughout each paddock – paddocks should initially be compositionally similar, with an increasing overall "paddock" effect over years, and increasingly significant pairwise comparisons, particularly between paddocks with the greatest contrast in utilisation level.

A plot of the movement in ordination space of the centroids for each paddock over the 5 years (Fig. 6.10) shows a general movement toward the middle of the ordination (except for the 17% treatment).

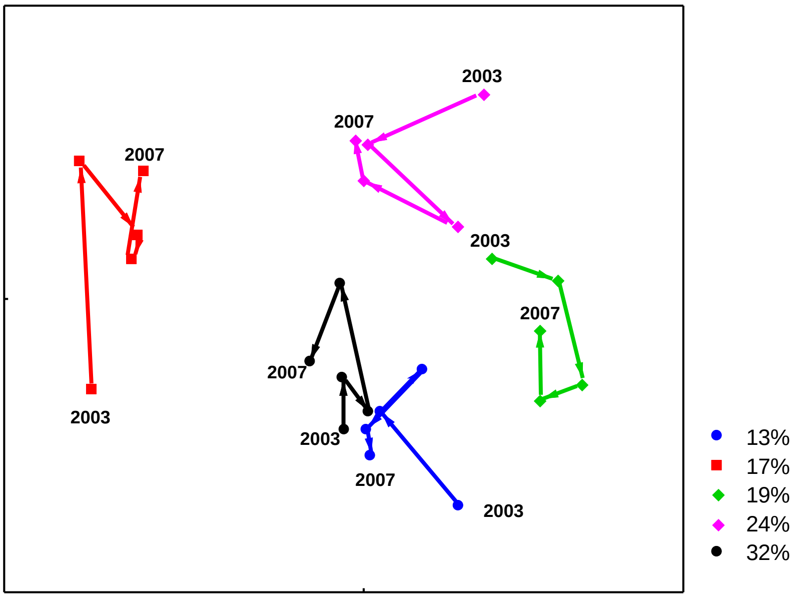


Fig. 6.10. Movement through ordination space of the centroids for each paddock, over 5 years from 2003 to 2007 (intermediate years are not labelled but arrows show progression). The centroid is the mean of the position in the ordination of all sites in that paddock in that year, based on plant species composition (as per Fig. 6.9).

6.4.3.1.2 Richness, diversity and structural variables

There was a highly significant year effect and a significant *year* treatment* interaction for plant species richness (Table 6.6, Fig. 6.11a). The interaction results from an idiosyncratic response to seasonal variation between utilisation treatment (the 13% and 32% paddocks were much more consistent across years than the other levels) rather than a coherent differentiation of paddocks. Throughout the trail, the 13% sites had a consistently low mean richness and the 24% sites a consistently high richness. A similar pattern is seen for the Shannon diversity index (Fig. 6.11b).

Total understorey cover (in the early dry season) had a very significant *year* effect, due to a pronounced peak in 2004 (Fig. 6.11c). There was no significant *year*treatment* interaction.

There was also a (less pronounced) peak in perennial grass cover in 2004, particularly in the 17% paddock (Fig. 6.11d). By 2007, mean perennial grass cover was slightly higher in the 13-17% paddocks than the 19-32% paddocks, although there was not a significant *treatment* or *treatment*year* effect.

Perennial grass basal cover declined in all treatments during the period of the trial (Fig. 6.11e). As for cover, perennial basal area was slightly higher in the 13-17% paddocks than the 19-32% paddocks in 2007, although this difference was not significant.

By contrast, mean perennial grass frequency did not vary across years, nor was there any significant treatment effect (Fig. 6.11f).

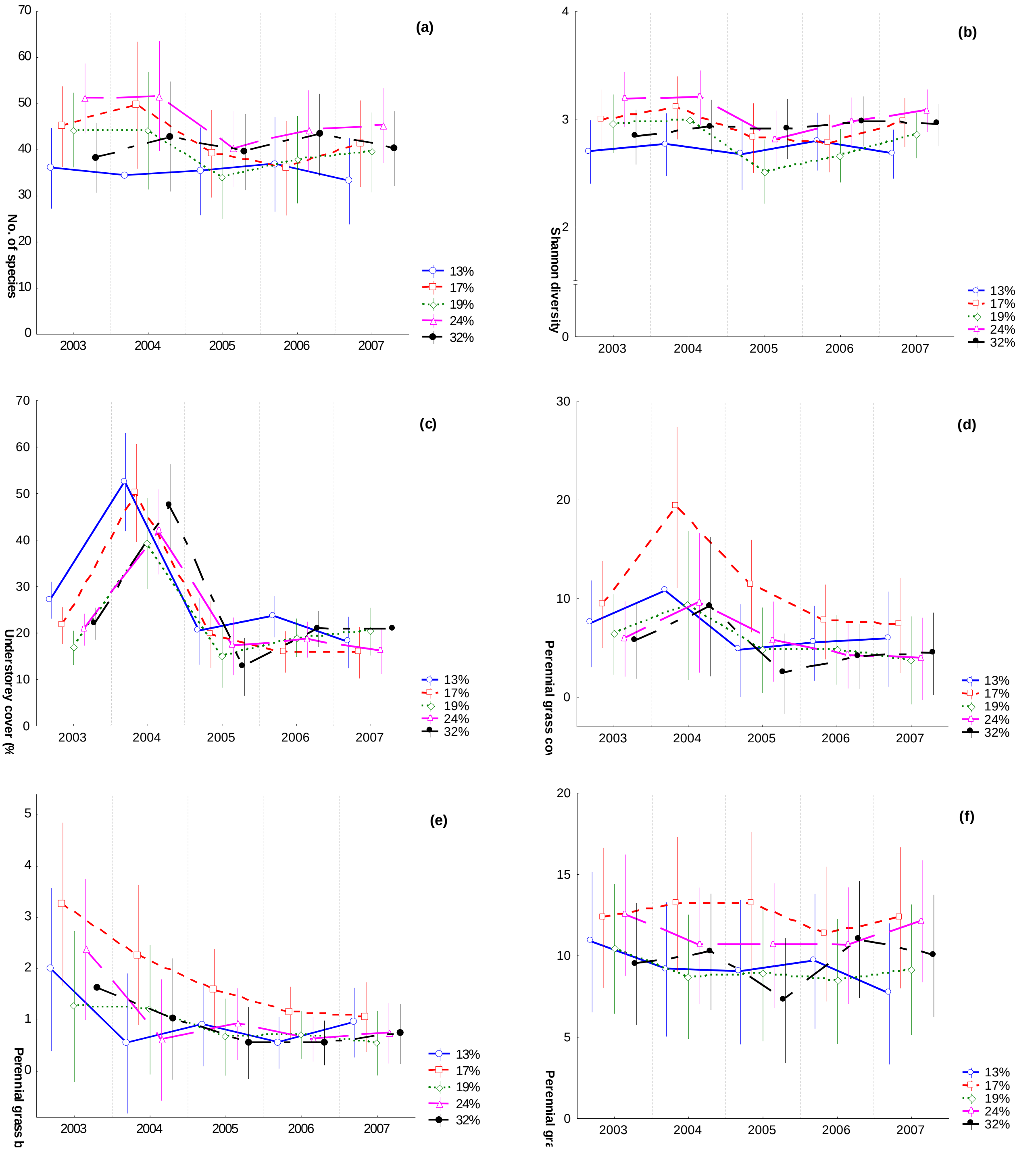


Fig. 6.11 Comparison between utilisation treatments for plant summary variables: a) species richness; b) Shannon diversity index; c) total understorey cover; d) perennial grass cover; e) perennial grass basal cover; f) perennial grass frequency. For this and subsequent similar figures, whiskers are 95% confidence intervals (but note that the repeated measures analyses reported in the text and tables are potentially more sensitive to differences between treatments/years than simple comparisons of treatment means). Data points for each year are offset for clarity; vertical broken lines are used to help distinguish years.

Table 6.6. Summary of repeated-measures ANOVA comparing utilisation treatments across years for plant summary variables. Table shows the F-ratio and p-value for each term in the GLM; significant (p<0.05) effects are bolded.

	Treatment		Year		Treatment*year	
df	*4*		*4*		*16*	
Variable	F	p	F	p	F	p
Species richness	0.856	0.501	**7.449**	0.000	**1.970**	0.020
Shannon diversity	1.373	0.267	**8.116**	0.000	**2.019**	0.017
Understorey cover	2.345	0.077	**82.317**	0.000	1.069	0.392
Perennial grass cover	1.160	0.348	**17.254**	0.000	0.963	0.502
Perennial grass basal cover	1.073	0.387	**13.005**	0.000	0.970	0.494
Perennial grass frequency	0.699	0.599	1.071	0.374	0.975	0.488

6.4.3.1.3 Individual species

62 plant species (29% of the total) occurred in sufficient sites in the utilisation paddock for analysis. Of these, 31 had a significant year effect, 10 a significant treatment effect, and 13 a significant *year*treatment* interaction (Table 6.7). Examination of the response patterns (e.g. Fig. 6.12) for species with a significant interaction term show that nearly all have an idiosyncratic response in some paddocks in some years, rather than a coherent differentiation of utilisation levels over time. For example, *Cucumis melo* had a very high frequency in the 19% paddock on 2003 and 2004, then declined to a low frequency comparable to the other paddocks in 2005-07. *Ptilotus spicatus* initially had a high frequency in the 17% paddock, which declined during the trial, but increased in frequency in the 32% paddock in 2006-07.

While many species showed a significant variation in frequency between years, the response pattern was quite variable between species. For example, *Chionachne hubbardiana* generally declined during the period of the trial, while *Abutilon hanni* increased. Many species had pronounced peaks in individual years, particularly in 2004. For a few species (e.g. *Iseilema fragile*) there was a clear pre-treatment difference between paddocks that was maintained for the period of the trial. The response of some of the dominant grass species is also shown in Fig. 6.12.

Table 6.7. Summary of repeated-measures ANOVA comparing utilisation treatments across years for individual plant species. Table shows the F-ratio and p-value for each term in the GLM; significant (p<0.05) effects are bolded. 'N' is the number of sites (n=32) at which the species was recorded (at least once in 5 years).

	N	Treatment		Year		Treatment*year	
		F	p	F	p	F	p
		df = 4		*df = 4*		*df = 16*	
Abelmoschus ficulneus	18	0.491	0.743	2.901	**0.026**	0.633	0.848
Abutilon hannii	30	1.740	0.176	3.757	**0.007**	0.773	0.711
Achyranthes aspera	19	1.447	0.251	1.710	0.155	0.537	0.920
Alysicarpus muelleri	32	0.583	0.678	3.934	**0.005**	0.958	0.508
Aristida latifolia	32	3.443	**0.024**	2.085	0.089	1.014	0.450
Astrebla elymoides	22	1.738	0.176	1.387	0.245	1.063	0.402
Bauhinia cunninghamii	12	0.204	0.933	1.501	0.208	0.973	0.492
Blumea tenella	27	3.569	**0.021**	1.081	0.363	1.066	0.401
Boerhavia spp.	29	0.748	0.569	1.503	0.208	0.791	0.692
Brachyachne convergens	30	0.982	0.437	4.024	**0.005**	1.082	0.383
Calotropis procera	15	2.234	0.097	2.375	0.058	1.200	0.283
Chionachne hubbardiana	23	0.522	0.720	5.702	**0.000**	1.106	0.362
Chrysopogon fallax	31	0.349	0.842	1.168	0.330	1.623	0.078
Commelina ciliata	29	2.914	**0.044**	3.797	**0.007**	3.106	**0.000**
Corchorus combined	28	0.430	0.785	4.220	**0.004**	0.777	0.707
Corchorus macropetalus	18	2.293	0.090	3.378	**0.013**	1.279	0.228
Corymbia terminalis	14	2.771	0.051	5.194	**0.001**	4.450	**0.000**
Crotalaria medicaginea	26	0.100	0.982	1.977	0.105	1.520	0.109
Crotalaria montana	11	1.209	0.334	1.843	0.127	0.872	0.602
Cucumis melo	28	5.282	**0.004**	9.047	**0.000**	2.597	**0.002**
Cyperus bifax	22	0.998	0.429	1.964	0.107	0.621	0.859
Desmodium muelleri	22	1.205	0.336	2.779	**0.031**	0.575	0.895
Dichanthium fecundum	19	2.936	**0.043**	1.784	0.139	0.814	0.666
Dichanthium sericeum	25	1.266	0.312	1.398	0.241	0.662	0.823
Eragrostis tenellula	22	0.763	0.560	4.776	**0.004**	1.838	0.059
Eulalia aurea	10	2.152	0.107	0.872	0.484	0.464	0.958
Euphorbia maconochieana	25	3.626	**0.020**	5.161	**0.001**	3.132	**0.000**
Euphorbia schizolepis	17	1.086	0.387	3.172	**0.017**	0.903	0.568
Evolvulus alsinoides	9	0.961	0.445	1.747	0.164	1.059	0.405
Fimbristylis schultzii	19	1.543	0.223	3.892	**0.006**	1.945	**0.026**
Flemingia pauciflora	31	1.786	0.166	1.907	0.116	0.823	0.656
Gomphrena affinis	19	1.014	0.421	0.555	0.696	1.038	0.426
Goodenia byrnesii	24	1.342	0.285	2.689	**0.036**	0.325	0.993
Heliotropium spp.	20	0.482	0.749	1.112	0.356	1.047	0.417
Hybanthus enneaspermus	12	0.948	0.454	0.497	0.738	1.255	0.243
Indigofera linifolia	24	1.409	0.263	2.811	**0.030**	0.984	0.481
Indigofera trita	18	0.746	0.571	0.694	0.598	1.309	0.209

	N	Treatment		Year		Treatment*year	
Iseilema ciliatum	20	2.062	0.119	3.333	**0.013**	2.408	**0.005**
Iseilema fragile	32	2.835	**0.048**	3.955	**0.005**	0.631	0.851
Iseilema mac/vag	32	2.274	0.092	1.705	0.156	1.995	**0.021**
Jacquemontia browniana	32	1.568	0.216	8.284	**0.000**	1.214	0.273
Neptunia dimorphantha	18	0.353	0.839	0.115	0.977	1.097	0.369
Neptunia gracilis	17	0.865	0.499	1.683	0.161	1.558	0.097
Panicum decompositum	32	0.925	0.466	0.583	0.675	0.970	0.496
Pentalepis ecliptoides	30	1.938	0.138	9.123	**0.000**	0.918	0.551
Phyllanthus maderaspatensis	32	0.923	0.468	7.822	**0.000**	1.599	0.085
Polygala sp.	24	3.938	**0.014**	7.966	**0.000**	2.388	**0.005**
Polymeria ambigua	31	1.704	0.183	6.160	**0.000**	1.957	**0.025**
Ptilotus spicatus	22	1.642	0.198	0.927	0.452	2.737	**0.001**
Rhynchosia minima	30	0.868	0.498	12.538	**0.000**	0.666	0.820
Sehima nervosum	13	1.589	0.211	1.962	0.107	2.392	**0.005**
Sesbania simpliciuscula	32	1.162	0.353	7.656	**0.000**	0.518	0.932
Sida fibulifera	13	1.197	0.339	0.958	0.435	0.826	0.653
Sida spinosa	24	0.858	0.504	1.059	0.381	0.928	0.540
Sorghum timorense	29	0.626	0.649	3.566	**0.009**	1.152	0.322
Spermacoce pogostoma	26	3.154	**0.033**	13.848	**0.000**	2.269	**0.008**
Streptoglossa bubakii	16	0.768	0.557	1.354	0.256	1.072	0.393
Tephrosia rosea	16	1.246	0.320	1.458	0.221	0.969	0.496
Terminalia arostrata	25	0.496	0.738	2.170	0.079	0.404	0.978
Terminalia volucris	23	2.629	0.061	4.572	**0.002**	1.452	0.136
Trichodesma zeylanicum	31	3.000	**0.040**	15.191	**0.000**	1.793	**0.044**
Wedelia asperrima	29	1.824	0.159	7.258	**0.000**	0.759	0.726

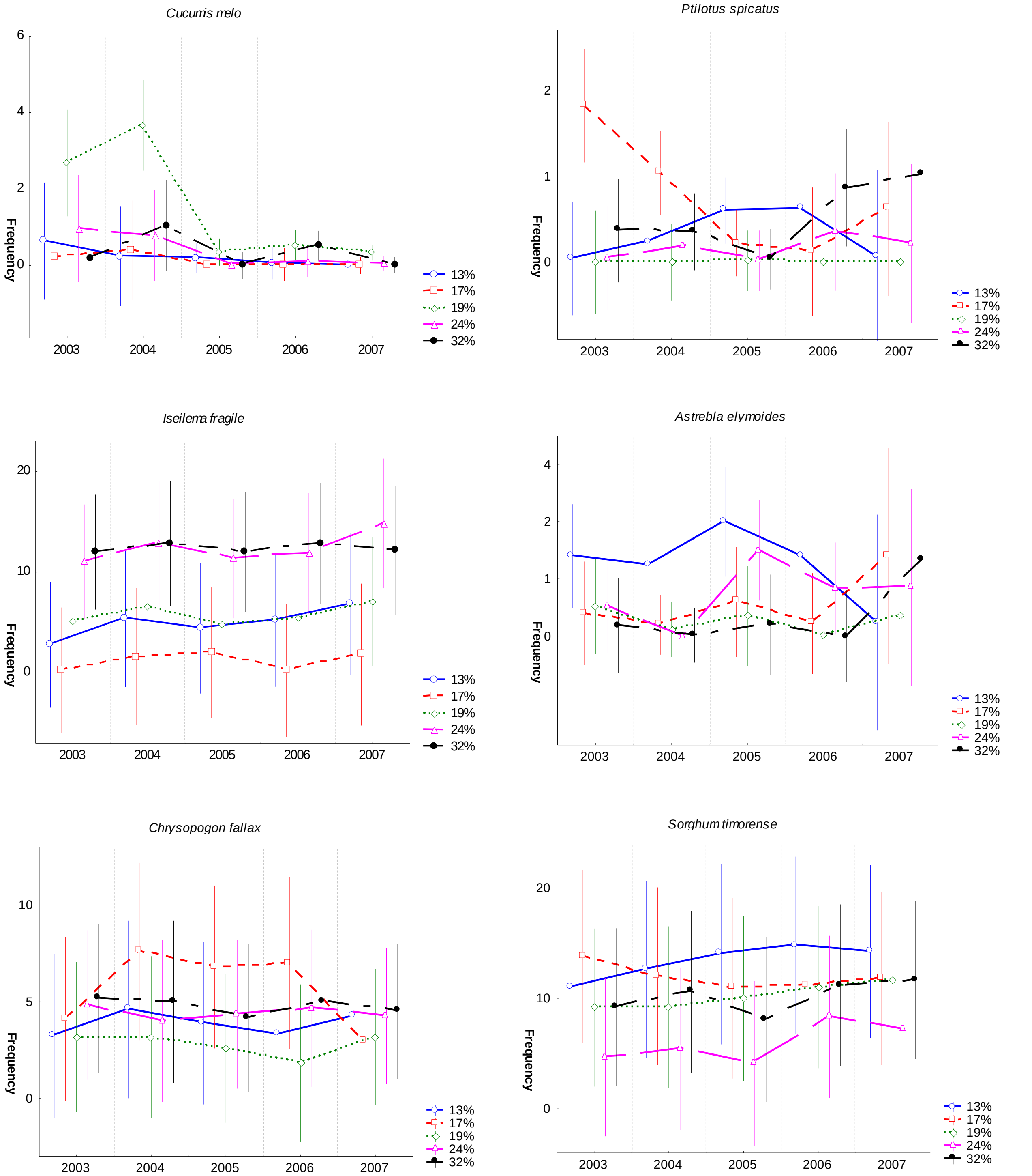


Fig. 6.12 Examples of the variation in the frequency of individual plants species between utilisation paddocks and over years: a) *Cucumis melo*; b) *Ptilotus spicatus*; c) *Iseilema fragile*; d) *Astrebla elymoides*; e) *Chrysopogon fallax*; f) *Sorghum timorense*.

6.4.3.2 Birds

6.4.3.2.1 Composition

The variation over years in compositional similarity between utilisation paddocks is more complex for birds than plants (Table 6.8, Fig. 6.13). The overall paddock effect is not significant in 2003, and only 3 of 10 pairwise comparisons are significant. Differences between paddocks increase in 2004 but decrease in 2005 and 2006, so that no pairwise comparisons are significant in 2006 (a homogenisation effect similar to that observed for plants). However, there is a significant paddock effect in 2007, with 4 significant pairwise comparisons (between the 17% paddocks and each of the higher utilisation paddocks, but also between the 13% and 24% paddocks).

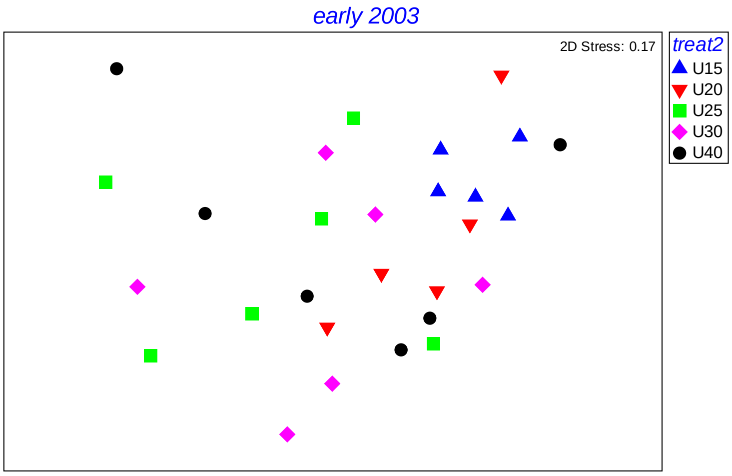
Table 6.8. ANOSIM analyses, comparing bird composition (frequency in transects + quadrat) of sites in the 5 utilisation level paddocks, for 2003-2007. Global R and pairwise comparisons are reported; significant R values (P<0.1) are bolded. Riparian and exclosure sites are excluded.

a) Late dry season

	2003		2004		2005		2006		2007	
Overall R	0.053		**0.133**		**0.081**		0.027		**0.175**	
Overall P	0.143		0.016		0.088		0.271		0.012	
Groups	*R*	*P*	*R*	*P*	*R*	*P*	*R*	*P*	*R*	*P*
15%, 20%	0.10	0.126	0.012	0.171	-0.08	0.690	-0.06	0.682	0.14	0.136
15%, 25%	**0.20**	0.035	**0.16**	0.061	**0.19**	0.037	0.06	0.275	0.07	0.216
15%, 30%	0.11	0.142	0.14	0.109	**0.15**	0.096	0.14	0.100	**0.26**	0.036
15%, 40%	**0.15**	0.071	**0.26**	0.028	**0.27**	0.035	0.07	0.236	0.16	0.130
20%, 25%	**0.20**	0.019	**0.16**	0.074	0.10	0.152	0.13	0.115	**0.36**	0.015
20%, 30%	0.03	0.340	**0.24**	0.042	-0.03	0.549	0.03	0.302	**0.34**	0.021
20%, 40%	0.05	0.219	**0.18**	0.076	**0.13**	0.130	-0.08	0.760	**0.39**	0.030
25%, 30%	-0.04	0.617	0.05	0.260	0.09	0.180	-0.03	0.570	0.05	0.264
25%, 40%	-0.07	0.734	0.06	0.253	**0.18**	0.091	-0.00	0.468	0.00	0.450
30%, 40%	-0.04	0.615	0.07	0.221	-0.09	0.776	0.01	0.409	0.04	0.299

b) Early dry season

	2003		2005		2006		2007	
Overall R	0.082		**0.183**		**0.198**		0.074	
Overall P	0.115		0.006		0.004		0.118	
Groups	*R*	*P*	*R*	*P*	*R*	*P*	*R*	*P*
15%, 20%	**0.32**	0.040	0.11	0.184	0.11	0.128	0.10	0.171
15%, 25%	**0.48**	0.006	0.08	0.195	**0.18**	0.078	0.01	0.366
15%, 30%	**0.39**	0.013	**0.27**	0.027	**0.42**	0.010	**0.17**	0.078
15%, 40%	0.13	0.117	**0.57**	0.006	**0.29**	0.024	0.10	0.199
20%, 25%	0.09	0.199	0.13	0.113	**0.18**	0.071	**0.14**	0.084
20%, 30%	-0.03	0.554	-0.00	0.421	**0.29**	0.031	**0.25**	0.036
20%, 40%	-0.05	0.656	**0.52**	0.006	**0.25**	0.037	**0.23**	0.061
25%, 30%	-0.12	0.805	0.02	0.345	0.04	0.313	-0.04	0.574
25%, 40%	-0.04	0.610	**0.15**	0.008	**0.19**	0.080	-0.07	0.645
30%, 40%	-0.13	0.894	0.17	0.069	0.11	0.140	-0.08	0.789



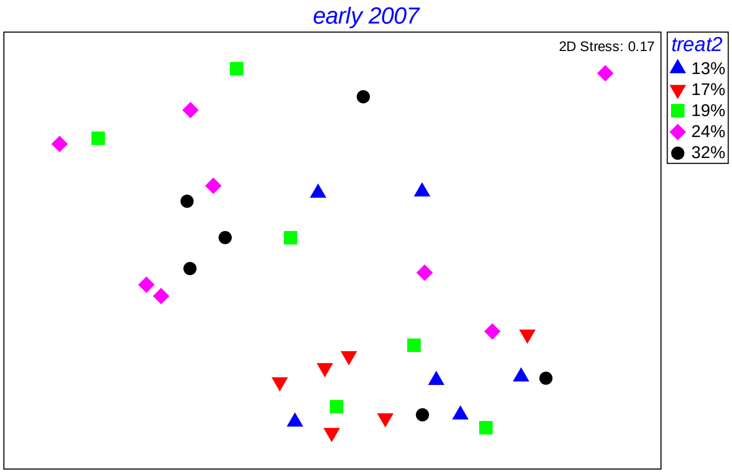


Fig. 6.13. Ordination of sites in utilisation paddocks by **bird composition** in (a) early 2003 and (b) early 2007.

Differences between paddocks also vary between the early and late dry season bird samples, with significant differences between most paddocks in the early 2006 sample, and a less pronounced paddock effect in the early 2007 sample.

A plot of the movement over years of paddock centroids in ordination space (Fig. 6.14) shows the large, and generally congruent, movements due to seasonal effects, and also demonstrates how pre-treatment differences are generally maintained.

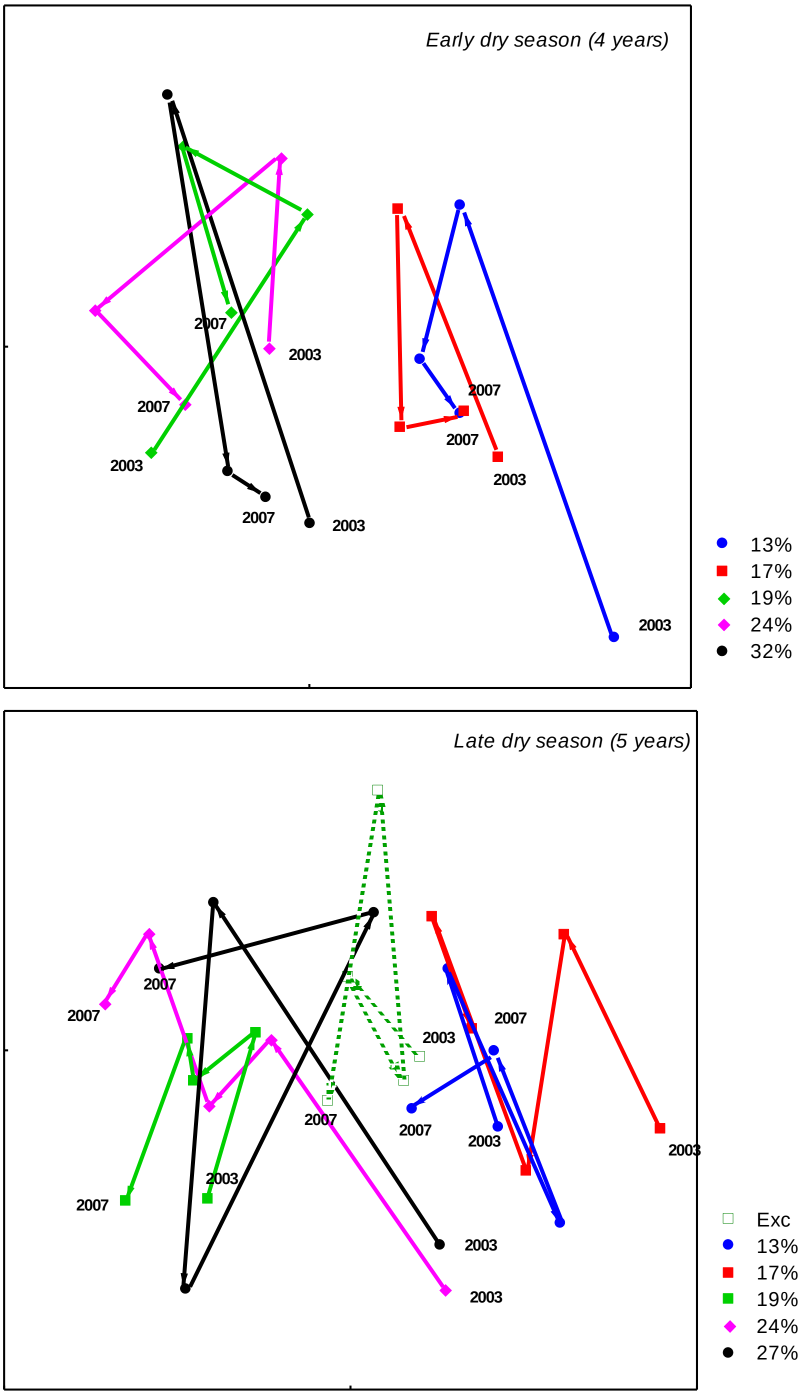


Fig. 6.14. Movement through ordination space of the centroids for each paddock, based on **bird composition**, for the early dry season (4 years, without 2004) and late dry season (5 years). Intermediate years are not labelled but arrows show progression). Exclosure sites are included in the late dry season plot for comparison.

6.4.3.2.2 Richness and diversity

There is a strong *year* effect for all bird richness variables (Table 6.9), reflecting a peak in bird richness and frequency in 2005 (early dry season) and 2006/07 (late dry season). There are no significant *treatment* or *treatment*year* effects for any variables, except for a significant interaction for early season richness (site and adjacent), although the interaction is close to significant (p<0.10) for several variables. This reflects idiosyncratic variation between some paddocks and years, rather than a consistent response (Fig. 6.15).

Table 6.9. Summary of repeated-measures ANOVA comparing utilisation levels (*treatment*) across years for bird summary variables. Table shows the F-ratio and p-value for each term in the GLM; significant (p<0.05) effects are bolded. Late dry season comparisons are for 2004-2007; early dry season for 2003, 2005-07.

	Treatment		Year		Treatment*year	
	df = 4		*df = 3*		*df = 12*	
Variable	F	p	F	p	F	p
Species richness						
Early dry season (site and adj)	0.805	0.534	**9.840**	0.000	**2.162**	0.023
Early dry season (site only)	0.578	0.681	**18.036**	0.000	1.470	0.157
Late dry season (site and adj)	1.640	0.193	**6.530**	0.001	1.488	0.146
Late dry season (site only)	0.979	0.436	**6.298**	0.001	1.647	0.095
Total frequency						
Early dry season	0.180	0.947	**17.210**	0.000	1.386	0.194
Late dry season	1.662	0.188	**4.113**	0.009	1.280	0.247
Shannon diversity						
Early dry season	0.533	0.713	**9.983**	0.000	1.711	0.083
Late dry season	0.967	0.442	**3.078**	0.032	1.819	0.058

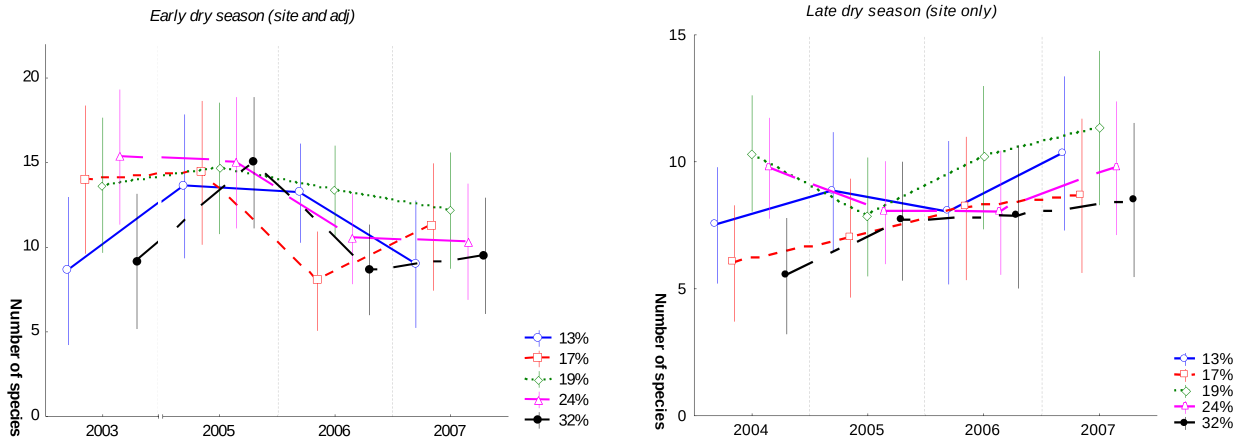


Fig. 6.15. Comparison between utilisation treatments for **bird richness** (early dry season: species in site and adjacent; late dry season: species in site only).

6.4.3.2.3 Individual species

40 and 27 bird species occurred in sufficient sites in the early and late dry season, respectively, for analysis (Table 6.10). In the early dry season, 23 species had a significant *year* effect, 6 species a significant *treatment* effect and 7 species a significant *year*treatment* interaction. In the late dry season, the equivalent numbers were 10, 2 and 4 species. Examination of the plots for each species showed that, as for plant species, significant interaction terms generally arose because of idiosyncratic variation between some paddocks and some years, rather than consistent responses over the course of the trial. For example, budgerigars were only abundant in 2005, and were more abundant in the 19%-32% paddocks than the 13%-17% paddocks.

Table 6.10. Summary of repeated-measures ANOVA comparing utilisation treatments across years for individual bird species. Separate comparisons were made for early and late dry season samples.

	Treatment		Year		Treatment*year	
	df = 4				*df* = 12	
	F	p	F	p	F	p
Early dry season						
Australian Bustard	1.579	0.213	**3.006**	0.036	1.004	0.455
Australian Hobby	0.518	0.724	0.802	0.454	0.928	0.503
Black Kite	1.170	0.350	**2.867**	0.043	0.694	0.752
Black-faced Cuckoo-shrike	0.717	0.589	0.788	0.504	0.869	0.581
Black-faced Woodswallow	0.259	0.901	**3.665**	0.016	1.105	0.370
Brolga	1.459	0.247	**4.153**	0.009	0.987	0.470
Brown Falcon	1.138	0.364	**5.972**	0.001	0.581	0.850
Brown Honeyeater	2.116	0.112	2.420	0.073	1.369	0.202
Brown Quail	1.040	0.408	0.850	0.471	0.699	0.747
Brown Songlark	1.881	0.148	**9.471**	0.000	**3.612**	0.000
Budgerigar	**2.932**	0.043	**17.110**	0.000	**3.009**	0.008
Button-quail spp.	**4.827**	0.006	**3.947**	0.012	**2.349**	0.014
Cockatiel	0.544	0.705	1.137	0.340	0.796	0.653
Crested Pigeon	2.010	0.127	2.308	0.084	1.352	0.210
Diamond Dove	0.626	0.649	**4.972**	0.004	0.769	0.680
Galah	1.433	0.255	1.978	0.125	0.383	0.965
Golden-headed Cisticola	**3.914**	0.014	2.484	0.068	1.155	0.333
Grey-crowned Babbler	0.746	0.571	0.442	0.724	0.898	0.553
Little Friarbird	0.929	0.464	3.149	0.052	0.729	0.665
Magpie-lark	**3.729**	0.018	**3.792**	0.014	1.201	0.300
Martin spp.	**3.640**	0.019	**9.211**	0.000	**3.464**	0.003
Masked Woodswallow	2.034	0.123	**3.268**	0.047	2.100	0.055
Nankeen Kestrel	1.495	0.236	**14.515**	0.000	1.298	0.240
Peaceful Dove	2.211	0.099	**7.532**	0.000	**2.519**	0.008
Pictorella Mannikin	1.346	0.283	2.172	0.099	1.066	0.402
Pied Butcherbird	1.116	0.373	**3.591**	0.018	1.742	0.076
Red-backed Fairy-wren	0.802	0.536	**5.385**	0.002	1.257	0.264
Red-backed Kingfisher	2.731	0.054	2.545	0.063	**2.025**	0.035
Red-tailed Black-Cockatoo	0.789	0.544	**5.714**	0.001	0.561	0.866
Rufous Songlark	1.209	0.334	0.940	0.426	1.045	0.419
Rufous-throated Honeyeater	0.633	0.644	**2.935**	0.039	0.759	0.689
Singing Bushlark	1.417	0.260	**6.177**	0.001	1.076	0.393
Singing Honeyeater	1.178	0.347	2.327	0.082	1.208	0.296
Spotted Harrier	0.385	0.817	2.370	0.078	1.345	0.214

	Treatment		Year		Treatment*year	
Torresian Crow	0.606	0.662	**2.911**	0.041	1.788	0.067
Weebill	**2.845**	0.043	2.036	0.140	1.306	0.260
White-winged Triller	0.825	0.522	1.492	0.224	**3.328**	0.001
Willie Wagtail	1.180	0.346	**19.033**	0.000	1.619	0.106
Yellow-throated Miner	1.816	0.160	**3.787**	0.014	1.084	0.387
Zebra Finch	0.381	0.820	**5.533**	0.002	0.562	0.865
Late dry season						
Australian Bustard	0.691	0.605	0.673	0.571	1.298	0.236
Black-faced Cuckoo-shrike	0.167	0.953	1.366	0.259	1.556	0.122
Black-faced Woodswallow	1.207	0.331	1.484	0.225	0.923	0.528
Brown Quail	1.166	0.348	1.748	0.164	**2.436**	0.009
Button-quail spp.	**5.132**	0.003	**3.258**	0.026	1.366	0.199
Cockatiel	0.739	0.574	1.999	0.121	1.147	0.335
Crested Pigeon	1.137	0.360	**2.642**	0.055	1.160	0.326
Diamond Dove	1.417	0.255	0.826	0.483	1.089	0.380
Galah	1.612	0.200	**3.615**	0.017	0.818	0.632
Golden-headed Cisticola	2.015	0.121	**12.834**	0.000	1.223	0.282
Little Friarbird	0.726	0.582	1.566	0.218	0.469	0.873
Magpie-lark	1.337	0.282	**4.188**	0.008	1.198	0.299
Martin spp.	1.860	0.146	1.173	0.325	0.681	0.764
Peaceful Dove	1.834	0.151	**4.976**	0.003	1.252	0.264
Pictorella Mannikin	1.948	0.131	0.208	0.813	0.233	0.983
Pied Butcherbird	1.531	0.221	0.887	0.451	0.801	0.648
Red-backed Fairy-wren	1.616	0.199	**15.034**	0.000	0.399	0.960
Rufous-throated Honeyeater	1.935	0.133	0.448	0.719	1.013	0.445
Singing Bushlark	**3.816**	0.014	**4.423**	0.006	**2.964**	0.002
Singing Honeyeater	1.248	0.314	1.229	0.305	0.880	0.570
Spotted Harrier	0.807	0.532	0.072	0.975	**2.538**	0.007
Torresian Crow	0.630	0.645	1.813	0.151	1.062	0.403
Weebill	0.893	0.482	1.987	0.122	0.517	0.898
White-winged Triller	0.358	0.836	2.214	0.119	**2.359**	0.030
Willie Wagtail	1.161	0.350	1.529	0.213	0.804	0.645
Yellow-throated Miner	2.671	0.054	**6.073**	0.001	1.145	0.337
Zebra Finch	1.535	0.220	**3.435**	0.021	1.750	0.071

For a small number of species, there appeared to be a coherent response to different utilisation levels (although some of these were not, or only marginally, significant in the GLM) (Fig. 6.16):

- crested pigeon increased over time in the 24% and 32% paddocks, although they declined in 2007;
- magpie-lark and pied butcher-bird showed a similar pattern to crested pigeon;
- yellow-throated miner increased over time in the 19%-32% paddocks, but not the lower utilisation paddocks;
- golden-headed cisticola was more abundant in the 13% paddock in all years, and increased there in 2007;
- pictorella mannikin showed some evidence of increase in the 13% and 17% paddocks, compared to the higher utilisation levels;
- similarly, red-backed fairy-wren showed some increase in the 13%-19% paddocks, compared to the highest utilisation paddocks
- button-quail spp. were more abundant in the 13% and 17% paddocks than the higher utilisation ones, particularly in 2007 (late dry season)

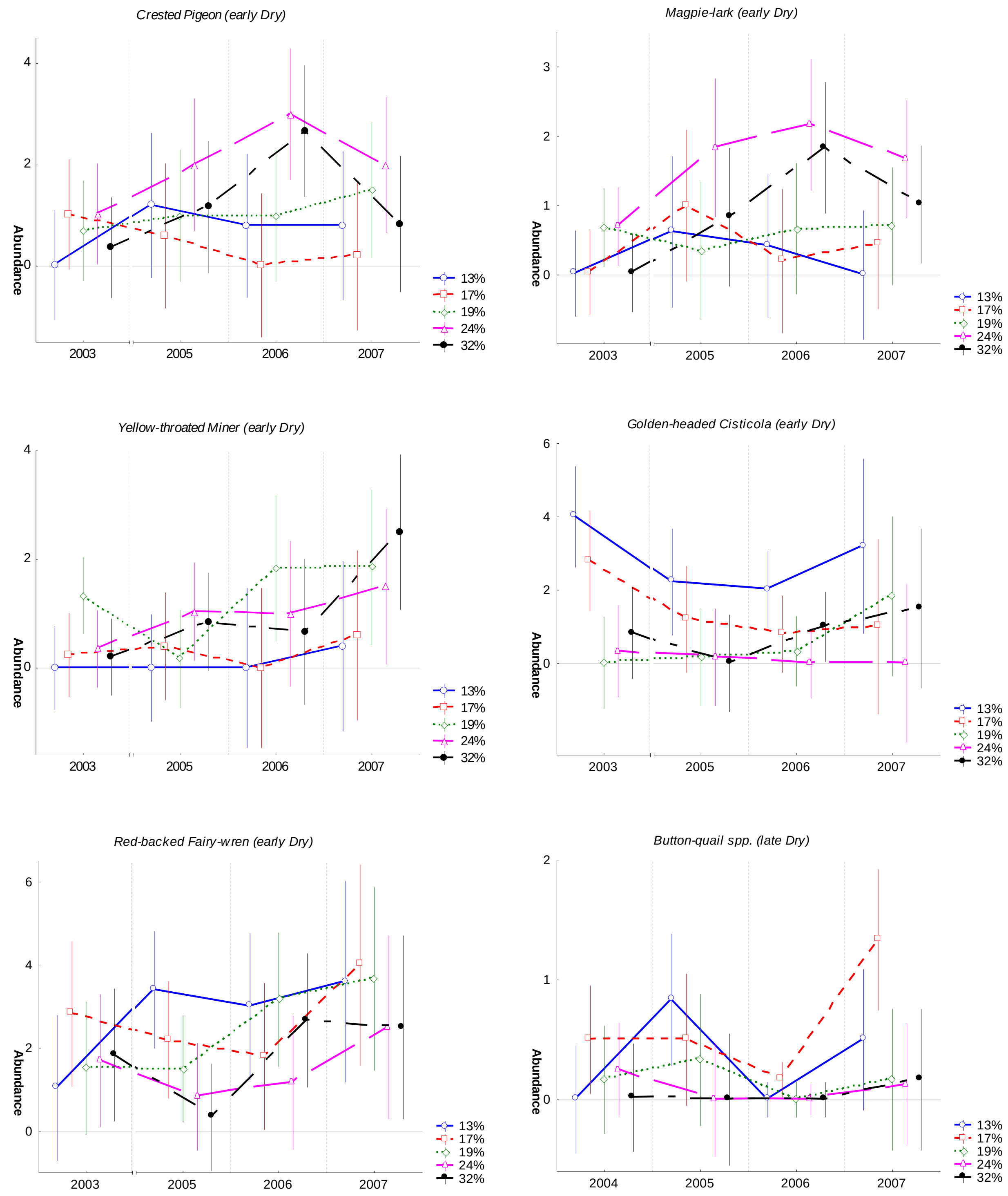


Fig. 6.16 Comparison between utilisation treatments for some **individual bird species.**

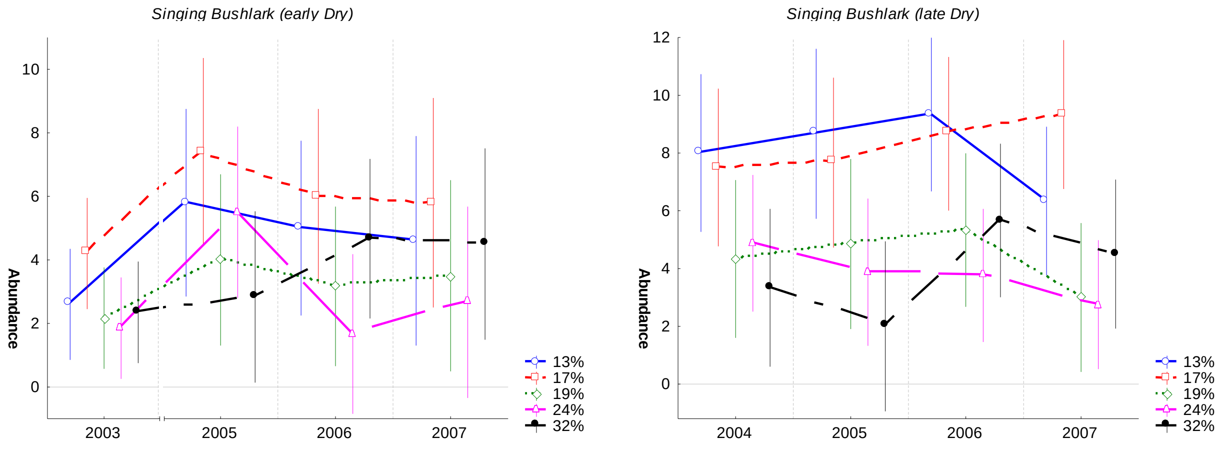


Fig. 6.16 (cont'd)

The response of the most common grassland bird species - singing bushlark - was complex, as it showed a higher pre-treatment abundance in the 13% and 17% paddocks. While it generally remained more abundant in these paddocks throughout the trial, it also increased in the 32% paddock in 2006/07.

6.4.3.3 Reptiles and small mammals

6.4.3.3.1 Composition

It was not possible to examine change in composition in this group using ordination and ANOSIM, due to the large number of sites with very few, or no, species in some years.

6.4.3.3.2 Richness and diversity

There were no significant *year* or *treatment* effects for any variables, but there was a significant *treatment*year* interaction for reptile richness, reptile+small mammal richness and reptile+small mammal diversity (Table 6.9). Reptile richness is quite consistent across years in the 13% and 17% paddocks but more variable in the others, particularly the 32% paddock (Fig. 6.17). Small mammal richness and abundance was initially higher in the 13% and 17% paddocks, but very similar in all paddocks in 2007.

6.4.3.3.3 Individual species

Only 9 reptile and 1 mammal species occurred in sufficient sites for analysis (Table 6.10; Fig. 6.18). Three species had a significant *year* effect and three had a significant *treatment* effect; none had a significant *year*treatment* interaction. Two reptiles (*Delma tincta* and *Ctenotus rimacola*) showed an unusual increase in the 32% paddock in 2006/07. Several species had obvious pre-treatment differences; *Varanus storri* was considerably more abundant in the 17% than other paddocks in 2003-2005, but declined markedly there in 2006-07.

The only common mammal species – *Planigale ingrami* – showed a complex pattern (Fig. 6.18), with relatively high pre-treatment frequency in the 13% and 17% paddocks, and variable abundance in this paddocks over time. In 2007, the mean abundance was very similar (and low) in all paddocks.

Table 6.9. Summary of repeated-measures ANOVA comparing utilisation treatments across years for **reptile and small mammal summary variables.**

	Treatment		Year		Treatment*year	
	df = 4		*df = 4*		*df = 16*	
Variable	F	p	F	p	F	p
Reptile richness	1.410	0.250	1.149	0.336	**2.032**	0.015
Reptile abundance	2.170	0.092	1.636	0.168	1.432	0.134
Small mammal richness	1.877	0.135	1.520	0.199	0.923	0.544
Small mammal abundance	2.306	0.076	1.863	0.120	1.287	0.213
Reptile + small mammal richness	2.077	0.104	1.650	0.165	**1.942**	0.021
Reptile + small mammal Shannon diversity	2.190	0.089	1.212	0.308	**1.951**	0.020

Table 6.10. Summary of repeated-measures ANOVA comparing utilisation treatments across years for individual **reptile** and **small mammal** species.

	Treatment		Year		Treatment*year	
	df = 4		*df = 4*		*df = 16*	
	F	p	F	p	F	p
Reptiles						
Cryptoblepharus plagiocephalus	1.244	0.310	0.811	0.520	0.727	0.763
Ctenotus rimacola	0.512	0.727	**2.997**	0.021	1.341	0.180
Delma tincta	0.541	0.707	0.113	0.978	1.371	0.164
Heteronotia binoei	2.093	0.101	1.713	0.150	0.809	0.674
Menetia maini	1.630	0.187	1.133	0.343	0.860	0.616
Proablepharus naranjicaudus	1.247	0.308	**3.888**	0.005	1.166	0.302
Proablepharus tenuis	**4.216**	0.007	**2.499**	0.045	1.342	0.180
Ramphotyphlops ligatus	**2.919**	0.034	0.282	0.889	1.142	0.323
Varanus storri	**3.198**	0.024	0.710	0.587	1.614	0.071
Mammals						
Planigale ingrami	1.750	0.160	2.372	0.055	1.304	0.202

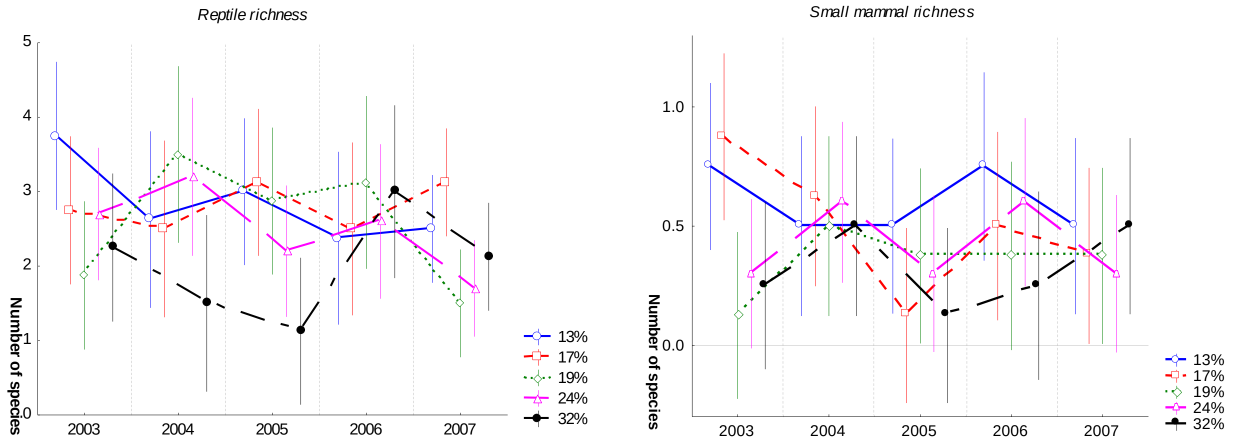


Fig. 6.17 Comparison between utilisation treatments for **reptile and small mammal richness**

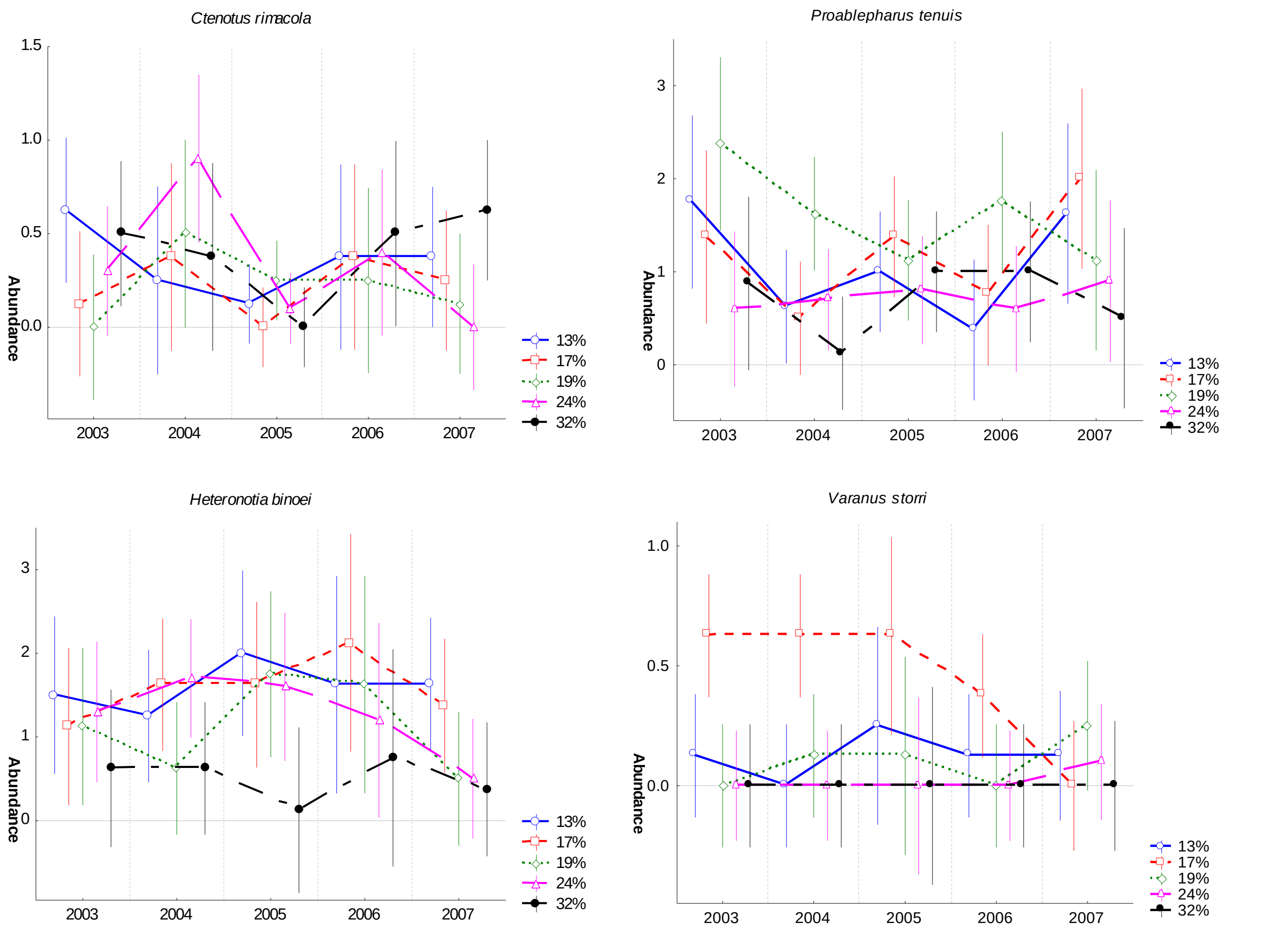


Fig. 6.18 Comparison between utilisation treatments for some **individual reptile and small mammal species**

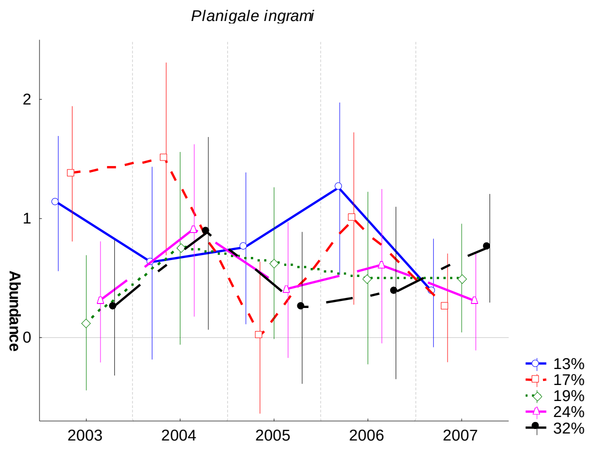


Fig. 6.18 (contd)

6.4.3.4 Ants

6.4.3.4.1 Composition

In 2003, there was a significant overall paddock effect (Table 6.11), and almost all pairwise comparisons between paddocks were significant. The paddock effect remained significant in 2005 and 2007 (although the ANOSIM R statistic reduced slightly). By 2007, the 13% and 17% sites had become more similar in ant composition, as had the 24% and 32% sites, while the 17% and 32% sites had become less similar. The movement of sites (paddock centroids) in ordination space over the 3 sample periods is shown in Fig. 6.19. The least movement over time is in the 24% and 32% sites – the centroids for these two paddocks move together, while the other centroids (particularly 13% and 17% sites) move away from them.

Table 6.11. ANOSIM analyses, comparing **ant composition** of sites in the 5 utilisation level paddocks, for 2003, 2005 and 2007. Global R and pairwise comparisons are reported; significant R values (P<0.1) are bolded. Riparian and exclosure sites are excluded.

	2003		2005		2007	
Overall R	**0.262**		**0.230**		**0.194**	
Overall P	0.002		0.002		0.002	
Groups	*R*	*P*	*R*	*P*	*R*	*P*
15%, 20%	**0.34**	0.008	**0.23**	0.052	0.10	0.139
15%, 25%	**0.68**	0.002	**0.45**	0.002	**0.17**	0.089
15%, 30%	**0.17**	0.076	**0.23**	0.036	**0.29**	0.017
15%, 40%	**0.23**	0.050	**0.45**	0.015	**0.54**	0.002
20%, 25%	**0.28**	0.041	**0.29**	0.024	**0.27**	0.011
20%, 30%	0.05	0.340	-0.06	0.679	0.06	0.270
20%, 40%	-0.03	0.580	**0.17**	0.011	**0.18**	0.071
25%, 30%	**0.52**	0.002	**0.34**	0.011	**0.16**	0.086
25%, 40%	**0.14**	0.069	**0.35**	0.015	**0.28**	0.013
30%, 40%	**0.18**	0.069	0.08	0.211	0.03	0.310

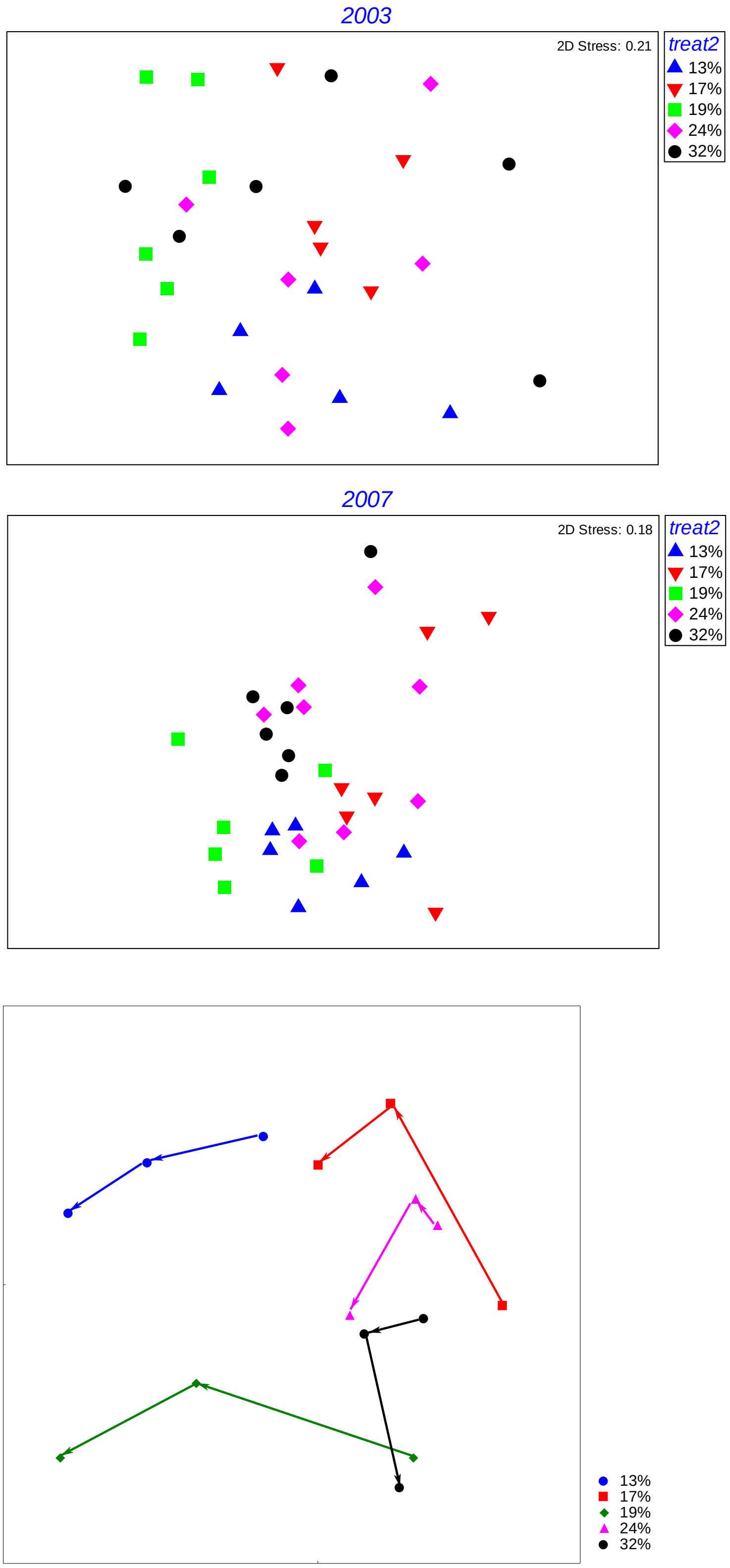


Fig. 6.19. Ordination of sites in utilisation paddocks by **ant composition** in (a) 2003 and (b) 2007; and (c) movement of centroids for sites in each paddock through ordination space over 3 sample periods (2003, 2005, 2007, in the direction of the arrows).

6.4.3.4.2 Richness and diversity

There was a significant effect of *treatment* and *year* for ant site richness, but no interaction. There was a pre-treatment difference in mean richness between paddocks, which was generally maintained through the trial, with higher richness in 2005. The only exception to this pattern was for the 13% paddock, which showed a slight decline in mean richness across the 3 samples.

A similar pattern occurs for the total frequency and Shannon diversity of ants, with the effect of year more pronounced for frequency.

Table 6.12. Summary of repeated-measures ANOVA comparing utilisation treatments across years for **ant summary variables.**

	Treatment		Year		Treatment*year	
df	*4*		*2*		*8*	
Variable	F	p	F	p	F	p
Richness	**7.334**	0.000	**6.771**	0.002	1.425	0.204
Total frequency	**4.031**	0.010	**11.593**	0.000	1.608	0.142
Shannon diversity	**7.567**	0.000	**7.178**	0.002	1.313	0.254

Fig. 6.20 Comparison between utilisation treatments for **ant richness.**

6.4.3.4.3 Individual species

Of the 28 individual ant species sufficiently frequent for analysis, 19 had a significant *year* effect (Table 6.13). The nature of this response differed widely between species, although the most common pattern was a decline in frequency in 2007. Eight species had a significant *year*treatment* effect: interpreting this effect was complicated in some cases by pre-treatment (2003) differences between paddocks, and some of the responses were idiosyncratic (Fig. 6.21). Three species (*Monomorium fieldi*, *Melophorus* spE) appeared to show a relative decline in the lowest utilisation paddock, while two species (*Monomorium* sp24, *Tetramorium* spA) showed a relative increase in this paddock. *Iridomyrmex* spE declined in all paddocks except the 32% utilisation level. Six species (including four with a significant interaction term) showed a significant *treatment* effect – one of these (*Rhytidoponera* spA) showed a declining trend in the 13% sites and one (*Camponotus* spA) an increasing trend in this paddock.

Table 6.13. Summary of repeated-measures ANOVA comparing utilisation treatments across years for individual **ant** species.

	Treatment *df = 4*		Year *df = 2*		Treatment*year *df = 8*	
	F	p	F	p	F	p
Camponotus sp9	1.230	0.319	20.482	**0.000**	1.041	0.416
Camponotus spA	3.292	**0.024**	3.286	**0.044**	1.368	0.229
Camponotus spC	0.733	0.576	2.342	0.105	1.440	0.199
Crematogaster queenslandica	1.237	0.316	6.041	**0.004**	1.153	0.342
Doleromyrma spA	1.325	0.283	3.208	**0.047**	1.449	0.195
Iridomyrmex sanguineus	1.609	0.198	0.204	0.816	2.768	**0.011**
Iridomyrmex sp1	0.785	0.544	3.615	**0.033**	0.469	0.873
Iridomyrmex sp2	0.935	0.454	3.235	0.080	1.442	0.239
Iridomyrmex spD	0.752	0.564	8.526	**0.001**	1.062	0.402
Iridomyrmex spE	7.010	**0.000**	13.225	**0.000**	2.606	**0.016**
Leptogenys adlerzi	1.703	0.175	1.295	0.281	1.199	0.315
Melophorus spC	4.204	**0.008**	14.768	**0.000**	2.642	**0.015**
Melophorus spE	0.827	0.519	11.291	**0.000**	1.979	0.065
Meranoplus oxleyi	1.114	0.368	9.816	**0.000**	1.017	0.433
Meranoplus pubescens	1.631	0.192	0.286	0.752	0.978	0.462
Monomorium anderseni	1.151	0.352	4.311	**0.018**	2.115	**0.048**
Monomorium fieldi	2.184	0.095	9.637	**0.000**	2.887	**0.009**
Monomorium sp24	1.198	0.332	11.928	**0.000**	4.160	**0.001**
Monomorium spE	2.663	0.052	2.044	0.138	0.793	0.611
Opisthopsis rufoniger	1.069	0.389	2.431	0.097	0.460	0.879
Pheidole impressiceps	2.150	0.099	4.782	**0.012**	1.543	0.162
Pheidole spC	1.260	0.308	0.065	0.937	1.239	0.293
Pheidole spD	1.787	0.158	2.974	0.059	1.139	0.351
Polyrhachis crawleyi	2.673	0.051	6.771	**0.002**	1.452	0.194
Rhytidoponera spA	4.065	**0.009**	12.799	**0.000**	1.775	0.100
Tapinoma spA	3.273	**0.024**	10.564	**0.000**	2.541	**0.019**
Tetramorium spA	3.207	**0.026**	4.007	**0.023**	3.228	**0.004**
Tetramorium spB	1.181	0.339	3.426	**0.039**	2.004	0.061

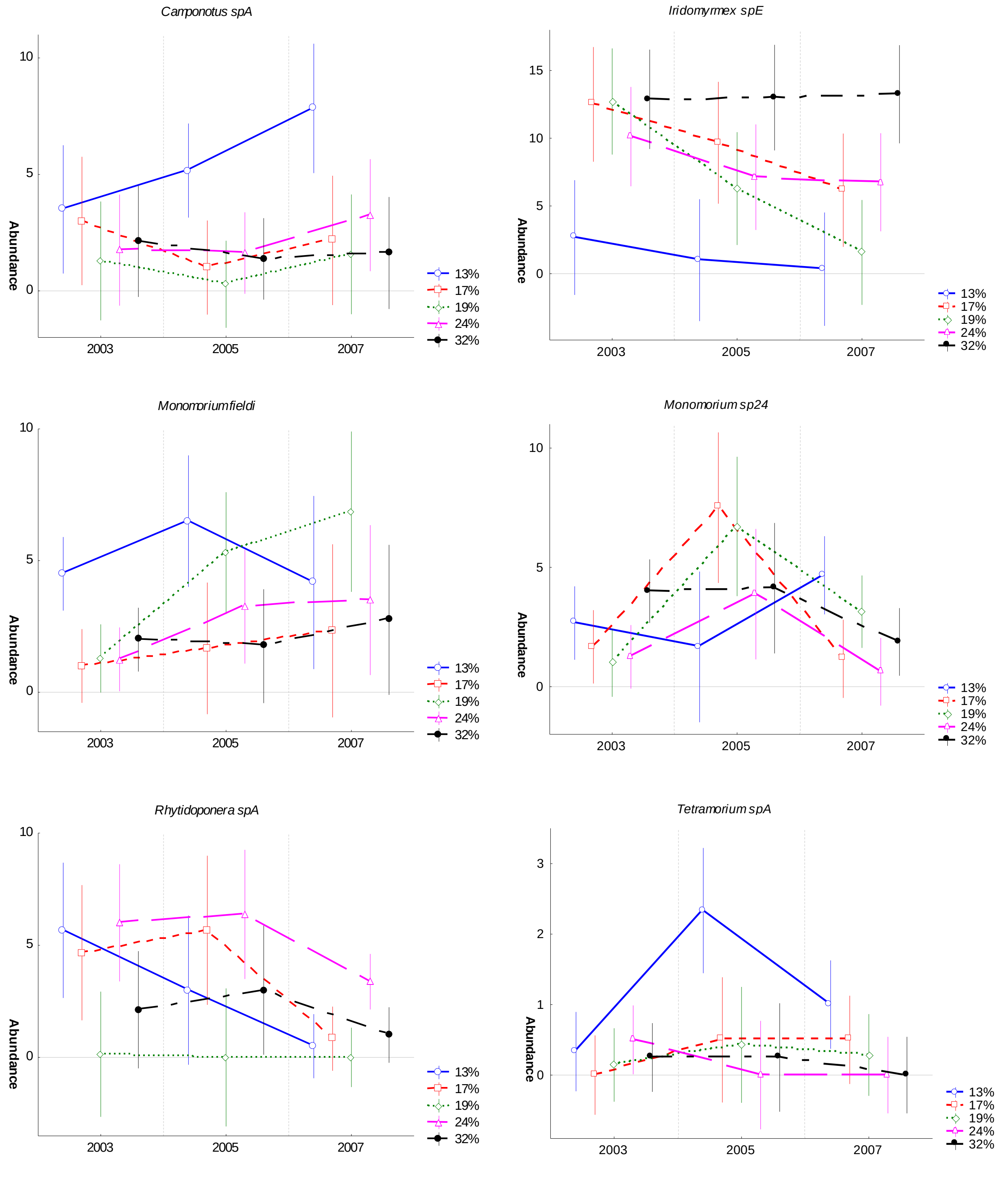


Fig. 6.21. Comparison between utilisation treatments for some **individual ant species**.

6.4.4 Other grazing systems

6.4.4.1 Species Composition

There was a significant difference between grazing system paddocks for **plant** species composition in 2004 (i.e. a pre-treatment effect) and this difference was maintained very consistently in subsequent years (Table 6.14, Fig. 6.22) – there was no evidence of treatments either diverging or converging in composition. A similar pattern was evident for **late dry season birds** (Fig. 6.23), although there was generally greater similarity between paddocks than for plants. However, for **birds sampled in the early dry season** there was no significant difference between treatments in composition in 2005 and 2006, but a significant difference in 2007. An examination of pairwise comparisons between paddocks showed that this was wholly due to increasing similarity between sites within the exclosures and increasing dissimilarity between these sites and other grazed treatments (Fig. 6.24). Ants also showed a significant difference between treatments in 2007, but not in 2005, although the ordination (Fig. 6.25) does not show any marked differentiation of grazing treatments.

Table 6.14. Results of ANOSIM analyses, comparing species composition of sites in grazing system paddocks (grazing radius, wet-season spelling, cell-grazing) for each taxonomic group. Intermediate utilisation paddocks (17% and 19%, combined) and exclosures (4 ha and 40 ha, combined) were included as treatments in the analyses. The years over which the comparison is made depends on the taxon. Cell grazing was excluded for birds (early dry season) and ants, as this treatment was not sampled in 2007. Significant R values (P<0.1) are bolded.

	2003		2004		2005		2006		2007	
	R	*p*	*R*	*p*	*R*	*p*	*R*	*p*	*R*	*p*
Plants			**0.196**	0.000	**0.169**	0.001	**0.196**	0.000	**0.199**	0.000
Birds (early dry season)					0.052	0.140	-0.002	0.654	**0.137**	0.007
Birds (late dry season)	**0.075**	0.062	0.050	0.127	**0.085**	0.034	**0.061**	0.090		
Ants					0.027	0.269			**0.127**	0.009

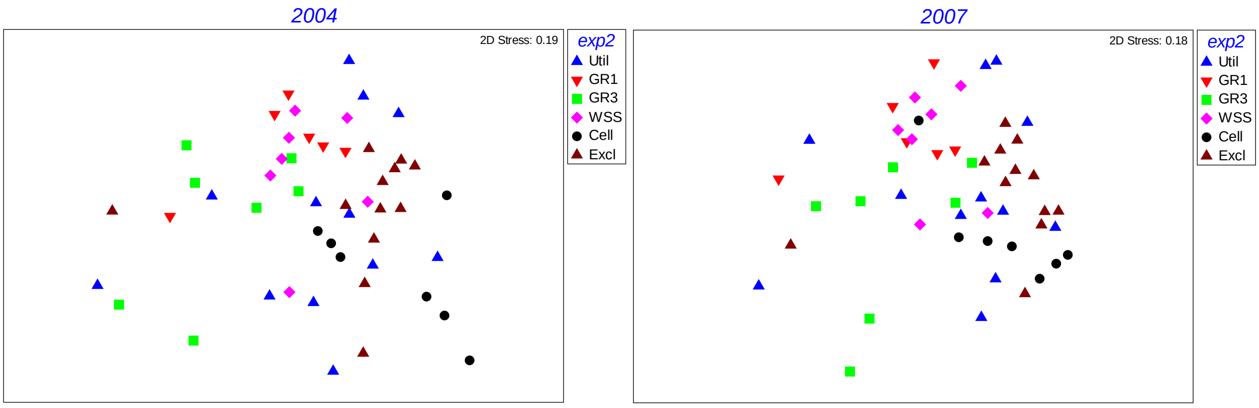


Fig. 6.22 Ordination of sites by **plant** composition in grazing system paddocks (1km & 3km grazing radius, wet-season spelling, cell-grazing) for 2004 and 2007. Intermediate utilisation paddocks (17% and 19%, combined) and exclosures (4ha and 40ha, combined) are included in the ordination.

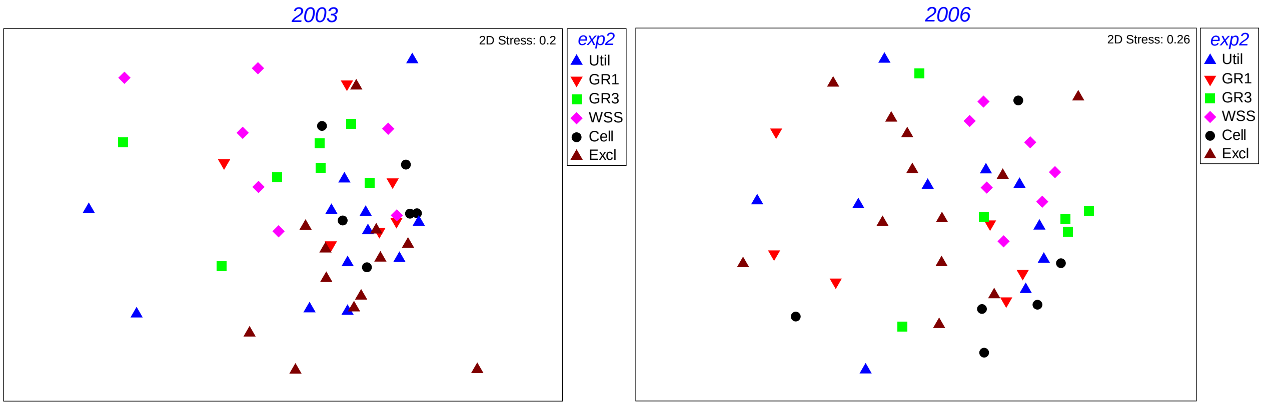


Fig. 6.23 Ordination of sites by **bird (late Dry season)** composition in grazing system paddocks (1km & 3km grazing radius, wet-season spelling, cell-grazing) for 2003 and 2006. Intermediate utilisation paddocks (17% and 19%, combined) and exclosures (4 ha and 40 ha, combined) are included in the ordination.

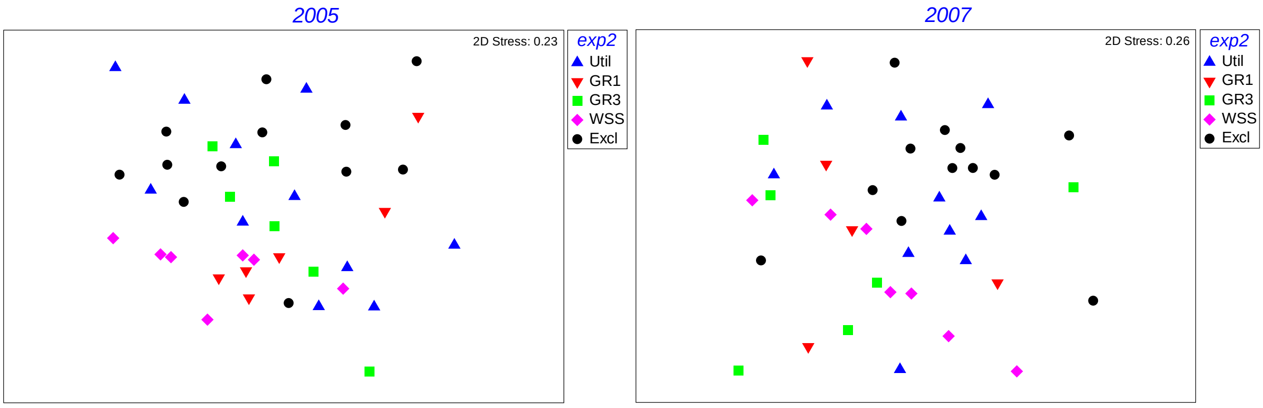


Fig. 6.24 Ordination of sites by **bird (early Dry season)** composition in grazing system paddocks (1km & 3km grazing radius, wet-season spelling) for 2005 and 2007. Intermediate utilisation paddocks (17% and 19%, combined) and exclosures (4 ha and 40 ha, combined) are included in the ordination.

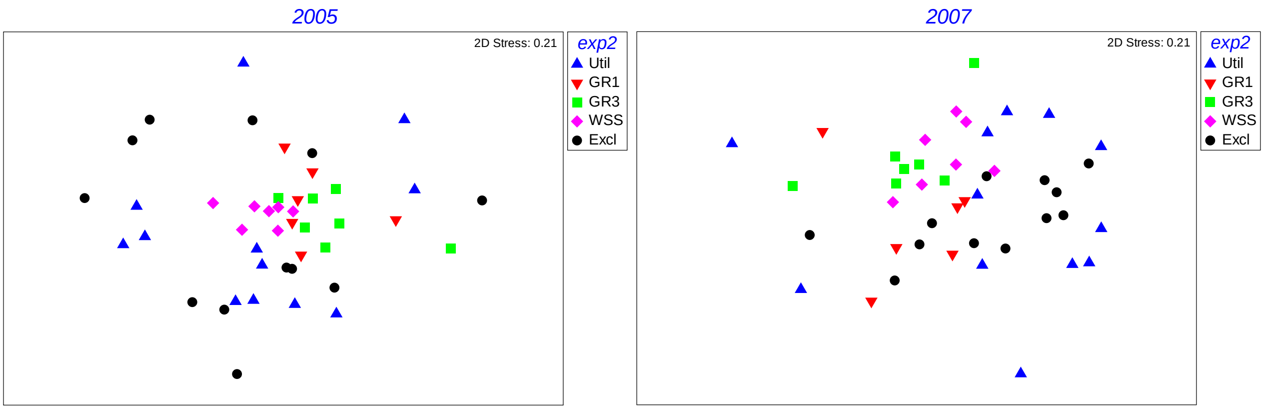


Fig. 6.24 Ordination of sites by **ant** composition in grazing system paddocks (1km & 3km grazing radius, wet-season spelling) for 2005 and 2007. Intermediate utilisation paddocks (17% and 19%, combined) and exclosures (4 ha and 40 ha, combined) are included in the ordination.

6.4.4.1.1 Richness, diversity and structural variables

As previously described for the utilisation paddock results, there was a significant *year* effect for all summary variables (Table 6.15). Some significant *treatment* effects also reflect differences between treatments that are consistent across years, for example low plant diversity in the cell grazing paddocks (Fig. 6.25b).

There was a significant *treatment*year* effect for total understorey cover, perennial grass basal cover and perennial grass frequency. Total cover declined between 2004 and 2007 in all treatments, but more markedly in cell grazing, which may be related to the initial dominance of dense annual sorghum in these sites (Fig. 6.25c). Unlike all other treatments, cover increased in the 1km grazing radius treatment between 2004 and 2005, which is likely to be a recovery from the effects of a fire which burnt most of this paddock in 2003. Perennial grass basal area was markedly higher in the 3km grazing radius sites in 2004 (suggesting this paddock had a better initial condition) but declined to a similar level as other treatments by 2007 (Fig. 6.25e). There was no significant interaction effect for either plant richness or diversity.

There was no significant *treatment*year* effect for **birds** sampled in either the early or late dry season, or for **small mammal** richness or abundance (Fig. 6.26). The significant interaction term for **reptile** richness and abundance appears to arise because of an unusual response in cell grazing sites, where reptile numbers declined between 2003 and 2004, but then showed a marked increase in 2005 and 2006 (Fig. 6.26c). Examination of the data shows this was primarily due to an increase in the frequency and abundance of *Heteronotia binoei*, a small ground-active gecko which tends to show a preference for open areas.

There was also a significant *treatment*year* effect for **ant** richness and diversity, although data for this group is only available for 2005 and 2007. Compared to the slight decline between years for other treatments, there was a greater decline for the 1km grazing radius treatment, and no change for exclosure sites (Fig. 6.26e).

Table 6.15. Results of repeated-measures ANOVAs comparing grazing system paddocks (1km and 3km grazing radii, wet-season spelling, cell-grazing) for selected summary variables for each major taxa. Utilisation paddocks (17% and 19%, combined) and exclosures (4 ha and 40 ha, combined) were included in the analyses. Years for which data was included in the analyses are shown; cell grazing was excluded from some analyses due to insufficient sampling periods.

	Treatment		Year		Treatment*year	
Variable	F	p	F	P	F	p
Plants (2004-2007)						
Richness	1.97	0.100	**15.25**	0.000	1.27	0.233
Shannon diversity	**3.72**	0.007	**27.15**	0.000	0.70	0.779
Total understorey cover	**4.38**	0.002	**90.55**	0.000	**5.83**	0.000
Perennial grass cover	2.38	0.054	**22.55**	0.000	1.70	0.057
Perennial grass basal cover	**4.08**	0.004	**7.42**	0.000	**1.79**	0.042
Perennial grass frequency	1.94	0.106	**2.81**	0.042	**2.26**	0.007
Birds – early Dry season (2005-2007, excluding Cell)						
Richness	2.49	0.059	**13.93**	0.000	0.57	0.802
Shannon diversity	1.19	0.331	**8.31**	0.001	0.20	0.989
Birds – late Dry season (2003-2006)						
Richness	2.05	0.090	**14.03**	0.000	1.37	0.172
Shannon diversity	1.92	0.110	**10.01**	0.000	1.40	0.155
Reptiles (2003-2006)						
Richness	**2.85**	0.026	**4.34**	0.006	**1.82**	0.038
Abundance	**3.38**	0.011	**4.39**	0.006	**2.09**	0.014
Small mammals (2003-2006)						
Richness	0.70	0.626	**6.44**	0.000	1.04	0.421
Abundance	0.64	0.670	**3.62**	0.015	1.15	0.321
Reptiles + small mammals (2003-2006)						
Richness	**2.46**	0.047	**3.69**	0.014	1.39	0.162
Shannon diversity	**2.44**	0.049	**3.88**	0.011	1.54	0.100
Ants (2005,2007, excluding Cell)						
Richness	**4.36**	0.005	**40.05**	0.000	**5.16**	0.002
Shannon diversity	**4.78**	0.003	**47.47**	0.000	**6.81**	0.000

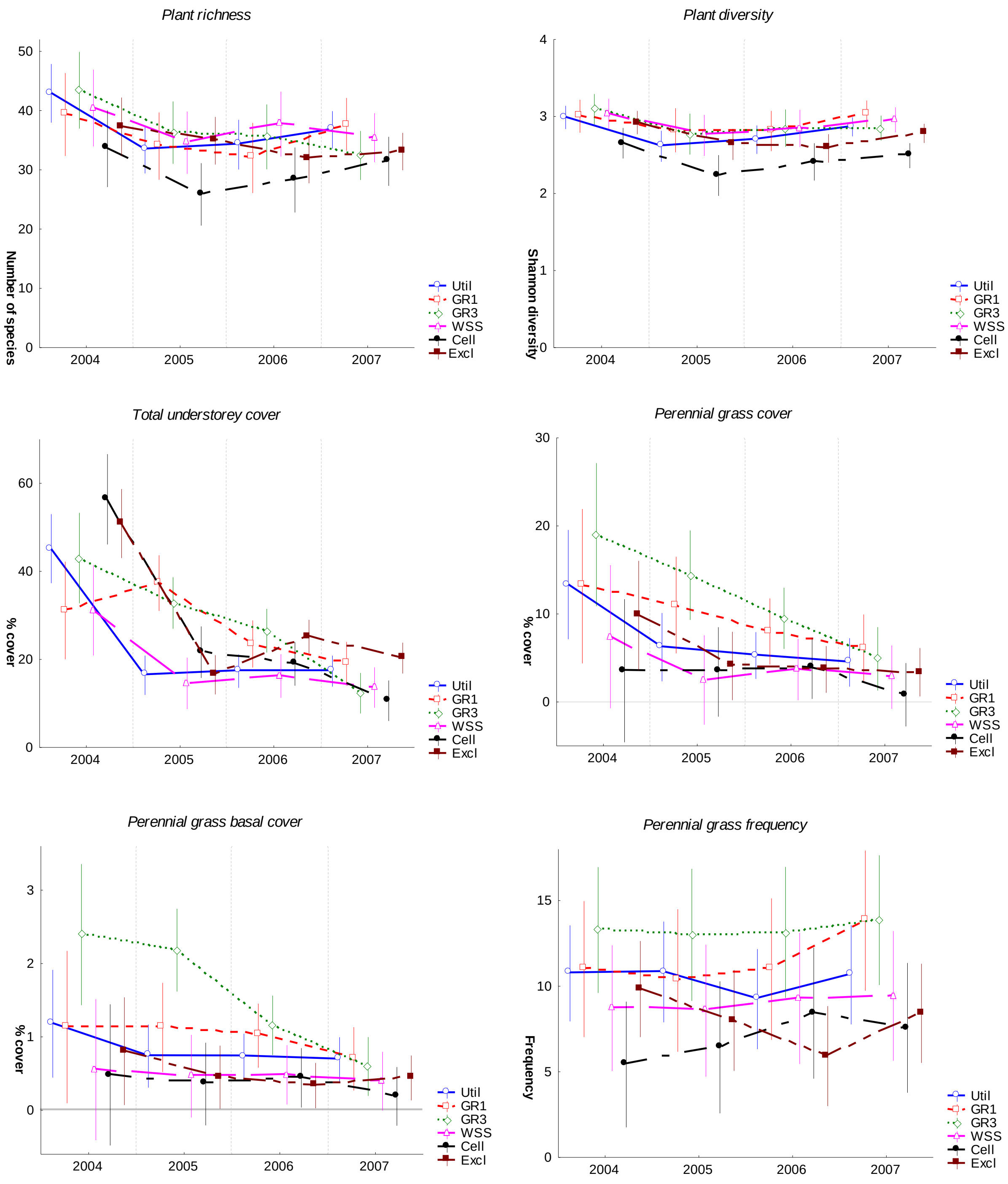


Fig. 6.25 Comparison between grazing systems treatments (1 km and 3 km grazing radii, wet-season spelling, cell-grazing) for **plant summary variables**: a) species richness; b) Shannon diversity index; c) total understorey cover; d) perennial grass cover; e) perennial grass basal cover; f) perennial grass frequency. Utilisation paddocks (17% and 19%, combined) and exclosures (4 ha and 40 ha, combined) were included in the analyses.

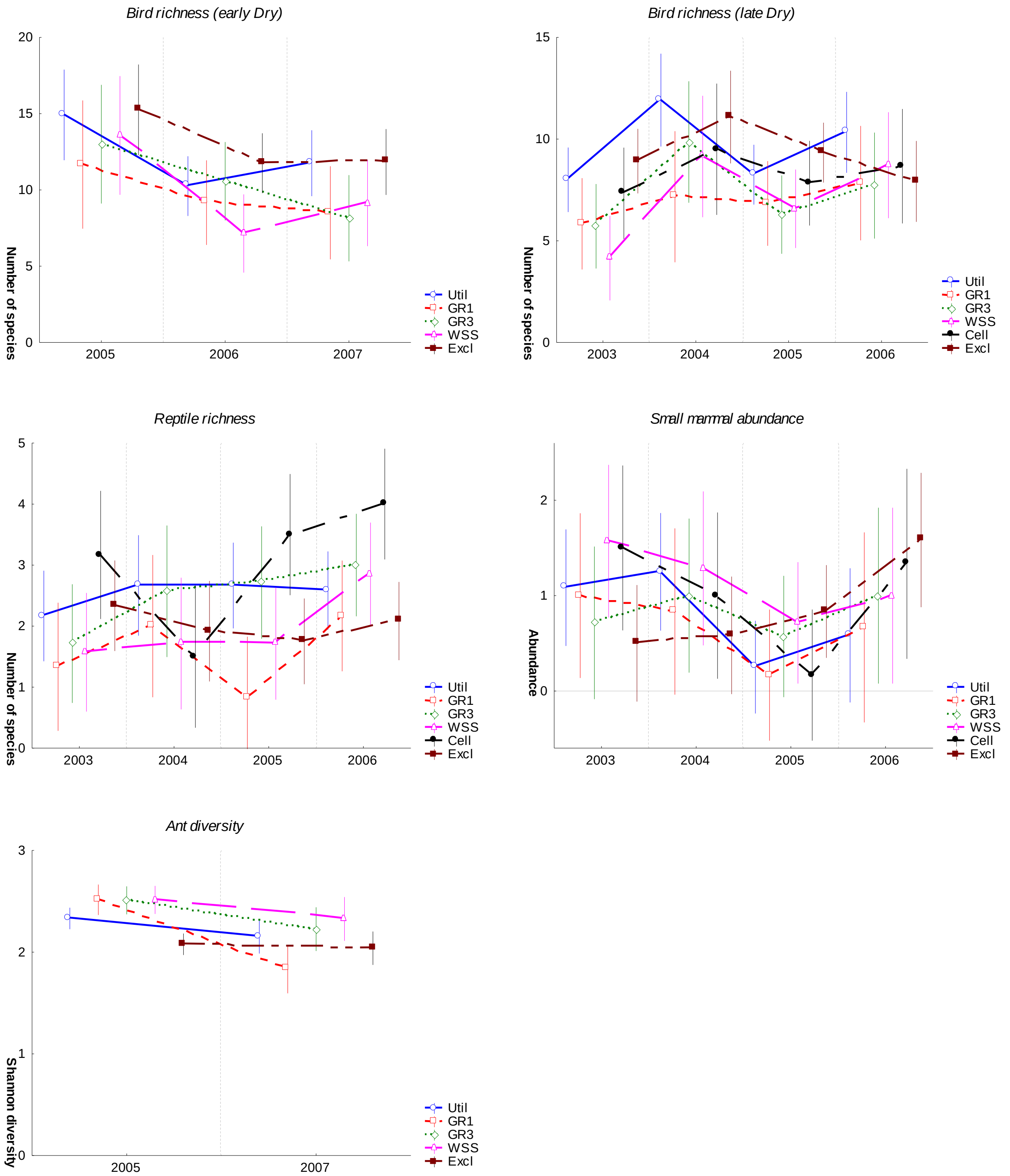


Fig. 6.26 Comparison between grazing systems treatments for some fauna summary variables (as per Table 6.15): a) bird richness (early Dry season); b) bird richness (early Dry season); c) reptile richness; d) small mammal abundance; e) ant diversity.

6.4.5 Exclosures – comparison with utilisation paddocks

6.4.5.1 Species composition

There was no significant difference in species composition between exclosure sites and grazed sites at the start of the trial (2003/04) for plants, birds or ants (Table 6.14) and no evidence of a separation of exclosure from grazed sites in their overall composition for any of the groups by 2007 (Table 6.16, Fig. 6.27). While the ANOSIM R value increased for all taxa in 2006, it declined to very low values in 2007.

Table 6.16. ANOSIM analysis, comparing species composition of sites in exclosures and grazed (utilisation) paddocks, for each taxonomic group. The number of years over which the comparison is made depends on the taxon. 0.4ha exclosures were not included for birds, and riparian sites were excluded from the grazed set. In most comparisons there are 23 exclosure sites (17 for birds) and 32 grazed sites. Note there are no significant R values (P<0.1).

	2003		2004		2005		2006		2007	
	R	*P*	*R*	*P*	*R*	*P*	*R*	*P*	*R*	*P*
Plants	0.060*	0.252	-0.016	0.646	-0.014	0.623	0.014	0.271	-0.012	0.581
Birds (early dry season)					-0.004	0.491	0.048	0.160	-0.016	0.568
Birds (late dry season)	-0.045	0.760	-0.087	0.977	-0.014	0.572	0.014	0.357	-0.040	0.815
Ants	-0.035*	0.638			0.020	0.239			-0.020	0.706

* only 10 exclosure sites in 2003

6.4.5.2 Richness, diversity and structural variables

There was no significant *treatment*year* interaction for any of the plant variables (Table 6.17), and a significant *treatment* effect for richness and understorey cover. Mean understorey cover was slightly higher in exclosure sites in all years. Mean plant richness was higher in grazed sites than exclosure sites in 2004 (just after the exclosures were established, and presumably a pre-treatment difference) and remained consistently higher until 2007, with mean richness in exclosure sites showing a slight decline in 2007 (Fig. 6.28). Perennial grass cover and basal cover were very similar in the two treatments in all years.

There was a significant *treatment*year* interaction for ant richness, with mean richness in exclosures increasing slightly between 2005 and 2007, but declining in grazed sites (Fig. 6.29). A similar pattern is found for total frequency and Shannon diversity.

For bird variables, the only significant interaction term was for total bird frequency in the early dry season, reflecting an increase in frequency in 2007 in exclosures, but not in grazed sites (Fig. 6.30). Bird richness and diversity was slightly higher in exclosure sites than grazed sites at the end of the trial, but this was not a significant effect.

There was a significant interaction term for mammal abundance, with a consistent increase in exclosure sites from 2005 to 2007 (Fig. 6.31a). There appears to be a similar increasing trend in exclosures for reptile richness, although variation is high and there is no significant difference with grazed sites (Fig. 6.31b).

Year effects are generally as described above in the utilisation section, and are not dwelt on further here.

Table 6.17. Summary of repeated-measures ANOVA comparing exclosure and grazed (all utilisation levels) treatments across years for summary variables for each taxa.

	Treatment		Year		Treatment*year	
Variable	F	p	F	P	F	p
Plants (4 years)						
Richness	**3.899**	0.052	**11.604**	0.000	1.216	0.305
Shannon diversity	2.619	0.110	**25.642**	0.000	0.600	0.616
Total understorey cover	**10.261**	0.002	**134.897**	0.000	0.896	0.444
Perennial grass cover	0.033	0.856	**34.129**	0.000	1.796	0.149
Perennial grass basal cover	0.231	0.632	**3.617**	0.014	1.236	0.298
Perennial grass frequency	1.749	0.190	0.759	0.518	1.193	0.313
Birds (4 years)						
Richness – early dry season (site & adj)	0.864	0.357	**21.67**	0.000	0.066	0.936
Richness – early dry season (site only)	0.205	0.653	**17.22**	0.000	1.085	0.342
Richness – late dry season (site & adj)	0.119	0.732	**10.044**	0.000	2.022	0.114
Richness – late dry season (site only)	0.001	0.983	**8.719**	0.000	1.219	0.305
Total frequency – early dry season	0.124	0.726	**10.624**	0.000	**3.378**	0.038
Total frequency – late dry season	0.595	0.444	**7.659**	0.000	2.347	0.075
Shannon diversity – early dry season	0.017	0.898	**14.764**	0.000	0.341	0.712
Shannon diversity – late dry season	0.008	0.928	**5.454**	0.001	1.278	0.284
Reptiles (5 years)						
Richness	1.111	0.296	0.434	0.784	1.503	0.202
Abundance	0.148	0.702	0.534	0.711	1.661	0.160
Small mammals (5 years)						
Richness	**5.139**	0.027	**2.703**	0.031	0.685	0.603
Abundance	**9.272**	0.003	1.881	0.114	**2.619**	0.036
Reptiles + small mammals						
Richness	0.076	0.784	1.335	0.257	1.559	0.186
Shannon diversity	0.000	0.985	1.449	0.218	1.065	0.374
Ants (2 years)						
Richness *	0.367	0.547	1.773	0.189	**5.351**	0.025
Total frequency *	0.574	0.452	**5.443**	0.023	**4.091**	0.048
Shannon diversity*	0.056	0.814	**5.429**	0.024	**10.969**	0.002

* 2003 is not included because only 10 of 23 exclosure sites were sampled then

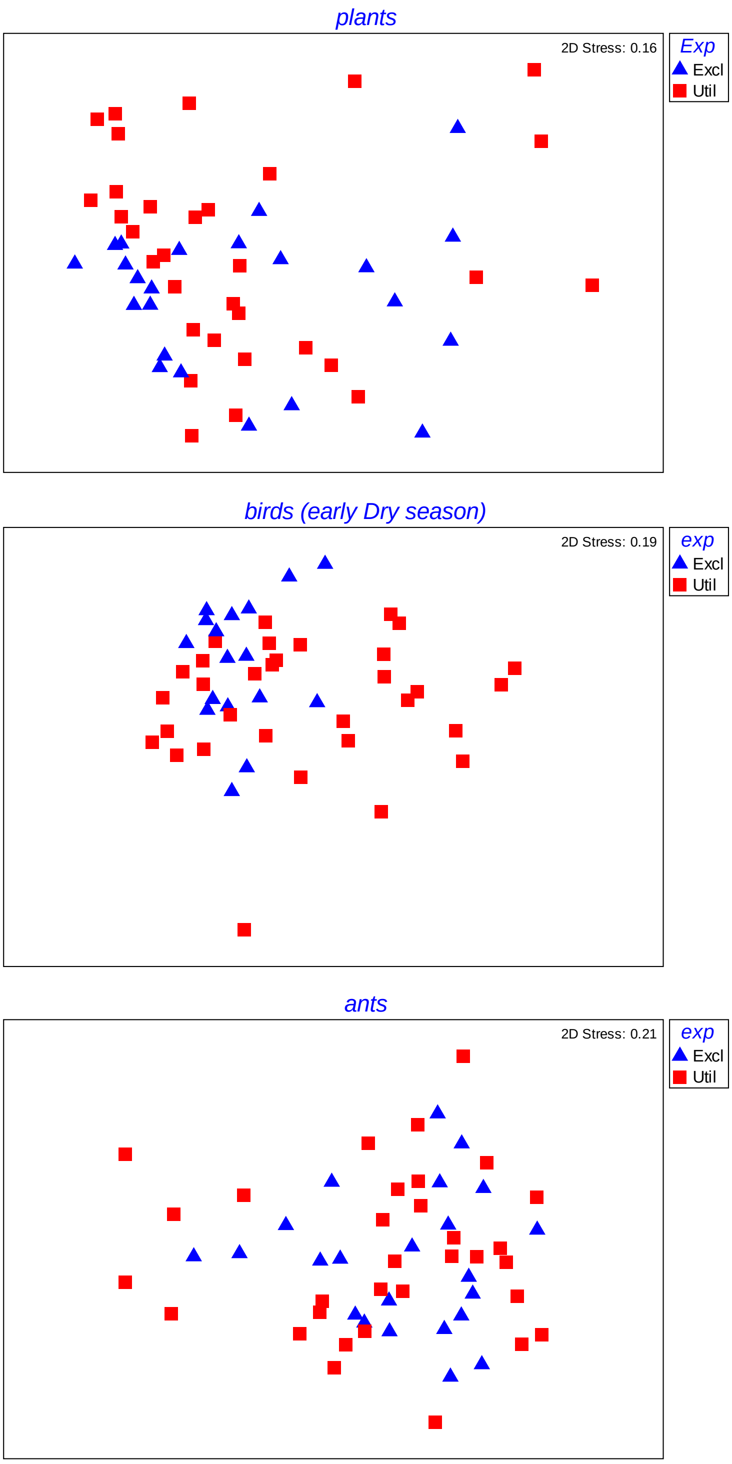


Fig. 6.27 Ordination of sites in exclosures and grazed (utilisation) paddocks in 2007 for (a) plants, (b) birds, (c) ants. Small (0.4 ha) exclosures were not included for birds, and riparian sites were not included in the grazed set.

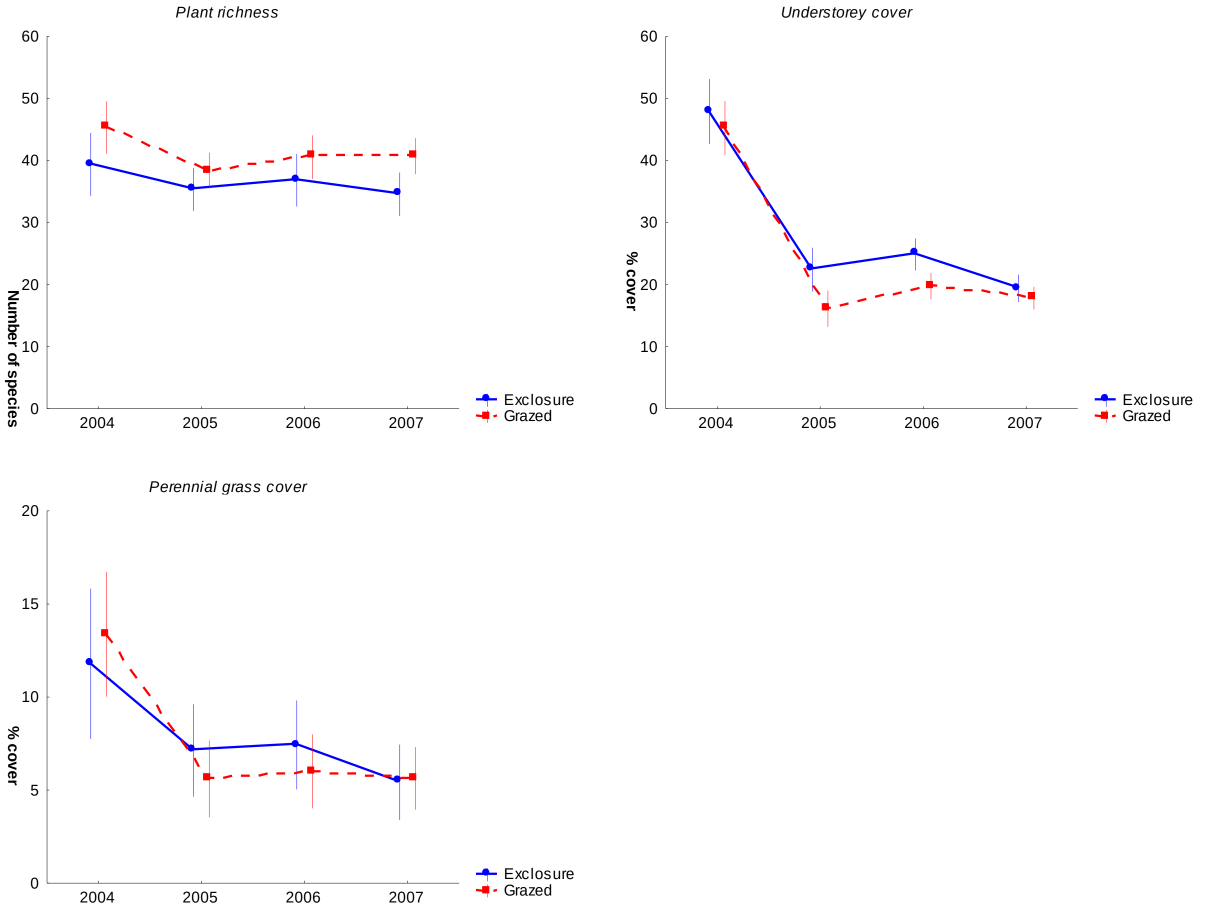


Fig. 6.28 Comparison between exclosure and grazed (utilisation paddocks) sites for some plant variables; a) plant richness; b) understorey cover; c) perennial grass cover.

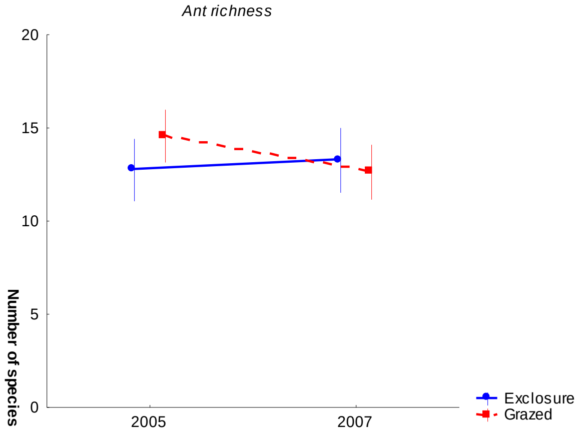


Fig. 6.29 Comparison between exclosure and grazed (utilisation paddocks) sites for ant richness.

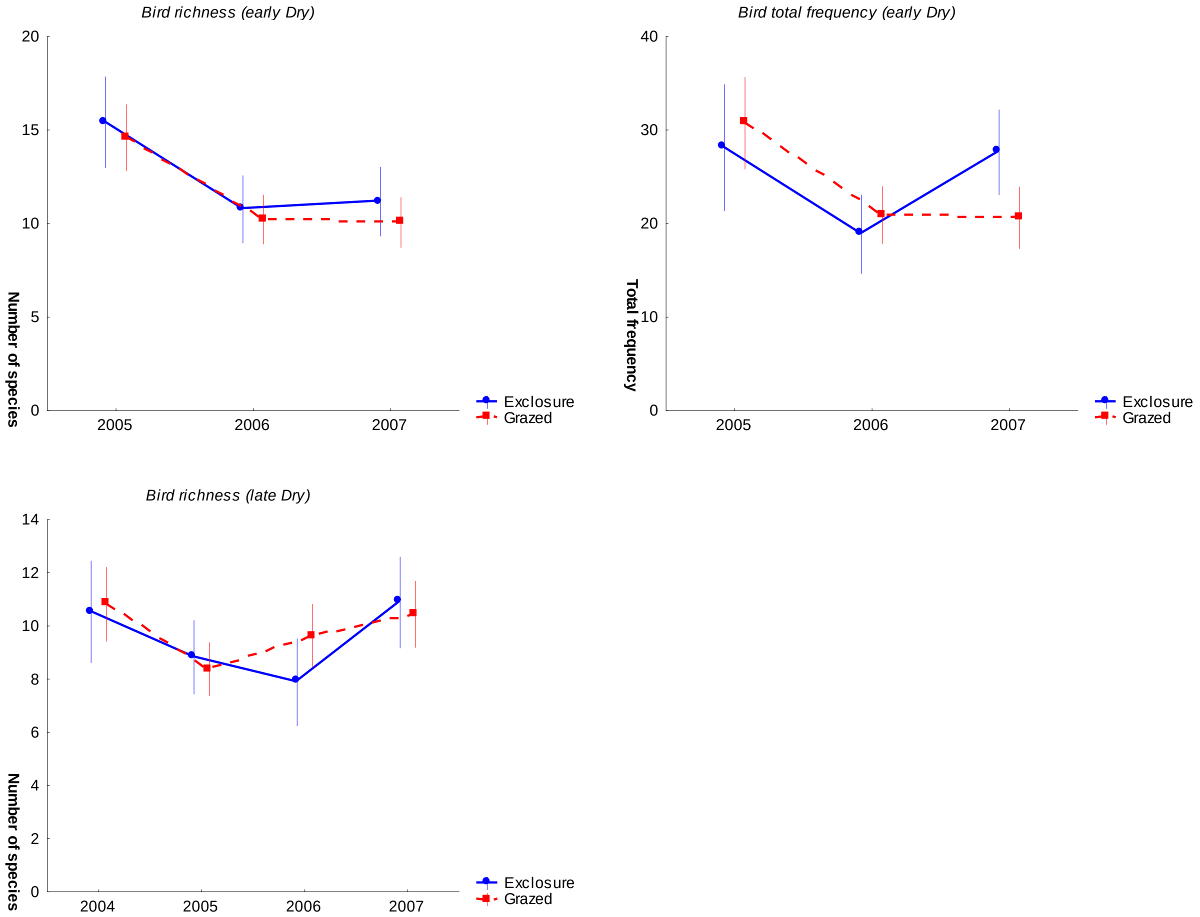


Fig. 6.30 Comparison between exclosure and grazed (utilisation paddocks) sites for a) bird richness (early dry season); b) bird total frequency (early dry season) and c) bird richness (late dry season).

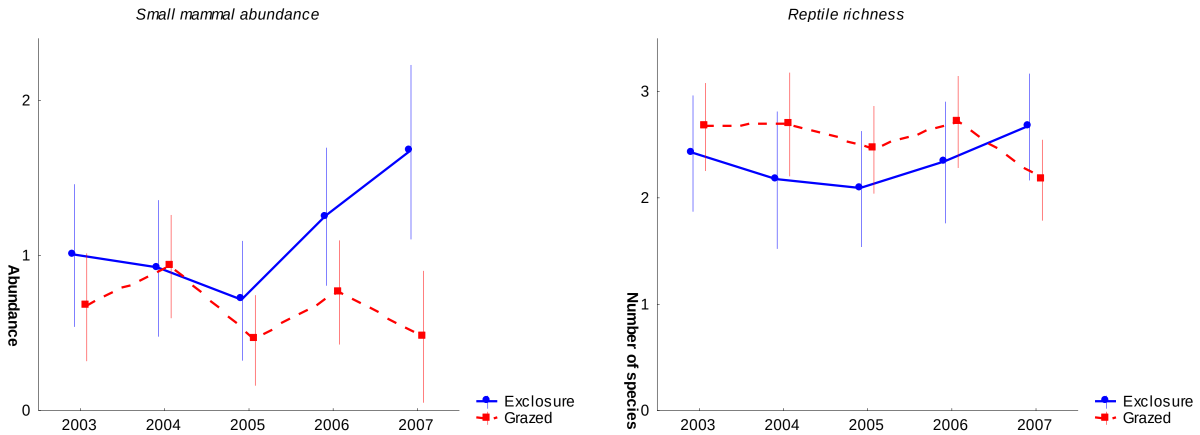


Fig. 6.31 Comparison between exclosure and grazed (utilisation paddocks) sites for a) small mammal abundance; b) reptile richness.

6.4.5.3 Individual species

6.4.5.3.1 Plants

There were significant *treatment*year* interactions for only 6 of the 62 plant species tested (Table 6.18). *Aristida latifolia* showed a large increase in exclosure sites in 2007; four species (*Brachyachne convergens, Crotalaria medicaginea, Indigofera linifolia* and *Ptilotus spicatus*) declined in exclosures relative to grazed sites; while *Bauhinia cunninghamii* showed idiosyncratic variation over years. A number of other species (e.g. *Panicum decompositum*) showed some indication of an exclosure effect developing by the end of the trial, although this was not significant (Fig. 6.32).

Table 6.18. Summary of repeated-measures ANOVA comparing exclosures and grazed sites (*treatment*) across years for individual **plant** species. Comparisons were made over four years of sampling (2004-2007).

	Treatment *df =1*		Year *df =3*		Treatment*year *df =3*	
	F	p	F		F	p
Abelmoschus ficulneus	0.053	0.818	3.823	0.011	0.504	0.680
Abutilon hannii	0.492	0.486	1.997	0.117	0.411	0.746
Achyranthes aspera	0.033	0.856	1.417	0.240	2.133	0.098
Alysicarpus muelleri	0.169	0.683	7.832	0.000	0.548	0.650
Aristida latifolia	0.013	0.911	6.154	0.001	**3.344**	0.021
Astrebla elymoides	1.603	0.211	1.237	0.298	1.719	0.165
Bauhinia cunninghamii	0.035	0.852	2.844	0.040	**2.810**	0.041
Blumea tenella	0.458	0.501	2.104	0.127	0.361	0.698
Boerhavia spp.	0.350	0.556	3.148	0.027	0.212	0.888
Brachyachne convergens	**5.530**	0.022	3.473	0.018	**3.132**	0.027
Calotropis procera	0.154	0.696	1.033	0.380	0.715	0.545
Chionachne hubbardiana	1.547	0.219	8.007	0.000	1.111	0.346
Chrysopogon fallax	0.153	0.698	0.484	0.694	1.151	0.330
Commelina ciliata	0.528	0.471	2.852	0.039	0.456	0.713
Corchorus combined	1.100	0.299	8.190	0.000	1.637	0.183
Corchorus macropetalus	0.582	0.449	6.434	0.000	0.864	0.461
Corymbia terminalis	**3.510**	0.067	1.100	0.351	1.146	0.333
Crotalaria medicaginea	2.910	0.094	7.234	0.000	**3.863**	0.011
Crotalaria montana	0.002	0.963	6.105	0.001	0.672	0.571
Cucumis melo	0.116	0.735	11.073	0.000	0.528	0.664
Cyperus bifax	1.893	0.175	1.702	0.169	0.730	0.535
Desmodium muelleri	0.664	0.419	6.164	0.001	0.831	0.479
Dichanthium fecundum	2.690	0.107	1.207	0.309	0.145	0.933
Dichanthium sericeum	0.490	0.487	1.252	0.293	0.512	0.674
Eragrostis tenellula	1.114	0.296	5.630	0.001	0.340	0.797
Eulalia aurea	0.049	0.825	0.392	0.759	1.776	0.154
Euphorbia maconochieana	**10.660**	0.002	0.971	0.408	0.835	0.477
Euphorbia schizolepis	0.099	0.754	5.317	0.002	0.260	0.854
Evolvulus alsinoides	0.190	0.665	0.323	0.809	1.766	0.156
Fimbristylis schultzii	0.222	0.640	12.389	0.000	0.523	0.667
Flemingia pauciflora	0.035	0.852	3.079	0.029	1.324	0.269
Gomphrena affinis	0.149	0.701	1.141	0.334	1.312	0.272
Goodenia byrnesii	0.332	0.567	8.194	0.000	0.191	0.902
Heliotropium combined	1.776	0.188	0.867	0.459	1.689	0.172

	Treatment		Year		Treatment*year	
	df =1		*df =3*		*df =3*	
	F	p	F		F	p
Hybanthus enneaspermus	3.431	0.070	1.003	0.393	0.653	0.582
Indigofera linifolia	0.198	0.658	0.473	0.701	**3.124**	0.028
Indigofera trita	2.049	0.158	0.374	0.772	1.121	0.342
Iseilema ciliatum	0.000	0.987	0.456	0.714	0.575	0.632
Iseilema fragile	0.019	0.890	4.624	0.004	2.116	0.100
Iseilema mac/vag	1.129	0.293	6.166	0.001	0.435	0.728
Jacquemontia browniana	0.310	0.580	10.546	0.000	0.292	0.831
Neptunia dimorphantha	0.443	0.509	0.484	0.694	0.061	0.980
Neptunia gracilis	2.364	0.130	1.331	0.266	1.095	0.353
Panicum decompositum	0.029	0.866	3.003	0.032	0.919	0.433
Pentalepis ecliptoides	0.040	0.843	20.159	0.000	0.234	0.873
Phyllanthus maderaspatensis	1.756	0.191	8.547	0.000	2.268	0.083
Polygala sp.	0.316	0.577	14.608	0.000	1.090	0.355
Polymeria ambigua	0.043	0.837	9.158	0.000	0.482	0.695
Ptilotus spicatus	**6.295**	0.015	3.784	0.012	**3.406**	0.019
Rhynchosia minima	2.706	0.106	9.763	0.000	0.743	0.528
Sehima nervosum	0.873	0.354	2.605	0.054	1.077	0.361
Sesbania simpliciuscula	0.017	0.897	17.791	0.000	1.044	0.375
Sida fibulifera	0.005	0.942	3.049	0.030	0.316	0.814
Sida spinosa	0.319	0.575	1.218	0.305	0.080	0.971
Sorghum timorense	3.000	0.089	13.100	0.000	0.215	0.886
Spermacoce pogostoma	0.126	0.724	6.923	0.000	0.099	0.960
Streptoglossa bubakii	1.672	0.202	4.228	0.007	2.307	0.079
Tephrosia rosea	3.465	0.068	0.950	0.418	0.778	0.508
Terminalia arostrata	0.008	0.929	5.953	0.001	0.039	0.990
Terminalia volucris	0.362	0.550	1.331	0.266	2.399	0.070
Trichodesma zeylanicum	0.030	0.863	37.057	0.000	0.334	0.801
Wedelia asperrima	0.716	0.401	13.875	0.000	0.125	0.945

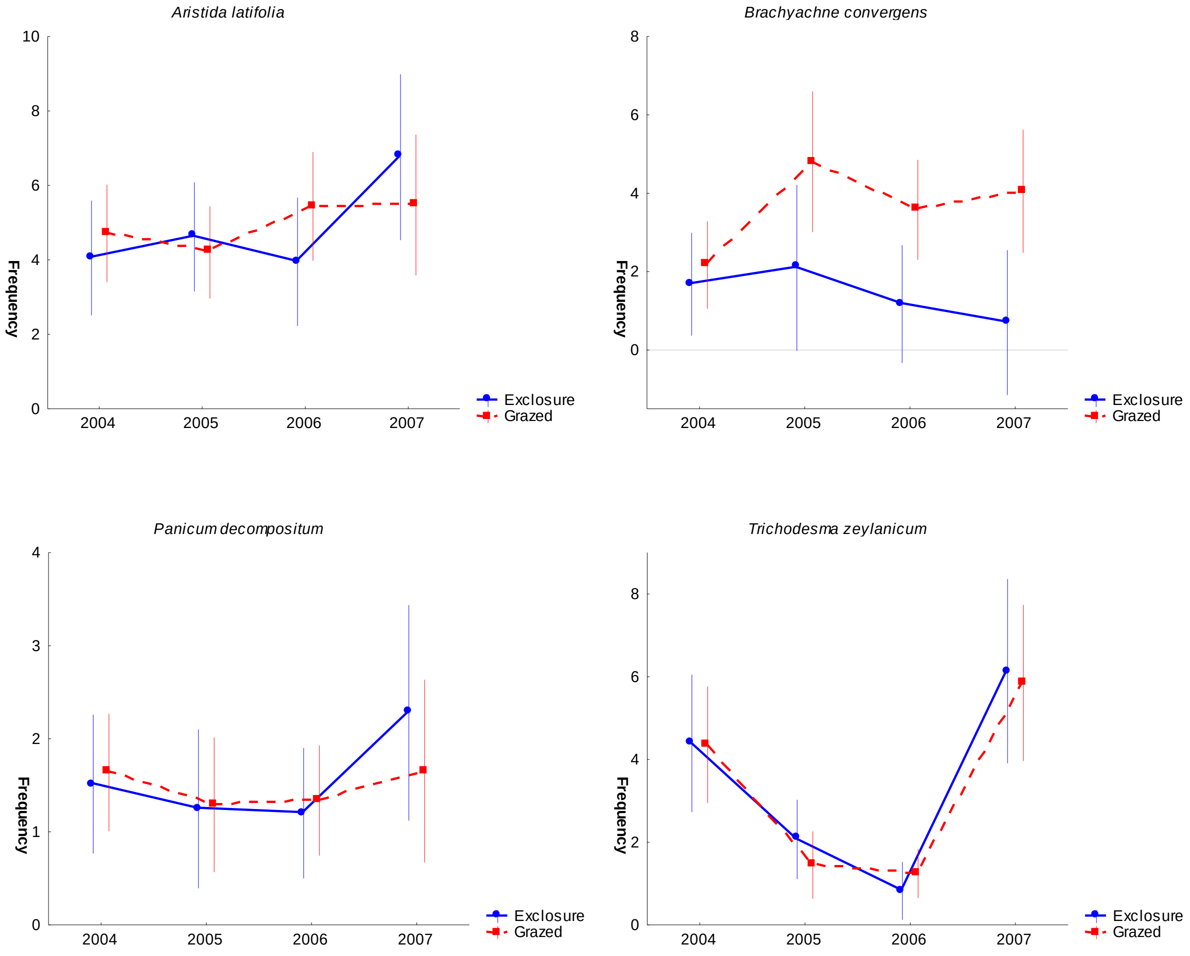


Fig. 6.32 Comparison between exclosure and grazed (utilisation paddocks) sites for some plant species: a) *Aristida latifolia*; b) *Brachyachne convergens*; c) *Panicum decompositum*; d) *Trichodesma zeylanicum*.

6.4.5.3.2 Birds

Four bird species had a significant *treatment*year* interaction in the early dry season, and six species in the late dry season (with no consistency in significant species between the two seasons; Table 6.19). All four species significant in the early dry season were doing better in exclosure sites than grazed sites (e.g. red-backed fairy-wren; Fig. 6.33). Some species (such as golden-headed cisticola) were also doing better in exclosure sites in the late dry season, while others (such as magpie-lark) had an increasing pattern in grazed sites. Singing bushlark had a complex response, with a lower abundance in exclosure than grazed sites in 2006, but higher in 2007.

Table 6.19. Summary of repeated-measures ANOVA comparing exclosures and grazed sites (*treatment*) across years for individual **bird** species. Comparisons were made over four years of sampling (2004-2007) for the late dry season and 3 years for the early dry (2005-2007).

	Treatment *df =1*		Year *df =1*		Treatment*year *df =1*	
	F	p	F	p	F	p
Early dry season						
Australian Bustard	0.652	0.423	0.199	0.820	2.938	0.058
Australian Hobby	3.760	0.059	0.425	0.517	0.309	0.581
Black Kite	1.013	0.319	2.532	0.085	0.095	0.909
Black-faced Cuckoo-shrike	0.781	0.381	2.808	0.065	0.356	0.701
Black-faced Woodswallow	0.016	0.901	2.699	0.073	0.666	0.516
Brolga	1.233	0.272	**3.515**	0.034	0.768	0.467
Brown Falcon	0.004	0.951	**16.058**	0.000	0.344	0.710
Brown Honeyeater	0.698	0.408	**4.405**	0.015	**3.661**	0.029
Brown Quail	2.394	0.129	1.634	0.201	2.984	0.055
Brown Songlark	0.324	0.572	**4.173**	0.018	**4.703**	0.011
Budgerigar	1.200	0.279	**14.650**	0.000	1.397	0.243
Button-quail spp.	1.376	0.247	**6.687**	0.002	0.350	0.706
Cockatiel	0.333	0.567	0.891	0.414	2.631	0.077
Crested Pigeon	2.000	0.164	1.811	0.169	0.320	0.727
Diamond Dove	0.682	0.413	**9.085**	0.000	0.380	0.685
Galah	3.002	0.090	1.373	0.258	0.444	0.643
Golden-headed Cisticola	0.041	0.840	**11.224**	0.000	2.317	0.104
Grey-crowned Babbler	0.032	0.860	1.114	0.333	0.461	0.632
Little Friarbird	0.086	0.771	**4.611**	0.012	0.348	0.707
Magpie-lark	**8.645**	0.005	1.314	0.274	0.358	0.700
Martin spp.	0.798	0.376	**14.017**	0.000	0.471	0.626
Masked Woodswallow	0.697	0.408	3.828	0.056	0.187	0.667
Nankeen Kestrel	0.010	0.923	**18.524**	0.000	0.290	0.749
Peaceful Dove	0.001	0.976	**7.453**	0.001	0.956	0.388
Pictorella Mannikin	**7.611**	0.008	1.514	0.225	0.524	0.594
Pied Butcherbird	4.409	0.041	1.134	0.326	0.784	0.460
Red-backed Fairy-wren	**36.408**	0.000	**26.134**	0.000	**4.785**	0.010
Red-backed Kingfisher	**5.095**	0.029	**2.771**	0.068	0.103	0.902
Red-tailed Black-Cockatoo	2.546	0.117	**5.961**	0.004	1.909	0.154
Rufous Songlark	1.156	0.288	**2.813**	0.065	0.986	0.377
Rufous-throated Honeyeater	1.196	0.280	**4.082**	0.020	0.650	0.524
Singing Bushlark	0.051	0.822	**2.938**	0.058	0.691	0.504
Singing Honeyeater	1.759	0.191	1.671	0.194	0.930	0.398
Spotted Harrier	0.006	0.941	2.093	0.129	0.545	0.581
Torresian Crow	2.987	0.091	**2.652**	0.076	0.566	0.570
Weebill	0.000	0.997	**3.199**	0.045	0.053	0.948
White-winged Triller	0.680	0.414	**3.705**	0.028	**3.371**	0.039
Willie Wagtail	2.404	0.128	**28.297**	0.000	0.161	0.852
Yellow-throated Miner	3.271	0.077	0.682	0.508	2.752	0.069
Zebra Finch	0.099	0.755	**15.353**	0.000	0.172	0.843
Late dry season						
Australian Bustard	0.852	0.361	0.138	0.937	0.787	0.503
Black Kite	3.938	0.053	**5.894**	0.004	1.654	0.197

	Treatment *df =1*		Year *df =1*		Treatment*year *df =1*	
	F	p	F	p	F	p
Black-faced Cuckoo-shrike	0.054	0.818	**4.671**	0.004	1.210	0.309
Black-faced Woodswallow	0.417	0.521	**8.912**	0.000	**6.331**	0.000
Brown Falcon	0.123	0.727	**5.522**	0.005	0.615	0.543
Brown Quail	**4.807**	0.033	0.415	0.742	0.765	0.515
Budgerigar	3.145	0.083	**16.019**	0.000	**3.355**	0.039
Button-quail spp.	3.876	0.055	**6.017**	0.001	1.273	0.286
Cockatiel	0.594	0.445	1.932	0.127	0.310	0.818
Crested Pigeon	0.100	0.753	2.590	0.055	1.215	0.307
Diamond Dove	0.136	0.714	2.101	0.103	1.176	0.321
Galah	0.070	0.793	**5.006**	0.003	0.141	0.935
Golden-headed Cisticola	**8.144**	0.006	**24.241**	0.000	**4.417**	0.005
Grey-crowned Babbler	1.424	0.239	0.326	0.807	1.138	0.336
Little Friarbird	0.004	0.952	0.919	0.402	1.403	0.251
Magpie-lark	**6.490**	0.014	1.906	0.131	**2.788**	0.043
Martin spp.	0.590	0.446	**5.035**	0.002	1.617	0.188
Peaceful Dove	0.000	0.988	**9.033**	0.000	0.259	0.855
Pictorella Mannikin	1.671	0.202	2.211	0.089	0.803	0.494
Pied Butcherbird	0.482	0.491	0.567	0.638	0.330	0.804
Red-backed Fairy-wren	**19.101**	0.000	**18.011**	0.000	2.423	0.068
Rufous-throated Honeyeater	1.153	0.288	0.479	0.698	0.021	0.996
Singing Bushlark	0.143	0.707	0.461	0.710	**2.817**	0.041
Singing Honeyeater	0.207	0.651	0.738	0.531	**3.333**	0.021
Spotted Harrier	0.583	0.449	1.735	0.163	1.615	0.189
Torresian Crow	**6.951**	0.011	1.614	0.189	0.559	0.643
Weebill	0.028	0.868	1.839	0.143	0.543	0.654
White-winged Triller	0.128	0.722	2.702	0.072	0.110	0.896
Willie Wagtail	3.185	0.081	2.320	0.078	0.743	0.528
Yellow-throated Miner	1.715	0.197	**5.542**	0.001	0.565	0.639
Zebra Finch	0.910	0.345	**7.015**	0.000	1.451	0.230

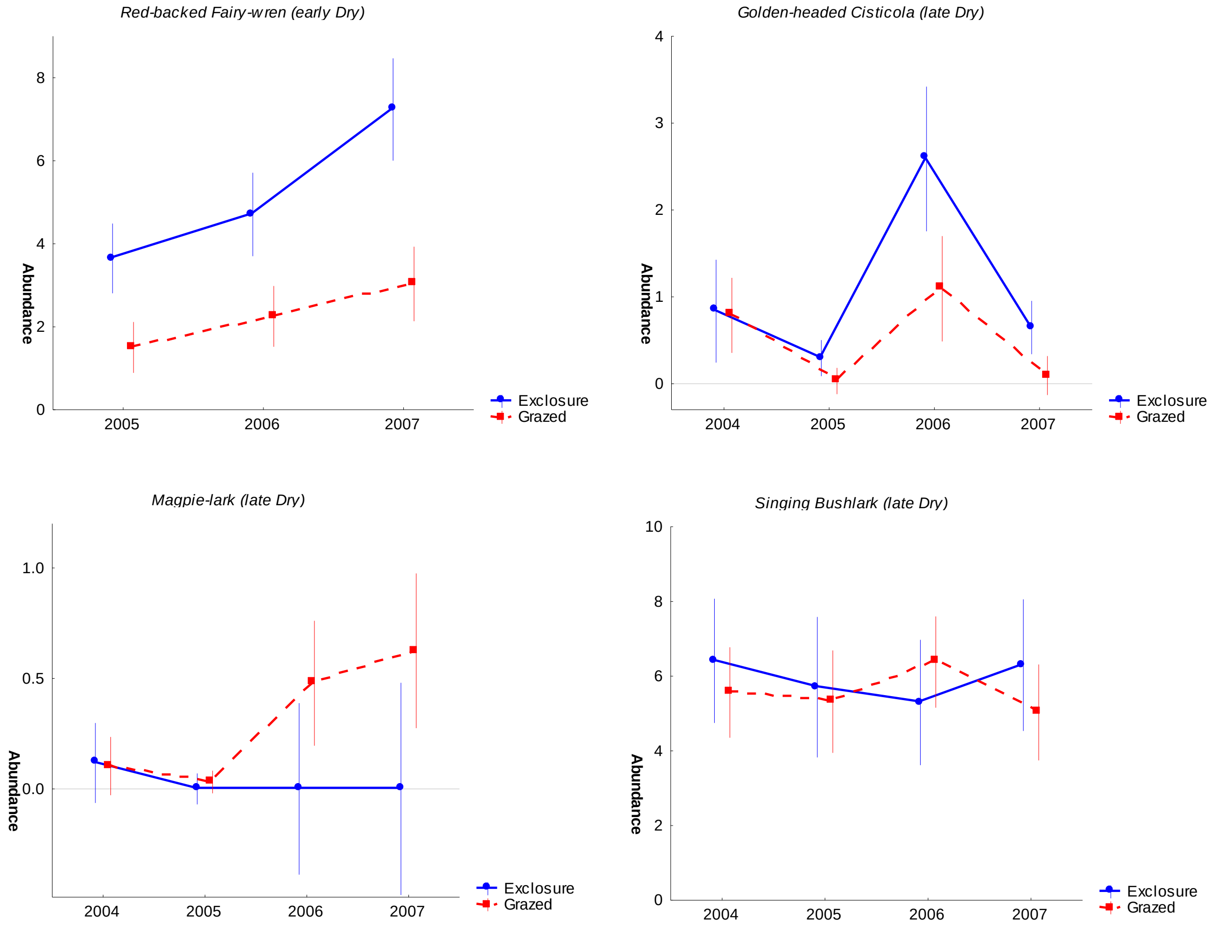


Fig. 6.33 Comparison between exclosure and grazed (utilisation paddocks) sites for some bird species: a) red-backed fairy-wren (early dry season); b) golden-headed cisticola (late dry season); c) magpie-lark (late dry season); d) singing bushlark (late dry season).

6.4.5.3.3 Reptiles & small mammals

Two reptile and one small mammal species had a significant treatment*year interaction (Table 6.20) – in each case these species are doing better over years in exclosure sites, with both *Planigale ingrami* and *Ctenotus rimacola* showing a marked increase from 2005 to 2007 (Fig. 6.34).

6.4.5.3.4 Ants

Of the 28 ant species tested, three (*Doleromyrma* spA, *Melophorus* spC, *Melophorus* spE) had a significant *year*treatment* interaction (Table 6.21); all declined within the grazed sites, although only one (*Doleromyrma* spA) also increased in the exclosures. Three additional species had an interaction term significant at p<0.1; two (*Iridomyrmex* spD, *Monomorium fieldi*) had a greater increase in exclosure than utilisation sites, while *Monomorium* spE declined in the exclosures and increased in the grazed sites (Fig. 6.35).

Table 6.20. Summary of repeated-measures ANOVA comparing exclosures and grazed sites (*treatment*) across years for individual **reptile** and **small mammal** species. Comparisons were made over five years of sampling.

	Treatment *df =1*		Year *df =4*		Treatment*year *df =4*	
	F	p	F	p	F	p
<u>Reptiles</u>						
Cryptoblepharus plagiocephalus	**5.845**	0.018	1.013	0.401	0.277	0.893
Ctenotus rimacola	**9.510**	0.003	**7.347**	0.000	**6.540**	0.000
Delma tincta	0.240	0.626	0.676	0.609	0.806	0.522
Heteronotia binoei	0.722	0.399	**3.854**	0.005	1.292	0.274
Menetia maini	0.395	0.532	1.203	0.310	0.282	0.890
Proablepharus naranjicaudus	0.674	0.415	**5.427**	0.000	0.602	0.662
Proablepharus tenuis	0.722	0.399	**4.213**	0.003	0.500	0.736
Ramphotyphlops ligatus	0.009	0.927	0.149	0.963	0.530	0.713
Varanus storri	2.292	0.135	**3.824**	0.005	**2.883**	0.023
<u>Mammals</u>						
Planigale ingrami	**10.605**	0.002	2.091	0.082	**2.922**	0.022

Fig. 6.34 Comparison between exclosure and grazed (utilisation paddocks) sites for some mammal and reptile species: a) *Planigale ingrami*; b) *Ctenotus rimacola.*

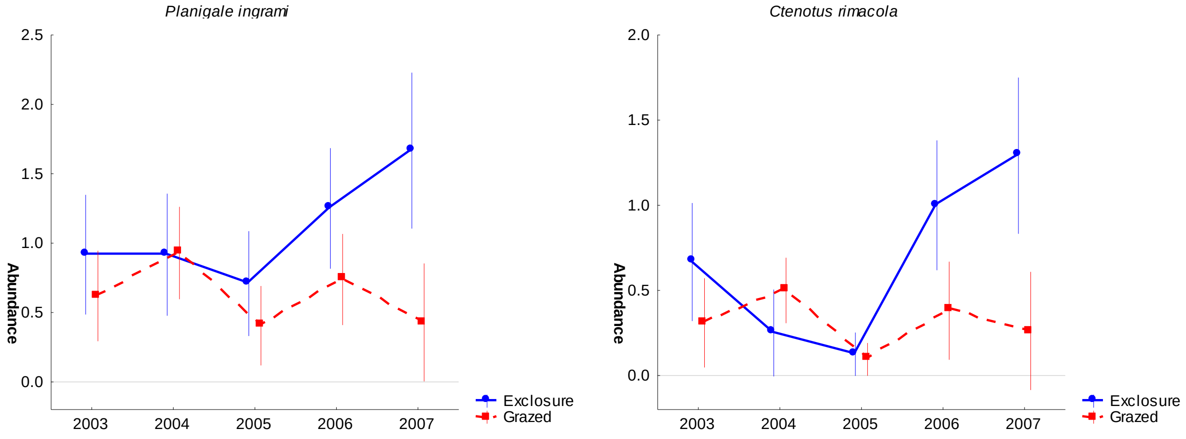


Table 6.21. Summary of repeated-measures ANOVA comparing exclosures and grazed sites (*treatment*) across years for individual **ant** species. Comparisons were made over two sampling years (2005,2007).

	Treatment		**Year**		**Treatment*year**	
	df =1		*df =1*		*df =1*	
	F	p	F	p	F	p
Camponotus sp9	0.029	0.866	5.287	**0.025**	0.000	0.985
Camponotus spA	1.141	0.290	12.641	**0.001**	0.211	0.648
Camponotus spC	0.019	0.890	5.052	**0.029**	1.285	0.262
Crematogaster queenslandica	0.079	0.779	17.711	**0.000**	0.000	0.988
Doleromyrma spA	0.521	0.473	0.061	0.806	4.438	**0.040**
Iridomyrmex sanguineus	2.839	0.098	0.081	0.778	0.129	0.721
Iridomyrmex sp1	0.080	0.778	5.516	**0.023**	0.621	0.434
Iridomyrmex sp2	0.017	0.897	8.125	**0.006**	0.528	0.471
Iridomyrmex spD	1.773	0.189	19.159	**0.000**	3.238	0.078
Iridomyrmex spE	0.000	0.996	7.518	**0.008**	0.253	0.617
Leptogenys adlerzi	1.132	0.292	3.382	**0.072**	0.013	0.911
Melophorus spC	2.519	0.118	17.047	**0.000**	4.179	**0.046**
Melophorus spE	0.318	0.575	9.179	**0.004**	5.034	**0.029**
Meranoplus oxleyi	0.560	0.457	1.871	0.177	1.217	0.275
Meranoplus pubescens	2.259	0.139	2.196	0.144	0.201	0.655
Monomorium anderseni	0.028	0.867	16.441	**0.000**	0.592	0.445
Monomorium fieldi	0.258	0.614	6.192	**0.016**	3.092	0.084
Monomorium sp24	0.316	0.576	8.299	**0.006**	0.076	0.784
Monomorium spE	3.269	0.076	0.607	0.440	2.817	0.099
Opisthopsis rufoniger	0.522	0.473	2.453	0.123	2.453	0.123
Pheidole impressiceps	0.466	0.498	3.195	0.080	2.357	0.131
Pheidole spC	0.245	0.623	3.373	**0.072**	1.269	0.265
Pheidole spD	0.728	0.397	0.028	0.869	0.854	0.360
Polyrhachis crawleyi	0.746	0.392	11.308	**0.001**	1.786	0.187
Rhytidoponera spA	3.470	0.068	15.764	**0.000**	0.374	0.543
Tapinoma spA	0.186	0.668	0.886	0.351	0.165	0.686
Tetramorium spA	0.121	0.729	7.364	**0.009**	0.040	0.842
Tetramorium spB	0.563	0.456	0.092	0.762	0.092	0.762

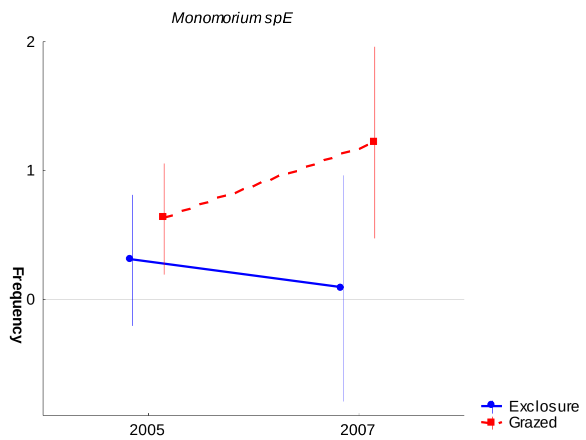


Fig. 6.35 Comparison between exclosure and grazed (utilisation paddocks) sites for some ant species: a) *Doleromyrma* spA; b) *Monomorium* spE.

6.4.6 Exclosures – size effect

6.4.6.1 Species Composition

There was a significant difference in **plant composition** between exclosure size classes in 2004 (i.e. a pre-treatment effect), and this was maintained throughout the trial (Table 6.22a, Fig. 6.36a). The pairwise comparisons show that this effect was due to differences between Gregory National Park and the largest exclosure (which represent geographically separate “paddocks”) and the other size classes, and not between smaller exclosures scattered in the utilisation paddocks. For these three smaller exclosure classes, there was no indication that exclosure size had any influence over time on plant composition.

By contrast, there was no global difference in **bird composition** between exclosure size classes in 2003 and 2004 (late dry season), but this difference became increasingly significant from 2005 to 2007 (Table 6.22b, Fig. 6.36b). A similar pattern is found for early dry season data from 2005 to 2007. However, in both cases the significant pairwise comparisons are not entirely consistent across years.

There was only a significant global difference between size classes for **ants** in 2007: pairwise comparisons show that this was mostly due to differences between Gregory National Park and the largest exclosure, and the other smaller classes (Table 6.22c, Fig. 6.36c). There was no indication that, for example, the smallest exclosure had diverged in composition from the two next larger classes.

Table 6.22. ANOSIM analyses, comparing composition of sites in different exclosure size classes, for different groups. Global R and pairwise comparisons are reported; significant R values (P<0.1) are bolded. Exclosures were not established until 2004, smallest exclosures were excluded for bird analyses

a) plants

	2004		2005		2006		2007	
Overall R	**0.197**		0.045		**0.166**		**0.179**	
Overall P	0.006		0.223		0.011		0.005	
Groups	*R*	*P*	*R*	*P*	*R*	*P*	*R*	*P*
GNP, 400ha	**0.54**	0.008	**0.31**	0.048	**0.50**	0.016	**0.26**	0.056
GNP, 40ha	**0.51**	0.002	**0.26**	0.026	**0.37**	0.011	**0.41**	0.002
GNP, 4ha	**0.20**	0.076	**0.18**	0.076	**0.24**	0.043	**0.23**	0.045
GNP, 0.4ha	**0.22**	0.082	**0.12**	0.152	**0.33**	0.017	0.16	0.102
400ha, 40ha	**0.71**	0.002	**0.21**	0.089	**0.50**	0.004	**0.65**	0.002
400ha, 4ha	**0.32**	0.045	0.01	0.385	**0.30**	0.048	**0.32**	0.041
400ha, 0.4ha	0.17	0.130	-0.08	0.682	0.11	0.173	0.19	0.108
40ha, 4ha	-0.09	0.868	-0.14	0.985	-0.13	0.929	-0.02	0.563
40ha, 0.4ha	0.00	0.426	-0.09	0.755	-0.08	0.72	-0.04	0.610
4ha, 0.4ha	-0.12	0.933	-0.15	0.959	-0.11	0.931	-0.09	0.844

Table 6.22 (cont'd)

b) birds – late dry season

	2003		2004		2005		2006		2007	
Overall R	0.079		0.074		**0.106**		**0.183**		**0.385**	
Overall P	0.111		0.146		0.083		0.005		0.0001	
Groups	*R*	*P*	*R*	*P*	*R*	*P*	*R*	*P*	*R*	*P*
GNP, 400ha	-0.05	0.667	-0.07	0.667	-0.18	0.937	-0.02	0.556	**0.25**	0.063
GNP, 40ha	**0.17**	0.087	**0.21**	0.063	**0.42**	0.009	**0.16**	0.084	**0.60**	0.006
GNP, 4ha	-0.10	0.775	0.10	0.165	0.13	0.147	**0.20**	0.080	**0.31**	0.028
400ha, 40ha	**0.34**	0.004	**0.21**	0.076	**0.31**	0.009	**0.27**	0.015	**0.67**	0.002
400ha, 4ha	-0.01	0.515	0.05	0.266	-0.01	0.509	0.12	0.145	**0.45**	0.011
40ha, 4ha	0.06	0.199	-0.01	0.506	-0.05	0.675	**0.33**	0.011	0.12	0.136

c) birds – early dry season

	2005		2006		2007	
Overall R	**0.119**		**0.224**		**0.280**	
Overall P	0.071		0.003		0.0008	
Groups	*R*	*P*	*R*	*P*	*R*	*P*
GNP, 400ha	0.18	0.119	**0.34**	0.016	0.14	0.151
GNP, 40ha	0.11	0.186	**0.20**	0.087	**0.39**	0.019
GNP, 4ha	0.08	0.277	0.04	0.355	**0.23**	0.048
400ha, 40ha	**0.24**	0.061	**0.52**	0.006	**0.70**	0.009
400ha, 4ha	**0.28**	0.017	0.10	0.206	**0.19**	0.054
40ha, 4ha	-0.14	0.900	**0.16**	0.089	0.06	0.234

d) ants

	2003		2005		2007	
Overall R	-0.069		-0.061		**0.192**	
Overall P	0.714		0.822		0.005	
Groups	*R*	*P*	*R*	*P*	*R*	*P*
GNP, 400ha			0.13	0.222	**0.44**	0.008
GNP, 40ha			0.16	0.132	**0.27**	0.035
GNP, 4ha	-0.06	0.600	-0.07	0.753	0.04	0.327
GNP, 0.4ha	0.09	0.286	-0.15	0.955	**0.20**	0.052
400ha, 40ha			**0.22**	0.087	**0.53**	0.002
400ha, 4ha			-0.15	0.894	**0.53**	0.006
400ha, 0.4ha			-0.07	0.636	**0.36**	0.026
40ha, 4ha			-0.06	0.621	-0.03	0.522
40ha, 0.4ha			-0.20	0.974	-0.10	0.788
4ha, 0.4ha	-0.18	0.895	-0.23	0.987	-0.115	0.868

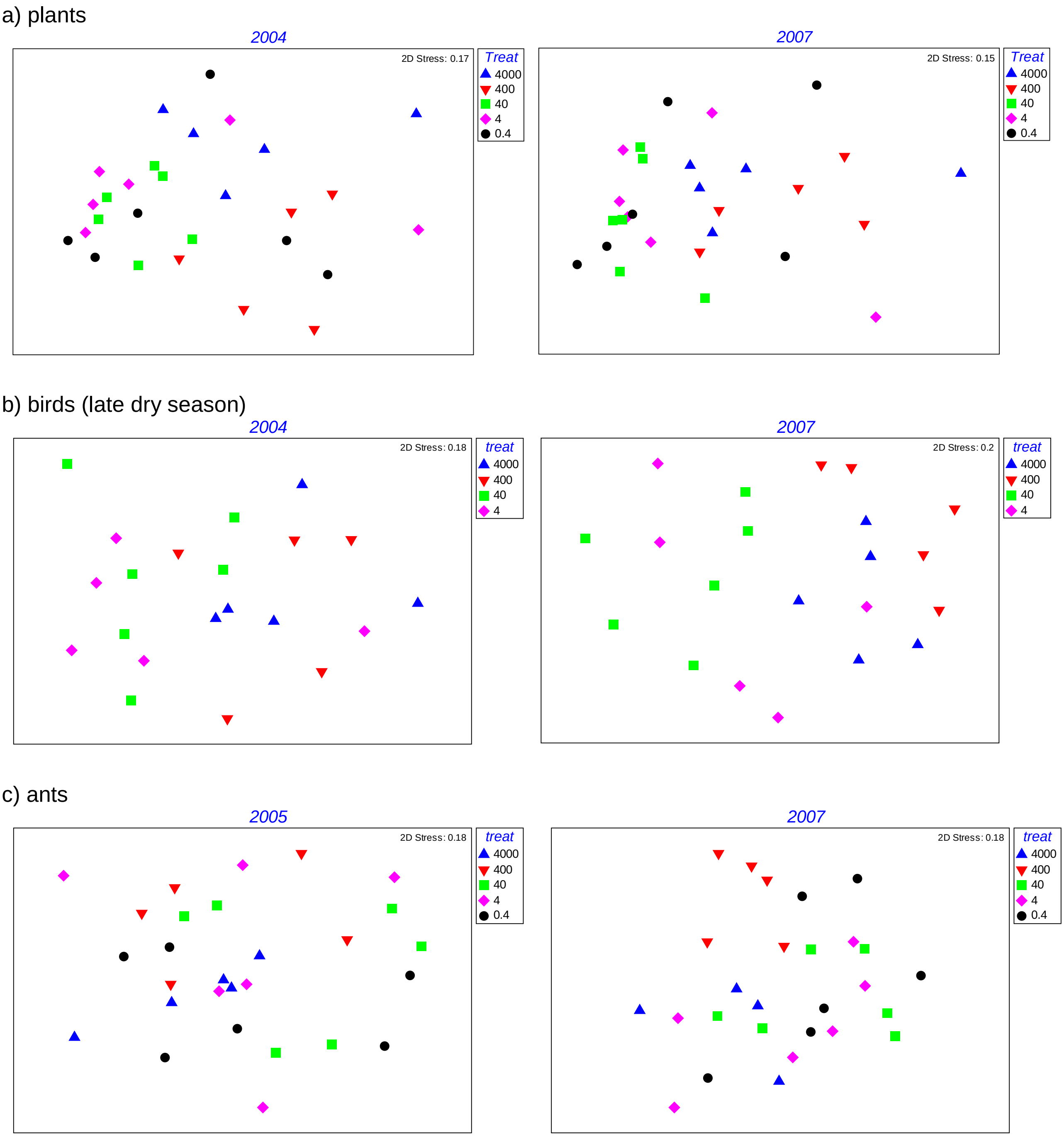


Fig. 6.36 Comparison of ordinations by species composition of sites in different exclosure size classes in 2004 and 2007 for plants and birds, and 2005 and 2007 for ants.

6.4.6.2 Richness, diversity and structural variables

Across all the taxa, the only significant *treatment*year* interactions were for ground cover variables, and ant total frequency (Table 6.23). The significant result for each of these variables largely arise from inconsistent responses across years for sites in Gregory National Park and/or the large exclosure, which are more likely to be a location effect than relate to exclosure size.

Table 6.23. Summary of repeated-measures ANOVA comparing exclosure sizes (*treatment*) across years for summary variables of each taxa.

	Treatment		Year		Treatment*year	
Variable	F	p	F	P	F	p
Plants (4 years)						
Richness	1.199	0.338	**3.722**	0.015	1.242	0.274
Shannon diversity	1.146	0.360	**12.469**	0.000	0.761	0.688
Total understorey cover	**2.811**	0.049	**48.697**	0.000	**3.308**	0.001
Perennial grass cover	1.360	0.278	**11.474**	0.000	**3.525**	0.000
Perennial grass basal cover	2.097	0.114	**2.435**	0.072	**2.668**	0.005
Perennial grass frequency	0.697	0.602	1.157	0.333	**5.219**	0.000
Birds (4 years)						
Richness – early dry season (site & adj)	1.587	0.225	**8.792**	0.001	0.468	0.827
Richness – early dry season (site only)	1.716	0.198	**8.596**	0.001	0.624	0.710
Richness – late dry season (site & adj)	2.946	0.059	**5.799**	0.002	0.753	0.660
Richness – late dry season (site only)	2.880	0.063	**6.355**	0.001	0.971	0.473
Total frequency – early dry season	1.474	0.253	**6.593**	0.003	0.564	0.756
Total frequency – late dry season	1.865	0.170	**8.660**	0.000	0.684	0.720
Shannon diversity – early dry season	1.995	0.149	**8.316**	0.001	0.451	0.840
Shannon diversity – late dry season	**3.154**	0.049	**5.733**	0.002	1.125	0.361
Reptiles (5 years)						
Richness	**4.362**	0.009	0.648	0.630	0.605	0.873
Abundance	**5.570**	0.003	0.505	0.732	1.305	0.210
Small mammals (5years)						
Richness	0.535	0.711	1.747	0.146	0.578	0.893
Abundance	1.224	0.327	2.090	0.088	0.876	0.598
Reptiles + small mammals						
Richness	**4.420**	0.008	1.389	0.244	0.306	0.995
Shannon diversity	**2.976**	0.040	1.378	0.247	0.315	0.994
Ants (2 years)						
Richness *	1.504	0.232	0.011	0.918	1.375	0.272
Total frequency *	1.547	0.220	0.417	0.524	**2.470**	0.072
Shannon diversity*	**3.769**	0.016	0.023	0.880	2.145	0.106

* 2003 is not included because only 10 of 23 exclosure sites were sampled then

6.4.6.3 Individual species

Five of the plant species tested had a significant interaction term (Table 6.24). In each case, these arise because of greater variation in frequency across years in either the largest exclosure or Gregory National Park, than in other exclosure size classes.

Nine bird species had a significant interaction term, in either the early or late dry season (Table 6.25). For golden-headed cisticola, increase over time was proportional to exclosure size (Fig. 6.37). Button-quail species showed some indication of a decline in the smaller exclosure sizes., while diamond dove and peaceful dove appeared to favour smaller exclosures. In other species there was idiosyncratic variation in some size classes across years.

Only one mammal and reptile species had a significant interaction term (Table 6.26) – the skink *Proablepharus naranjicaudus,* which had a highly variable abundance over years in Gregory National Park. Of the three smaller exclosure sizes, *Planigale ingrami* appeared to show the greatest proportional increase in the largest (40 ha) sites (Fig. 6.38).

Three ant species had a significant interaction term (Table 6.27) - as for plants, these arise because of variable responses across years in either Gregory National Park or the largest exclosure, and there is no significant pattern amongst the smaller exclosures.

Fig. 6.37. Comparison between exclosure sizes for some bird species: a) golden-headed cisticola; b) diamond dove; c) button-quail species. The smallest (0.4 ha) exclosures were excluded from the analyses for birds.

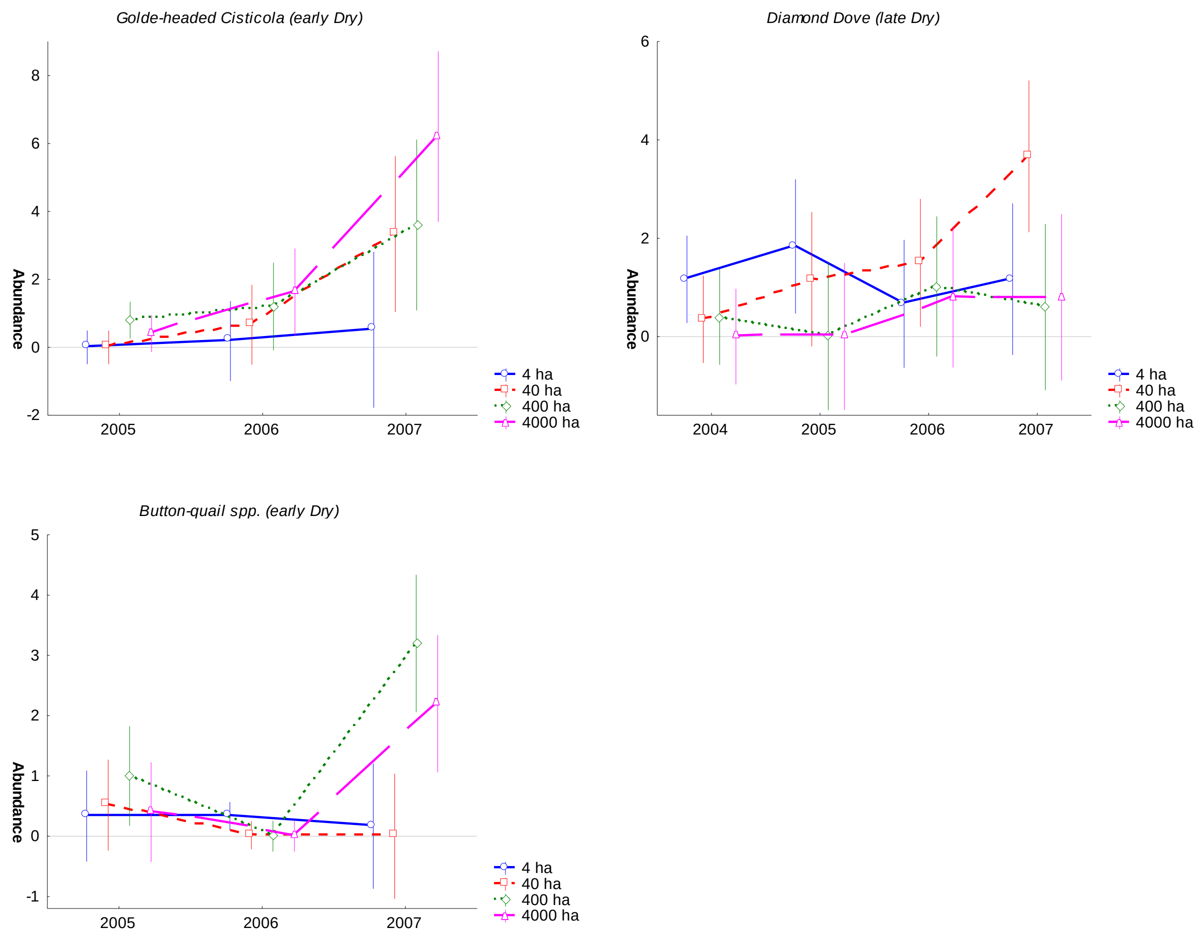


Table 6.24. Summary of repeated-measures ANOVA comparing exclosure size classes (*treatment*) across years for individual **plant** species. Comparisons were made over four years of sampling (2004-2007).

	Treatment *df =4*		Year *df =3*		Treatment*year *df =12*	
	F	p	F	p	F	p
Abutilon hannii	0.844	0.512	0.100	0.960	0.679	0.766
Alysicarpus muelleri	0.427	0.788	**4.028**	0.011	1.254	0.266
Aristida latifolia	0.863	0.501	**6.348**	0.001	1.657	0.096
Boerhavia spp.	0.912	0.474	0.784	0.507	0.896	0.555
Brachyachne convergens	1.026	0.415	**2.865**	0.043	0.611	0.826
Chrysopogon fallax	0.537	0.710	1.246	0.300	1.028	0.434
Commelina ensifolia	1.286	0.305	1.961	0.128	1.870	0.054
Crotalaria medicaginea	0.457	0.766	**5.533**	0.002	1.194	0.305
Cucumis melo	0.789	0.544	**2.806**	0.046	1.505	0.144
Desmodium muelleri	0.738	0.576	2.106	0.107	1.634	0.102
Dichanthium fecundum	**4.506**	0.008	0.151	0.929	0.516	0.897
Euphorbia schizolepis	0.905	0.477	2.652	0.055	1.031	0.431
Flemingia pauciflora	1.469	0.244	2.523	0.065	1.522	0.137
Goodenia byrnesii	**3.345**	0.027	**8.917**	0.000	**3.648**	0.000
Indigofera linifolia	**2.963**	0.041	2.057	0.114	**2.774**	0.004
Iseilema fragile	1.609	0.206	2.135	0.104	1.167	0.324
Iseilema mac/vag	0.865	0.500	**3.338**	0.024	1.133	0.349
Jacquemontia browniana	1.169	0.350	**5.963**	0.001	**2.291**	0.016
Panicum decompositum	1.349	0.282	**3.712**	0.015	0.803	0.646
Pentalepis ecliptoides	1.170	0.350	**7.719**	0.000	1.513	0.141
Phyllanthus maderaspatensis	0.326	0.858	**8.413**	0.000	0.698	0.748
Polygala sp.	**7.336**	0.001	**22.880**	0.000	**4.816**	0.000
Polymeria ambigua	0.213	0.929	**4.939**	0.004	0.941	0.512
Ptilotus spicatus	0.767	0.557	**4.457**	0.006	**2.388**	0.012
Rhynchosia minima	2.495	0.071	**4.233**	0.008	1.379	0.197
Sesbania simpliciuscula	**3.829**	0.016	**11.920**	0.000	1.802	0.065
Sorghum timorense	1.455	0.248	**3.542**	0.019	1.438	0.170
Spermacoce pogostoma	0.546	0.704	**7.665**	0.000	1.339	0.217
Terminalia arostrata	0.810	0.532	2.499	0.067	1.181	0.314
Terminalia volucris	1.185	0.344	1.374	0.258	1.854	0.056
Trichodesma zeylanicum	**2.801**	0.050	**18.517**	0.000	1.444	0.168
Wedelia asperrima	**3.672**	0.019	**9.373**	0.000	1.843	0.058

Table 6.25. Summary of repeated-measures ANOVA comparing exclosure size classes (*treatment*) across years for individual **bird** species in the early (E) and late (L) dry season. Comparisons were made over three (early: 2005-07) and four (late: 2004-07) years of sampling.

		Treatment		Year		Treatment*year	
		df =3		*df =2(E), 3(L)*		*df =6(E), 9(L)*	
		F	p	F	p	F	p
Australian Bustard	E	2.122	0.133	0.222	0.802	1.614	0.172
	L	0.064	0.978	0.798	0.500	1.078	0.394
Black-faced Cuckoo-shrike	E	1.730	0.197	2.066	0.142	1.658	0.160
	L	0.389	0.762	1.455	0.237	1.105	0.375
Black-faced Woodswallow	E	2.582	0.085	0.205	0.815	0.675	0.670
	L	0.049	0.985	**26.473**	0.000	0.657	0.743
Brown Falcon	E	2.886	0.064	**24.433**	0.000	**2.766**	0.026
	L	-		-		-	
Brown Quail	E	0.883	0.469	1.864	0.170	1.803	0.126
	L	2.311	0.111	0.385	0.764	0.347	0.955
Budgerigar	E	0.758	0.532	**4.564**	0.047	0.444	0.725
	L	-		-		-	
Button-quail spp.	E	**6.378**	0.004	**12.673**	0.000	**5.815**	0.000
	L	2.707	0.076	**9.812**	0.000	**8.591**	0.000
Crested Pigeon	E	0.479	0.701	2.670	0.083	0.829	0.555
	L	0.999	0.416	1.140	0.341	**2.089**	0.047
Diamond Dove	E	-		-		-	
	L	2.448	0.097	2.350	0.083	1.760	0.098
Galah	E	2.779	0.071	2.109	0.136	1.223	0.318
	L	**5.495**	0.007	1.324	0.276	0.812	0.607
Golden-headed Cisticola	E	**4.872**	0.012	**21.004**	0.000	2.562	0.036
	L	**4.463**	0.016	**13.488**	0.000	0.378	0.941
Magpie-lark	E	1.285	0.310	1.190	0.316	0.982	0.452
	L	-				-	
Martin spp.	E	0.258	0.854	**8.678**	0.001	0.551	0.766
	L	-		-		-	
Peaceful Dove	E	**7.331**	0.002	**4.668**	0.016	**6.554**	0.000
	L	**12.038**	0.000	**5.555**	0.002	**2.505**	0.018
Pictorella Mannikin	E	2.611	0.083	1.350	0.272	**3.292**	0.011
	L	1.653	0.213	1.790	0.160	0.543	0.837
Pied Butcherbird	E	0.375	0.772	0.435	0.651	0.835	0.551
	L	0.283	0.837	0.403	0.752	1.234	0.294
Red-backed Fairy-wren	E	1.961	0.156	**16.335**	0.000	0.765	0.602
	L	1.936	0.160	**7.180**	0.000	0.474	0.886
Rufous-throated Honeyeater	E	1.805	0.182	1.364	0.269	0.096	0.996
	L	**3.547**	0.035	0.129	0.942	1.333	0.242
Singing Bushlark	E	1.622	0.219	**4.829**	0.014	**3.071**	0.016
	L	2.015	0.148	**3.746**	0.016	1.533	0.160
Spotted Harrier	E	1.055	0.393	1.875	0.168	2.303	0.055
	L	-		-		-	
Torresian Crow	E	0.626	0.608	1.626	0.211	0.667	0.677
	L	2.075	0.139	**4.891**	0.004	0.966	0.478
White-winged Triller	E	2.732	0.074	**3.312**	0.048	0.755	0.610
	L	**5.876**	0.006	2.045	0.144	**4.259**	0.002
Willie Wagtail	E	2.896	0.064	**25.534**	0.000	2.330	0.053

		Treatment		Year		Treatment*year	
		df =3		*df =2(E), 3(L)*		*df =6(E), 9(L)*	
		F	p	F	p	F	p
	L	1.429	0.267	1.385	0.263	1.080	0.393
Yellow-throated Miner	E	0.577	0.637	0.642	0.532	1.120	0.370
	L	1.283	0.310	**3.082**	0.035	**2.230**	0.034
Zebra Finch	E	0.220	0.881	**7.826**	0.002	0.569	0.752
	L	0.932	0.446	2.019	0.148	**3.626**	0.006

Table 6.26. Summary of repeated-measures ANOVA comparing exclosure size classes (*treatment*) across years for individual **reptile** and **small mammal** species. Comparisons were made over five years of sampling.

	Treatment		Year		Treatment*year	
	df =4		*df =4*		*df =16*	
	F	p	F	p	F	p
Cryptoblepharus plagiocephalus	1.395	0.265	0.414	0.743	1.639	0.100
Ctenotus rimacola	**2.462**	0.073	**4.761**	0.002	1.263	0.237
Delma tincta	0.408	0.801	1.331	0.264	0.840	0.638
Heteronotia binoei	2.606	0.061	**3.348**	0.013	1.341	0.189
Menetia maini	1.050	0.403	0.493	0.741	1.113	0.355
Planigale ingrami	1.241	0.320	2.316	0.063	0.848	0.629
Proablepharus naranjicaudus	**4.775**	0.006	**6.020**	0.000	**2.216**	0.009
Proablepharus tenuis	**7.146**	0.001	**2.768**	0.032	0.944	0.523
Ramphotyphlops ligatus	0.838	0.514	0.360	0.837	0.916	0.553
Varanus storri	**4.263**	0.010	1.409	0.247	1.593	0.113

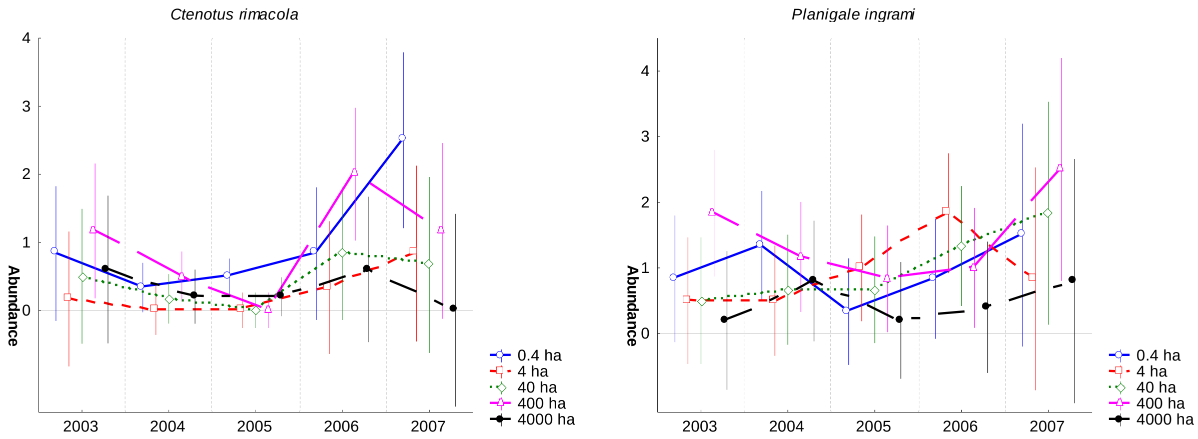


Fig. 6.38. Comparison between exclosure sizes for a) the skink *Ctenotus rimacola* and b) the small mammal *Planigale ingrami*.

Table 6.27. Summary of repeated-measures ANOVA comparing exclosure size classes (*treatment*) across years for individual **ant** species. Comparisons were made over two years of sampling (2005, 2007).

	Treatment *df =4*		Year *df =1*		Treatment*year *df =4*	
	F	p	F	p	F	p
Camponotus sp9	0.937	0.460	**3.060**	0.094	0.671	0.619
Camponotus spA	1.631	0.200	**16.771**	0.000	**6.174**	0.002
Camponotus spC	**4.313**	0.009	**17.498**	0.000	**8.080**	0.000
Crematogaster queenslandica	1.342	0.285	**7.960**	0.010	0.722	0.586
Doleromyrma spA	1.415	0.260	**4.705**	0.041	0.411	0.799
Iridomyrmex sp1	0.614	0.657	0.489	0.491	1.420	0.259
Iridomyrmex sp2	0.399	0.807	**6.693**	0.016	0.414	0.797
Iridomyrmex spD	1.064	0.397	**13.900**	0.001	0.598	0.667
Iridomyrmex spE	1.408	0.263	**4.723**	0.040	0.842	0.513
Leptogenys adlerzi	0.522	0.721	0.786	0.384	1.921	0.141
Melophorus spC	1.267	0.312	3.872	0.061	0.438	0.780
Melophorus spE	0.524	0.719	**5.937**	0.023	**3.821**	0.016
Meranoplus oxleyi	0.944	0.456	0.093	0.764	1.504	0.234
Meranoplus pubescens	1.967	0.133	0.205	0.655	0.815	0.529
Monomorium anderseni	0.845	0.511	**10.937**	0.003	0.826	0.522
Monomorium fieldi	0.498	0.737	**6.035**	0.022	0.361	0.833
Monomorium sp24	0.961	0.448	**7.993**	0.010	0.769	0.556
Pheidole impressiceps	1.589	0.211	0.057	0.814	1.390	0.269
Pheidole spC	2.729	0.054	**4.403**	0.047	1.347	0.283
Rhytidoponera spA	0.154	0.959	**6.345**	0.019	1.560	0.219
Tapinoma spA	0.255	0.904	0.165	0.688	0.520	0.722
Tetramorium spA	0.436	0.781	0.159	0.694	1.205	0.335
Tetramorium spB	0.353	0.839	0.002	0.966	0.362	0.833

6.4.7 Mt. Sanford

6.4.7.1 Description of biota

A total of 124 plant species and 60 bird species were recorded from all Mt Sanford sites during the 3 sample years (Table 6.28).

Mean site richness for plants was c. 42 species (Table 6.29). On average, including a timed search added an addition 12 species to the complement recorded from the 16 subplots in a site. The total number of plant species recorded and the mean site richness was slightly higher in 2003 than the other two years, and site richness was relatively low in 2006. Only c. 61% of all plant species recorded over the 3 years were recorded in each individual year. From a total of 72 site-years, 16 species were recorded only once, and 48 species 5 times or fewer.

Site richness of birds was very low (c. 4 spp) within the quadrats, although this increased to c. 11 spp when transects were included (Table 6.29). Total and site richness of birds was slightly higher in the early dry season than the late dry season. There was little variation between years in mean site richness or the total number of species recorded.

Table 6.28. Total number of species recorded Mt Sanford biodiversity sites (*n=24*) in the 3 years sampled.

	2002	2003	2006	Total
Plants	72	80	76	124
Birds – early				
Quadrat only	27	28	-	37
Quadrat + transect	-	46	-	46
Birds – late				
Quadrat only	20	20	24	34
Quadrat + transect	-	37	38	45
Birds - all				60

Table 6.29. Mean site richness for each taxon in 2003-2007. Numbers in bracket are ranges.

	2002	2003	2006	Total (mean across years)
Plants (subplots only)	30.0 (22-40)	32.8 (24-42)	26.5 (19-31)	29.8 (22-42)
Plants (subplots + search)	42.3 (31-54)	-	41.2 (28-66)	41.8 (31-66)
Quadrat only				
Birds – early	4.8 (3-10)	4.2 (1-8)	-	4.4 (1-10)
Birds – late	4.0 (1-7)	3.9 (2-8)	4.3 (2-7)	4.1 (1-8)
Quadrat + transect				
Birds – early	-	11.9 (5-25)	-	-
Birds – late	-	10.5 (5-19)	8.8 (4-15)	9.7 (4-19)

6.4.7.1.1 Comparison with Pigeon Hole

Although all of the plant species recorded at the Mt Sanford sites were also recorded at Pigeon Hole sites, the two locations separate completely in an ordination based on overall plant composition (Fig. 6.39). This is consistent with the pre-treatment differences between Pigeon Hole paddocks (Figs 6.5 & 6.6). Compared to sites within the utilisation paddocks at Pigeon Hole, Mount Sanford sites had a low abundance of *Sarga timorense* and *Flemingia pauciflora*, and a high abundance of *Astrebla* spp, *Dicanthium sericeum* and *Iseilema* spp. While this may be partly due to a slightly lower mean annual rainfall at Mt Sanford, it also suggests that this area has better pasture condition than Pigeon Hole.

By contrast, the two locations have very similar bird composition (Fig. 6.40). Some differences between sites from the two locations may also relate to lower habitat diversity on the smaller Mount Sanford paddocks, and small differences in the timing of sampling and variation between observers.

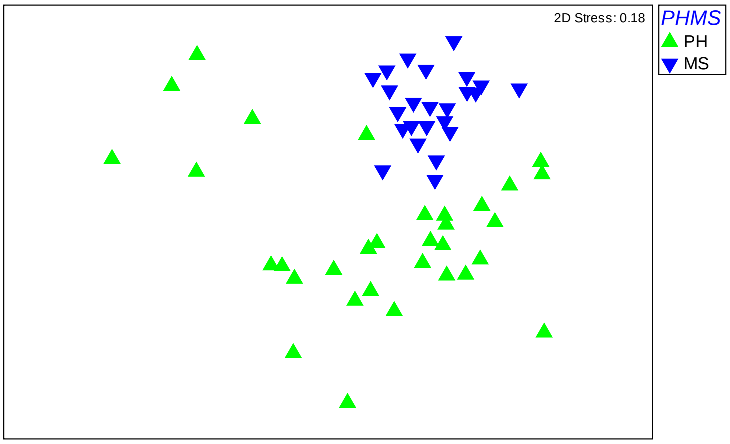


Fig. 6.39. Ordination of biodiversity sample sites at Mt Sanford (MS) and Pigeon Hole (PH) (non-riparian, grazed sites in utilisation paddocks only), using **plant composition** (frequency data) from 2006.

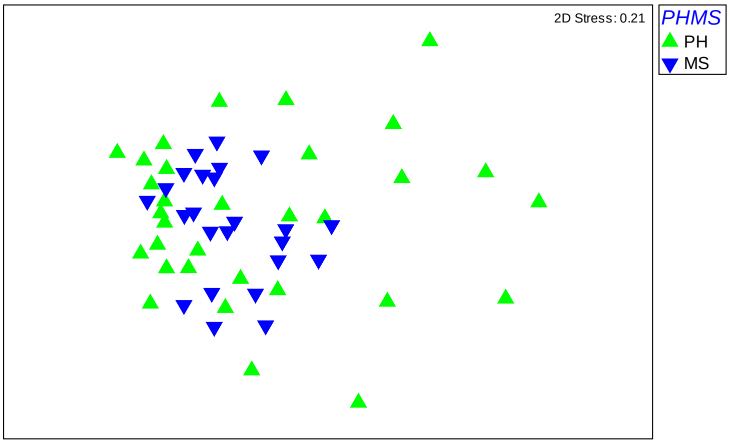


Fig. 6.40. Ordination of biodiversity sample sites at Mt Sanford and Pigeon Hole (non-riparian, grazed sites in utilisation paddocks only), using **bird composition** (frequency data from quadrats + transects) from late 2006.

6.4.7.2 Effect of utilisation level - composition

6.4.7.2.1 Plants

There was a significant difference in plant composition between treatment paddocks in 2002 (i.e. a pre-treatment difference) (Table 6.30a, Fig. 6.41). Pairwise comparisons show that all paddocks differed from each other except for 13% and 23% treatments. Similar differences were found in 2006 (although the global and most pairwise R values were lower than for 2002).

There was a strong seasonal effect on plant composition, with the overall difference in composition between 2002 and 2006 being more marked than the difference between paddocks (Fig. 6.42). Centroids in ordination space for each paddock showed similar trajectories between the 3 sample years, with some indication that the composition of the 13% treatment was converging with that of the other paddocks (Fig. 6.43).

Distance from water points (near vs far) did not have a significant effect on plant composition in either 2002 or 2006 (Table 6.30b). Very similar results were found using a reduced data set (without timed searches) and including plant data from 2003 (Table 6.30c).

Table 6.30. a) ANOSIM analyses comparing plant composition of sites in the 4 Mt Sanford paddocks, for 2002 and 2006. Frequency data including timed searches were used and tree and shrub species were excluded. Global R and pairwise comparisons are reported; significant R values (p<0.1) are bolded.

	2002		2006	
Overall R	**0.428**		**0.285**	
Overall P	0.0001		0.0002	
Groups	*R*	*P*	*R*	*P*
13%,23%	0.15	0.141	0.09	0.175
13%,39%	**0.24**	0.050	**0.33**	0.022
13%,47%	**0.58**	0.002	**0.43**	0.006
23%,39%	**0.55**	0.002	**0.30**	0.013
23%,47%	**0.51**	0.006	**0.28**	0.004
39%,47%	**0.57**	0.002	**0.20**	0.048

b) as for (a), but using a two-way ANOSIM including a distance from water category ("near" or "far"). Only the global R is reported.

	2002		2006	
	Util	**DW**	**Util**	**DW**
Overall R	**0.446**	0.083	**0.255**	-0.037
Overall P	0.0002	0.300	0.007	0.584

c) as for (b), but including 2003 data – in this case frequency data without timed searches was used.

	2002		2003		2006	
	Util	DW	Util	DW	Util	DW
Overall R	**0.449**	0.120	**0.230**	0.065	**0.215**	-0.056
Overall P	0.0001	0.197	0.018	0.326	0.022	0.684

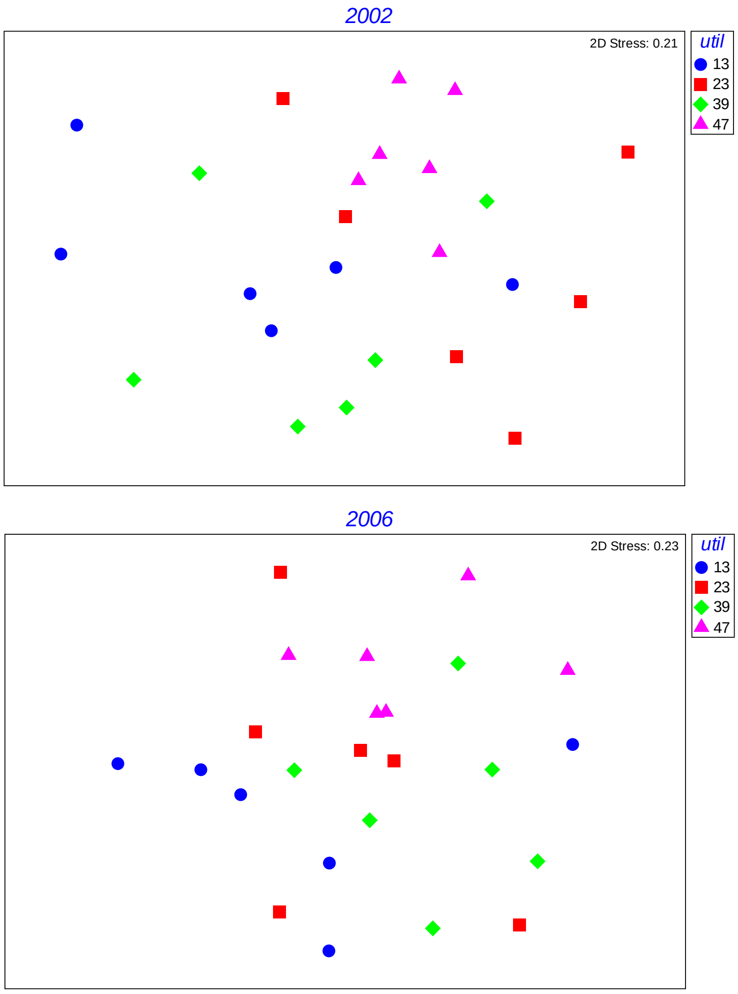


Fig. 6.41. Ordination of Mt Sanford sites by plant composition in a) 2002 and b) 2006. Symbols show utilisation rates.

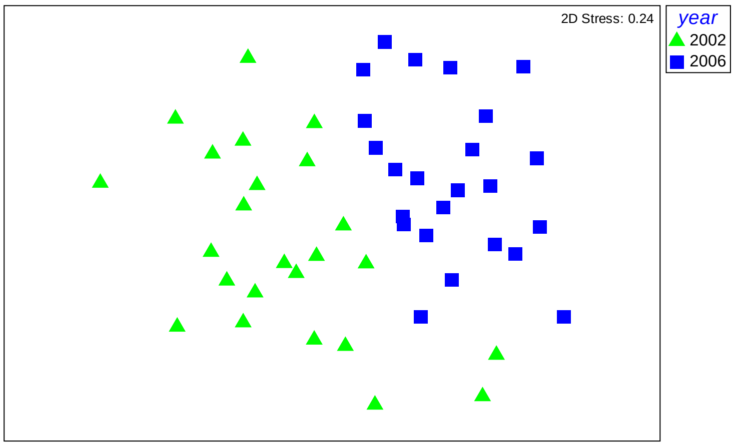


Fig. 6.42. Ordination of Mt Sanford sites by plant composition in 2002 and 2006 combined, showing separation of sites according to year of sampling.

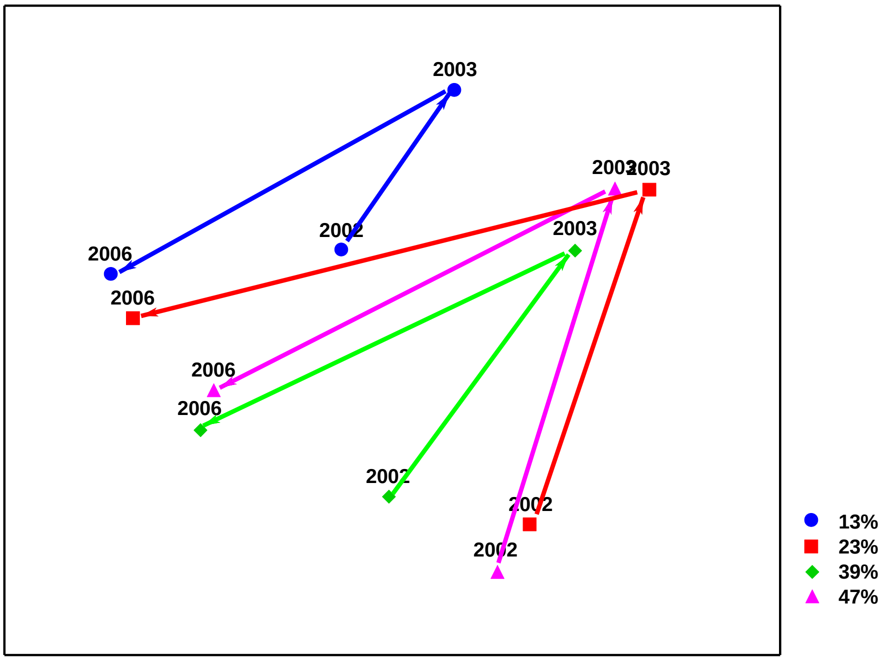
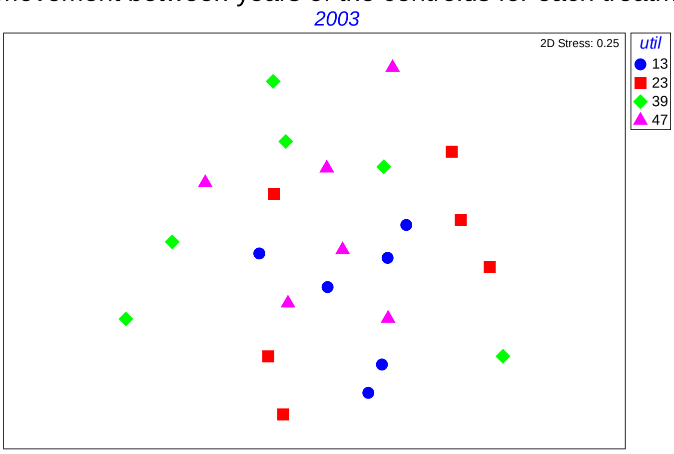


Fig. 6.43. Summary of ordination of Mt Sanford sites by plant composition in 2002, 2003 and 2006 combined, showing movement between years of the centroids for each treatment.



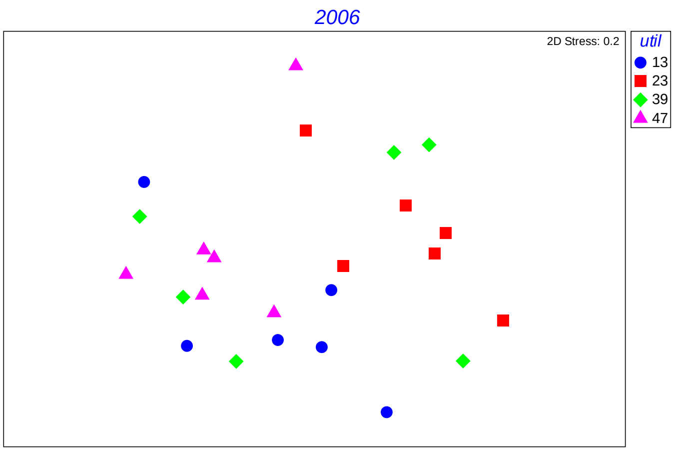


Fig. 6.44. Ordination of Mt Sanford sites by **bird composition** in a) 2003 and b) 2006 (late dry season).

6.4.7.2.2 Birds

There was a significant difference in bird composition between treatment paddocks in the late dry season of 2003, and most pairwise comparisons were significant (Table 6.31a). A similar global difference was found in 2006, although the 39% treatment had become more similar to the other treatments, and the 47% less similar. In neither case is there a clear ordering of sites according to utilisation level (Fig. 6.44).

A similar level of difference between paddocks was found using data from the early dry season in 2003 (Table 6.31b). There was a significant effect on composition of distance from water (near vs far) in 2003 (early and late dry season) but not in late 2006 (Table 6.29b).

Using a reduced data set (bird abundance within quadrats), there was a significant treatment and distance form water effect in late 2002 (i.e. a pre-treatment difference), but not in late 2003 or late 2006 (Table 6.31c).

As for plants, there was a substantial overall difference in bird composition between years (Fig. 6.45).

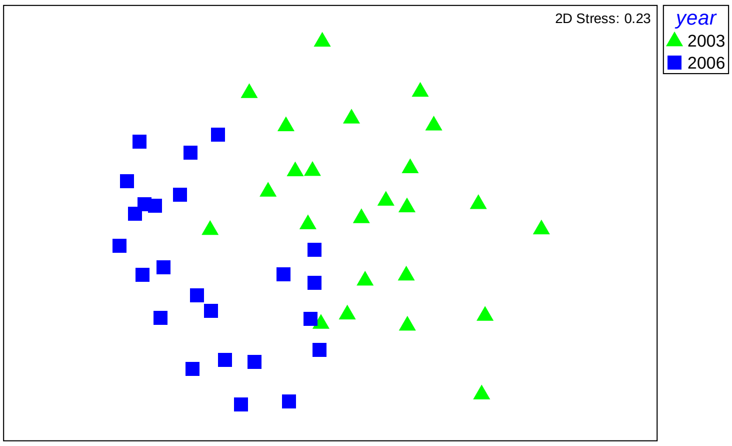


Fig. 6.45. Ordination of Mt Sanford sites by bird composition in 2003 and 2006 (late dry season) combined.

Table 6.31. a) ANOSIM analyses comparing bird composition of sites in the 4 Mt Sanford paddocks, for late dry season 2003 and 2006. Frequency data from quadrats and transects were used. Global R and pairwise comparisons are reported; significant R values (p<0.1) are bolded.

	2003L		2006L	
Overall R	**0.198**		**0.245**	
Overall P	0.004		0.004	
Groups	*R*	*P*	*R*	*P*
13%,23%	**0.33**	0.011	**0.44**	**0.004**
13%,39%	**0.39**	0.002	-0.01	0.465
13%,47%	**0.25**	0.019	**0.17**	0.080
23%,39%	**0.28**	0.022	0.03	0.366
23%,47%	-0.03	0.561	**0.64**	0.002
39%,47%	0.04	0.346	**0.18**	0.078

Table 6.31. b) as for (a), but using a two-way ANOSIM including a distance from water category (“near” or “far”). Only the global R is reported. Results from early dry season 2003 are also included.

	2003E		2003L		2006L	
	Util	DW	Util	DW	Util	DW
Overall R	**0.457**	**0.296**	**0.367**	**0.250**	**0.159**	-0.157
Overall P	0.0002	0.028	0.002	0.057	0.097	0.899

c) as for (b), but using abundance data from quadrat counts, and including late dry season 20023 data.

	2002L		2003L		2006L	
	Util	DW	Util	DW	Util	DW
Overall R	**0.211**	**0.269**	0.031	-0.093	-0.019	0.046
Overall P	0.020	0.010	0.354	0.752	0.575	0.344

6.4.7.3 Effect of utilisation level - richness, diversity and other summary variables

6.4.7.3.1 Groundcover

There was a significant *year*treatment* interaction for total groundcover (3 years data) in both the early and late dry season (Table 6.32), although this appears to be mainly due to an idiosyncratic response across years in the 39% treatment (Fig. 6.46). In 2006 there was no significant difference in mean total groundcover between any of the utilisation levels.

There was also a significant *year*treatment* interaction for total understorey cover (2003 vs 2006) in both seasons; for annual grass cover in the early dry season; and for perennial grass cover in the late dry season. Again these are idiosyncratic effects: there was a pronounced increase in late dry season understorey cover between 2002 and 2003 in the 39% paddock; and a pronounce decrease in early dry season cover between 2003 and 2006 in the 13% paddock (Fig. 6.47). Mean perennial grasscover increased in all treatments between 2003 and 2006, but the increase was largest in the 23% and 47% paddocks (Fig. 6.48).

When a distance-from-water factor is included in the analysis, there are significant interaction terms involving distance and year for total ground cover in both early and late dry seasons (Table

6.31). Again, this is quite idiosyncratic, with cover being lower close to water in some years (and some treatments) but not in others (Fig. 6.49).

Table 6.32. Summary of repeated-measures ANOVA comparing utilisation treatments across years for groundcover summary variables in the early and late dry seasons. Table shows the F-ratio and p-value for each term in the GLM; significant (p<0.05) effects are bolded. The only variable recorded in 2002 was total ground cover, so this year is not included in most comparisons.

	Treatment		Year		Treatment*year	
	F	p	F	p	F	p
Early – 2002, 2003, 2006						
Total ground cover	2.65	0.077	**43.47**	**0.0000**	**2.58**	**0.033**
Early – 2003, 2006						
Understorey cover	**6.00**	**0.004**	0.80	0.381	**4.79**	**0.011**
Perennial grass cover	**3.40**	**0.038**	**25.83**	**0.0001**	1.89	0.165
Annual grass cover	**6.21**	**0.004**	1.23	0.281	**4.05**	**0.021**
Herb cover	1.05	0.393	0.59	0.450	1.74	0.192
Litter cover	2.62	0.079	1.38	0.254	1.69	0.201
Late – 2002, 2003, 2006						
Total ground cover	0.76	0.529	**17.17**	**0.0000**	**5.23**	**0.0005**
Late – 2002, 2003						
Understorey cover	0.86	0.480	0.26	0.619	**7.41**	**0.002**
Perennial grass cover	0.52	0.674	0.91	0.352	**5.24**	**0.008**

Table 6.33. As for Table 6.30, but with distance from water (DW: "near" or "far") as a factor in the analysis. All interactions were tested, but only significant ones are reported (T=treatment, Y=year, D=distance).

	Treatment		Year		DW		Significant Interactions		
	F	p	F	p	F	p		F	p
Early – 2002, 2003, 2006									
Total ground cover	**3.72**	**0.033**	**42.71**	**0.0000**	1.85	0.193	T*Y D*T	2.54 3.43	**0.040** **0.043**
Early – 2003, 2006									
Understorey cover	**9.97**	**0.001**	0.75	0.399	**10.26**	**0.006**	T*Y	4.49	**0.018**
Perennial grass cover	**3.39**	**0.044**	**22.12**	**0.0002**	0.03	0.862	-		
Late – 2002, 2003, 2006									
Total ground cover	1.77	0.193	**24.40**	**0.0000**	0.04	0.848	T*Y D*T D*T*Y	7.43 10.16 3.28	**0.0000** **0.001** **0.013**

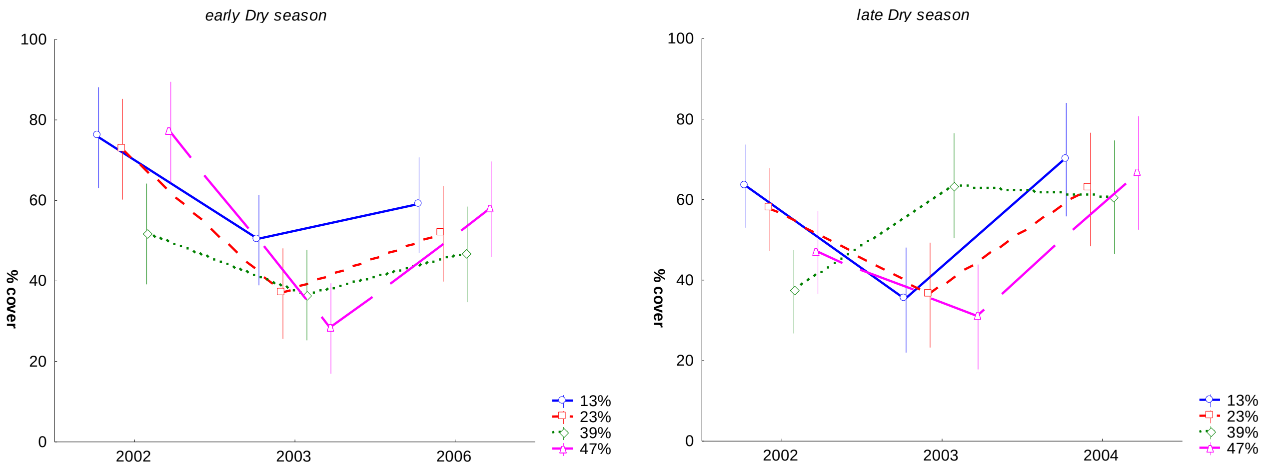


Fig. 6.46. Comparison between utilisation treatments at Mt Sanford for **total groundcover** in the a) early and b) late dry season.

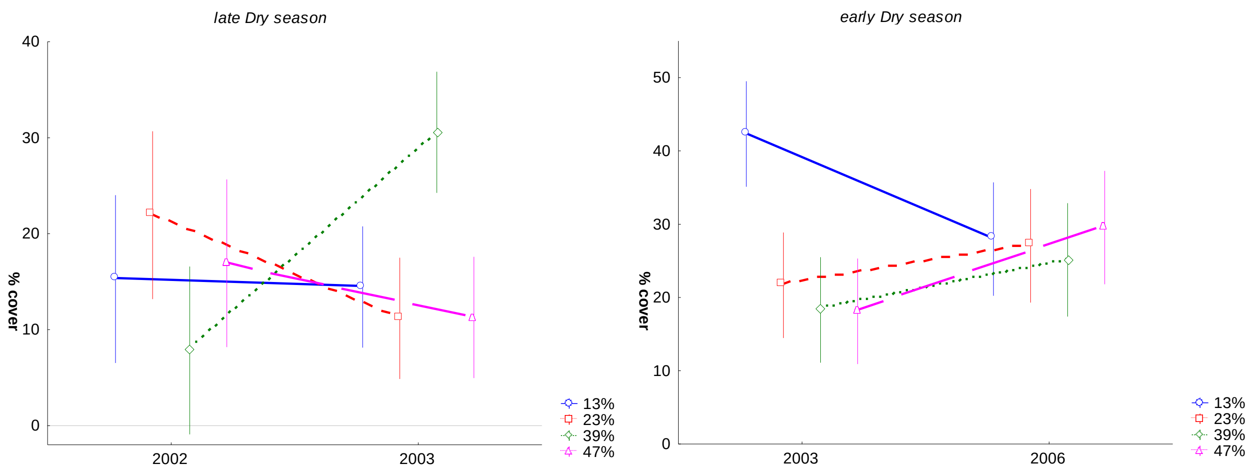


Fig. 6.47. Comparison between utilisation treatments at Mt Sanford for **total understorey cover** in the a) late dry season, 2002 & 2003; b) early dry season, 2003 & 2006.

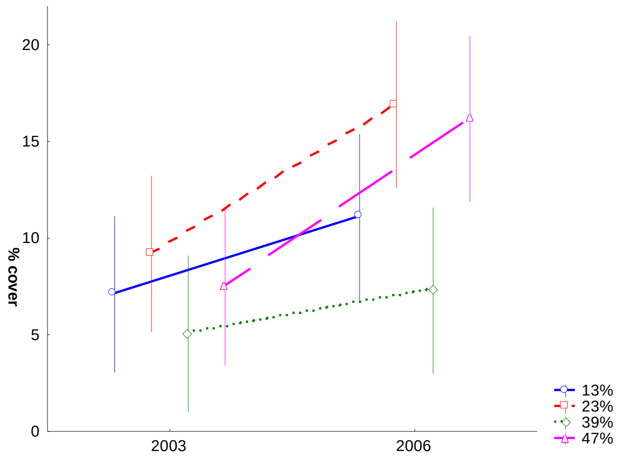


Fig. 6.48. Comparison between utilisation treatments at Mt Sanford for **perennial grass cover** in the early dry season, 2003 & 2006.

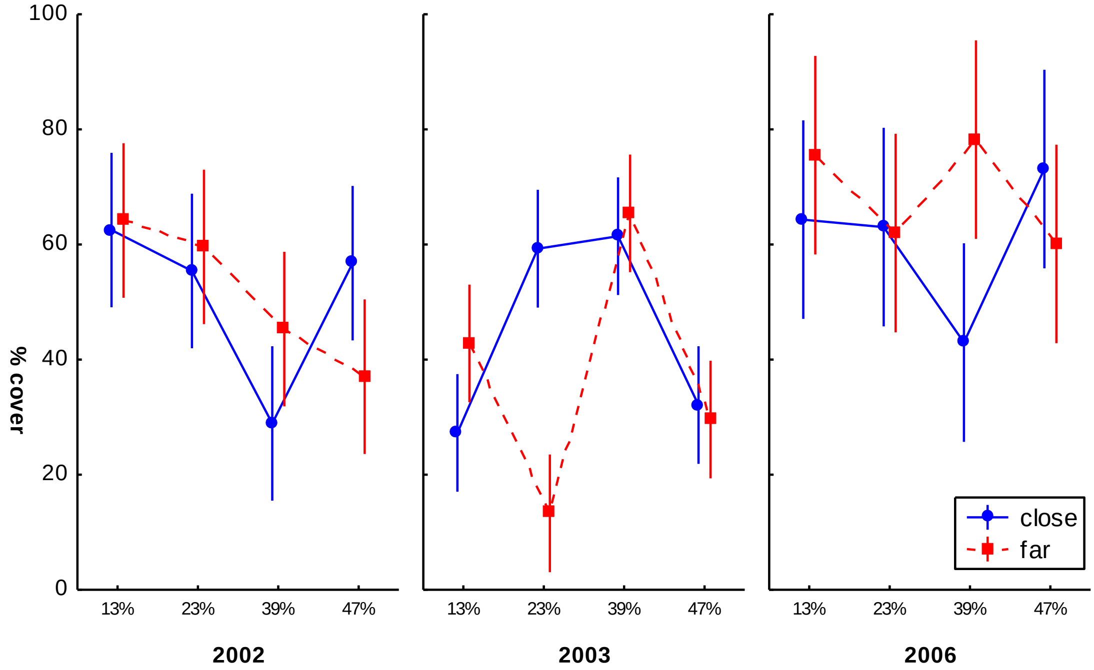


Fig. 6.49. Comparison between utilisation treatments and distance classes ('close' or 'far') at Mt Sanford for **total understorey cover** in 2002, 2003 & 2006.

6.4.7.3.2 Plant richness & diversity

There was no significant *treatment*year* interaction for plant richness or diversity, using either plot+search (3 years) or plot only (2 years) data (Table 6.34). There was a strong year effect for diversity, and for richness using plot only data (Fig. 6.50).

When a distance-from-water factor was included in the analysis, there were no significant interactions involving distance, nor was this significant as a main term (Table 6.35).

Table 6.34. Summary of repeated-measures ANOVA comparing utilisation treatments across years for plant richness and diversity. Comparison between 2002 and 2006 includes a timed search within each site; no search was included in sampling 2003 so a reduced dataset is used to compare the 3 years.

	Treatment		Year		Treatment*year	
	F	p	F	p	F	p
Plots + search (2002,2006)						
Plant richness	0.36	0.781	1.65	0.213	1.68	0.203
Plant diversity	0.89	0.465	**29.92**	**0.0000**	0.48	0.697
Plots only (2002, 2003, 2006)						
Plant richness	1.25	0.319	**25.95**	**0.0000**	0.48	0.817
Plant diversity	1.57	0.228	**42.98**	**0.0000**	0.42	0.863

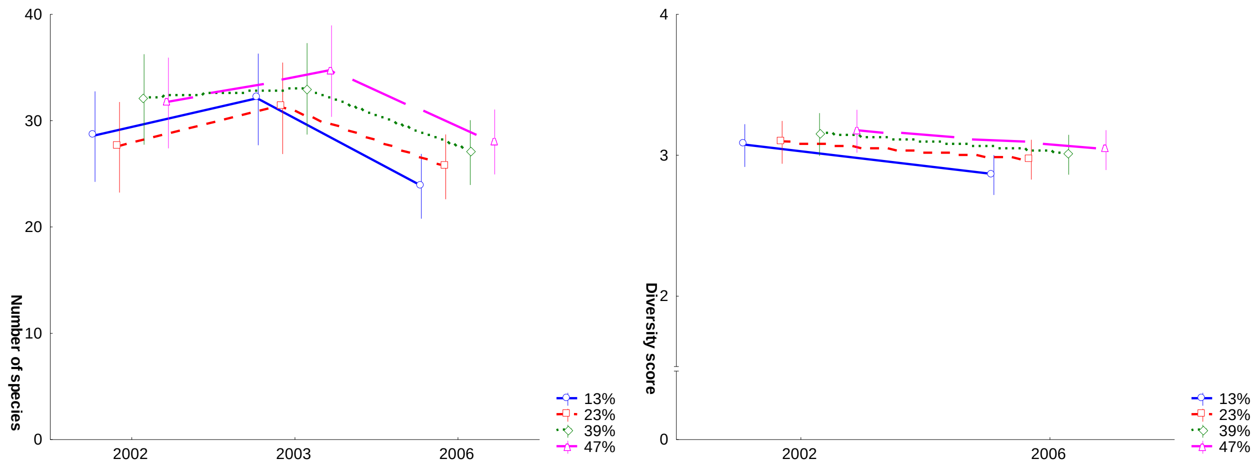


Fig. 6.50. Comparison between utilisation treatments at Mt Sanford for a) **plant richness** (plot data only: 2002, 2003 & 2006) and b) **plant diversity** (plot + search data: 2002, 2006).

Table 6.35. As for Table 6.32, but with distance from water (DW: "near" or "far") as a factor in the analysis. All interactions were tested, but only significant ones are reported (T=treatment, Y=year, D=distance)

	Treatment		Year		DW		Significant Interactions		
	F	p	F	p	F	p		F	p
Plots + search (2002,2006)									
Plant richness	0.33	0.803	1.74	0.205	0.11	0.740	none	-	-
Plant diversity	0.81	0.506	**31.61**	**0.0000**	0.06	0.818	none	-	-
Plots only (2002, 2003, 2006)									
Plant richness	1.10	0.379	**24.19**	**0.0000**	0.04	0.843	none	-	-
Plant diversity	1.37	0.288	**42.74**	**0.0000**	0.04	0.839	none	-	-

6.4.7.3.3 Bird richness & diversity

There were significant *treatment*year* interactions for bird richness, total frequency and diversity using full 2003 and 2006 data (Table 6.36). There were no significant interaction terms using the abundance data from 3 years, although it should be noted that the data for most bird species is much sparser without the transect counts. Between 2003 and 2006, mean bird richness declined in all treatments except 23%, while total bird frequency increased in this paddock but not the others (Fig. 6.51).

As for plants, there were no significant interaction or main effect terms involving distance from water, when this was included as a factor in the analysis (Table 6.37).

Table 6.36. Summary of repeated-measures ANOVA comparing utilisation treatments across years for bird richness, abundance and diversity. Comparison between 2003 and 2006 use frequency data based on quadrat and transect counts; no transects were included in sampling in 2002 so abundance data from quadrat counts is used to compare the 3 years.

	Treatment		Year		Treatment*year	
	F	p	F	p	F	p
quadrats + transects (2003, 2006)						
Bird richness	0.682	0.573	**7.36**	**0.013**	**4.23**	**0.018**
Bird total freq	1.86	0.168	3.37	0.081	**4.01**	**0.022**
Bird diversity	0.85	0.483	**17.59**	**0.0004**	**7.01**	**0.002**
quadrats only (2002, 2003, 2006)						
Bird richness	**3.54**	**0.033**	0.78	0.466	0.49	0.812
Bird abundance	**3.61**	**0.031**	**7.07**	**0.002**	1.16	0.349
Bird diversity	2.18	0.122	0.13	0.881	1.30	0.278

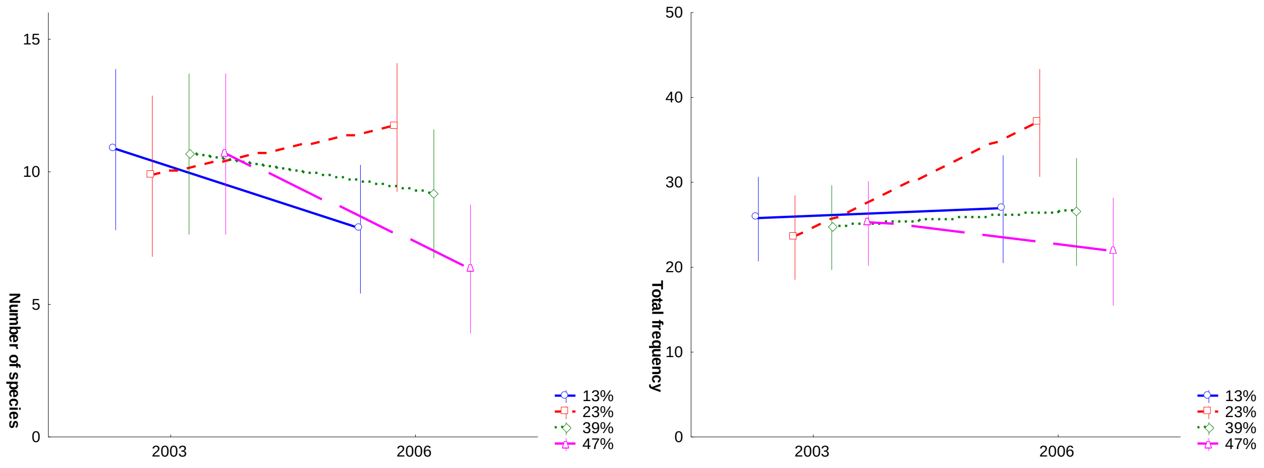


Fig. 6.51. Comparison between utilisation treatments at Mt Sanford for **bird** a) **richness** and b) **total frequency**, for 2003 and 2006

Table 6.37. As for Table 6.34, but with distance from water (DW: "near" or "far") as a factor in the analysis. All interactions were tested, but only significant ones are reported (T=treatment, Y=year, D=distance)

	Treatment		Year		DW		Significant Interactions		
	F	p	F	p	F	p		F	p
quadrats + transects (2003, 2006)									
Bird richness	0.79	0.520	**6.81**	**0.019**	3.20	0.093	T*Y	**3.92**	**0.028**
Bird frequency	2.00	0.154	3.95	0.064	0.13	0.727	T*Y	**4.70**	**0.015**
Bird diversity	0.98	0.427	**18.16**	**0.0006**	3.51	0.079	T*Y	**7.24**	**0.003**
quadrats only (2002, 2003, 2006)									
Bird richness	**3.94**	**0.028**	0.73	0.489	0.05	0.834	none	-	-
Bird abundance	**4.42**	**0.019**	**7.82**	**0.002**	0.24	0.634	none	-	-
Bird diversity	2.41	0.105	0.11	0.900	0.01	0.918	none	-	-

6.4.7.4 Effect of utilisation level - individual species

6.4.7.4.1 Plants

Of the 43 plant taxa tested, 28 had a significant *year* effect (Table 6.38). Many species had a higher abundance in 2003, and some species were virtually absent (across all treatments) in some years (e.g. Fig. 6.52c). Six species had a significant *treatment* effect, and showed consistent differences between treatments across all years. For example, *Flemingia pauciflora* had a relatively high abundance in 39% and 47% paddocks and low abundance in the 13% and 23% paddocks (Fig. 6.52b), but this represents a pre-treatment difference that was maintained throughout the trial. Only 2 species had a significant year*treatment interaction: for *Abelmoschus ficulneus* this reflects a relatively large peak in the 23% treatment in 2003 (Fig. 6.52a); and for *Galactia tenuiflora* a relatively large decline in the 47% treatment between 2002 and 2003.

Table 6.38. Summary of repeated-measures ANOVA comparing utilisation treatments across years for individual **plant** species. Comparisons were made using frequency data from plots only, for all 3 sample years (2002, 2003, 2006).

		Treatment (df=3)		Year (df=2)		Treatment*year (df=6)	
	sites	F	p	F	p	F	p
Abelmoschus ficulneus	*51*	2.08	0.135	**26.22**	**0.0000**	**3.31**	**0.010**
Abutilon hannii	*66*	1.67	0.206	1.22	0.305	1.19	0.329
Alysicarpus muelleri	*46*	1.57	0.228	**11.71**	**0.0001**	0.91	0.501
Aristida latifolia	*69*	1.50	0.246	**6.13**	**0.005**	0.91	0.494
Astrebla spp	*67*	0.82	0.499	0.17	0.848	1.32	0.273
Blumea tenella	*45*	0.93	0.446	**6.75**	**0.003**	0.35	0.904
Brachyachne convergens	*44*	1.40	0.272	**10.52**	**0.0002**	1.02	0.426
Chionachne hubbardiana	*48*	0.52	0.671	**32.18**	**0.0000**	2.04	0.083
Chrysopogon fallax	*53*	1.87	0.168	**3.30**	**0.047**	1.08	0.392
Commelina ensifolia	*32*	0.47	0.703	**14.35**	**0.0000**	0.42	0.862
Crotalaria medicaginea	*20*	4.43	0.015	**4.94**	**0.012**	1.88	0.109
Cucumis melo	*22*	2.97	0.057	**5.19**	**0.010**	1.74	0.137
Cyperus bifax	*24*	0.24	0.867	1.13	0.335	1.96	0.094
Dichanthium fecundum	*26*	1.51	0.244	0.78	0.465	0.93	0.485
Dichanthium sericeum	*70*	**3.16**	**0.047**	**6.19**	**0.005**	1.22	0.316
Euphorbia maconochieana	*42*	4.71	0.012	2.07	0.140	1.45	0.221
Euphorbia schizolepis	*52*	4.06	0.021	1.30	0.284	0.84	0.546
Flemingia pauciflora	*51*	**6.22**	**0.004**	0.13	0.883	1.99	0.090
Galactia tenuiflora	*21*	0.76	0.527	**4.57**	**0.016**	**3.60**	**0.006**
Glycine falcata	*23*	**3.32**	**0.041**	1.60	0.215	1.94	0.098
Goodenia byrnesii	*38*	0.66	0.588	**25.48**	**0.0000**	1.05	0.406
Indigofera trita	*23*	0.74	0.543	**4.18**	**0.022**	1.80	0.123
Ipomoea nil	*22*	**8.41**	**0.001**	1.16	0.324	1.63	0.165
Iseilema ciliatum	*24*	1.41	0.269	**15.91**	**0.0000**	1.87	0.111
Iseilema fragile	*71*	2.49	0.090	**3.52**	**0.039**	2.10	0.075
Iseilema vag/mac	*63*	**5.19**	**0.008**	**8.49**	**0.001**	1.16	0.349

		Treatment (df=3)		Year (df=2)		Treatment*year (df=6)	
	sites	F	p	F	p	F	p
Iseilema windersii	*41*	0.58	0.636	**12.07**	**0.0001**	1.29	0.286
Jacquemontia browniana	*69*	**3.14**	**0.048**	**12.06**	**0.0001**	1.22	0.318
Neptunia gracilis	*52*	0.63	0.606	**6.63**	**0.003**	1.46	0.217
Oldenlandia argillacea	*26*	1.60	0.222	**4.06**	**0.025**	1.63	0.165
Panicum decompositum	*36*	1.25	0.318	1.19	0.314	1.96	0.095
Pentalepis ecliptoides	*42*	2.03	0.142	**13.84**	**0.0000**	0.73	0.632
Phyllanthus maderaspatensis	*68*	1.12	0.364	**15.01**	**0.0000**	0.64	0.697
Polygala rhinanthoides	*28*	0.54	0.659	**10.74**	**0.0002**	0.74	0.622
Polymeria ambigua	*53*	3.39	0.038	**5.68**	**0.007**	1.45	0.219
Rhynchosia minima	*67*	3.93	0.024	2.82	0.071	1.55	0.188
Sesbania simpliciuscula	*55*	1.27	0.312	0.45	0.641	1.13	0.363
Sida spinosa	*46*	1.18	0.342	0.47	0.629	0.55	0.767
Spermacoce pogostoma	*25*	3.07	0.051	**42.76**	**0.0000**	1.86	0.111
Stemodia glabella	*24*	2.69	0.074	4.45	**0.018**	1.38	0.245
Trichodesma zeylanicum	*61*	1.86	0.170	**71.25**	**0.0000**	1.67	0.153
Wedelia asperrima	*35*	0.62	0.613	**8.54**	**0.001**	0.69	0.657

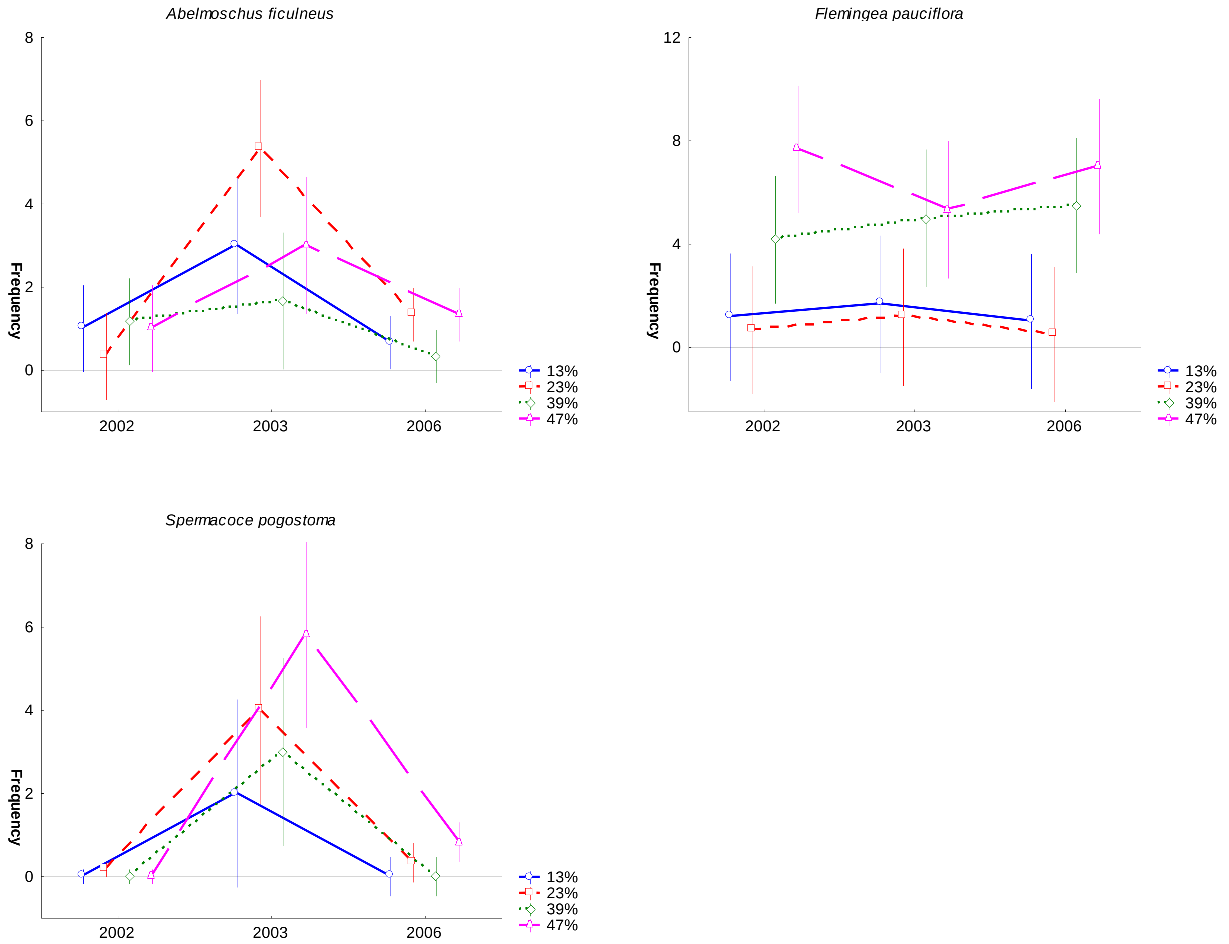


Fig. 6.52. Examples of the variation in the frequency of **individual plant species** between utilisation treatments and over years: a) *Abelmoschus ficulneus*; b) *Flemingia pauciflora; c) Spermacoce pogostoma.*

6.4.7.4.2 Birds

For the bird abundance data, no species has a significant *treatment*year* interaction (Table 6.39). For the frequency data, three species had a significant interaction term. Between 2003 and 2006, black-faced woodswallow appeared to show a slight decline in the two highest utilisation paddocks, but a slight increase in the lower utilisation paddocks (Fig. 6.53a). Crested pigeon, however, increased in the 23% and 47% paddocks while decreasing in the other treatments, while singing honeyeater increased markedly in the 23% paddock but not the other paddocks. A number of species showed a significant *year* effect: red-backed fairy-wren increased in all paddocks between 2003 and 2006, and may also be beginning to show some sorting of abundance according to utilisation level, although this was not a significant effect (Fig. 6.53b). Singing bushlark were more abundant in the lower utilisation paddocks in 2003, although this effect did not persist in 2006 (Fig. 6.53c).

Table 6.39. Summary of repeated-measures ANOVA comparing utilisation treatments across years for individual **bird** species. Comparisons were made using abundance data in quadrats (2002, 2003, 2006), and frequency data from quadrat and transect counts (2003, 2006).

Birds

		Treatment		Year		Treatment*year	
	sites	F	p	F	p	F	p
Abundance in quadrats (2002, 2003, 2006)	*72*	(3)		(2)		(6)	
Black-faced Woodswallow	*57*	1.86	0.170	1.42	0.253	1.79	0.126
Button-quail spp	*12*	2.33	0.105	0.07	0.934	1.49	0.206
Golden-headed Cisticola	*12*	0.48	0.700	1.09	0.309	0.61	0.613
Red-backed Fairy-wren	*42*	2.26	0.113	2.06	0.141	0.93	0.487
Singing Bushlark	*72*	2.79	0.067	**13.92**	**0.0000**	2.17	0.067
Singing Honeyeater	*14*	**3.21**	**0.045**	0.33	0.719	0.38	0.887
Frequency in quadrats + transects (2003, 2006)	*48*	(3)		(1)		(3)	
Black-faced Cuckoo-shrike	*12*	0.69	0.571	2.88	0.105	0.37	0.774
Black-faced Woodswallow	*48*	0.52	0.671	3.89	0.062	**4.15**	**0.019**
Brown Quail	*12*	0.98	0.421	**5.26**	**0.033**	1.45	0.258
Budgerigar	*14*	1.15	0.355	**17.78**	**0.0004**	1.85	0.170
Crested Pigeon	*24*	0.57	0.643	3.33	0.083	**5.56**	**0.006**
Galah	*17*	0.17	0.912	1.92	0.181	0.69	0.567
Magpie-lark	*16*	**4.48**	**0.015**	2.21	0.153	0.89	0.465
Pied Butcherbird	*24*	2.29	0.110	2.18	0.155	2.28	0.110
Red-backed Fairy-wren	*38*	0.89	0.461	**40.30**	**0.0000**	0.76	0.532
Singing Bushlark	*48*	**5.01**	**0.009**	**36.64**	**0.0000**	1.84	0.173
Singing Honeyeater	*30*	**4.97**	**0.010**	**5.03**	**0.036**	**11.86**	**0.0001**
Willie Wagtail	*15*	0.43	0.737	1.14	0.298	0.21	0.889
Yellow-throated Miner	*29*	0.57	0.643	**34.75**	**0.0000**	1.04	0.396
Zebra Finch	*18*	0.41	0.744	**6.66**	**0.018**	1.77	0.186

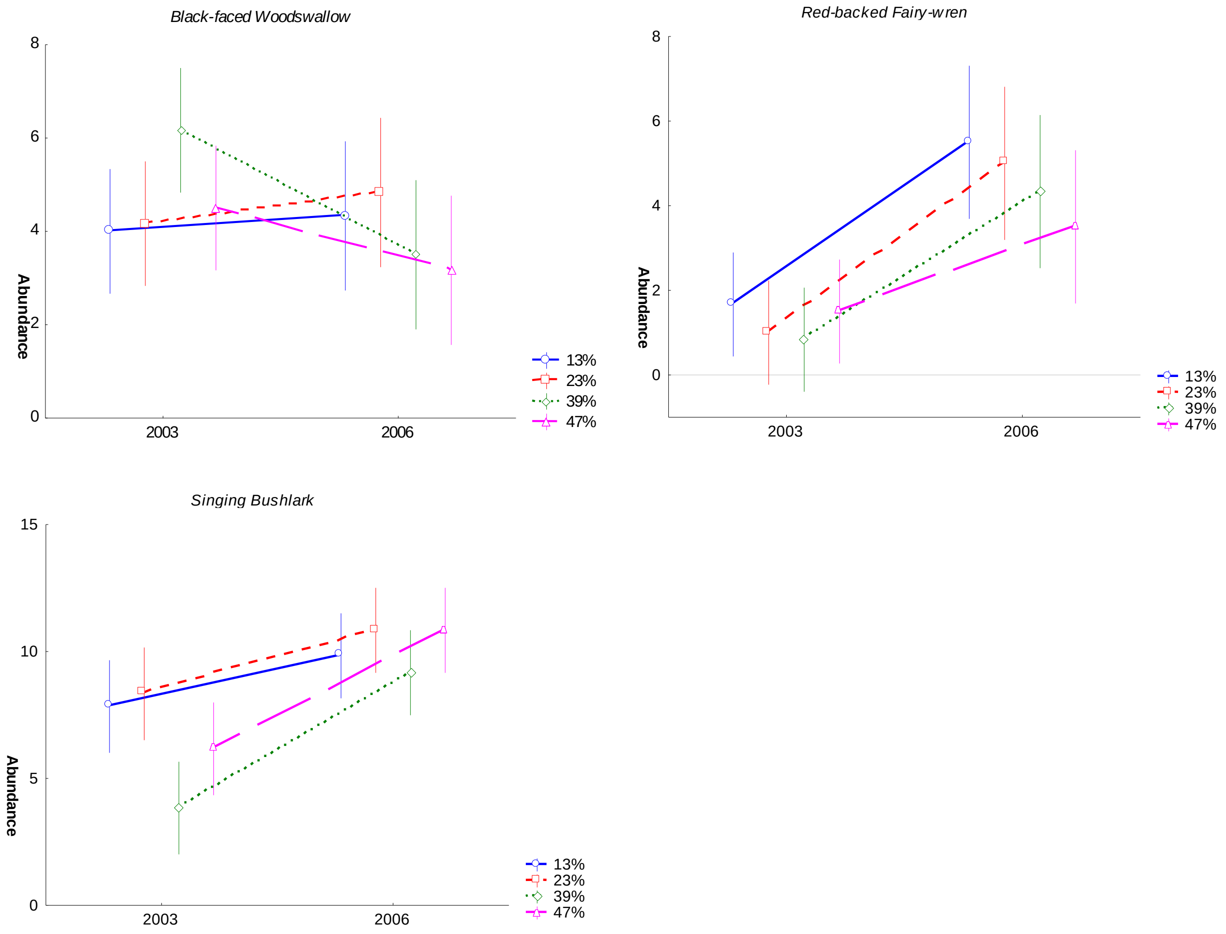


Fig. 6.53. Examples of the variation in the frequency of **individual bird species** between utilisation treatments and over years: a) black-faced woodswallow; b) red-backed fairy-wren*;* c) singing bushlark.

6.5 Discussion

Within the 5 years of the study there was no obvious effect of different utilisation levels, or different grazing systems on the biodiversity within the paddocks. A small proportion of species showed significant changes in abundance over time, but this was generally in idiosyncratic, rather than consistent, patterns amongst treatment paddocks (and may reflect patchiness in grazing intensity even within small paddocks). A similar result was found at Mt Sanford, where there was no significant effect of the different utilisation levels on plant and bird richness or composition across 3 years of sampling.

These results are consistent with other evidence that blacksoil grasslands are one of the ecosystems in northern Australia most resilient to the impacts of grazing on biodiversity. It also meshes with other results from Pigeon Hole that found no consistent changes in land condition or pasture composition in the various utilisation or grazing systems paddocks. However, it is very important to note that changes in native plant and animal populations in response to changes in grazing regimes are likely to be gradual, only becoming evident over longer time periods than these grazing trials, and particularly following a period of poor seasons. The study clearly demonstrated the large amount of natural variation between years for many native species (partly related to rainfall patterns), which also makes it harder to detect changes due to grazing treatments. Additionally, there was a high proportion of “rare” plant and animal species - which are seen only in some years and/or are sparsely scattered throughout the paddocks - and the impacts of grazing on these species is very difficult to determine.

A number of cattle exclosures of varying size (up to 400 ha) were established within the grazed paddocks at Pigeon Hole. After five years there was some evidence that plant and animal composition in these exclosures was diverging from that in grazed lands. In particular, the abundance of some grazing-sensitive species was starting to increase within the exclosures by the end of the study, including some species restricted to this ecosystem. There is clearly value in maintaining such exclosures in order to track changes in species composition in ungrazed “reference” areas over a longer period. It was not possible in the period of the study to determine a suitable size for ungrazed “conservation areas”, although theory suggests these need to be relatively large (square kilometres rather than hectares) to maintain viable populations of larger organisms such as birds.

Intensification of pastoral use may have minimal implications for biodiversity conservation within this land type if it occurs at a small or localised scale, but impacts on biodiversity are likely to become more pronounced if a high proportion of the land-type is subject to intensification, particularly over longer (decades) time scales. Recommendations to protect biodiversity values in the context of broad-scale intensification include:

- Conservative utilisation rates, that maintain a good ground cover and a diversity of desirable perennial grasses;
- As a general guideline, at least 10% of each land type within a region should be maintained with minimal grazing pressure. As the proportion of intensified land increases, the proportion of lightly grazed land should also increase as an offset;
- Lightly grazed “conservation areas” should ideally be scattered across the landscape, both at property and regional scales (to maximise landscape connectivity and capture the geographic turnover of species). This may take some planning at a regional scale to develop the best network;
- The ideal size of individual “conservation areas” is uncertain, but should be as large as possible. However, a number of medium size “conservation areas’ scattered across a property are likely to be more effective than a single large one;
- Biodiversity “hotspots” – such as waterholes, riparian zones and the habitat of threatened species – should be protected from overgrazing. Some significant sites may have specific management needs (such as a certain fire regime);

- Establishment of a robust, regional-scale biodiversity monitoring program, with sufficient sampling intensity to detect any long-term decline in identified decreaser species (from a range of broad taxonomic groups).

We caution that the biodiversity results from the Pigeon Hole and Mt Sanford studies cannot be simply generalised to other land types in northern Australia – particularly those where the pasture, soils and biodiversity are more sensitive to impacts from grazing.

7 Innovative technologies - infrastructure and mustering

7.1 Key messages

- A range of technologies and innovations were developed and/or tested to assess their value in improving the efficiency and reducing the operating costs of an intensively developed pastoral business.
- The innovations tested were telemetry for remotely managing water points, water medicators for providing dietary supplements, electric fencing, the use of laneways and additional stockyards, and the use of more efficient mustering techniques.
- The use of telemetry for remotely managing water points appears to be a practical and cost-effective innovation with savings of ~$20,000+ per year being achieved in initial installations.
- Water medication can be successfully implemented at a commercial scale and can reduce the supplementation cost to approximately 25% of nutrient blocks. However, it is a high risk strategy and requires a high level of management and technical skill to maintain.
- Electric fencing has a role in smaller paddocks in northern Australia where cattle can be trained to respect the fence and the fencing can be properly maintained. It has limited application in the large paddocks typical of the majority of northern Australia.
- While some newer technologies can offer substantial improvements in efficiency and cost-savings in an intensified production system, they can require specific skills and some adaptation to incorporate successfully into the management system.

7.2 Introduction

This project suggests more intensive development of the black soil pastures in this region appears to be practically achievable, environmentally sustainable and economically feasible where annual pasture utilisation rates are currently less than 20%. More intensive development will require the establishment of additional fencing, waters and roads within the existing paddocks to promote more even grazing of the native pastures.

An implication of the establishment of the additional infrastructure is the higher cost to monitor the waters and maintain the infrastructure in the smaller paddocks. These higher operating costs need to balance with improvements in productivity per unit area or a reduction in operating costs per head. The results of the economic analyses suggested that, although operating costs did increase, the increased stocking rate improved the profitability of the business. Can the profitability be further increased through more efficiently utilising the additional infrastructure or through the adoption of innovative technology that reduces the operating costs?

To manage any potential increase in cost per head, it was decided to investigate strategies and infrastructure that are likely to reduce the operating costs of an intensively developed pastoral business. These strategies included:

1. The use of telemetry to reduce the cost of maintaining the waters;
2. Laneways and additional yards to reduce the mustering costs;
3. More efficient mustering options;
4. Water medication to reduce the cost of supplementation.

There were many other technologies considered, but these were selected as the most likely to reduce operating costs in this region.

7.3 Telemetry

The Pigeon Hole Telemetry Trial was conducted over a five year period with a mandate to explore the use of telemetry and solar power to reduce the costs of water infrastructure monitoring and management.

As a result of intensification, northern cattle stations were experiencing a significant increase in the number of water points and infrastructure required, and this was driving up operating costs. On a typical station, a boreman has to check each water stock point, dam and bore pump 2 to 3 times a week to ensure livestock have sufficient water. This requires the boreman to drive 48 to 60 hours a week. Failure to reach a dry, damaged or polluted trough in time, or fix a malfunctioning medicator, can also result in significant stock loss.

By allowing station staff to monitor and control the water infrastructure over the radio, it was expected the solution would deliver significant savings in workload, time and vehicle costs.

After an exhaustive search, it was determined that no suitable commercially available telemetry system would meet the specific needs of the northern pastoral industry. In contrast to other industries already using telemetry, the pastoral sector could not afford a solution that was overly technical or that placed additional burden on already stretched station staff. Furthermore, the price point for traditional solutions primarily used in the resources sector was prohibitively high.

The project elected to contract with a private company called Balmon W.A. who had developed a prototype that showed promise but was not market ready. This prototype formed the basis for the ultimate solution that was delivered. During the five year period of the trial, Balmon WA was transformed into Observant Pty Ltd, a company dedicated to providing remote management solutions to the pastoral industry. The advantage of this strategy was that a commercial entity could ensure the development of the product past the project conclusion.

During the trial period, the technology base used to form the system went from prototype to full commercial availability. What started as a solution to monitor water points evolved into a comprehensive system for remote infrastructure management.

7.4 Project scope and objectives

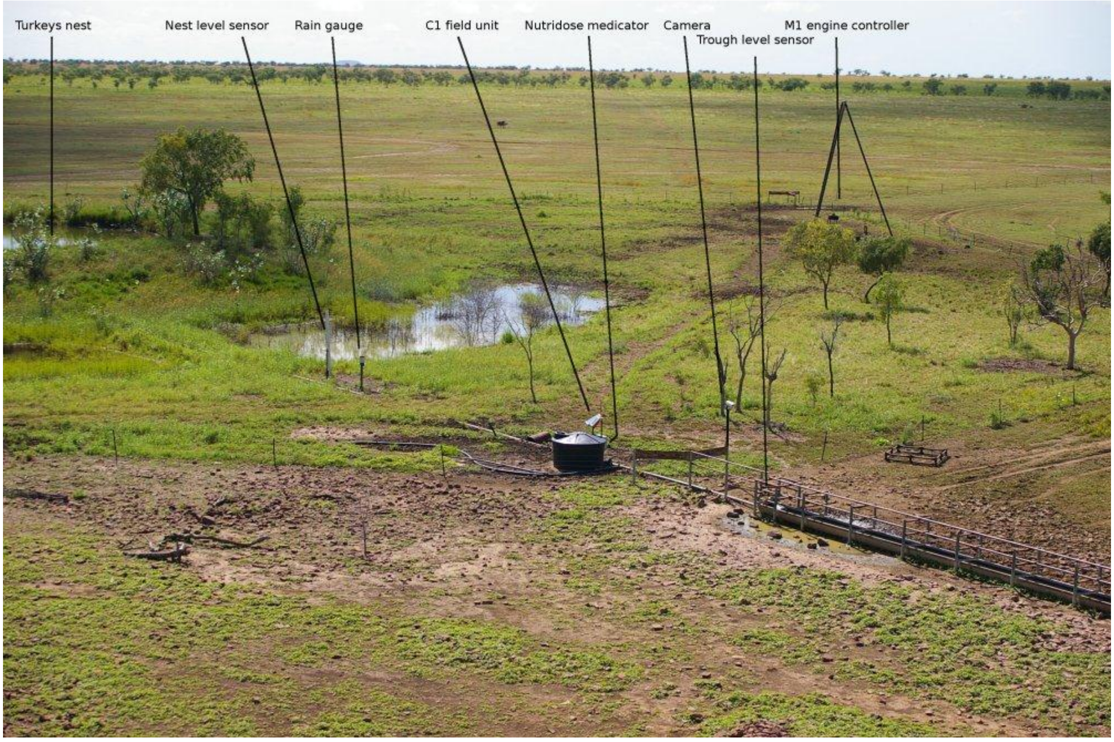
The major objective of the project was to assess if telemetry could be used to lower the cost of monitoring livestock water points in the face of more intensive production. Over the course of the trial, the objectives changed as the technology was used to provide more intelligent solutions beyond what had been scoped.

Developed in consultation with multiple stakeholders, the original scope for the telemetry system included:

- monitor the level of water in the bore and troughs;
- provide additional features such as pump automation, Nutridose monitoring and rainfall monitoring;
- capture images of cattle watering;
- capture, record and report data to improve decision-making for station management;
- reduce costs, improve reliability and be easy for station staff to install and operate with little (if any) technical expertise;
- deliver a system that was robust and reliable enough to survive years in the harsh northern environment.

7.5 Phase I Telemetry Trial

7.5.1 System Overview



Phase I Trial: Equipment layout at Pigeon Hole site No 12.

Observant produced a water resource management solution for Pigeon Hole called the C1 that comprised self-contained, solar powered, radio-equipped telemetry units and a monitoring and management system. It provided the first integrated approach to managing all aspects of bore control and monitoring.

The key features of the initial C1 system included:

- self-contained, solar-powered system
- wide-area, radio-controlled telemetry (in excess of 25 km)
- back-to-homestead reporting of key information
- remote control of bores
- sophisticated data logging
- alarms on key conditions
- easy-to-use software.

Phase I Trial: C1 Telemetry Unit

Phase I Trial: Trough Level Sensor

Phase I Trial: Prototype Pump Controller

Phase I Trial: Prototype Pump Controller

7.5.2 Technical challenges and issues

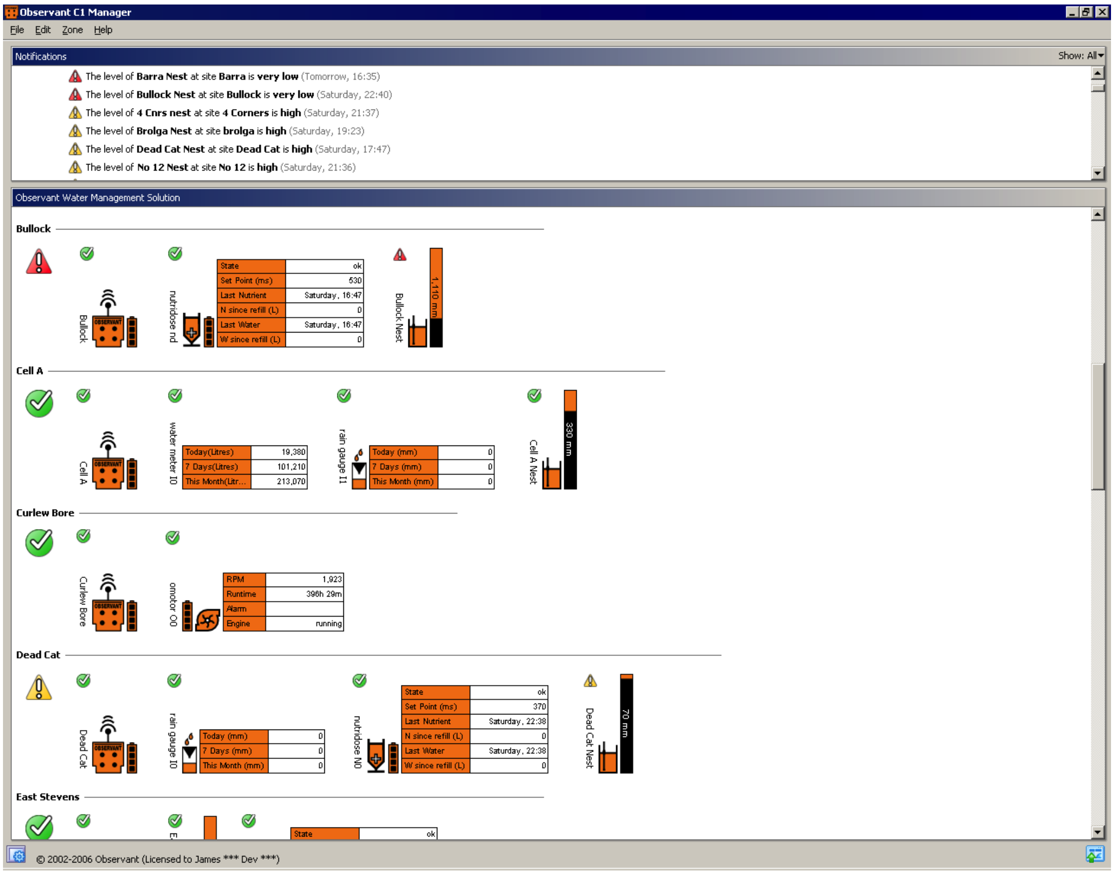
Many challenges were encountered and eventually overcome as the system was put to active use during the project.

Challenge / Issue	Solution
Harsh environmental factors such as large temperature variations and dramatic rainfall events were not conducive for the operation of specialised electronic equipment.	Use of smart industrial design that is robust and protects the equipment from the harsh conditions.
Station staff not equipped to diagnose faults within the telemetry solution and the remote location makes physical visits time consuming and expensive.	Software designed to self-diagnose and allow Observant staff to connect via internet connection to diagnose any faults.
The first version of the water level sensor was not adequately protected against water ingress.	Level sensor manufacturing process was redesigned to include complete potting of electronics to protect against water/moisture.
Trough based level sensors proved to be impractical in most cases due to complexities of cabling and protecting equipment from livestock.	Data provided by water flow meters attached to storage outflows was used in place of trough level sensor data and proved to be an adequate measure of water safety for livestock.
Capacity to capture still images of cattle and transfer via UHF	Images were first captured to flash memory of telemetry device where they could then be relayed to PC software as power and transmission limitations permitted.
Operating a system that provided up-to-date information that could still operate on very low power	Software-introduced concepts to inform the user about how up to date information was. Balance was sought between recent enough information, and the power demands of a truly real-time system.
Resolution of issues was slow and time consuming because of the remoteness and distances to the equipment	To the greatest extent possible, information was gathered at a very fine level of detail about the overall performance of the telemetry system itself. This allowed technical staff to diagnose and often remedy problems before they became serious issues.

7.5.3 Technical Achievements

Several significant technical achievements have directly resulted from the work at Pigeon Hole including:

- **Capturing still images**: this was previously thought unfeasible due to the limited speed of UHF for data communications and the power requirements to operate a UHF radio over large distances. Still images were captured and transmitted via UHF radio on an on-demand basis and could be displayed on the PC based software.
- **Automation of diesel pumps**: remotely starting and stopping pumps was previously possible but not particularly easy to set up or operate. Significant work was undertaken as part of the project to simplify the task of remotely managing diesel engines and to allow them to be automatically started when a tank or nest was empty.
- **Operating electronic equipment in remote low power settings**: the nature of the project was such that low power operation was a mandatory requirement to ensure equipment costs were as low as possible. Project participants and related entities have been able to incorporate improvements in to their research and commercial offerings to improve their operation under these circumstances.



Phase I Trial: Observant end user software showing equipment status information.

7.5.4 Product Specifications

Key Area	Specifications
Enclosure	• IP66 aluminium extrusion (115mm x 105mm x 265mm) • Shaded from elements by solar panel • Fully self-contained (computer, radio, battery, charger) • Antenna, mounting frame and solar panel supplied
Field Unit Computer	• Very low power micro controller • Firmware remotely upgradeable over radio • Extensible device-driver architecture • Real-time clock with network time synchronization
Communications	• Observant radio modem (4800 baud GMSK over 5W UHF radio 450 - 490 MHz) • Conservatively 25km line-of-sight range • Support for additional internal communication boards • Advanced messaging protocol with forward error correction • Units can repeat messages to extend range or route around terrain
Power	• Internal, user-replaceable lead acid battery • Optimising solar charger and advanced power saving algorithms • Supplied with either 11W solar panel or mains plug-pack • Supports charging from any power source from 10 - 30 V
Devices Supported	• Observant L1 level sensor • Observant M1 motor controller • Axis digital camera • Nutridose water medicator • Tipping bucket rain gauge • Generic digital input and output
Data Logging	• Internal flash memory for data logging • Any parameter on any device can be logged at any interval or upon change • Logs are automatically synchronised back to a desktop PC database

7.6 Phase II Telemetry Trial

During the course of the Pigeon Hole trial, both as part of this trial and as part of many other trials and commercial installations, Observant continually refined the products that made up its remote management system. Through interacting with station staff, retrieving non-operational equipment & analysing its faults and other careful processes, Observant was able to significantly improve the overall performance of its solutions.

7.6.1 System Overview

Today, the remote management system based on learnings from Pigeon Hole and beyond is capable of a significant contribution to the management of a pastoral property. The cost savings originally outlined at the beginning of the project have been validated extensively.

Observants modified remote management system consists of the C2 – a self contained unit that allows a large range of equipment to be remotely managed by the Observant System. It integrates with the following specifically designed add-ons - L1 Water Level Sensor and M1 Engine Controller.

The key features of the modified C2 system include:

- checks water levels in storage facilities (nests, tanks, troughs, dams)
- accurately measures water usage at very high resolution (by minute, hour, day etc)
- automatically operates and protects pumping equipment used to manage water supplies
- provides regular still photography of points of interest at sufficient resolution to make out important detail
- monitors electric fences
- accurately measures rainfall at very high resolution (by minute, hour, day etc)
- interfaces with power monitoring equipment to help manage remote power generation facilities
- manages livestock performance systems such as NLIS tag readers and animal walk-over-weigh and auto-draft facilities
- plug and play set up for standard equipment

Phase II Trial: C2 Telemetry Unit

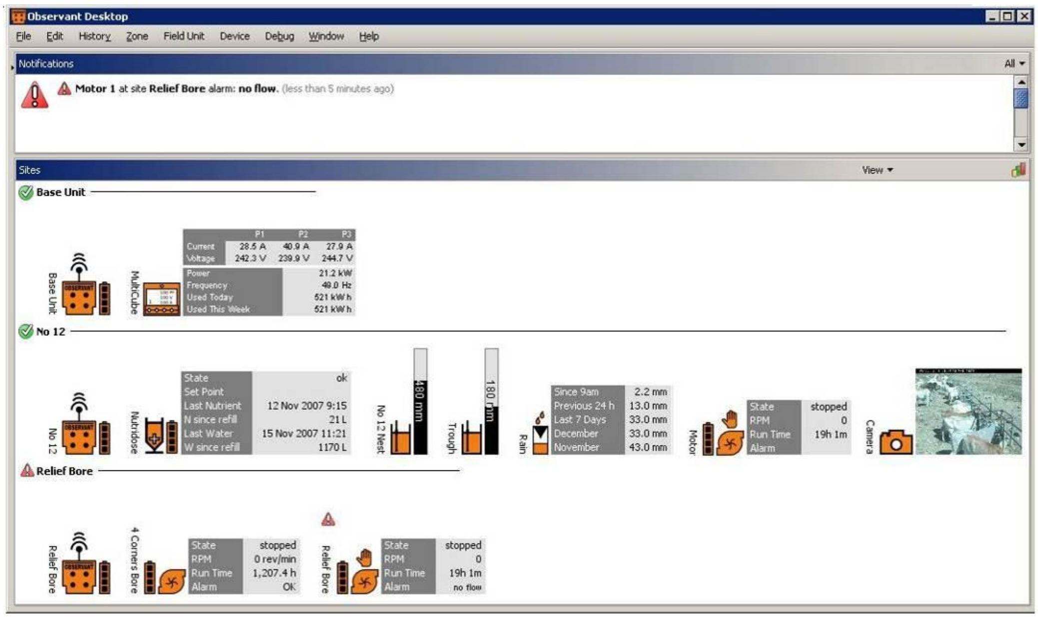
Phase II Trial: M1 Pump Controller

Phase II Trial: M1 Pump Controller installed at No 12

7.6.2 Product Specifications

Key Area	Specifications
Enclosure	• Weatherproof, vandal resistant, environmentally sealed • Fully self-contained (computer, radio, battery, charger) • No exposed wiring or UV sensitive components • Fully integrated solar panel, antenna and bird deterrent • Pole or wall mount options with concealed fasteners • Lockable wiring and battery compartment
Field Unit Computer	• Ultra-low power (less than 50 mW average) • Firmware remotely upgradeable over radio • Extensible device-driver architecture • Real-time clock with network time synchronisation • Extensive system diagnostics and self-monitoring
Communications	• Supports UHF, NextG, 900Mhz and direct internet • Advanced messaging protocol with error detection and correction • All units capable of acting as repeaters (to extend range or route around terrain)

Key Area	Specifications
Power	• Internal, user-replaceable lead acid battery (12HRr) • Can operate for 3+ days without any solar power • Sophisticated power management • Maximum power from solar panels • Integrated 11 W solar panel • Charge from a wide range of power sources up to 30 V, e.g. engine alternator, wall plug pack or another battery
Devices Supported	• Device driver architecture • Observant L1 level sensor • Observant M1 motor controller • Mono® Sun-Sub® solar pumping products • Tru-Test XR 3000 weighting system • Allflex NLIS tag readers • AXIS digital camera • Norprim® and Nutridose™ water medicators • Northern Designs Multicube energy meter • Pakton PTE0703 electric fence monitor • Large range of water meters • Tipping bucket rain gauge, windmills and more.
Data Logging	• Sensor measurements can be logged at any interval • Internal flash storage can store months of data • Logs are automatically synchronised back to a central repository for viewing with export capabilities.
Additional Features	• In-built GPS (for geo-coding of logged data and asset tracking) • Battery-backed real time clock • Operator ‘visit’ pushbutton • Enclosure ‘door open’ detection



Phase II Trial: Observant end user software showing equipment status information

7.7 Project Outcomes

One of the major outcomes from the project has been to heavily influence the development of a mature and nationally recognised market for the supply of telemetry or remote management systems. When the project commenced, there were few companies focussed on providing specific products for the pastoral industry. Today, there is significant focus on the provision of products and services in this area and an array of commercial providers offering solutions.

Specific project outcomes include:

- a system which is able to remotely monitor and control a wide range of equipment deployed on station to aid in the production activities of northern pastoral producers
- water tank, nest and trough levels (accurate to 2 cm)
- full automatic monitoring, protection and control of diesel, solar and electric pumping equipment
- rainfall and water flow measurement with up to 1 second resolution
- deployment of the system on to 21 water points situated throughout the trial sites
- the development of a comprehensive log of rainfall, water and nutrient usage across many trial sites for large parts of the trial duration. This data has also been used to support other research conducted by Damien Effeney and directed by Dennis Poppi
- delivery of sophisticated diesel engine control and protection systems that include the capability to automate pumps using tank water levels
- improved techniques for managing environmental and vermin protection through better industrial design and manufacturing techniques
- the development of sophisticated remote error diagnosis tools to significantly aid in trouble-shooting problems without needing to physically visit equipment
- delivery of a viable, still image camera solution that works on solar power and UHF radio; this was previously thought to be technically unfeasible
- a greater understanding by producers and equipment suppliers in relation to how telemetry can be used more effectively within the pastoral industry.

Phase I and II: Camera and Medicator

Phase I and II: Example of livestock images captured on camera

7.7.1 Cost savings / performance data

Large and small producers have repeatedly demonstrated that use of a remote management system results in significant reductions in staff, fuel and vehicle expenses related to livestock water monitoring.

Pigeon Hole
The telemetry system at Pigeon Hole was not designed to deliver the maximum cost savings for Pigeon Hole station. It was primarily set up to test and develop an integrated telemetry system with a regular monitoring system to confirm the operation. It was therefore situated within the R&D complex, close to the homestead. Once the system was established it did, however, deliver cost savings.

Before the telemetry system was set up the boreman would check all of the waters in the R&D complex 3 times a week during his bore run. At the end of the experiment the boreman and manager had the confidence to reduce the bore runs to once a week, with the telemetry system providing feedback on the level of waters for the balance of the week.

A reduction in bore runs from 3 per week to one per week resulted in 8,400 less km travelled per week by the boreman. This provided an $8,800/year reduction in vehicle running costs (fuel, tyres, maintenance and depreciation), a $16,600/year reduction in labour and a $500/yr reduction in bore running costs. This equates to $25,900/year savings. There were 21 sites monitored at Pigeon Hole. Therefore these savings resulted in a 3 year payback of the capital.

The reduction in time to complete bore runs had other advantages. For example it also allowed the station to use the boreman to operate the grader part of the time and other staff the balance. Therefore there is no need to employ a grader driver. The additional potential savings from this are significant but have not been estimated or included in the analysis above.

7.8 Beyond Pigeon Hole

It is important to note that there have been several important flow-on effects from the collaborative and iterative nature of the Pigeon Hole project. One of the challenges with gathering performance improvement metrics at Pigeon Hole was due to the fact that it was not a strict before & after scenario. The equipment that was operating on-site at the end of the project gradually evolved and improved over the course of the trial, so capturing precise operating costs before and after its installation was not possible.

In addition, the location of the monitoring sites did not take in to account locations that would deliver the greatest cost reduction benefit. Most of the sites were in fact those closest to the homestead; chosen because the telemetry equipment and indeed all other equipment used during the trial was by its very nature experimental, so convenience dictated it should be as close as possible to station staff.

For that reason, and as part of a broad commitment to quantitative analysis, Observant equipment was subjected to many other trials, both as formal research and informally by customers. We present below some excerpts from case studies which have resulted from those activities by way of highlighting the benefits that have flowed on as a direct outcome of the Pigeon Hole project.

7.8.1 Monkira Station, Queensland

NAPCO-owned Monkira Station is located in south-west Queensland, in one of the most isolated areas within the channel country. Having the opportunity to be involved in the WaterSmart™ Pastoral Production project aimed at reducing water monitoring costs meant installing the Observant Remote Management System™ and showcasing the outstanding results to neighbours and fellow pastoralists at the Monkira Station March 2008 field day. Observant's CEO Matthew Pryor was able to clearly demonstrate the benefits of the Observant system which has been part of the WaterSmart™ Pastoral Production trial, conducted by the Desert Knowledge Cooperative Research Centre (DKCRC).

The project, run in conjunction with DPI&F (Queensland) sustainable grazing trials, established records over 12 months which measured the time and costs associated with managing water supplies across large pastoral areas. At Monkira Station the use of the Observant system resulted in a huge reduction of hours spent each month driving around the property checking water points from between twenty-five and fifty hours in 2006 before it was installed to an average of around fifteen hours afterwards.

Monkira Station manager Anthony Desreaux became convinced early on in the trial that the Observant system saved time and money, to the extent that he show cased his system at the NAPCO managers meeting in late 2007. Monkira recorded annual savings of $25,000, reduced their mileage by 3,000 kilometres and halved labour hours associated with monitoring water, all from a one-off investment of $32,000.

Anthony Desreaux's involvement and feedback on how the system operated was integral to the trial. "At Observant our priority is to develop and manufacture systems that are suited to the needs of the pastoralists who use them," Matthew said. "This means that an essential part of the development of our equipment is to work with and learn from pastoralists to see where improvements can be made."

One of the outcomes of the Monkira Station trial was the improvement in environmental hardiness of Observant products. The field components of the Observant system, which include the newly released Observant C2, are tougher and more pest resistant than before. Observant has also developed a web interface enabling users to log into a secure website to check on what is happening at all the monitored points.

The Desert Knowledge CRC has published a telemetry cost savings calculator to help prospective users get an idea about the sort of cost savings they might achieve by using a remote monitoring system.

7.8.2 Glenalpine Station, Bowen, Queensland

Having installed Observant initially to manage their medicator program for their 4,500 Braham cattle, Barry and Leanne O'Sullivan are finding that the benefits from the system in terms of time saving, water-saving and consequently money saving are impressive.

Their system includes four solar-powered Observant units on spears in the creek, river and tanks which record and relay information about the water flow and water levels to the homestead computer. At any time they can see what the water is doing at these monitored sites by looking at a simple series of illustrations on the computer.

“Observant was recommended to us for monitoring the Nutridose™ system, but we realised pretty quickly that this was something that was going to provide us much more than monitoring the medicators,” said Leanne. “We've had the system in for just under a year and the biggest benefit we are seeing is in identifying quickly when there is either a leak or overflow—the way the information is presented on screen makes it very easy to see if and where there are any problems.”

When you are operating a 23,170 hectare property without permanent on-farm assistance there is much to be gained from a system that reliably monitors the water. “It's been labour saving material already. Barry is saving time by checking the spears and tanks less often, and after he has fixed a problem it is very easy to see if the work has actually returned the flow to normal just by looking at the tank levels on the computer,” she said.

“We are now doing one water run a week to check stock conditions and pastures, because on a daily basis the tank levels are monitored by the Observant system. You can plan your day much more efficiently if you don't have to spend the first hour or so checking water.”

The monitoring is backed up with sophisticated but simple software that records information to help with whole-of-farm management. “It's a simple system and you can use it as much or as little as the program has to offer. The great thing is that I can call Observant at any time and ask them a question about our system and they can help me straight away over the phone—so it's not a piece of technology that I'm intimidated by—I can really use it very effectively.”

“I am quite interested in some of the more sophisticated features such as patterns of consumption over time and Barry is happy using the home page with the whole of property diagram that gives him the water snapshot. We predict that we will see a return on our investment in 1-2 years and I'd conservatively estimate that we are gaining 10 hours each week by using Observant to monitor the water instead of physically checking it every day,” she said.

7.8.3 Mt Riddock Station, Alice Springs, Northern Territory

At the Cadzow family’s 2,635 sq km Mount Riddock Station on the Plenty Highway, North East of Alice Springs, the closest water tank is a 15 km round trip from the homestead and the farthest is 140 km. This means that a lot of time and diesel is spent travelling to these tanks to make ‘just-in-case' checks on the water. When Rebecca saw Observant Pty Ltd's Remote Management System on trial at Pigeon Hole Station, she knew the system had the potential to save a lot of time and worry.

Since installing their Observant Remote Management System™ in April 2007 for an initial investment of $16,000 they are checking the computer three-to-four times each day to see the water level of the tanks, turning the pump on and off and checking rainfall from their homestead computer. Steve and Rebecca estimate their savings in the first 9 months to be around $20,000 (because solar bores were also introduced at the same time to reduce fuel costs) and as a result, they have installed five more units during the summer of 2007/08.

"The basic style of the system appealed to me straightaway," said Rebecca. "It's so simple—the base unit and the C1 units are just about one piece and have their own solar panel and you literally put them together, put them in the ground and you are up and running. This was a system that allowed me to keep track of the water and any problems with it. I was the one to go ahead with the ordering and installation of the initial units (of which there was one motor controller, four tank level sensors, one repeater station, one base unit and computer program and six C1 units), and since it has well and truly demonstrated its worth, my husband, Steven and I are now looking to install an additional five units so that more of the property can be monitored from home."

"We have been out and checked it a couple of times to see whether what it's telling us on the computer is what's going on at the site and it's been the same every time—which is a great relief that it does what it's supposed to do!" says Rebecca. The Cadzows now check the computer three to four times a day to see what their water is doing. Instead of doing a bore run of up to 140 kms round trip every day, they now do the bore run twice a week.

Water is a critical part of farming in the pastoral region and the Cadzows, who graze their 7,000 head of cattle in large mobs must have certainty about water in particular paddocks at particular times. "At any one time we can have up to 400 steers on one watering point so knowing the water is secure is crucial. It will only take one summer and if there was an incident whereby our cattle are without water then we would be in serious trouble. Four hundred animals at one watering point means we have to be right on top of what is going on from a water front and we are confident that Observant helps us with this," says Rebecca.

The Cadzows consider this knowledge and security to be one of the biggest returns on their investment. However, Rebecca has also captured the dollar savings associated with the Observant system in a recent review of the time and money spent on monitoring and managing their waters and bores for the period March 2006 to March 2008.

The results show that in the 12 months since they installed Observant the Cadzows and their staff have travelled 27,768 km less on bore runs, generated savings of $8,000 on diesel alone, realised significant savings in labour costs, vehicle costs and vehicle maintenance (poor corrugated roads are a big issue), and reduced diesel use by 13,000 litres (a saving of $20,000, but note that solar power also contributed to this saving).

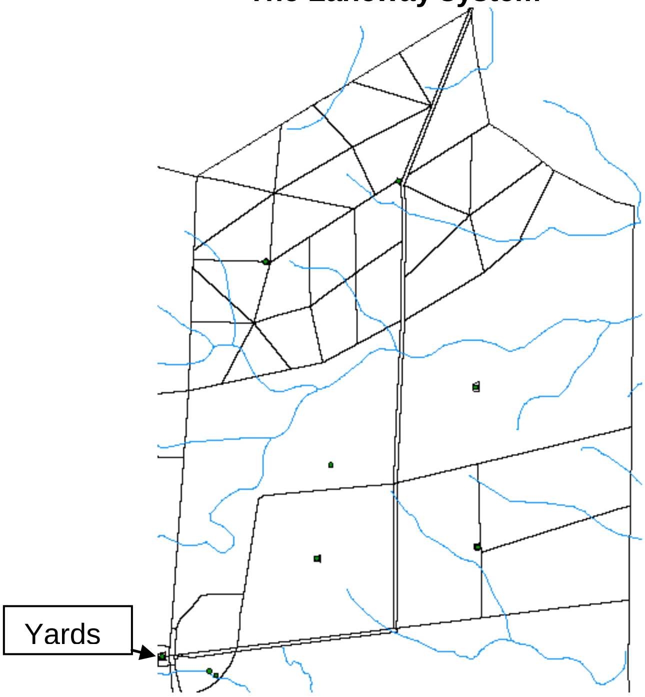
7.9 Laneways and additional yards

This section discusses some of the alternative paddock layouts used in the experiment and provides some anecdotal information on the benefits and problems with these designs. The optimum paddock design for a particular site will obviously be dependent on the layout of the existing infrastructure, the site structure, budget and management preferences.

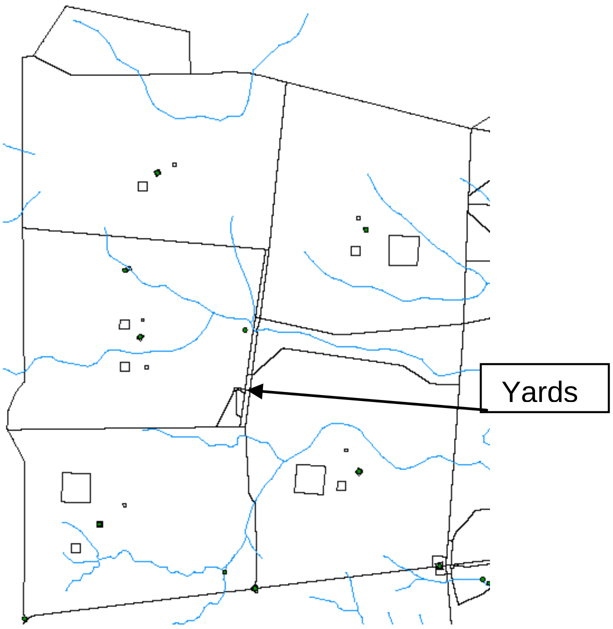
Two broad designs were tested;

1. A laneway system where all of the paddocks front onto a laneway and the cattle are moved to the yards and back via this laneway.
2. The placement of a new yard in the centre of a set of paddocks to minimise the distance the cattle have to walk to the yards and back again.

The Laneway system



The central yards



With the fence and yard design used in this experiment, the laneway cost in the order of $6,000/km (2009 value) and the central yards cost in the order of $55,000 (2009 value) plus holding paddocks of $15,000 to make $70,000. The fencing consisted of 3 strand high tensile steel barb wire with 1.8 m pickets spaced at 7 m and strainer posts every 500 m. This cost included the corner assemblies and gates. The yard had the capacity for 3,000 hd, had a fixed steel round yard, race, vet crush, and calf race while the remainder of the yard was made from portable panels.

The advantages and disadvantages of the laneways and central yards are summarised in Table 2.

Table 2. Comparison of the advantages and disadvantages of laneways and central yards.

	Advantages	Disadvantages
Laneways	• Minimise the labour requirement to move cattle. • Minimise the need for skilled staff to move cattle • Help educate cattle to be managed by horses and staff • Provide a natural road with minimal gates through developed country • Help make more efficient use of existing yards • Provide a valuable holding paddock with annual wet season spelling • Provide additional separation between paddocks • Doubles as a fire break at the end of the season	• Can be expensive if they are set up over large distances • Loss of grazing land in paddocks. • Cattle need to walk some distance from their paddock to the yards. This can increase the time cattle are out of their paddock.
Central Yards	• Cattle can be mustered and returned to their paddocks in a short period. • Cattle do not have to walk great distances from their paddocks. • Less stress on cattle, possibly resulting in higher productivity or lower mortality.	• It is very costly to set up additional yards and they are only used for a short period of time each year (4 to 8 weeks/year). • Additional facilities to maintain each year

7.10 Mustering technique

The most appropriate mustering technique will be a function of the topography, labour costs, helicopter costs, management system and other site related factors. A number of mustering styles were tested at Pigeon Hole to determine the most cost effective within the intensively developed paddock complex. The staff costs and aircraft costs were recorded for each system and the systems compared. It should be noted that some of these comparisons were between years and there were changes in staff and management over the period of the experiment. Therefore the results should be treated as a general indication rather than as a definitive guide.

The results of this comparison are summarised in Table 3. The cheapest mustering strategy tested was the helicopter alone with no support staff on the ground, followed by men on horses only, with the traditional strategy of helicopter plus men being the most expensive per head. Although the helicopter alone was the cheapest strategy the impact of this strategy on the productivity of the cattle also needs to be considered.

After the paddocks were mustered by the helicopter alone the staff noticed a number of calves left behind in the paddocks by the helicopter. It is unknown exactly how many were left behind, but this is expected to negatively impact the branding percentages and is likely to increase calf mortalities. Estimates in a number of paddocks suggest such calves represented in the order of 1% of the breeder numbers. This could be equated to $2.50/hd loss across the herd if all of the calves left behind died and if you value the calves at $250 each.

Table 3. Comparison of the cost of 4 mustering strategies on the intensively developed paddocks on Pigeon Hole.

Mustering technique	Cost/hd	Cost/km^2
Helicopter + Men on horses	$4.80	$55
Plane + Men on horses	$3.50	$40
Men on horses	$3.00	$34
Helicopter alone	$1.80	$21

Another factor to consider is the efficiency of the muster. Anecdotal evidence collected during the experiment suggested 98 to 100% of the cattle were consistently mustered with the first 3 mustering strategies, where the helicopter alone achieved a mustering efficiency in the order of 95%. This efficiency figure is highly dependent on the experience and attention to detail by the pilot. In large-scale commercial paddocks (150 km^2) in this region a mustering efficiency of 90 to 95% with helicopter-alone mustering is considered common.

Many commercial businesses in this region are using only helicopters to muster the cattle with little or no staff on the ground to support the aircraft. This strategy is being adopted to combat the rising costs of running these cattle businesses in this region, in particular the high cost of staff. The loss of calves and unmustered cattle is potentially a hidden cost of this strategy. More traditional cattlemen suggest this strategy may be unsustainable and lead to cattle with poor temperament and increased mustering difficulty. This remains to be seen.

7.11 Electric fencing

Electric fencing has not traditionally been used in the far north of Australia due to the perception that it does not provide a sufficient barrier to the stock and is too costly to maintain.

In this project electric fencing was installed in the cell grazing complex to reduce the capital development costs. This complex required 75 km of fencing in an area of 33 km^2. The majority of the fencing was 3-strand plain wire with 10 m picket spacings and a dropper between the pickets. The fence was designed and the final electrical fit-out completed by an expert in electric fencing.

The complete cost of the electric fencing was $1,288/km (2009 value) versus barb at $2,320/km (2009 value, 3-strand barb, 7 m picket spacing). The significantly lower cost of the electric fencing is the main attraction of this style of fencing. Our key conclusions on the use of electric fencing in this environment are:

- Cattle needed to be initially trained to respect the electric fence before they are placed in larger paddocks with electric fencing. Post-training of cattle, this fencing was effective at keeping the breeders in their paddocks although not as effective as barb fencing. Over the 4 years of the trial very few breeders got through the fence and generally had a healthy respect for the fence.
- Over this period calves continued to walk under the fences on get into the neighbouring paddocks, but they nearly always returned to their mothers at the end of the day. As the calves grew bigger they developed more of a respect for the electric fencing and by weaning age (>6 months old) also had a healthy respect for the fencing.
- Grass did continue to grow up through the wires during the wet season. This did not pose a significant problem in the mid to late wet season as the cattle generally did not pressure the fences and in the later part of the wet and dry season there did not appear to be a great deal of electrical current loss through the grass.

- At least 2 to 3 wires are required to provide the visual barrier to stop the cattle pressuring the fence.
- There is a need to clear the fence line at least once a year and maintaining all of the connections to maximise the power output.

In conclusion, electric fencing has a role in smaller more-controlled paddocks where cattle can be trained and the fencing properly maintained. It has limited application in the large paddocks and minimal maintenance conditions of the majority of far northern Australia.

7.12 Water Medication

Water medication was used to supplement the majority of the experimental cattle in the Pigeon Hole project. Water medication is the provision of nutrients to cattle via the drinking water. Water medication systems and strategies have been described in detail in the MLA publication "Water Medication. A guide for beef producers" by K. Entwistle and S. Jephcott (2005).

Water medication was used to provide a nitrogen supplement in the dry season and a phosphorus plus nitrogen supplement in the wet season. The aim of using water medication in this project was to:

- Ensure all of the cattle consistently received the supplement
- Keep the supplement costs as low as possible
- Test water medication at a commercial scale (11 dispensing units across 17 water points)
- Evaluate the linkage between the telemetry systems and the water medication units.

The Nutridose^{R} water medicator units were used in this project. A Nutridose supplement was also used in the water medicators for the period of the project. The medication units were set up to provide a dose rate of 1 g of urea per litre of water in the troughs in the wet and dry season. Cattle are reported to drink 10% of their body weight in water per day. This provides approximately 20 g urea per head per day for the growers and 45 g urea per head per day for the breeders. Water intake obviously varied with season and therefore urea intake also varied.

A system for practical and consistent maintenance of the water medication system has evolved over the 5 years of trial. This system attempted to address the problems and risk issues and provide practical management guidelines.

The key aim of the system was to maintain a consistent dose rate in all of the troughs. In the early stages of the trial the concentration of nutrient in the trough was extremely variable, varying between 0 g and 2 g urea per litre of water. This appeared to be a function of mixing errors by staff, chemical reactions between the site water and the nutrient, and incomplete mixing of the nutrient. To address this:

- All nutrient was mixed at the homestead and delivered to the nutrient tanks in a small tank on a 3 tonne truck. This ensured consistency in the nutrient supply and allowed the manager to oversee all mixes.
- All of the medicators were set up to consistently dose the same level of nutrient
- All of the water troughs were regularly tested for urea concentration using a Urea test kit.
- Smaller float valves (1.5 inch) were installed on all troughs to ensure the units consistently dosed when small numbers of cattle were drinking.
- Only staff with moderate to good technical skills managed the water medication system
- Every year all of the medicator units were fully serviced by the manufacturing company with any worn or damaged components being replaced
- All filters were cleaned regularly
- Nutrient tanks were emptied and cleaned every 3 months
- Only good quality, good condition nutrients were used during the experimental period.
- All tanks were regularly inspected for settled nutrient or other signs of chemical reactions.

- The telemetry system was used to monitor all of the water medication units and any breakdowns fixed immediately.

Conclusions

- Water medication can be successfully implemented at a commercial scale.
- Water medication can reduce the supplementation cost to approximately 25% of nutrient blocks.
- Water medication is a high risk strategy and requires a high level of management and technical skill to maintain.
- A high level of maintenance is required to minimise breakdowns of the units.
- Linking telemetry with the water medicators provides additional confidence and reliability.

8 Development potential in the VRD

8.1 Key messages

- Economic modelling and an assessment of current pasture utilisation rates on a sample of properties in the VRD were used to determine the likely potential for pastoral intensification in the VRD.
- A comparison of the economic performance of an intensively developed station with a ‘typical’ undeveloped commercial cattle business showed that intensive development could produce almost twice the annual profit compared with the undeveloped business and increase the return on invested capital from 5.4% to 8.7%.
- Half the case study properties had current pasture utilisation rates that were equal to or greater than the recommended utilisation for that property, meaning only half the properties had potential for development and increases in livestock numbers. The properties with development potential would be able to increase utilisation levels (with the addition of infrastructure) by on average 5%.
- Development of the properties with potential for intensification could result in an estimated increase in cattle numbers in the VRD of about 154,000 AE, generating an additional annual gross margin of about $17m.
- Herd modelling suggests it would take about five years for cattle numbers to grow to this level.
- A large number of assumptions have been incorporated in these analyses, so some caution is warranted. Also, the run of good seasons since about 1992 may also have generated an over-optimistic view of the potential productivity of the land that may not be sustained should there be a return to drier years.

8.2 Impact of intensive development on a VRD cattle business: case study

8.2.1 Introduction

Pigeon Hole station has an area of 1,795 km^2 and carrying capacity of 16,353 AEs before any development. The southern four paddocks of Pigeon Hole station (Bullock, Steven’s Creek, Racecourse and Villiers, encompassing 369 km^2) were intensively developed to run the Pigeon Hole R&D project (see Fig. 2.2 and Fig. 2.3). The paddock sizes and water point configurations were established to accommodate each of the experiments in the study, but a common design criterion across all paddocks included water development with a maximum of 3 km grazing radius to allow cattle access to 100% of the available pasture. This complete access plus additional fences and yards to manage grazing distribution and minimise operating costs can be described as ‘intensive development’.

The intensive development across the R&D site and the commercial scale (5,900 AEs) of this project, provides the opportunity to use the production and economic data from the site to evaluate the economic benefits of intensive development in this environment. The production data from the site and the recommended optimum sustainable stocking rate can also be used in the evaluation.

It is important to also compare the economic performance of this intensively developed area with a ‘typical’ commercial cattle business in the same area over the same period. The Pigeon Hole commercial business is a logical area to use as a control.

8.2.2 Methods

8.2.2.1 Basis for the comparative analysis

The analysis is based on two areas of Pigeon Hole over the years 2003 to 2006:

1. **Control area (1,426 km^2)**. This is the non-intensively developed area of Pigeon Hole to the north of the R&D site. This area was run as a commercial cattle business for the period of this experiment. The herd numbers, productivity, operating costs and returns from this area were used as input into a herd and economic model (developed by Jim Coulthard) to estimate the potential returns from a stabilised station with this area. The economic results generated in the summary tables are similar to those achieved on the station over this period.

2. **The intensively developed R&D site (369 km^2)**. The herd productivity, operating costs and returns from this area were proportionally scaled up to a similar size station (1,426 km^2) to provide a direct comparison with the control station. The herd and economic model used these scaled-up input numbers to estimate the economic returns of an intensively developed station of this size. The R&D specific costs of data collection, water medication development costs and telemetry development costs were excluded from the cost data. The capital costs to set up this site were also proportionally increased to assume 70% of the station was intensively developed. The balance of the land was assumed to be uneconomical to intensively develop and stocked at the commercial level. The R&D specific capital costs, such as the smaller paddocks, additional yards and telemetry were not included in the capital costs. Capital costs and operating costs have been converted to be equivalent to 2008 costs, using a CPI of 3.5%.

8.2.2.2 Base value of the land and capital costs of improvements

The R&D site had an area of 369 km^2 and before the commencement of the project carried approximately 3,376 AEs at an average stocking rate of 9.1 AE/km^2 (Table 8.1). After the site had been intensively developed with 15 additional water points and 213 km of fencing, the site had the capacity to carry 5,904 AEs stocked at an average rate of 16 AE/km^2. This development increased the carrying capacity of the site by 2,528 AE at a cost of $867,038 or $343/AE. During the experimental period this site carried an average of 5,977 AEs which varied from 4,749 AEs (2007) to 6,644 AEs (2004).

Table 8.1. Assumptions to up scale the R&D site to that of the control station.

Site		Area	AE/km2	AE's	Increase AE's	Capital
1) Control station		1,426	9.1	12,977		
R&D Site	Pre development	369	9.1	3,376	2,528	$ 867,038
R&D Site	Post development	369	16.0	5,904		
2) Scaled up intensified station		1,426	13.9	19,885	6,839	$ 2,345,467

To scale this site up into a similar size (1,426 km^2) to the control station, the AEs, capital costs and operating costs were scaled up with an assumption of 70% of the site being intensively developed. The assumed capital costs in 2008 figures are summarised in Table 8.2.

Table 8.2. Capital investment in the R&D site.

Item	R&D Sites actual		Intensive model assumptions	
Yards	$	82,171	$	222,285
Fencing	$	373,593	$	1,010,625
Waters	$	411,274	$	1,112,557
Total	**$**	**867,038**	**$**	**2,345,467**

8.2.2.3 Levels of productivity and efficiency achieved

The average branding percentage across the treatments over the period of the experiment was 79%. A similar branding percentage was achieved within the control herd. The breeder mortality within the R&D site averaged 1.3% versus 2.0% over the commercial herd. This difference in mortality is likely to be a function of the smaller more controlled paddocks in the R&D site relative to the commercial paddocks. The annual weight gain of the growers in the R&D site averaged 137 kg/year which was similar to the commercial paddocks in the control area. The R&D site had a lower cost per AE for management compared to the commercial control area as a result of factors such as: the additional infrastructure reducing mustering and management costs, the higher density of cattle per unit area reducing the mustering costs, and many other advantages. For example, the mustering costs (aircraft + staff) were reduced from approximately $9/hd to an average of $5/hd, with individual treatments having a mustering cost of as low as $1.20/hd.

8.2.2.4 Economic return

The returns for the commercial business were determined using the Pigeon Hole operating costs (adjusted to current day values using a CPI of 3.5%), productivity and returns over the experimental period within the non-intensively developed area. The financial and herd data were entered into the economic model and calibrated to produce typical returns from the business at this time. This is assumed to be a typical return for a commercial cattle business in this environment over this period (Table 8.3).

The assumptions used in the herd and economic model for the intensively developed site were similar to the commercial control, other than the additional AE capacity, cost of the capital, cost of the additional cattle, replacement capital and lower operating costs per AE. These variables are summarised in Table 8.3. All other variables and assumptions were the same and are as follows:

- Stabilised static herd with no growth or decline in numbers;
- Sale of steers and heifers to live export at 18 m old;
- Cows culled at 10 to 12 yr old;
- Bulls culled at 8 yr old;
- Bull percentage of 4% for cows and 5% for heifers;
- Cull for type for breeders of 2%;
- Sale price for steers of $1.70/kg ex station;
- Sale price for heifers of $1.60/kg ex station;
- Sale price of cull cows of $1.20/kg ex station;
- Average breeder value of $300.

8.2.3 Results

The economic modelling suggested the profitability of the intensively developed station in the VRD region could be increased from $941,243 to $1,871,732, an increase of $930,000 or almost double the profit (99% increase) (Table 8.3). This improvement in profit is a function of:

- An increase in sale kilos of 692,720 kg (55% increase);
- An increase in total revenue of 55%;

- A reduction in operating costs per AE from $68 to $48 (29% reduction).

The return on invested capital (ROIC) also increased from 5.4% to 8.7%, an increase of 61%. This return was influenced by the higher profit, but was also tempered by the increase in capital value of the business of $4.0 m. The higher capital value consisted of $2.8 m in increased herd value from the extra 7,023 AEs and $1.3 m increase in infrastructure value due to the infrastructure developments.

It should be noted that although these results are based on actual levels of productivity, operating costs and capital costs, the economic returns presented in Table 8.3 are outputs from the herd and economic model. The levels of productivity of the commercial station are very similar to the actual returns from the commercial station over this period, but the results from the intensively developed station are output of the model.

Table 8.3. The financial and herd data for two modelled stations, control and intensively developed, in the VRD region.

		Control Station		Intensive Development		Percentage
		Total	**Per AE**	**Total**	**Per AE**	**Increase (%)**
Financial Data	Replacement Capital	$ 60,962	$ 5	$ 70,567	$ 4	16%
	Fixed Costs	$ 273,664	$ 21	$ 273,664	$ 14	0%
	Direct Costs	$ 556,474	$ 43	$ 611,151	$ 30	10%
	Total Operating	$ 891,100	$ 68	$ 955,382	$ 48	7%
	Livestock Revenue	$ 1,940,179	$ 149	$ 3,006,038	$ 150	55%
	Total Revenue	$ 1,961,569	$ 150	$ 3,027,428	$ 151	54%
	EBIT	$ 941,243	$ 72	$ 1,871,732	$ 93	99%
	Capital value ($)	$ 17,552,665	$ 1,344	$ 21,615,829	$ 1,076	23%
	ROIC	5.4%		8.7%		61%
Herd Data	Branding Percentage	79%		79%		0%
	Herd Mortality	2.0%		1.3%		-35%
	Breeders	4,843		7,446		54%
	Total Herd (AE's)	13,063		20,086		54%
	Sale Cows	591		931		57%
	Sale Steers	1,820		2,797		54%
	Sale heifers	1,110		1,736		56%
	Total sale kg's	1,255,520		1,948,240		55%

8.3 Current levels of utilisation in the VRD

8.3.1 Introduction

Considerable investment has been directed towards understanding the potential sustainable development for the Victoria River District of the Northern Territory. Previous studies have estimated utilisation levels in the Victoria River District to be between 12 and 16% (Dyer *et al.* 2003 and Cobiac 2006a). At Mt Sanford on the productive Wave Hill land system, 20% utilisation was found to be sustainable (this study, Cowley *et al.* 2006, 2007), suggesting the potential to increase cattle production in the region through the development of infrastructure and better management. However, the VRD is not all fertile black cracking clay. Large areas are considerably less productive and less resilient to cattle grazing. Hence 20% utilisation is not likely to be sustainable across the entire region.

This study aimed to compare current utilisation rates across the VRD with recommended rates, taking into account factors previously not considered: namely accessibility of land to cattle, distance from water, and different land type utilisation potentials. This provides a more realistic estimate of the potential to increase stock numbers in the VRD with the addition of infrastructure while maintaining recommended utilisation levels.

8.3.2 Methods

8.3.2.1 Location

Twelve properties were selected to represent the geographical range across the VRD and were located from the northern to southern (550km) and eastern to western (330 km) edges of the region. Three stations were located in the northern VRD, three in central VRD and six in the southern VRD.

The combined area of the stations was 39,852 km^2, and comprised thirty of the fifty-one land systems found in the region, 38% of the stations, and 30% of the total Victoria River District area.

8.3.2.2 Data analysis

8.3.2.2.1 Utilisation

Utilisation was calculated using the equation following Johnston *et al.* (1996):

$$Annual\,utilisation = \frac{annual\,animal\,intake\ (stocking\ rate\ \times intake)}{annual\,pasture\ growth}$$

8.3.2.2.2 Accessible and watered area

GIS was used to calculate total land system area and land system watered area within a 3 km and 5 km radius of known artificial and natural waters. Waters used included all dams or weirs, bores and wells, turkey nests and water troughs from DNRETA Pastoral Branch. The dataset is current to at least 2004. Perennial natural waters were based on 1:250 000 topographic mapping from Geoscience Australia. Perennial creeks and rivers were overlaid with satellite imagery to identify permanent and near permanent linear waters and waterholes. Internal property fencing was not taken into account when estimating watered area, as previous work in the Barkly region (Fisher 2001) suggested that there was little difference in watered area when internal fencing was taken into account.

Land system area was discounted for accessibility, where land was inaccessible to cattle due to cliffs, rugged terrain or submersion (lakes and coastal saline mudflats). 12% of the total case study area was inaccessible.

8.3.2.2.3 Pasture growth

Pasture growth for the years 1891 to 2007, and for the fifteen years of station cattle data presented (1992 to 2007), was modelled using GRASP. GRASP was run for the land systems of the 12 cattle properties using VRD parameter sets (Cobiac 2006a) and a Barkly Spinifex parameter set (Pettit *et al.* 2011). For land types where there was no relevant parameter set available, methods outlined in Cobiac (2006a) were followed to assign soil and vegetation parameter values to the model based on land system descriptions, and for sandy soils, water holding capacity was assumed to be 10mm/10cm. Historical climate files for each station were derived from data drills from the SILO web site for each station. Tree basal area was estimated for each land system by property, based on woody vegetation surveys in the VRD (Cowley, unpublished data; Dyer *et al.* 2000, unpublished; and Cowley 2004, unpublished). Assumptions for each land system are shown in Table 8.4. For land systems with large inaccessible areas such as Pinkerton and Wickham, only the accessible land units (which happened to be more productive) were modelled.

Total available pasture growth was calculated for each land system by total and accessible watered areas. Eight calculations of annual pasture growth were calculated for each station. These were long-term historical median pasture growth and recent (15 years) average pasture growth for:

- Total property area
- Accessible area
- Accessible area within 5km from water (assuming cattle graze primarily within 5km from water)
- Accessible area within 3km from water (assuming cattle graze primarily within 3km from water)

Land system pasture growth was calculated as land system area x average pasture growth (kg/ha/ annum) for that land system. Where topographical accessibility was taken into account, accessible land system pasture growth was calculated as land system area x land system accessibility x average pasture growth/ha/annum for that land system. Where watered area was taken into account, pasture growth per property was based on accessible watered area for each land system. Total property pasture growth was calculated as the sum of all land system pasture growth for that property.

Station managers tend to adjust animal numbers to varying seasons. Given the large effect of rainfall patterns on pasture growth, pasture growth from the years surrounding the animal data was the most appropriate for utilisation analysis.

Table 8.4. Assumptions for different land systems (Based on Cobiac 2006a, Pettit *et al.* 2011).

Land system	Vegetation type - model used	Soil type	WHC (mm)	Soil depth (cm)	Safe utilisation level	Accessibility
Argyle	Barley Mitchell grass	alluvial grey cracking clay	258	100	20	100
Angallari	White grass VRD	red earth	182	100	15	100
Antrim	Annual short grass VRD	red earth	101	50	10	65
Birrimbah	Annual short grass VRD	red earth	101	50	10	100
Barry	Spinifex	red earth	182	100	5	100
Carpentaria	Saline short grass (used Ivanhoe)	alluvial saline clay mudflats (used Ivanhoe)	258	100	15	10
Cockatoo	White grass VRD	red earth	182	72	15	100
Coolindie	Spinifex	deep red sand	100	100	5	100
Cockburn	Spinifex	rocky skeletal red earth	63	30	5	100
Dinnabung	White grass soil and structured red earth past	loamy red earth	147	72	15	100
Frayne	White grass soil and structured red earth past	loamy red earth	147	72	15	100
Franklin	Spinifex 60% and white grass 40%	gravelly skeletal and brown loams	101	50	10	75
Geebee	Spinifex	gravelly red soils	182	100	5	100
Gordon	Annual short grass VRD	calcareous desert soil	63	30	10	100
Hawk	Alluvial Mitchell and white grass	grey cracking clay 40%, sandy loam 60%	258&101	100&50	15	90
Humbert	Annual short grass VRD	rocky skeletal red earth	63	50	10	100
Inverway	Alluvial Mitchell	alluvial grey cracking clay	258	100	20	100
Ivanhoe	Alluvial ribbon grass	alluvial grey cracking clay	258	100	20	100
Lake					0	0
Legune	Alluvial ribbon grass (used Ivanhoe)	estuarine alluvial floodplain (used Ivanhoe)	258	100	20	100
Montejinni	Annual short grass VRD	calcareous desert soil (used red earth)	63	30	10	100
Mullaman	White grass VRD	rocky skeletal red earth	63	30	10	25
Napier	White grass VRD	rocky skeletal red earth	101	50	10	100
Pinkerton	White grass VRD	red earth	182	100	10	30
Redsan	Spinifex	sandy red earths	100	100	5	100
Wingate	White grass VRD	sandy red earths	182	50	10	100
Wickham	White grass VRD	red earth	63	30	5	20
Winnecke	Spinifex	gravelly skeletal and deep red sands	101	72	5	100
Wave Hill	Basalt VRD	basalt	291	88	20	100

8.3.2.2.4 Intake

Property intake was estimated based on cattle numbers and class. Data on station cattle numbers were supplied by DNRETA with the proviso that property information remained anonymous. Hence stations are not identified. Only stations where cattle numbers were thought to be reliable (DNRETA pers. comm.) were used. Between one to three years cattle data were supplied for each station, but more usually two years. Animal data was from between 1993 to 2007. Numbers were averaged where there was more than one year of data.

Where cattle numbers were not broken down to class, total cattle numbers were converted to numbers by class using knowledge of the station, or the average class breakdown for the Victoria River District from the 2004 Pastoral Industry Survey (Oxley 2006). Cattle numbers were converted to adult equivalents using GLM conversion tables. Intake for an AE was calculated using Quik Intake (McLennan 2005) assuming 50% dry matter digestibility (DMD). DMD was based on monthly NIRS data collected over a period of two years at Kidman Springs. This gave an intake estimate for non-supplemented animals of 7.6 kg/AE/day. Intake was assumed to be 15% higher where supplemented, at 8.74 kg/day. 66% of stations were assumed to be supplemented, based on Oxley (2006). This gave an average estimated intake (actual consumption) across the region of 8.27 kg/day for an AE.

8.3.2.2.5 Recommended utilisation assumptions

Calculated utilisation was compared to recommended utilisation for each property. Recommended utilisation rates are based on GLM recommendations for different land types, which were based on the Mt Sanford trial for black soil (Cowley *et al.* 2007), and Scott Creek trial for red soils (Ash and McIvor 1998). Spinifex dominated pastures are further discounted for low palatability and are assigned 5% utilisation, which is consistent with recommended stocking rates for this land type (Oxley pers. comm.).

Utilisation rates used to calculate recommended property utilisation were:
- Black soil 20%
- Good red soil 15%
- Poor red soil 10%
- Spinifex 5%

Average recommended property utilisation was weighted by land type area for that property (See equation).

$$Recommended\ property\ utilisation = \frac{area_{(land\ type\ 1)} \times utilisation_{(land\ type\ 1)} + area_{(land\ type\ n)} \times utilisation_{(land\ type\ n)} + \cdots}{Total\ property\ area}$$

8.3.3 Results

8.3.3.1 Land types

Twenty five percent of the case study region was the more productive black soil land type that can withstand the higher levels of utilisation (

Table 8.5). Conversely 43% of the case study area was from sandy and skeletal red soil Spinifex land types with safe utilisation levels of only 5%. This is why the weighted average safe utilisation for the region for the region is so low at only 11%.

Table 8.5. Land type composition and safe utilisation rates for the case study area**.**

Broad land type	Total land area	% land area	Safe utilisation rate
Basalt cracking clay	5130	13%	20%
Alluvial clay	4916	12%	20%
Tall grass red earth	4582	11%	15%
Annual short grass red earth	8370	21%	10%
Skeletal red earth spinifex	4260	11%	5%
Spinifex sand	12612	32%	5%

8.3.3.2 Pasture growth

Overall the pasture growth was higher when using more recent pasture growth data, than the long term average. This is because rainfall has been higher in the region over the last thirty years (CSIRO and BOM 2007) (Figure 203). Managers may have increased stock numbers to reflect pasture availability, but this study has no data on earlier stocking rates. However, the effect of the higher rainfall varied between properties. Generally properties that had the lowest long term median pasture growth had greater increases in pasture growth when using more recent rainfall records (

Table 8.6). This is because they are more likely to be water limited. Stations that already received high rainfall, are more likely to be limited by nitrogen and hence additional water has little impact on pasture growth.

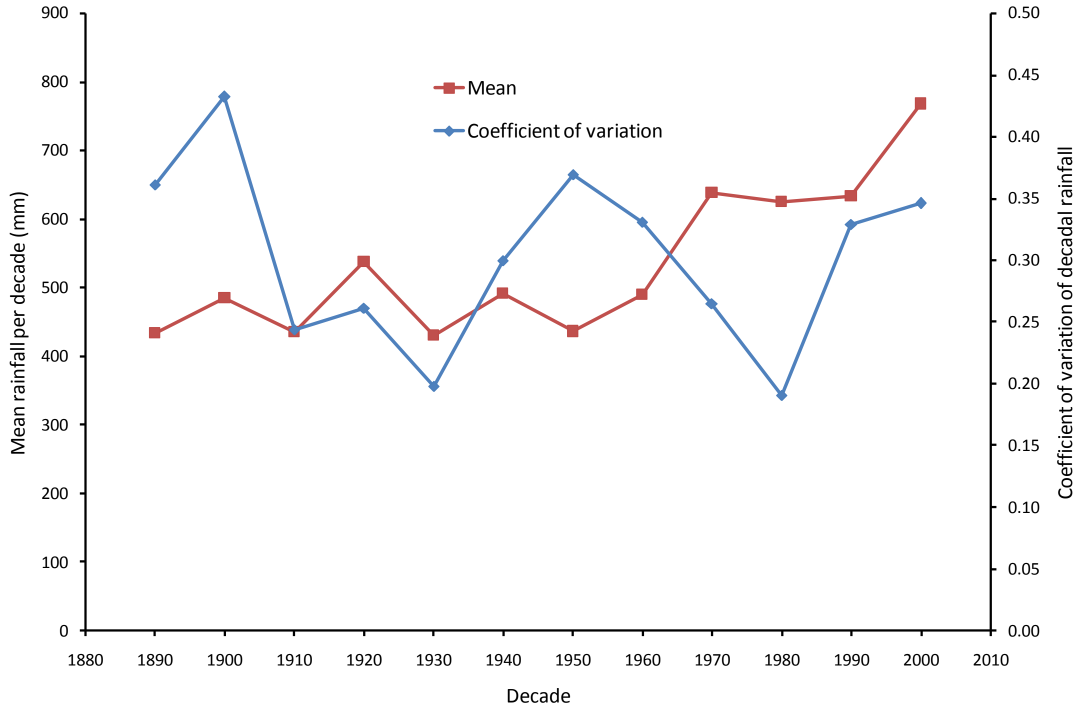


Figure 2: Change in mean decadal rainfall and coefficient of variation through time at Wave Hill Station, VRD. Source SILO datadrill.

Table 8.6. Difference in median pasture growth (kg/ha/year) over the long term versus the last 15 years.

Initial pasture growth bracket (kg/ha)	Average long-term pasture growth (1891-2007)	Recent change in pasture growth (long term – average for last 15 years)	% change long-term vs. last 15 years
1500+	1856	-51	0.4%
1250-1500	1395	159	11.3%
1000-1250	1042	195	18.7%

8.3.3.3 Utilisation

Calculated utilisation based on the long-term median pasture growth is shown in Table 8.7, and utilisation based on average pasture growth between 1992 and 2007 is shown in Table 8.8.

Average *safe* utilisation over the whole property area varied two fold from 7 to 15% for different stations (Table 8.8). This variation reflects the varying proportions of land types found on stations. Properties with a higher proportion of black soil, have a higher average ‘safe utilisation’.

On average, current *actual* utilisation over the accessible land area was equal to the recommended utilisation for this area (Table 8.8). However, half the case study properties had current utilisation in accessible land that was equal to or greater than the recommended utilisation for that station. The remainder of the stations had average utilisations that were on average 5% lower than recommended for the accessible land area (Table 8.8).

Utilisation within the watered area (<5 km) was 1.4 times higher than ‘safe’ levels, suggesting that despite the low average utilisations across the region, actual utilisations may be exceeding recommended levels in most cases. Conversely regions greater than 5 km from water are probably only very lightly grazed.

Table 8.7. Summary pasture growth and utilisation based on median pasture growth 1891 to 2007.

Station	Median pasture growth (kg/ha/yr)	Safe utilisation per whole property (%)	Actual utilisation per whole property (%)	Safe utilisation accessible area (%)	Actual utilisation accessible area (%)	Safe utilisation accessible area <5 km (%)	Actual utilisation accessible area <5 km water (%)	Safe utilisation accessible area <3 km (%)	Actual utilisation accessible area <3 km water
1	1993	14	8	15	10	16	12	17	14
2	1362	11	8	12	19	13	25	13	31
3	1444	13	16	14	17	15	20	17	30
4	1058	9	19	12	28	13	33	13	39
5	1368	13	14	13	16	14	20	14	28
6	897	8	4	8	5	9	15	8	23
7	1305	8	19	8	20	11	36	13	56
8	1771	12	6	14	9	15	11	15	14
9	1346	11	4	11	4	11	12	13	41
10	1486	12	10	12	10	15	17	16	26
11	1803	15	10	15	10	16	12	16	21
12	1170	7	8	7	8	12	30	13	44
Average	1285	11%	11%	12%	14%	13%	20%	14%	32%

Table 8.8. Summary pasture growth and utilisation based on average pasture growth 1992 to 2007.

Station	Average pasture growth (kg/ha/yr)	Safe utilisation per whole property (%)	Actual utilisation per whole property (%)	Safe utilisation accessible area (%)	Actual utilisation accessible area (%)	Safe utilisation accessible area <5 km (%)	Actual utilisation accessible area <5 km water (%)	Safe utilisation accessible area <3 km (%)	Actual utilisation accessible area <3 km water
1	1962	14	8	15	10	16	12	17	15
2	1499	11	7	12	17	13	24	13	30
3	1740	13	13	14	14	15	17	17	25
4	1312	9	15	12	22	13	27	13	32
5	1532	13	13	13	14	14	18	14	25
6	1211	8	3	8	3	9	11	8	17
7	1336	8	19	8	19	11	32	13	47
8	1830	12	6	14	9	15	11	15	14
9	1549	11	4	11	4	11	10	13	17
10	1658	12	9	12	9	15	15	16	23
11	1752	15	10	15	11	16	14	16	23
12	1186	7	8	7	8	12	24	13	34
Average all stations	1547	11%	10%	12%	12%	13%	18%	14%	25%
Average of under-utilised stations		12%	7%	13%	8%				
Average of over-utilised stations		10%	13%	11%	16%				

8.3.3.4 Current development of the VRD by land type

Across the twelve VRD stations, more productive land types were better watered (Table 8.9 - Table 8.10).

Table 8.9. Proportion of different broad land types that are within 5 and 3 km from water.

soil type	% within 5 km from water	% within 3 km from water
black	92	71
red earth	84	55
skeletal red earth	57	34
red gravel	39	17
red sand	30	12

Twenty seven percent of the case study area was poorly watered (greater than 5 km from water). Two thirds of the unwatered area had relatively low productivity, with an indicative potential carrying capacity of 3 AE/km^2 or less (Table 8.10). About 2000 km^2 of the most productive land types were unwatered across the study region.

Table 8.10. Area of land systems within the study area greater than 5 km from water, and indicative carrying capacity.

Land system	Area (km^2)	Percent total watered area	AE/km^2
Barry	2924	27.5%	1
Geebee	1694	15.9%	2
Franklin	1444	13.6%	3
Wave Hill	955	9.0%	13
Inverway	845	8.0%	14
Frayne	707	6.7%	6
Pinkerton	375	3.5%	5
Gordon	368	3.5%	3
Montejinni	285	2.7%	3
Antrim	275	2.6%	3
Dinnabung	191	1.8%	6
Ivanhoe	120	1.1%	14
Birrimbah	110	1.0%	4
Wingate	73	0.7%	5
Hawk	65	0.6%	7
Cockburn	57	0.5%	2
Angallari	43	0.4%	7
Mullaman	28	0.3%	4
Argyle	28	0.3%	14
Wickham	27	0.3%	2
Napier	9	0.1%	4
Legune	5	0.05%	14
Sum area greater than 5 km from water	10628		

8.3.4 Discussion

8.3.4.1 Utilisation findings in this study compared to previous studies

While utilisation has been estimated before for the VRD, this is the first time that watered area and other accessibility issues have been taken into account. Similarly this is the first time that estimates of actual utilisation in the VRD have been compared to the recommended utilisation rates for the same area.

Average pasture growth was 500kg/ha less than in Cobiac (2006a) perhaps reflecting the bias towards stations situated in the southern VRD in this study, where rainfall and pasture growth is lower.

Estimates of the average utilisation actually being applied over the total area of stations was within recommended or 'safe' levels for the case study area. The total property area estimate of utilisation (10%) was somewhat less than estimated by Dyer *et al.* (2003) and Cobiac (2006a) (at 12 and 16% respectively). The Cobiac (2006a) study used longer term pasture growth to estimate utilisation (1957-2004). This means his estimate is more comparable to estimates using long term pasture growth in this study (Table 8.7), where total property area utilisation rate was 12%, but this is still somewhat lower than Cobiac's estimates. Differences may simply reflect the subset of stations selected, as there was considerable variation between station utilisations both in this and the Cobiac (2006a) study. The southern bias in locations of case study properties could be influencing lower utilisation rates found here, as safe utilisation rates have been found to be lower with higher rainfall variability (Hall *et al.* 1998), and there is a gradient of increasing rainfall variability north to south across the VRD. However, the possibility of under-reporting cattle numbers to DNRETA, the source of AE estimates for this study, cannot be discounted. This would have the effect of under-estimating utilisation estimates in this study.

However, the 10% utilisation over the total area found here *is* very close to that estimated by Carter *et al.* (unpublished, AussieGRASS web site, time series graphs for VRD sub-IBRA regions) for recent time series (at around 11%). This suggests that despite the variety of approaches, there is considerable consistency between this and other studies in estimates of utilisation in the VRD.

8.3.4.2 Safe utilisation estimates

The low safe average safe utilisation levels across the region highlights the caution needed in applying results from grazing trials on more fertile land types to the broader region. Not all land types have the capacity for development as the black soils of the VRD. Cobiac's (2006a) findings of 16% utilisation (representing 22 stations in the VRD) (which is probably equivalent to 14% if recent pasture growth was used to calculate utilisation), is worrying given the recommended level of 11% found in this study.

8.3.4.3 Utilisation in accessible and watered areas

This study provides a more realistic assessment of utilisation than comparable studies were able to, because it has calculated utilisation in areas where cattle actually graze, rather than just an average across the entire region. For the topographically accessible area, the current average estimated utilisation was equal to the estimated safe level, but again there was considerable variation between stations.

We know that cattle do not use areas further than 5 km from water very much (Fisher 2001). Hence actual utilisation is likely to be mostly within 5 km from water. Assuming all grazing occurs within 5 km from water, the utilisation levels here were 18%, or 1.4 times higher than safe levels.

Given that 27% of the case study area was unwatered, this suggests that there is potential to reduce actual utilisation levels to recommended levels with further water development, by spreading grazing across total accessible property area. There was considerable variation between properties, and some with lower utilisation rates may have the potential to sustainably increase stock numbers with additional infrastructure.

8.3.4.4 Assumptions used in the analysis

Many assumptions were required to conduct this analysis of utilisation in the VRD. Potential flaws in these assumptions are explored.

While the best estimates of 'safe' or recommended utilisations for different land types were used as a benchmark to compare actual utilisation rates against, these 'safe' levels are based on a limited number of studies on a limited number of land types. However, they are consistent with Queensland recommendations for similar land types (e.g. Hall *et al.* 1998). Further information regarding safe utilisations for different land types may alter recommended utilisation rates for land types. If so, this would change the interpretation of the results found here.

Parameter sets for land systems are a best estimate or average based on modelling from the VRD. Individual property land systems may vary from regional averages, due to differences in soil and vegetation and trend in land condition.

The watered area is an estimate only. Area around artificial point waters is likely to be overestimated because no internal fencing was taken into account, and not all bores have water available to cattle. However a similar analysis of watered area in the Barkly found little difference when internal fencing was accounted for (Fisher 2001) so watered area estimates here were probably satisfactory. Areas that were identified as permanent and near permanent natural waters may not all be permanent, and some creek lines that are permanent may not have been identified. Case studies working with producers to identify watered areas across the stations would provide a more accurate picture.

Although wet season grazing ranges are 20-30% greater than dry season range (Hunt in this volume), no seasonal differences were accounted for in watered area analysis. Most grazing was assumed to be within 5 km, which is consistent with findings in commercial paddock where 90% of grazing was within 5.3km from water (Hunt this volume).

AEs were often based on a total stock number for each station, without any indication of class breakdown. Assumptions were made about the breakdown of the herd to convert this number to AEs. The breakdown was based on the average herd makeup for that region, but this may vary for some properties leading to miscalculations for AEs.

Land condition and tree basal area may be different to model assumptions, which assumed at least B condition and average tree basal area for the region, unless field information was available for that station / region.

Analyses could be improved if done on a paddock basis, both for stock numbers and watered area.

Intake per AE is assumed to be the same for all stations, but would vary depending on supplementation management. It is low compared to GLM recommended assumptions of 10kg/day/AE, and is thought to be a more accurate reflection of intake in this environment.

8.3.4.5 Implications

50% of stations reviewed had current utilisation levels equal to or above recommended utilisation levels. The remainder could increase utilisation levels with the addition of infrastructure by an average of 5%. Whether the additional stock numbers could pay for the cost of infrastructure development depends on the productivity of unwatered land types. In the case study properties most of the unwatered land area was of the less productive land types, reducing the cost-effectiveness of development.

8.4 Development potential of the northern pastoral regions

8.4.1 Introduction

A major aim of the Pigeon Hole study was to assess the potential for increasing livestock production across the northern grazing lands based on sustainable development. In practice increased production means more cattle carried without adverse effects on the native pasture resource. There are two main ways that this study concludes that this could be brought about:

- by providing more watering points so that all grazing areas are within a minimum recommended distance to water;
- by more closely matching the stocking rate to the long-term carrying capacity of individual land systems.

In this section we estimate the potential for development in the VRD and the approximate economic value of this, and discuss some of the implications. Other possible methods of increasing cattle numbers are not included in this assessment because their feasibility and sustainability was not proven by the Pigeon Hole project. These include employing higher utilisation rates in conjunction with spelling and rotational grazing, and adjusting stock numbers on a short-term basis to take advantage of seasonal and yearly feed abundance.

8.4.2 Methods

The study of recent pasture utilisation rates in the VRD presented in the previous section (Section 8.3) was used as the basis for the development scenario explored here. This study compared current stocking rates and fully developed carrying capacity on 12 VRD properties, which make up 30% of the total area of the Victoria River District.

Overall, the study found that the current utilisation rate in the accessible area (i.e. excluding hills and lakes) was similar to the estimated safe utilisation rate of 12%. Six of the properties were under-utilised (8% instead of 13%) while the other six were over-utilised (16% instead of 11%). For this regional projection, only the under-utilised stations were considered. The question of the fate of the extra stock in the over-utilised properties is discussed below.

Currently the six under-utilised properties hold a total of 87,220 AEs and potential within the accessible areas was 142,970 AEs, leaving a potential increase of 55,750 AEs.

Even under full development in the future, it was considered unlikely that it would be cost-effective to put additional watering points on land with very low carrying capacity. Of the 30 land-systems on the 12 stations in the study, six had a carrying capacity of less than 3 AE per sq km. These land-systems comprised 50% of the unwatered study area but had the potential to hold only 17% of the increase in cattle numbers. In this exercise, these land-systems were therefore excluded from development.

8.4.3 Results

Table 8.11 shows the results of extrapolating the potential herd increase from the 12 stations studied in Section 8.3 (24,616 sq km) to all the pastoral land of the Victoria River District (82,053 sq km). From this study 10% of the land was considered inaccessible, 47% was considered to be accessible and within reach (5 km) of water, and 43% accessible but unwatered. Half of the unwatered area was considered to have such a low potential carrying capacity that it would not be worth developing, leaving 21% of the land unwatered and suitable for development.

Costs and returns are derived from a recent herd modelling exercise carried out on a typical station in the Katherine Region (T. Oxley pers. comm. 2009) and development costs are derived from Pigeon Hole data.

Table 8.11. Potential increase in stock numbers and livestock production in the VRD with full development of water points and stocking to safe carrying capacity.

		Source
Potential cattle number increase on stations studied (30% of VRD)	55,750 AEs	VRD utilisation study (Cowley 2007)
Cattle number increase as a percentage of 12 stations studied	32.0%	
Potential increase in the whole of the VRD (82,000 sq km) if all land developed	185,833 AEs	
Potential increase excluding six low potential land systems (64,000 sq km)	154,242 AEs	
Increase with low capacity land excluded as percentage of VRD cattle herd	26.5%	
Potential increase in breeders	89,614 breeders	Herd modelling using Breedcow/ Dynama (T. Oxley, pers. comm. 2009).
Potential increase in sales of steers	27,764	
Potential increase in sales of females	26,170	
Value of extra sales (per annum)	$24.9m	
Additional gross margin (per annum)	$17.2m	
Employment implications - additional staff requirements	45	Widely used company formula of one stockman per 2000 breeders
Investment	$52.9m	Pigeon Hole development costs of $343/AE

8.4.4 Discussion

This study suggests that with further development of water points and a closer match between stocking rate and safe carrying capacity on the under-utilised areas of productive land, the VRD could carry 26% more cattle that at present. This is not an unsubstantial figure and the benefits to the regional and Territory economy are very significant.

In considering this potential development, there are a number of provisos to be kept in mind.

1. The extra stock on stations in the VRD study which were theoretically overstocked have not been included in the projection because there was no obvious link between development in under-utilised stations and de-stocking others. It is also possible that some land systems are able to sustainably support higher utilisation rates than the present level of research indicates. A new study by the NT Department of Resources is about to test this possibility by examining actual long-term utilisation rates on properties with good records of stock numbers and associated land condition.

2. This projection assumes that the twelve stations sampled in the utilisation study were representative of the whole VRD. This may not be the case.
3. This projection has not allowed for a proportion of the grazing land to remain poorly watered for biodiversity conservation as recommended in this study. In some cases, this might be covered by land that is not considered accessible to cattle or is not of sufficient grazing value to be developed. In other cases land put aside for biodiversity will have an impact on stock numbers.

The potential for the Katherine region to expand cattle numbers has been widely discussed within the pastoral industry in the last few years.

For the Katherine Pastoral Survey of 2004, 70% of regional producers were interviewed (Oxley 2006). In the survey, VRD producers predicted that they would increase their cattle numbers by 21% within 5 years and a total of 39% in ten years. For the Katherine Region as a whole, the estimates were 25% in 5 years and 42% in ten years. Principally, the producers referred to increased water point and fencing infrastructure development as the reason for being able to carry higher numbers with many acknowledging the influence of the Pigeon Hole Project on their views.

Some of the optimism towards higher stock numbers may be based on the good run of seasons experienced in the VRD since about 1992. In parts of the district the rainfall over this period has been 40% above the long-term average. It is not clear whether this is the result of a permanently changing climate, or a temporary fluctuation. Since central and southern parts of the VRD are generally rainfall-limited, extra rainfall does lead to substantial extra pasture growth. As indicated in Section 8.3, it is estimated that since 1970 the pasture growth in the central and southern VRD would have been about 11-19% above the long-term average.

Although the results of this study do not support regional increases in stock numbers above 26%, there are other factors that might make greater increases possible.

1. The use of rotational grazing to carry more stock sustainably, although this remains unproven in this environment and was not supported by evidence in this trial.
2. Strategic use of improved pasture. There is currently very little sown pasture in the VRD, but it is logical to expect producers to invest in improving specialised areas such as holding paddocks and weaner paddocks in time. Financial modelling by DoR (Neil MacDonald pers. comm.) suggests that strategic planting of improved pastures is worthwhile but in areas like the VRD the rate of return is lower and risk of failure higher than some other development options.
3. Partitioning the industry so that the VRD concentrates on breeders, with growers being raised on improved pasture further north. A scenario from Ridley (1994) suggested that heifers consume 33% of the grazing resources of the VRD but yield only 17% of the calf crop. Raising the growing animals on improved pasture would be a significantly more efficient system and would allow more breeders to be carried for the same grazing pressure.

It is also worth considering the extent to which the intensification possible for the VRD would also apply to other extensive pastoral districts. Although the principles tested in the Pigeon Hole project could have application across broad areas of northern Australia, notably the black soil areas of the Barkly and East Kimberley, these areas have not been included in this projection as it cannot be assumed that they have similar utilisation rates and a similar amount of unwatered land as the VRD.

8.4.4.1 Herd build-up

Herd modelling by Trudi Oxley (pers. comm.) suggests that to maintain herd numbers, a typical station in the Katherine region with a weaning rate of 65% would have to keep 53% of its annual heifer production and would sell 47%. An annual rate of herd build-up of 5% from retaining additional heifers therefore appears realistic, which would mean that the 26% potential increase would be reached within 5 years. The current rate of increase may be stimulated partially by the favourable run of seasons over the last two decades. This appears to be a realistic scenario and is backed by evidence of current increases in cattle numbers in the region.

The 12 VRD stations included in the study of current utilisation rates had increased their numbers by about 5% per annum over an average of 4 years, although the data indicated major variation ranging from +18% per annum to -8% per annum. ABS data suggests that cattle numbers over the whole of the Northern Territory have increased by 3.5% pa between 2005 and 2007 and it is reasonable to suppose that the VRD would have a higher proportion of this increase than more arid parts of the Territory.

9 Analysis of economic and environmental tradeoffs

9.1 Key messages

- An assessment framework was used to calculate and compare the environmental and financial performance of a property under five property development scenarios. The five scenarios (increased water points, reduced paddock size, wet season spelling, cell grazing, and increased pasture utilisation) were compared to a scenario reflecting current management.
- Ecological health was assessed in terms of a range of attributes related to maintaining ecosystem function and stability and the conservation of biodiversity.
- The analysis suggested that installing more water points is likely to generate the greatest gains in return on capital with the smallest environmental trade-off.
- Scenarios involving wet season spelling and cell grazing showed no improvement in return on capital compared with current practice, but the former produced a substantial environmental benefit through improvements in pastures and soils.

9.2 Introduction

Management changes that involve the intensification of grazing on pastoral properties are likely to have both environmental and financial impacts. It is unlikely that the environmental and financial impacts will both always be positive, and tradeoffs will be required to meet both environmental and financial objectives. To assist the task of making sound choices, the nature of these trade-offs and their magnitude need to be identified and assessed.

Most decisions on grazing land management are made and implemented at the property level, and assessments of ecological and economic trade-offs need to be made at this level. McIvor and MacLeod (2004) developed an assessment framework that calculates and compares the environmental and financial performance of a property under some proposed management change with that of the current operation. The comparison is of two static situations (before and after implementing the change), not of what happens during the period of change. In the first step in using the framework, the existing management on the property is defined and then assessed in both ecological and financial terms, and an assessment of tradeoffs is made. A review is made of possible management options to determine what is technically possible and what fits with property management. These are then incorporated into a new management scenario, and the assessment of the ecological and financial impacts and tradeoffs is repeated.

The assessment framework was subsequently revised to improve the assessment of impacts on biodiversity and another environmental attribute (fire regime) was added to give a total of ten environmental attributes. Seven of these (soils and hydrology, pastures, weeds, feral animals, riparian areas, atmosphere and fire regime) describe the maintenance of ecosystem function and stability, and the other three (native vegetation communities, native plant and animal species, and significant sites and habitats) describe conservation of biodiversity.

The likely impacts of management options on carrying capacity, breeding performance and annual liveweight gain are combined with the costs of the activities to assess the changes to financial performance of the property (gross margin, net profit, return to capital and capital value). These are presented as indices relative to the baseline operation. Likely impacts of the management activities on each of the 10 environmental attributes are described on a scale from –3 (large negative impact) to +3 (large positive impact).

9.3 Methods

9.3.1 Property description

Pigeon Hole Station encompasses a land area of 1,833 km^2. The CSIRO Ord-Victoria survey (Stewart *et al*. 1970) recognised two major land types on Pigeon Hole (Wave Hill and Antrim) and four less common land types (Wickham, Ivanhoe, Gordon and Humbert). The most widespread land system, Wave Hill, occupies 56% of Pigeon Hole. This land system comprises cracking clay soils on undulating basalt plains supporting Mitchell grass and other grasses.

For the purpose of conducting the economic study, 6 scenarios have been developed to evaluate different grazing systems (continuous, wet-season spelling and cell grazing), different levels of utilisation, different paddock sizes, and increased numbers of water points.

In all cases, the scenarios have been applied only to the southern end of Pigeon Hole (Fig. 9.1), an area of approximately 384 km^2 or 21% of the total area of the property. The analysis treats this sub-area as if it were run as a single management entity, and the economic summary measures relate to that entity, rather than the actual property itself. The area is almost all comprised of the Wave Hill land system, and much of the area was used for the main experimental work.

Pigeon Hole is a breeding operation selling steers and heifers (i.e. heifers surplus to requirements for replacement breeders) at 18 months of age (weights of 340-360 kg). The total breeder herd on the property is approximately 8,000 head, with individual animals first entering the herd at 1.5 years and progressively culled from 8 years until all have been sold by 14 years. The bull percentage is 4% and branding percentage across the various age cohorts is approximately 85%.

For the economic analysis, the animal numbers on the sub-property were assumed to be in proportion to the carrying capacity of the whole property. For this purpose the relative carrying capacities of the different land types were assessed as 1.0 (Wave Hill), 0.6 (Ivanhoe), 0.48 Gordon and Humbert) and 0 (Antrim and Wickham). Using the areas of the land systems and these relative carrying capacities, the current operation would be equivalent to running the 8000 breeders on 1,097 km^2 of Wave Hill land system or 7.3 breeders per km^2. Applying this value to the 384 km^2 sub-property gives equivalent breeder numbers of 2803 – this has been rounded to 3000 for the analysis. When the bulls and their progeny to market age are included this gives the total number of livestock carried as 4680 adult equivalents (AE) or 12.2 AE/km^2.

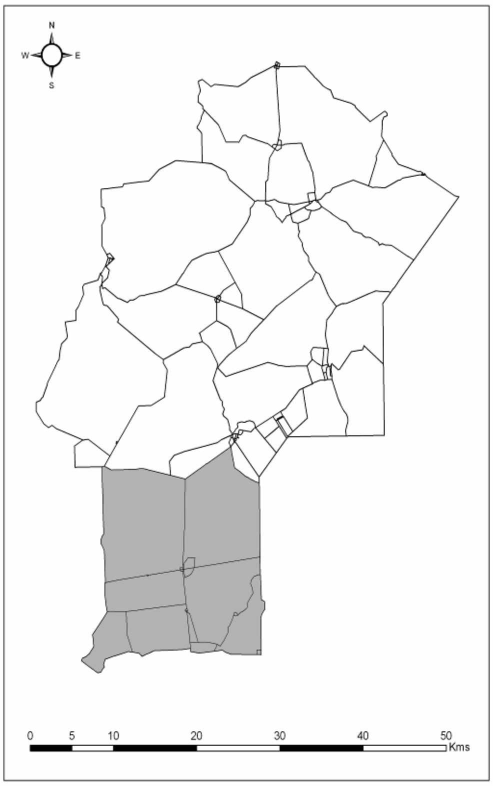


Fig. 9.1. Pigeon Hole Station showing the area (shaded grey) where the scenarios were applied.

9.3.2 Scenario 1 (Current management)

Scenario 1 (the base line under current management) is structured to approximately represent the management regime and land use on that part of Pigeon Hole before the present experiment was initiated. For this analysis, some small paddocks that existed on the holding have been ignored and the area is configured as comprising only 5 paddocks:

A - the original Villiers Paddock (approximately 111 km^2)
B - the original No. 13 Paddock (approximately 93 km^2)
C - the existing North Stevens Creek, South Stevens Creek and Drought Paddocks (approximately 90 km^2)
D - Racecourse Paddock and the small Delivery and Delivery Holding Paddocks (approximately 63 km^2)
E - Depot Paddock (24 km^2)

Water points are:

- Villiers Bore and trough supplying Paddock A;
- 4 Corners Turkeys Nest with troughs supplying Paddocks A, B, C and D;
- No. 8 Bore and troughs supplying Paddocks C and D;
- Racecourse Turkeys Nest and trough supplying D;
- No. 13 Bore and trough supplying Paddock B;
- No. 12 Bore and trough supplying Paddock B;
- A waterhole in the most easterly portion of Depot Paddock.

Cattle can walk up to 10 km from water and pasture use declines exponentially with distance from water as shown below. The “effective grazing area” in each paddock was calculated using total paddock area, the number and location of water points in the paddock, and the percentage use values with distance from water presented in Table 9.1. The effective grazing area for each paddock is presented in Table 9.2.

Table 9.1. Percentage use values with distance from water.

Distance from water (km)	Use (%)
0-1	100
1-2	80
2-3	65
3-4	50
4-5	40
5-6	30
6-7	22
7-8	15
8-9	10
9-10	5
>10	0

Table 9.2. Effective grazing area in each paddock and overall.

Paddock	Actual area (km^2)	"Effective area" (km^2)
A	110.7	54.9
B	94.5	53.1
C	90.8	29.6
D	63.3	37.9
E	24.3	13.1
Total	383.6	188.6

Thus the paddocks can be considered to be 49.2% effective. The area carries 4680 AE, so the baseline stocking rate for the area that actually can be grazed is assumed to be 25 AE/km^2, while the nominal stocking rate across the property is 12.5 AE/km^2.

A reasonable long-term annual pasture growth rate for the Wave Hill system at Pigeon Hole is 1900 kg/ha. Based on an AE consuming 8 kg DM/day and accessing the equivalent of 4 ha, this translates to an estimated annual utilisation of 38% of the herbage grown for this scenario.

9.3.3 Scenario 2 (Increased water points)

The availability of water supplies will generally determine where and when cattle can graze in the landscape. In extensive range situations where paddocks are large and permanent water is limiting, there are decreasing levels of grazing with distance from water points. Installing new water points can provide extra grazing opportunity by:

(a) allowing animals to access previously inaccessible areas that were too far distant from existing water supplies for animals to reach them; and
(b) decrease the distance from water within previously accessible areas so that grazing on these areas increases.

In this scenario, additional water points are installed with the aim that little or no land is more than 5 km from a water point. The new water points were assumed to have been installed on fence-lines, where possible, so they could serve two paddocks. An additional 5 water points were installed without changing fences and paddock layout. With this water point distribution, 99.3% of the existing paddock area is assumed to lie within 5 km of a water point of which 42% is within 2 km of a water point.

The five new water points were located as follows:

On the fence between paddocks A and B towards the northern end
On the fence between A and C towards the western end
On the fence between B and D towards the eastern end
In the south-west portion of paddock D
In the south-west portion of paddock E.

This scenario reduces the distance to water and increases the effective grazing area from 188.6 km^2 to 252 km^2 or 65.7% of the total. Cattle numbers were, accordingly, increased (from 4680 AE to 6240 AE) to keep the stocking rate per effective area constant at 4.0 ha/AE, but with no change assumed to per head animal production rates.

9.3.3.1 Capital costs

Provision of new water points involves a source of water (dams, bores), pumps (windmill, motor, electrical, solar), tanks, pipe, fittings and troughs, plus labour to install. For this scenario, we have assumed that the necessary tanks, troughs and associated facilities required to establish a new watering point can be provided through connection to existing bores. No allowance is made for the drilling and equipping of additional bores. There is no additional fencing associated with this scenario. The estimated cost per watering point is $20,000.

9.3.3.2 Annual operating costs

All items in the supply of water require maintenance and repairs. A depreciation charge on the new watering points of 7.5% of the installation cost has been applied to cover maintenance of this equipment.

9.3.4 Scenario 3 (Reduced paddock size)

The 5 large paddocks from the baseline case were subdivided, so that paddocks were generally between 20 and 30 km^2 in area. This is slightly smaller than the recommendation from the grazing distribution study for paddocks of between 30-40 km^2, although the recommendation was based on a compromise between reducing paddock size to improve grazing distribution and the financial cost of creating smaller paddocks. This scenario involved sub-dividing Paddock A into 4 new paddocks, B into 3 paddocks, and D into 2 paddocks. The distance of new fencing required to effect this scenario was assumed to be 37.5 km. An extra 3 water points were also installed to ensure that all paddocks have at least one watering point. As is the case with Scenario 2, these additional watering points have been placed on fence-lines so they can water more than one paddock. Using the same water to grazing distance ratios as for Scenario 1, these changes increased the effective area to 217.9 km^2 or 56.8% of the total. Given that original water points were kept as part of this scenario, the final distribution of water points is not optimal – if the water points were centrally located in each paddock then the effective area would be 262.6 km^2 or 68% of the total area. Cattle numbers were increased (from 4680 AE to 5400 AE) in order to keep the stocking rate per effective area constant, but with no change to per animal productivity rates.

We have chosen to assume that fencing has no direct impacts on animal production *per se*. This is not strictly correct, but impacts of installing fencing will depend on the land types and areas that are excluded from, or added to, a grazing area. Since responses may be positive or negative, and are so dependent on the actual situation, it is difficult to describe a general situation.

9.3.4.1 Capital costs

The installation of fences and water points involves the purchase of materials and labour to erect the fence and install water points. The estimated cost per watering point is $20,000, and the cost of new stock fencing erected on the property is $2400 per km.

9.3.4.2 Annual operating costs

Both fences and water points require maintenance and some repairs. Depreciation charges on the new watering points and fencing of 7.5% and 5% respectively of the installation cost has been applied to cover maintenance of these items.

9.3.5 Scenario 4 (Grazing systems – wet season spelling)

In this scenario 25% of the area is assumed to be rested from grazing during the wet season each year. During this time all of the animals graze on the remaining 75% of the area, increasing the grazing pressure on the remainder for this period. The area being rested is rotated around the paddocks, so that all paddocks are spelled once in four years. There are no changes to water points or paddock numbers, so the effective area is unchanged from Scenario 1.

There have been many claims for increases in animal production with new grazing systems and much research and experience showing no or only small responses when the only change that has been made is a change of grazing system. Given this diversity, we have chosen to set no changes to liveweight gain. However, grazing systems may be important for maintaining or improving pasture composition and condition that will influence long-term carrying capacity. This has been modelled by increasing carrying capacity (i.e. number of animals per unit of effective area) by 10% (from 4680 AE to 5190 AE) with this scenario.

9.3.5.1 Capital costs

More intensive grazing systems will usually require additional fencing and watering points, but none have been specifically included in this scenario, as these costs will depend strongly on the individual situation.

9.3.5.2 Annual operating costs

An extra muster is required to collect the animals from the paddock(s) to be spelled and to distribute them to the other paddocks. We assume the animals are returned to the paddock during the normal post-wet season muster.

9.3.6 Scenario 5 (Grazing systems – cell grazing)

This scenario has been based on having 200 paddocks of approximately 200 ha each, with 8 paddocks being watered from each water point. Assuming each of the 7 existing water points can each serve 8 paddocks, this required an extra 18 water points. With this layout almost all of the area is within 2 km of water and the effective grazing area is increased to 80.8%.

There is continuing debate about the impacts of cell grazing on animal production and impacts are likely to vary between situations with both increases and decreases possible. We have chosen to increase carrying capacity on the effective grazing area by 10% and annual liveweight gain by 10 kg with no change to branding percentage. Cattle numbers were increased (from 4680 AE to 8530 AE) to allow for the dual effect of both the increase in effective grazing area and the stocking rate across that area. Note that almost all of this increase is due to the increase in effective grazing area due to the increase in water points and paddocks, and only a small part is due to this assumed impact of cell grazing.

9.3.6.1 Capital costs

This scenario assumes the need to install approximately 4km of new fencing per paddock, to give a total fencing requirement of 800 km (200 x 4 km). The actual costs of constructing the cells is hard to estimate with any accuracy, as the task will vary considerably with the actual layout, laneways and siting of existing fence-lines. There will also be a requirement to augment the watering facilities with 18 new watering points. We have assumed that 4 of the new watering points will require the drilling and fitting of 4 new bores, while the remaining 14 watering points will be drawing water from existing bores.

9.3.6.2 Annual operating costs

Additional labour to manage the cell grazing systems has been costed at one full time adult worker employed at an annual cost of $40,000. An additional 4WD vehicle has been employed at a replacement cost of $60,000. Depreciation charges on the new watering points, additional fencing and 4WD vehicle of 7.5%, 5% and 15% respectively of the installation or acquisition cost has been applied to cover maintenance of these items.

9.3.7 Scenario 6 (Increased utilisation)

In this scenario animal numbers are increased by 50% (from 4680 to 7000 AE) over Scenario 1, but with no changes to water points or paddock numbers so the effective grazing area remains unchanged. This scenario would result in an annual pasture utilisation rate of over 50% across the area used by cattle.

As stocking rate increases, liveweight gain per animal decreases. Jones and Sandland (1974) have shown the relationship is approximately linear for a particular system, but the rate of decline varies between systems. There is insufficient data to provide to provide an accurate value for the changes, but we have assumed annual liveweight gain per animal declines by 20 kg, and the average branding percentage across the breeding herd declines by 5% with the 50% increase in animal numbers. The decline in annual liveweight gain of 20 kg per animal at this higher utilisation rate is consistent with the findings from the 43% utilisation treatment at Mt Sanford.

9.3.7.1 Capital costs

No additional capital costs have been included for changes in stocking rates. We have assumed that increased numbers come from stock bred on the property, and the larger herd size is reflected in the capital value of the property and hence affects return on capital.

9.3.7.2 Annual operating costs

No specific additional or reduced operating costs have been included, but these situations are covered in the financial model where operating costs are directly related to herd numbers. If numbers increase, the variable costs also increase commensurately, and vice versa.

9.3.8 Economic assessment

As noted in the Introduction, for the purposes of conducting the economic assessment, the portion of Pigeon Hole on which the experiments were largely sited has been assumed to represent a stand alone property. The financial performance of this property under the 6 scenarios was assessed using an economic model of a beef enterprise (MacLeod and McIvor 2006) that was calibrated for the Pigeon Hole case. The production and financial impacts were described in terms of:

(i) animal numbers - carrying capacity/stocking rate
(ii) animal performance - annual liveweight gain, branding percentage and mortality of breeders and dry stock

(iii) costs
  (a) initial capital costs
  (b) annual operating costs (including treatment reinforcement etc)
(iv) returns – based on animal performance [(ii) above] and market prices.

As mentioned earlier, the comparison is of two static situations [before (Scenario 1) and after implementing the change (Scenarios 2-6)], not of what happens during the period of change. The impact of adopting the management change associated with each Scenario on enterprise profitability is assessed in terms of changes to gross margins, return to capital etc. The initial capital costs associated with a given management option were added to the capital value of the property – they do not normally influence the running costs of the property, but are reflected in returns to capital investment. However, for the present analysis, an annual operating cost that is based on the initial capital outlay has been included in the enterprise overhead costs as an incremental depreciation charge.

9.3.9 Ecological health assessment

The current status of ecological health was assessed against 10 attributes (Table 9.3) using methods described in McIvor and MacLeod (in preparation). Briefly each of the ten attributes was given a subjective score between -3 (very poor condition for that attribute) and +3 (very good condition for that attribute). For example, for Attribute A1 Soils and hydrology, land with a rating of -3 (very poor condition) would show some or all of the following - saline outbreaks; severe erosion (large sheeted areas, gullies); compacted soils; soils with poor surface condition (hard, sealed); low pH; restricted rooting depth; low infiltration and high runoff; land with a rating of 0 (average condition) would show some or all of the following - no salinity present; may be minor sheet erosion but no gullies; soil surface in moderate condition; pH suitable; moderate infiltration and low runoff; and land with a rating of +3 (very good condition) would show some or all of the following - no evidence of salinity or erosion; surface soil friable with high infiltration and little runoff; soil pH in normal range; no restrictions to plant roots.

The summed values for Component A and Component B (see Table 9.3) were expressed as percentages of their maximum values to provide ratings for the two components.

Table 9.3. Components and attributes of ecological health.

Component A: Maintenance of ecosystem function and stability	
Attribute A1	Soils and hydrology
Attribute A2	Pastures (cover and composition, perennial grasses)
Attribute A3	Weeds (species, density/cover)
Attribute A4	Feral animals (species, density)
Attribute A5	Riparian areas
Attribute A6	Atmosphere (greenhouse gas emissions)
Attribute A7	Fire regime
Component B: Conservation of biodiversity	
Attribute B1	Native vegetation communities
Attribute B2	Native plant and animal species
Attribute B3	Significant sites and habitats

The impacts of the revised management scenarios on the ecological health of the affected area were predicted using the same ten attributes. The impact of the management change of an attribute was given a value between -3 (large negative impact) and +3 (large positive impact) where 0 = no impact. The management impact score was then added to the initial value to give a revised value for the particular scenario with the restriction that the final score remains between -3 and +3.

9.3.10 Trade-off assessment

The ecological and economic assessments were considered together for each scenario.

9.4 Results and Discussion

9.4.1 Environmental assessments

The environmental assessment of the current management (Scenario 1) is shown in Table 9.4, the environmental changes with the other five scenarios are discussed below, and summaries of the environmental scores of each scenario are given in Table 9.5.

Table 9.4. Environmental assessment of portion of Pigeon Hole under current management (Scenario 1).

Attribute	Comments	Score
A1 Soils and hydrology	There is no evidence of major soil problems but there have been some small changes after more than a century of pastoral use.	+1
A2 Pastures	The Mitchell grass content of the pastures has declined and *Chrysopogon fallax* is now the major perennial grass. Some areas are dominated by annual sorghum. Ground cover levels are high.	-1
A3 Weeds	There is some invasion/regrowth of native woody plants and small amounts of herbaceous weeds.	+2
A4 Feral animals	There are no feral animal problems.	+3
A5 Riparian areas	The only riparian area on this portion of Pigeon Hole is the Victoria River running through the south-east corner. This area has suffered from past grazing with some sediment in the water, bank erosion and loss of the herbaceous layer. There are drainage lines across the area but none of these could be considered to be riparian areas.	-1
A6 Atmosphere	There is little regrowth, animals are grazed at stocking rates judged sustainable by property management, fires are relatively infrequent, but there are some emissions.	+2
A7 Fire regime	There is little burning of this area although some accidental fires occur.	+3
B1 Native vegetation communities	There has been no clearing; the Wave Hill land system is widespread but there is little of it in reserves; some loss of important grass species (Mitchell grass) and increase in annual sorghum; no significant restricted native vegetation communities.	+1.3
B2 Native plant and animal species	There are no threatened, endemic or culturally significant species. Among the grasses there has been a shift in the decreaser/increaser balance towards the increasers.	+0.3
B3 Significant sites and habitats	There are no Ramsar sites, no wetlands on this part of Pigeon Hole, no threatened communities, no other special sites; and Pigeon Hole is not in one of the 15 national biodiversity hotspots.	0

For Scenario 2 (additional water points), there was no change in grazing pressure but with the more uniform distribution of grazing there was some improvement in the pastures and the decreaser/increaser balance. There was some increase in weeds in the sacrifice areas around the new water points. It is possible there could be some loss of grazing sensitive species in areas that were previously distant from water points but this has not been considered. The increase in cattle numbers results in an increase in greenhouse gas emissions.

For Scenario 3 (more paddocks), the increase in cattle numbers results in an increase in greenhouse gas emissions but otherwise there were no changes.

For Scenario 4 (wet season spelling), the pastures improve and are healthier but the increase in cattle numbers results in an increase in greenhouse gas emissions.

For Scenario 5 (cell grazing), the responses are similar to Scenario 4 but with a greater increase in cattle numbers.

For Scenario 6 (increased utilisation), there is a decline in pastures, vegetation condition and soils, increases in weeds and greenhouse gas emissions, and some deleterious impacts in the riparian zone from the large increase in cattle numbers.

Table 9.5. Summary of initial environmental conditions (Scenario 1) and environmental conditions with five management scenarios.

Attribute	Scenario					
	1	2	3	4	5	6
A1. Soils	+1	+1	+1	+2	+2	0
A2. Pastures	-1	0	-1	+1	+1	-2
A3. Weeds	+2	+1	+2	+3	+3	+1
A4. Feral animals	+3	+3	+3	+3	+3	+3
A5. Riparian areas	-1	-1	-1	-1	-1	-2
A6. Atmosphere	+2	+1.2	+1.6	+1.7	0	+0.8
A7. Fire regime	+3	+3	+3	+3	+3	+3
Total Component A	**+9**	**+8.2**	**+8.6**	**+12.7**	**+11**	**+3.8**
B1. Communities	+1.3	+1.3	+1.3	+1.5	+1.5	+1.2
B2. Species	+0.3	+0.5	+0.3	+0.8	+0.8	-0.3
B3. Sites	0	0	0	0	0	0
Total Component B	**+1.6**	**+1.8**	**+1.6**	**+2.3**	**+2.3**	**+1.1**
Ratings						
Component A	43	39	41	60	52	18
Component B	18	20	18	26	26	12
Overall	**31**	**30**	**30**	**43**	**39**	**15**

9.4.2 Economic assessment

The baseline productivity (measured in total stock numbers as AE) of the enterprise is presented in Table 9.6, along with the changes to stock numbers carried and the financial impact associated with the implementation of the management changes underpinning the other five scenarios. The financial information is presented in the form of index numbers, which capture the relative change in the magnitude of the different stock and financial metrics for each scenario from that of the baseline case (Scenario 1 = 100). The use of indices was justified on the basis of making the relative differences between the various scenarios more readily apparent, and also to give consistency with the use of indices and scores in the ecological assessment.

Table 9.6. Summary of initial economic assessment (Scenario 1) and economic values for five management scenarios presented as indices (Scenario 1 = 100).

Attribute	Scenario					
	1	2	3	4	5	6
Stock numbers (AE)	4,680	6,240	5,400	5,190	8,530	7,000
Stock numbers	100	133	115	110	182	150
Total revenue	100	134	115	111	187	138
Total variable costs	100	133	116	131	198	149
Total gross margin	100	134	116	106	184	136
Overhead costs	100	143	126	111	344	150
Net profit	100	130	110	106	170	130
Return to capital	100	121	107	100	100	114
Capital value	100	117	109	105	172	123

The baseline case runs 4,680 AE. Each of the management scenarios involves an increase in the total number of stock carried, ranging between 10% for the wet season spelling Scenario 4 (due to the better carrying capacity of the spelled pasture) and 82% for the cell grazing Scenario 5 (mainly due to the greatly expanded area reached for grazing plus a small assumed effect of cell grazing per se).

The total revenue, total gross margin, and net profit estimates for each of the Scenarios 2 to 6 also exceed the baseline case. There is a gain in net profit for each of the options (Scenarios 2 to 6), ranging from 6% to 70%. The gain for the wet season spelling option (Scenario 4) is fairly modest (6%). The last result stems from a significant increase in variable costs (31%) attributed generally to the need for an additional muster, as well as husbandry and marketing costs associated with running the additional stock.

The largest gain in projected profitability (70%) comes from the “cell grazing” option (Scenario 5) which stems from the much increased number of stock carried (82%) with commensurate increases in total revenue and total gross margin. As mentioned earlier most of the increase in stock numbers was due the increased water points and paddock numbers not cell grazing per se. The high labour and capital costs associated with the cell grazing option are reflected in the substantially increased levels of variable (98%) and overhead costs (344%). Nevertheless, net profit is increased by 70% relative to the baseline case (Scenario 1). However, the rate of return on total capital investment is essentially the same as that of the baseline case (~14%) because the total investment (including livestock capital and new infrastructure) involved with Scenario 5 has increased by 72%.

The highest gain in capital efficiency (21%) is for the Scenario 2 option of increasing access to grazing through the provision of additional watering points. While this option increased stock numbers carried and net profit by approximately 30% relative to the baseline case (Scenario 1), the gain was reaped with only a 17% increase in the level of total capital investment, most of which is the additional livestock.

For the more exploitative option that involved increasing pasture utilisation by 50% through raising stocking rates (Scenario 6), the projected gain in net profit is 30% above the baseline case (Scenario 1), despite the assumed deterioration in per animal productivity and herd reproductive performance. It is likely there would be a long-term decline in carrying capacity at this high utilisation rate which would reduce the returns for this scenario.

9.4.3 Environmental-economic trade-offs

The tradeoffs associated with the various management options are summarised as follows:

Scenario 1 (baseline) - the baseline assessment for the enterprise reflects reasonable environmental conditions for the property; but there are some deleterious effects projected from a previous history of land use. This is reflected in the negative ratings for the pastures and riparian areas and the low score for soils. The calculated long-term utilisation rate for this scenario is 38% and the deleterious pasture changes are consistent with this level being above accepted sustainable levels. However, it is quite a profitable operation with reasonable returns to capital investment.

Scenario 2 (more watering points) - the number of livestock carried has increased by 33% with a commensurate increase in net profit. However, there is a projected small environmental decline (overall score falling from 31 to 30), suggesting that the trade-off for this scenario is a relatively modest one.

Scenario 3 (more paddocks) - the increase in number of livestock carried is relatively modest (15%), as is the projected increase in net profit (10%). The projected ecological impact is also relatively small (overall score falling from 31 to 30).

Scenario 4 (wet season spelling) - the 10% increase in livestock numbers carried has given a small increase in net profit (6%). However, the projected environmental impact is quite significant (overall score rising from 31 to 43), largely due to assumed improvements in the pasture and associated changes in soil condition.

Scenario 5 (cell grazing) - there is a substantial increase in livestock numbers carried (82%), and a significant increase in net profit (70%). Nevertheless, the scenario also carried a large increase in overhead costs (244%) and a substantial increase in capital required to effect the change (72%). There is an improvement in ecological condition (overall score increase from 31 to 39), largely due to improvements in pastures and soils. However, this was partially offset by increased greenhouse gas emissions associated with the large increase in livestock numbers.

Scenario 6 (increased utilisation) - the doubling of livestock numbers carried has increased net profit by 30%. However, there are substantial environmental costs (overall score declines from 31 to 15), due to deleterious impacts projected on the pastures, soils and the riparian areas, as well as increased greenhouse gas emissions.

9.4.4 General comments and comparison with field study

Most of the environmental attributes in the baseline Scenario 1 were given values below the maximum to reflect some deleterious changes with current management. The current utilisation levels based on the assumptions in the analysis was estimated to be 38% across the area used by cattle. This obviously exceeds the 20-25% recommendation for long-term sustainability that emerged from the Mt Sanford study, so that the deleterious ecological consequences (and long-term effects on livestock production) may well be higher than the scenario suggests. It should be noted however that no marked deleterious effects of utilisation rates in excess of 20% were observed in the Pigeon Hole study, casting some doubt as to the level of utilisation that is sustainable in the long term.

The estimate of 38% utilisation under current management is also higher than earlier estimates that suggested current utilisation rates were in the order of 10% (and were the foundation of this study of the potential for sustainably increasing stocking rates). However, this discrepancy probably arises because the latter figure was calculated as an average over all land, rather than only the land accessible to cattle. In the scenarios explored here only 50% of the land was considered accessible to cattle under the ‘current’ scenario due to the sparseness of water points. When taking all land into account, the utilisation rate in the current management scenario would be 19% of all feed grown. This observation highlights the importance of distributing grazing pressure broadly across the land.

The conclusion that Scenario 2 (more water points) resulted in grazing pressure being more widely distributed across paddocks (if not more uniformly distributed) was consistent with the findings from the GPS collar observations. Unlike the suggestion from the scenario, the experimental work failed to detect any significant decline in pasture condition overall as a consequence of improved grazing distribution. However, new waters did result in the development of new piospheres (areas of degradation), with no apparent improvement in pasture condition around older established waters.

Results from Scenario 3 (more paddocks) in which the number of paddocks was increased (i.e. paddock size reduced) were broadly consistent with the overall observations of the Pigeon Hole study. Reducing paddock size allowed a modest increase in the number of cattle carried, with little environmental effect in the short term. The longer term consequences remain unknown.

Wet season spelling failed to result in improved land and pasture condition in the field study, although more cattle were carried in this treatment (pasture utilisation overall averaged approximately 22%) than the commercial operation. This contrasts with Scenario 4 which suggested a marked improvement in land condition as a result of wet season spelling. Other studies (e.g. Ecograze; Ash *et al*. 2001) have suggested that wet season spelling can lead to improved pasture condition at least when applied annually; also, Ecograze did not consider the impacts or costs of needing to accommodate cattle during the spelling period. It is possible that in the Pigeon Hole study improvement in the pasture may have occurred under wet season spelling over the longer term.

Conclusions from the cell grazing scenario (5) which indicated this was more profitable contrasted with those from the actual field study. Although more animals were run and more beef was produced per area of land in the field study, the high overhead and running costs made cell grazing a less profitable system. Also, high animal density, and cattle management generally, during the wet season proved costly to pasture/soils and labour. This suggests the costs used in the scenario were too low. There were also no effects on pastures detected in the field study, whereas the scenario assumed improved pasture and soil condition under cell grazing. The field study results are consistent with work overseas and in Australia regarding the benefits of cell grazing per se. It is important to note that the increased carrying capacity for this scenario was largely due to the additional infrastructure and not to cell grazing per se.

Increased pasture utilisation (i.e. Scenario 6, doubling livestock numbers so pasture utilisation was above 50%) resulted in marked deleterious effects on pastures, soils and riparian areas but increased profits. While we detected no adverse effects on the pasture at the highest utilisation rate (32%) in the field study at Pigeon Hole, negative effects were recorded at Mt Sanford at a utilisation rate of 43%. This level of utilisation also reduced branding rates at Mt Sanford by approximately 10%, compared with 5% used in the scenarios. Thus the short-term profitability of higher utilisation rates may be lower than suggested by the scenario.

It is important to remember in all these comparisons that the experimental studies at Pigeon Hole ran for only four years and that the growing seasons during this period were favourable. It is possible that a different picture may have emerged in the field study over a longer time frame.

10 Synthesis

Intensification of extensive beef enterprises in northern Australia's tropical savannas aims to increase productivity (largely by increasing the number of stock carried) and reduce running costs per head to help maintain or increase business profitability. This study suggested that an intensified system can generate a greater return on invested capital than a conventional, undeveloped commercial system.

However, intensification involves considerable financial and ecological risk. Before embarking on a program of intensification pastoralists must consider a range of factors and plan carefully to minimise these risks. Our analysis of economic and environmental tradeoffs (Chapter 9) provides a framework for considering these risks. Pastoralists must firstly consider the suitability of their property for development. They should also have a good understanding of the various components and management options in an intensified production system and how they interact to affect livestock production, economic performance and land condition. The effect on other ecological values such as biodiversity should also be considered and provisions made to protect these values.

This project examined the key elements of an intensified production system through experimental studies at the commercial scale, and the findings are summarised below. Factors that will affect the suitability of properties for intensification are described later.

10.1 Requirements for successful intensification

Sustainably intensifying the production system on northern beef enterprises will depend on putting in place a system of management that overcomes certain limitations in current approaches to grazing management, and understanding the ecological limits of the land for grazing livestock. The following questions are critical to the success of efforts at intensification:

- What is the optimum pasture utilisation rate that gives a balance between good levels of livestock production in the short term, while maintaining land condition and productivity in the long term?
- What extent and configuration of infrastructure developments (i.e. fences and water points) are the most appropriate to distribute grazing more widely over the landscape to improve the effective use of pasture resources?
- What is the most appropriate grazing system (or systems) in terms of livestock production, feasibility, cost and ecological sustainability?
- What management or other provisions are required to protect biodiversity values under an intensified production system?
- How can the efficiency of managing an intensified enterprise be improved to reduce running costs per head?

These elements are interdependent – each must be addressed for intensification to be successful. For example, recommended pasture utilisation rates will not be achieved for the majority of the pasture unless strategies are put in place to improve grazing distribution, so grazing pressure is spread more uniformly across the landscape. Putting these elements together in a system that is workable at the commercial scale is the challenge of sustainable intensification of beef production in northern Australia's savanna rangelands, and this challenge was the focus of this study. While the project was in the VRD, general principles can be extracted from the results to guide development elsewhere.

10.1.1 Safe pasture utilisation rate

The pasture utilisation study in small, experimental paddocks at Mt Sanford suggested that an annual utilisation rate of about 20% is appropriate on the black cracking clay soils of the Wave Hill land system (on which both the Mt Sanford and Pigeon Hole studies occurred), providing there is relatively even grazing distribution. At Mt Sanford, stocking at this utilisation rate provided good levels of livestock production whilst maintaining land condition. Palatable perennial grass populations were maintained at this utilisation rate for the period of the study (14 years), yield in May was sufficient to implement prescribed burning, and ground cover in the late dry season each year remained above the minimum level (40%) required to protect the soil from erosion in early wet season storms.

At pasture utilisation rates of 20%, individual animal production is close to its peak. The performance of individual animals declines as pasture utilisation rates increase. Although livestock production per land area can be increased in the short-term by using pasture utilisation rates above 20% (see Fig. 10.1 and Fig. 10.2), the risk of land degradation increases. Running costs also increase disproportionately relative to returns as the number of head increases.

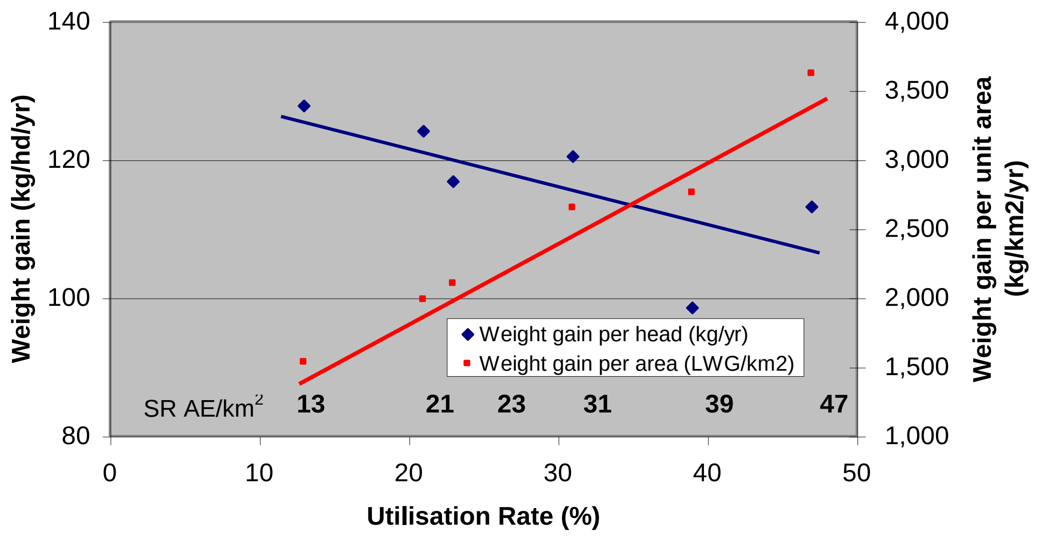


Fig. 10.1. Liveweight gain per animal and per unit land area in the Mt Sanford study.

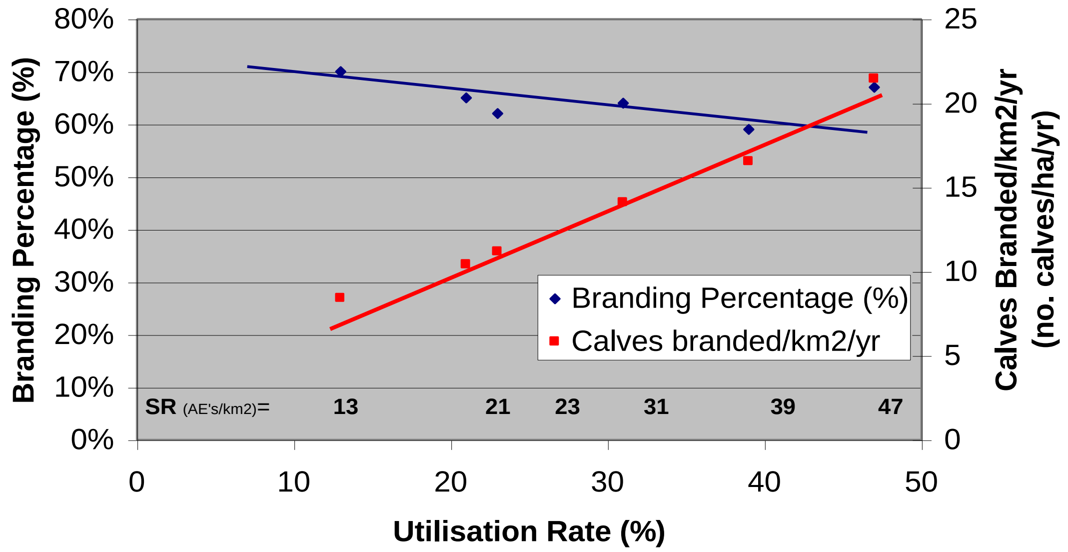


Fig. 10.2. Branding percentage and calf production per unit land area in the Mt Sanford study.

The aim of the utilisation study at Pigeon Hole was to assess whether a similar utilisation rate was appropriate in larger commercial paddocks. However after four years no clear differences were apparent amongst a range of utilisation rates in terms of effect on land condition or livestock production.

Whilst it could be argued that the lack of differences amongst utilisation rates at Pigeon Hole suggests that a utilisation rate above 20% would be safe, this is unlikely to be the case. Seasonal conditions during the few years of the Pigeon Hole study were reasonable to good, and no very dry years were encountered. Over the longer term below average seasons will occur and it will be in these years that it will be particularly important that annual utilisation rates do not exceed 20%, to avoid causing land degradation. For land in poor condition and less resilient land types a lower utilisation rate is also warranted. A recommended rate of 20% is consistent with findings elsewhere, falling in the middle of the range of utilisation rates suggested for other land systems in northern Australia.

The recommended annual utilisation rate of 20% should be viewed as the long term carrying capacity of the land. Pastoralists should therefore aim to carry the number of stock to achieve this utilisation rate in most years. To estimate stocking rates to achieve this will require knowledge of the average annual pasture production for a given site. The alternative approach of attempting to achieve a utilisation rate of 20% in a given year by adjusting cattle numbers to match pasture growth in that year does offer the potential for taking advantage of the more abundant pasture growth in above average seasons. However, this depends on getting good estimates of pasture availability and being able to readily adjust stocking rates, making this approach more demanding of management and more difficult to achieve. Modelling of pasture growth at Mt Sanford and Pigeon Hole suggests that the stocking rate to achieve 20% utilisation each year will generally vary from 15-23 AE/km^2 at Mt Sanford and 10-18 AE/km^2 at Pigeon Hole, depending on the season.

10.1.2 Paddock configuration

Achieving relatively even grazing distribution across the landscape is crucial to getting effective use of the pasture. This will benefit both livestock production and land condition compared to situations where distribution is poor. Paddock configuration has a strong influence on grazing distribution. Important considerations in this context are:

- paddock size
- the number of water points
- the spacing between water points, and
- the number of head per water.

Although this study showed no consistent difference amongst the various paddock configurations in terms of pasture productivity, pasture composition, or individual livestock production, the studies with the GPS collars provide some insights into the effectiveness of the alternative configurations in improving cattle distribution.

Reducing paddock size and installing more water points both improved the distribution of grazing across the landscape, effectively increasing the area of pasture that is available to the cattle. Reducing paddock size was generally more effective than adding more water points to large paddocks in improving overall use of the landscape. This is because in large paddocks with multiple waters cattle have greater opportunity to choose where they graze and which water points they use. Thus, they can choose to avoid large sections of these paddocks if they are not preferred areas, and concentrate on areas they do prefer – which will then be subject to overgrazing. Smaller paddocks partly overcome this issue because the cattle are confined to smaller areas.

Deciding on the optimum paddock configuration for a particular situation will need to consider the cost of infrastructure developments and the likely benefits, since the cost of the infrastructure for smaller paddocks and additional water points quickly becomes prohibitive with more intensive development. Given that paddock configuration appeared to have no effect on individual livestock production or on pasture condition, the decision about infrastructure development options comes down to a trade-off between the improvement in grazing distribution expected and the cost of the infrastructure needed. The capacity for increasing stock numbers following development should also be considered. The analysis of economic and environmental tradeoffs suggested that installing more water points is likely to generate the greatest gains in return on capital with the smallest environmental trade-off.

Based on the findings of this study, a paddock of 30-40 km^2 with two well-separated water points appears to offer a good compromise between improved grazing distribution and the cost of the infrastructure. In this study, this configuration resulted in approximately 81% of the land within the paddock being ‘used’ by the cattle herd, as measured by the combined cattle home ranges. Although, surprisingly, this was less than for a similar size paddock with a single water point (83% use), the benefit of the second water point is that it reduces the number of cattle on each water. At the stocking rates used in this study (equivalent to achieving an annual utilisation rate of 20%), this would mean there would be about 300 head per water point in a paddock with this configuration. In this study the 34 km^2 paddock with a single water point had the largest degraded ‘sacrifice’ area around the water point of any of the study paddocks.

Although the data indicate 81% of a paddock with this configuration would be used by cattle it is important to realise that uneven grazing does occur within these developed paddocks. Consequently other management tools such as the strategic placement of lick blocks, and the strategic use of fire to manage pasture structure should also be used to further improve grazing distribution.

In some cases it may not be feasible to reduce paddock size to the extent recommended, in part because of the cost. In larger paddocks where it is not feasible to reduce paddock size installing more waters will provide some improvement in grazing distribution. Ideally waters should be sited approximately 5-6 km apart (giving a grazing radius of 2.5-3 km), to ensure effective use of most of the land. This is roughly equivalent to allowing one water point per 20-25 km^2 of land. However, with this configuration attempts should be made to ensure the cattle in the paddock are split evenly amongst the water points to avoid high numbers on particular water points. Limiting the number of head per water point to approximately 300 should help limit the degradation that occurs around each water point and help to maintain productivity in the short and longer term. While adding more waters to large paddocks will improve grazing distribution, managers in the VRD should nevertheless aim for paddocks not exceeding 50-60 km^2 to make the most of available forage and to maintain some control over grazing distribution.

Naturally these recommendations should be seen as guidelines rather than as a strict recipe for property development. The above recommendations represent a high level of development compared with the situation currently on most properties in the VRD, and the cost for this level of development may be prohibitive. The recommendations will need to be adapted and fine-tuned to suit the particular circumstances on a given property. The economic costs and benefits of different levels of development should be evaluated for each individual property.

10.1.3 Grazing system

Although set stocking (where paddocks are stocked continuously with stocking rates remaining approximately the same in most years) is the most common grazing system in the VRD, there has been much interest in recent years in various alternative systems. These alternatives include variable continuous stocking and systems that involve rotation of livestock around a series of paddocks that are generally smaller than average so that paddocks are periodically rested from grazing. Such systems are often promoted as offering a number of inter-related benefits:

- improved grazing distribution;
- better land condition (in particular the abundance and productivity of palatable perennial grasses);
- sustainable increases in pasture utilisation rates (i.e. stocking rates);
- increased livestock production.

To implement these alternative systems usually requires investment in additional infrastructure (smaller paddocks and more water points), which increases the cost of implementing these systems. Most of the systems also have higher labour requirements because of the need to move cattle between paddocks and maintenance of the additional infrastructure.

Our research suggested that none of the grazing systems that involved rotation and resting offered benefits in terms of financial performance or pasture condition, although annual liveweight gain was slightly greater under wet season spelling. However it is not clear if this increase under wet season spelling can be attributed to the grazing system or instead was an artefact of the study paddock. Because of the increased costs, the economic performance of these systems was worse than the set stocking treatment in this study. The results suggest that even when paddock size is reduced to improve grazing distribution, there is no advantage to be gained from using a rotational system. This was largely supported by the analysis of economic and environmental tradeoffs, where scenarios involving wet season spelling and cell grazing showed no improvement in return on capital compared with current practice, although the former produced a substantial environmental benefit through improvements in pastures and soils.

Set utilisation (where paddocks are grazed continuously but are adjusted each year to achieve a set utilisation rate) at a comparable annual utilisation rate (in this case using the U25% paddock which averaged 19% annual utilisation) marginally outperformed set stocking (21% utilisation) in financial returns, with a return on invested capital of 8.7% compared to 8.1%. It therefore also outperformed the other systems. The reason for this small advantage arising from set utilisation was not clear, since the average stocking rate was the same as for set stocking. It may have been a consequence of the inherent characteristics of the respective paddocks.

10.1.4 Biodiversity

Extensive pastoral systems based on native vegetation support much of northern Australia's biodiversity resources, and pastoral management has an important role in biodiversity conservation in this region. This is particularly so as many of the more productive ecosystems are very poorly represented in conservation reserves, and many native species are found only in these habitats. While the maintenance of good pastoral land condition will be sufficient to protect many native species, previous studies in a variety of rangelands have shown that a proportion of species (of the order of 20%) are 'decreasers' – that decline with increasing grazing pressure. Areas with no, or only very light, grazing form a refuge for the most grazing-sensitive of these species.

An intensified production system has potential to adversely affect biodiversity values, and this risk will increase as the proportion of the landscape under intensified use increases. An overall increase in pasture utilisation is likely to further suppress the populations of decreaser species, and possibly affect a larger number of species. Increasing the number of water points, while improving grazing distribution, will reduce or eliminate the refuge areas for the most grazing-sensitive species. Additionally, the spread of water points may facilitate the spread of predators (such as feral cats), pests such cane toads, and 'weedy' increaser species (such as galahs) that may compete with other native species. Management specifically directed toward maintaining biodiversity values may therefore be required in intensified production systems.

A total of 223 plant, 119 bird, 30 reptile, 8 native mammal and 76 ant species were recorded from sample sites within the grazing trial at Pigeon Hole. This assemblage is generally typical of black-soil grasslands in northern Australia, but includes a number of rare or poorly known species, and some species found only in the VRD.

Within the 5 years of the study (2003-2007), there was no obvious effect of different pasture utilisation levels, or different grazing systems on the biodiversity within the paddocks. A small proportion of species showed significant changes in abundance over time, but this was in idiosyncratic, rather than consistent, patterns amongst treatment paddocks (and may reflect patchiness in grazing intensity even within small paddocks). A similar result was found at Mt Sanford, where there was no significant effect of the different pasture utilisation levels on plant and bird richness or composition across 3 years of sampling (2002, 2003 and 2006).

These results are consistent with other evidence that black-soil grasslands are one of the ecosystems in northern Australia most resilient to the impacts of grazing on biodiversity. It also meshes with other results from Pigeon Hole that found no consistent changes in land condition or pasture composition in the various utilisation or grazing systems paddocks. However, it is very important to note that changes in native plant and animal populations in response to changes in grazing regimes are likely to be gradual, only becoming evident over longer time periods than these grazing trials, and particularly following a period of poor seasons. The study clearly demonstrated the large amount of natural variation between years for many native species (partly related to rainfall patterns), which also makes it harder to detect changes due to grazing treatments. Additionally, there was a high proportion of ‘rare’ plant and animal species – which are seen only in some years and/or are sparsely scattered throughout the paddocks – and the impacts of grazing on these species is very difficult to determine.

A number of cattle exclosures of varying size (up to 400 ha) were established within the grazed paddocks at Pigeon Hole. After five years there was some evidence that plant and animal composition in these exclosures was diverging from that in grazed lands. In particular, the abundance of some grazing-sensitive species was starting to increase within the exclosures by the end of the study, including some species restricted to this ecosystem. There is clearly value in maintaining such exclosures in order to track changes in species composition in ungrazed ‘reference’ areas over a longer period. It was not possible in the period of the study to determine a suitable size for ungrazed ‘conservation areas’, although theory suggests these need to be relatively large (square kilometres rather than hectares) to maintain viable populations of larger organisms such as birds.

Intensification of pastoral use may have minimal implications for biodiversity conservation within this land type if it occurs at a small or localised scale, but impacts on biodiversity are likely to become more pronounced if a high proportion of the land type is subject to intensification, particularly over longer time scales (decades). Recommendations to protect biodiversity values in the context of broad-scale intensification include:

- Conservative pasture utilisation rates, that maintain a good ground cover and a diversity of desirable perennial grasses;
- As a general guideline, at least 10% of each land type within a region should be maintained with minimal grazing pressure. As the proportion of intensified land increases, the proportion of lightly grazed land should also increase as an offset;
- Lightly grazed ‘conservation areas’ should ideally be scattered across the landscape, both at property and regional scales (to maximise landscape connectivity and capture the geographic turnover of species). This may take some planning at a regional scale to develop the best network;
- The ideal size of individual ‘conservation areas’ is uncertain, but should be as large as possible. However, a number of medium size ‘conservation areas’ scattered across a property are likely to be more effective than a single large one;
- Biodiversity ‘hotspots’ – such as waterholes, riparian zones and the habitat of threatened species – should be protected from overgrazing. Some significant sites may have specific management needs (such as a certain fire regime);

- Establishment of a robust, regional-scale biodiversity monitoring program, with sufficient sampling intensity to detect any long-term decline in identified decreaser species (from a range of broad taxonomic groups).

We caution that the biodiversity results from the Pigeon Hole and Mt Sanford studies cannot be simply generalised to other land types in northern Australia – particularly those where the pasture, soils and biodiversity are more sensitive to impacts from grazing.

10.1.5 Improving management efficiency

Intensifying the production system on a beef property will naturally mean running more livestock and having more water points and fences. Management, labour and maintenance costs can therefore be expected to increase. It will be important in an intensified system to seek improved operating efficiencies to keep costs manageable.

The results of this project suggest innovative electronic technologies offer potential for achieving efficiency gains in monitoring and managing water points and the provision of dietary supplementation, and careful planning of infrastructure developments such as laneways and cattle yards will facilitate mustering, cattle movement and handling.

The use of telemetry to remotely monitor and manage water points and dietary supplementation proved cost-effective in this study, with a break-even period of about three years. The adoption of such technology can be daunting in the early stages, and managers may have concerns about its reliability. As the technology continues to improve, it is expected these systems will become more reliable, robust and easy to use and become an important management tool. It is also important to recognise that these technologies should be seen as an adjunct to normal management activities rather than being a substitute. It will still be necessary for station staff to visit water points regularly, but the use of telemetry should reduce the frequency of visits without increasing the risk to the stock.

10.2 Potential for intensification in the VRD

Overall, the results of this project suggest that the development at Pigeon Hole did allow more stock to be run on the same area of land without adverse consequences for the pasture or individual livestock production in the short term. Getting the cattle more widely distributed over the land by using smaller paddocks and more water points was a key to allowing this increase in stocking rates. Thus, on properties that currently have little infrastructure, poor grazing distribution and low stocking rates the development of the infrastructure will likely be beneficial.

An economic assessment of the development on Pigeon Hole indicated that intensification was cost effective, with an increase in return on invested capital from 5.4% for an undeveloped commercial operation to 8.7% for a developed property.

Because the results from most of the research activities in this study were inconclusive, some uncertainty remains about the longer term effects of intensification on land condition, biodiversity and livestock production. These uncertainties arose because of the relatively short time the grazing treatments were in place, the relatively good run of years experienced, and the difficulty in obtaining consistent results when conducting research at large scales (in this case the scale of a commercial property). Therefore some caution is warranted in the development of properties until we have a better understanding of the long-term sustainability of intensification in the VRD.

Furthermore, an assessment of recent pasture utilisation rates on a selection of properties in the VRD suggest that about half of the properties in the region are currently stocking at utilisation rates in excess of the recommended 20%. Thus there is potential for only about half the properties to increase stocking rates (assuming grazing can be spread relatively uniformly across the land).

On other properties that have stocking rates near the long-term carry capacity but have only poorly developed infrastructure, property development should lead to better grazing distribution, improving the sustainability of the enterprise.

The analysis also suggested that there were generally fewer water points in country of lower productivity. Sixty-six percent of the area greater than 5 km from water had a carrying capacity of 3 AE/km^2 or less. Hence careful economic appraisal is required before investing in additional infrastructure, as much of the land that is currently ‘unwatered’ is not very productive.

10.3 The suitability of properties for intensification

The inherent productivity and resilience of the land, the stocking rates currently in use on a property, the current extent of infrastructure development and availability of water will all influence the potential for intensification on a given property. As indicated above, on properties currently with sparse infrastructure and where stocking rates are generally below the overall carrying capacity of the land there is likely to be potential to sustainably increase stocking rates (and thus livestock production) providing grazing pressure can be spread more evenly over the landscape.

Producers will need to consider these factors in deciding what type and level of property development is appropriate for their situation. Generally, development of more productive country is likely to be more worthwhile (profitable) than lower productivity country. This would also apply within a property, so that intensive development would be concentrated on the more productive land. Thus, in the VRD development should be focused on the black cracking clay soils, while rocky and sandy Spinifex country should see a lower degree of development.

For less resilient land systems a lower pasture utilisation rate will be required to minimise the risk of land degradation and adverse impacts on biodiversity. Recommended annual pasture utilisation rates for other land types are: good red soil – 15%, poor red soil – 10%, Spinifex-based pastures – 5%.

10.4 Contingency planning

Because an intensified production system operates closer to ecological limits (due to higher stocking rates) than under traditional management, and all paddocks on a property will generally be stocked most of the time, there is an increased risk of substantial land degradation over large areas in the case of management errors or when seasonal conditions deteriorate. With most paddocks stocked, the possibility for moving cattle to other paddocks on the property is limited. Consequently, it is a crucial part of a more intensive production system to develop contingency plans to cope with such situations. There are several components to such contingency planning:

- Regularly monitoring pasture condition and pasture availability to provide a basis for decision-making.
- Having predetermined decision points (related to pasture condition and availability) to guide when management action is necessary.
- Having predetermined actions (e.g. destocking) that are to be implemented following the passing of a decision point. These plans should specify details such as the order in which different classes of livestock will be removed and what will be done with them (e.g. be sold, agisted).

Given the long recovery times of degraded pasture, avoiding overstocking is preferable (ecologically and economically) to attempting to recover poor land condition.

10.5 Producers' perspective on project outcomes

To assess the relevance and practicality of the project's recommendations to northern beef producers, and to enable fine-tuning of recommendations to enhance uptake by the industry in the extensive grazing areas, we solicited the views of pastoralists who attended the project field day in August 2007. Approximately 40 pastoralists were asked to complete a questionnaire that asked about their own plans for property development and the relevance of the project's outcomes to their management. Only 12 completed questionnaires were returned (despite efforts to encourage more people to complete them). Table 10.1 presents a summary of the key aspects of the survey.

Table 10.1. Summary of producer responses to questions about project recommendations. The table presents the percentage of respondents agreeing with the statement, although for the questions on what is a reasonable utilisation rate and the proportion of property to be set aside to protect biodiversity producers were asked to nominate a figure. Note that not all respondents answered all questions.

Issue	Percentage of respondents			
Have plans to develop property to increase livestock production	92			
What is a reasonable annual pasture utilisation rate?*	*0-15%*	*15-30%*	*30-50%*	*>50%*
		33		17
Likely to use utilisation rate concept for setting stocking rates	50			
More even grazing use is important	100			
Paddocks of 30-40 km^2 are realistic	75			
Biodiversity is an important consideration when setting stocking rates	75			
Part of a property should be set aside to protect biodiversity	25			
Proportion of property that should be set aside to protect biodiversity*	*0%*	*1-10%*	*10-20%*	*>20%*
	42	25		
Type of grazing system most suited to your area	*Continuous*	*Wet season spelling*	*Cell*	*'Rotational'*
	25	42	8	17

* responses grouped

The majority of respondents were interested (or have already started) developing their properties to increase livestock production. Most reported that installing more water points was the main development they were planning. Only about 33% percent of respondents nominated a pasture utilisation rate between 15 and 30% as being reasonable; several suggested rates in excess of 50%. Several producers answered the question about a reasonable utilisation rate in terms of a stocking rate. Nominated rates were in the range of 8-15 head/km^2. Only half of the respondents indicated they were likely to use the pasture utilisation rate concept to set stocking rates, although another 25% said they might use it in future.

The importance of improving the evenness of grazing was universally accepted, but not all thought paddocks of 30-40 km^2 were realistic. Issues that were raised as being potential problems with paddocks of this size include the cost of the infrastructure, the need for more labour to deal with more small mobs of cattle (i.e. for mustering and branding), higher maintenance costs due to the additional fences and water points and increased parasite (worm) problems. The lack of adequate water to provide for the additional water points that would be needed was also mentioned. Some producers thought there would be a gradual move towards paddocks of this size over time.

While 75% of respondents acknowledged the importance of considering biodiversity when setting stocking rates, only 25% thought land (which might include productive land) should be set aside to protect biodiversity. However, several other producers thought low productivity land could be set aside to protect biodiversity. One producer mentioned the need for protected areas to be actively managed (possibly by burning) so they don't become 'stagnant'.

Many producers nominated wet season spelling as the grazing system most suited to their area. Several other producers indicated that 'anything apart from set stocking' was appropriate, with some implying they spell opportunistically (although no specific details were provided). A few producers mentioned the importance of spelling, but still use set or continuous stocking.

Overall, producers thought the study was interesting and relevant, but that it is unlikely that many people will implement a development program as occurred on Pigeon Hole. Instead, it is likely that they will choose elements of the project that are relevant to their situation and within financial reach. Apart from installing more water points (or subdividing paddocks), this will potentially include the implementation of wet season spelling and the use of more laneways. A number of producers said that the cost and reliability of water medicators and telemetry systems to manage water points need to improve before they would consider using them on their property.

11 Success in Achieving Project Objectives

Objective 1

One hundred percent of producers in the VRD will be aware of locally derived relationships between pasture utilisation and pasture and animal parameters, including the impact of variable levels of pasture utilisation on pasture dynamics, pasture condition trends and pasture sustainability.

We expect that close to 100% of producers in the VRD are aware of the results from the Pigeon Hole and Mt Sanford projects regarding the effect of different levels of annual pasture utilisation on pasture dynamics, pasture condition trends and livestock production. The findings were communicated to producers at field days at Mt Sanford in 2003 and Pigeon Hole in 2005 and 2007. The project and its results were also promoted by a number of interviews on ABC Radio, in newsletter and newspaper articles (Katherine Times newspaper and the Rural Review newsletter), in MLA's Frontier magazine, in a Landline television feature, and at conferences (including NABRUC and the Australian Rangeland Conference).

Objective 2

The key factors and processes influencing sustainable grazing at the paddock scale in the VRD, Northern Territory will have been identified and understood, in particular: optimal levels and systems of pasture utilisation; the distribution patterns of grazing cattle; the role of pastoral development options of fencing, paddock design and water placement; and, the impact of pastoral development options on biodiversity conservation.

Although some of the results did not show strong trends, an annual pasture utilisation rate of 20% was recommended as appropriate to balance livestock production and land condition objectives over the long term (Chapter 3). The effect of reducing paddock size and establishing additional water points on the distribution of cattle in paddocks and the consequences for land condition and livestock production were determined, as were the limitations in these techniques for managing grazing distribution (Chapter 4). Different systems of pasture utilisation (i.e. grazing systems) were compared for their effect on livestock production, land condition and financial returns. There were few (or only minor) differences amongst systems, although set utilisation at about 20% annual pasture utilisation appeared to perform the best financially (Chapter 5). The effect of various development options on biodiversity (including fauna and flora) was also investigated (Chapter 6), although the relatively short duration of the study limited the development of a better understanding of the long-term effects of pastoral development on biodiversity.

Objective 3
Management guidelines for achieving sustainable and profitable pastoral development will have been identified.

A range of management guidelines for sustainable and profitable pastoral development were identified including optimal pasture utilisation rates, optimum paddock configurations, and recommendations for protecting biodiversity under pastoral development. Guidelines were also identified for aspects of the practical development and management of an intensified production system, including the use of telemetry to manage water points, the development of laneways and stockyards for handling and moving stock, the cost effectiveness of different mustering techniques and the use of water medicators to provide nutrient supplementation to the livestock. These guidelines will be published in a separate booklet for producers.

Objective 4
Twenty percent of beef producers in northern Australia will be aware of the relationship between grazing behaviour, land condition and animal production and have the information and decision support tools to implement change on their properties to improve financial and land management performance.

While 20% of producers in northern Australia are likely to be aware of the relationship between grazing behaviour, land condition and livestock production, the availability of decision support tools to implement change on their properties remains limited at this stage. The equivocal results from this study in relation to the effect of development on land condition will constrain the development of detailed decision support tools, but the production of a best-practice manual for the intensive development of northern beef properties will provide producers who wish to develop their properties with some guidelines for development.

12 Impact on Meat and Livestock Industry

This study demonstrated that there is some scope for intensification of beef properties in the VRD and this should lead to greater financial returns for these properties. Properties that currently are poorly developed (i.e. large paddocks and sparse water points) and stock at less than the long-term carrying capacity of the land have the opportunity of benefiting from property development since this should allow more cattle to be carried sustainably. Our analyses suggested that about half the properties in the VRD have that opportunity. It is possible that intensification could see an increase in cattle numbers in the VRD of about 154,000 AE, generating an additional annual gross margin of about $17m. It is reasonable to assume that some potential for intensification also exists for other extensive grazing lands in northern Australia, such as the Barkly Tableland and the Kimberley, although the magnitude of the increase that is possible in these regions is not known.

It is probably the case that some enterprises were already moving towards intensifying their production before this project came about. However, it is likely the project has increased the level of interest in property development, and the responses to the producer survey following the Pigeon Hole field day in 2007 support this notion. The project has also generated a range of guidelines for the sustainable development of properties which we expect will influence the plans for intensification on individual properties. Given the large capital expense involved in property development the process of intensification is likely to be a gradual one, continuing over the next 10 or more years as producers spread the cost of development over time and as financial resources allow. As the cost of land has increased over recent years, the option of buying more land to increase the number of stock carried by a business has become much less attractive. As a result interest in property development as a way to increase financial returns is likely to increase. Larger commercial businesses are most likely to be the first to develop their properties, and we have already seen this occurring.

Intensification may lead to a modest increase in demand for labour on properties, although the use of new technology such as telemetry to manage water points may counteract this to some extent. This project demonstrated that the use of these systems can reduce costs for large, intensified cattle enterprises. Already the adoption of water point telemetry has increased across Australia’s extensive rangelands largely as a result of the technology that was developed as part of this project. This may well represent the vanguard of increased use of cutting edge technology and automation in the extensive livestock industry as other new technology for handling, managing and monitoring livestock becomes available.

The project developed land management guidelines for use in intensified production systems, but many of these would apply equally where intensive property development does not occur. Adoption of recommendations such as an annual pasture utilisation rate of about 20% should improve sustainability on many properties, given that some currently operate at levels well in excess of this. Such a shift in management would also reduce risk associated with drought and thus help to maintain good land condition. Similarly, the use of strategies to improve the spread of grazing across the landscape on properties where utilisation rates are already around 20% or higher should also reduce the risk of long-term land degradation, and may allow the recovery of some areas. However, reductions in stocking rates may also be necessary to ensure long-term sustainability. Guidelines presented in this report for protecting biodiversity values have broad relevance and can also be adopted regardless of the level of pastoral development.

A notable finding of the project was that there were no financial or land condition incentives for the adoption of intensive rotational grazing systems in this region. These systems are expensive to establish and manage and thus can represent a major investment by a property. Although some properties have established such systems in various regions across northern Australia and claim there are benefits to their enterprise, the project indicated that these systems cannot be justified in the VRD. Our findings should save properties the expense of investing in these costly and difficult-to-manage systems.

13 Conclusions and Recommendations

This study suggests there is potential for the intensive development of many beef properties in the VRD and that these developments will increase the profitability of these businesses. For the development to be a success, a number of factors should be considered. This report has highlighted the requirements in terms of sustainable pasture utilisation rates, optimal paddock and water point configurations, grazing management system and ways to protect biodiversity under grazing. It appears complex grazing management systems are not required, but the use of innovative technologies such as the remote management of water points using telemetry can reduce the running costs of an intensified system.

It is important to acknowledge that this work was carried out in the grasslands found on the cracking black clay soils of the VRD. This system is relatively resilient to the effects of grazing. Caution is required in extrapolating the results presented here to other regions. Work is required to determine what are safe pasture utilisation rates for other land types.

The long-term effects of pastoral intensification on pasture condition and biodiversity remain uncertain. An assessment of these effects over the longer term is warranted and provisions made to protect these values. Although there was no apparent benefit to the pasture from resting in this study, it may be necessary to occasionally spell paddocks to maintain pasture condition in the longer term. Work is also required to develop better methods for achieving more uniform grazing distribution within paddocks, since with the higher utilisation rates (and hence stocking rates) there is potential for patch degradation to occur.

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Appendix A: Additional data for the Mt Sanford utilisation study

A.1 Annual stocking rates

Table A.1. Stocking rates (AE/ sq. km) for utilisation treatment paddocks at Mt Sanford.

Muster date	13%	21%	23%	31%	39%	42%
16/05/2001	10.6	13.7	20.2		31.4	41.1
10/10/2001	10.6	14.0	20.2		31.4	40.4
15/05/2002	13.4	15.9	22.4	26.9	33.2	36.7
10/10/2002	13.3	15.9	22.8	26.3	32.7	36.7
15/05/2003	8.7	11.0	15.5	18.5	21.6	28.6
08/10/2003	8.3	11.2	15.1	18.8	21.6	28.3
12/05/2004	11.7	24.3	16.1	18.2	20.8	43.5
06/10/2004	10.5	24.6	16.1	15.5	18.3	43.5
11/05/2005	11.5	21.6	19.2	24.6	27.4	41.4
13/10/2005	11.9	21.6	18.8	24.9	27.4	41.4
08/05/2006	15.6	17.0	12.1	22.9	26.2	36.0
13/10/2006	15.3	17.0	11.7	22.2	25.7	36.0

A.2 Growth estimate

Estimated growth (intake + TSDM in May) generally declined with average utilisation (Figure A.1), except in 2003, when growth was uniformly low. However the 42% treatment usually didn’t follow this trend, except for in 2002. It is possible the apparent decline in growth estimate with utilisation may be due to lower carryover and higher detachment at higher utilisations, or simply a reflection of inherent paddock differences.

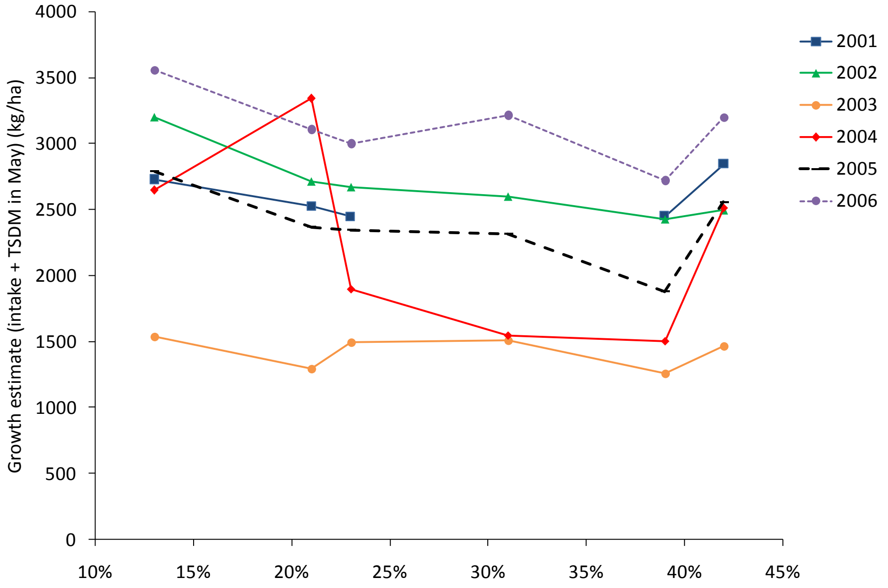

Figure A.1. Change in growth estimate with average annual utilisation at Mt Sanford station.

Appendix B: Pasture utilisation rates for treatments at Pigeon Hole

Pasture utilisation rates are presented in Table B.1.

While it was intended that cattle numbers be adjusted to achieve a constant utilisation for the utilisation, grazing radius and grazing distribution treatments, this was not achieved during the study. However the variability in utilisation between years was less in these 'constant utilisation' treatments than for the set stocked and cell grazing treatments.

Table B.1. Calculated annual pasture utilisation rates (%) for experimental paddocks by year in the study at Pigeon Hole station.

Treatment	2003[a]	2004	2005	2006	2007	Average 2004-2007	Std dev
U15%	21	11	12	17	14	13	4.2
U20%	23	11	15	22	20	17	5.1
U25%	33	11	17	24	23	19	8.1
U30%	31	15	27	24	30	24	6.7
U40%	32	23	43	29	35	32	7.4
GR1	33	11	19	22	24	19	7.9
GR3	40	10	13	20	19	15	11.8
2waters	38	9	16	18	19	15	11.0
Mwaters	40	9	15	22	19[b]	16	11.6
SS	43	9	16	31	29	21	13.5
WSS	45	14	22	24	30	22	11.6
Cell Grazing	31	15[c]	21	21	21[b]	20	5.9
Cell Grazing control	32	16[d]	23	19	10[b]	17	8.4
Average	34	12	19	23	24	19	9

Notes:

a Utilisation for 2003 was based on July 2002 animal numbers, and is indicative only.
Because paddocks were not subdivided until mid-2003, and cattle may have grazed the original large paddocks unevenly, 2003 estimated defoliation may be more indicative of relative utilisation between treatment paddocks.

b Adjusted in 2007 for the period when stocked.

c Cell Grazing was not fully stocked until 3 months into the growing season.

d Cell Grazing Control was not fully stocked until 1 month into the growing season.

The effect of fire on utilisation rate was not specifically calculated. However for fires that occurred after the start of the wet season and before the vegetation sampling in May when TSDM was estimated, the effect of fire is included by default in the resulting lower yields. Where fires occurred after the May sampling, then the effect of fire on utilisation is not included in the utilisation calculation. Fires on 19/11/04 in the Cell Grazing (21% of paddock burned) and 15% Utilisation (42% of paddock burned) treatments occurred nearly a full month prior the start of the 04-05 wet season. No adjustment had been made for this, which means that the 2004 utilisations for this treatment may be slightly higher than calculated here.

Appendix C: Additional data for the Pigeon Hole utilisation study

C.1 Land condition

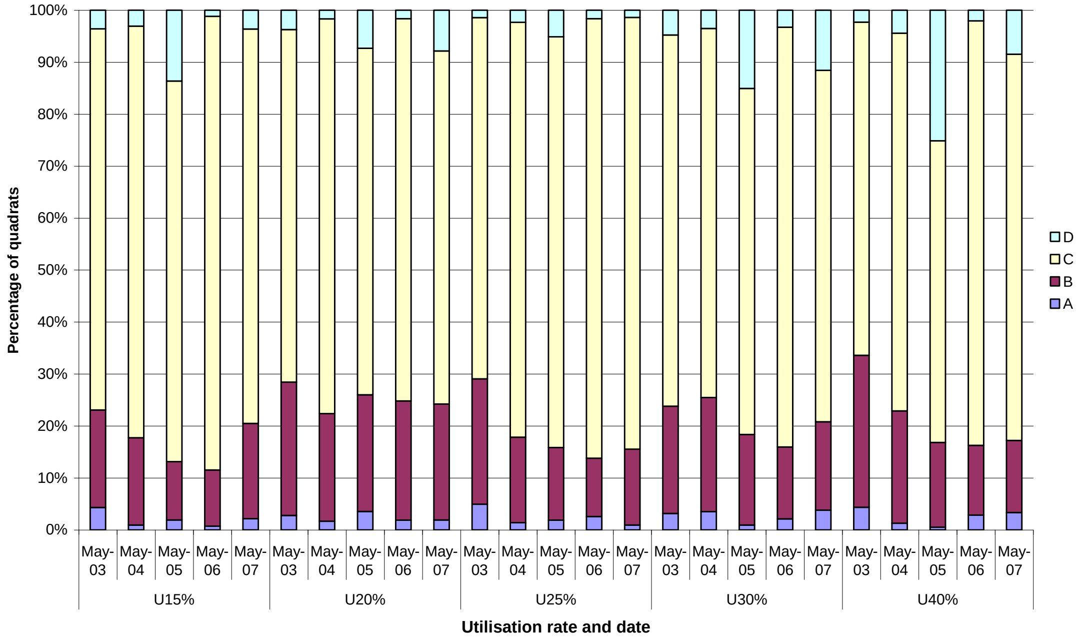

Figure C.1. Land condition of utilisation paddocks through time at Pigeon Hole station.

C.2 Effect of fire on Pigeon Hole utilisation treatments

Fires were randomly distributed through time and utilisation treatments, adding additional variation to the already highly variable paddock responses to utilisation treatments. Generally the effect of fires were short lived, but there were occasions where wet season fires resulted in increased crude protein, dry matter digestibility, increased defoliation, and lower yield, cover and sometimes grass basal area following fires which lasted for up to several samplings. There were secondary effects of fire in 32% utilisation in 2005, as stock numbers were reduced and weaners were weaned earlier to reduce pressure on the remaining pasture. Resulting changes in forage yield and quality appears to have influenced some cattle production variables in affected paddocks through the trial.

The greatest effect of fire was in 2003 and 2005 when average to below average seasons coincided with or immediately followed extensive fires across the site. In these years there was a general trend of lower ground cover where there had been more recent or more numerous fires.

Fire tended to reduce yield and cover and sometimes increase defoliation in the following May (Figure C.2 - Figure C.4) in utilisation paddocks. Note that the 19% utilisation paddock is not shown in time since fire graphs, as it was not burnt during the trial.

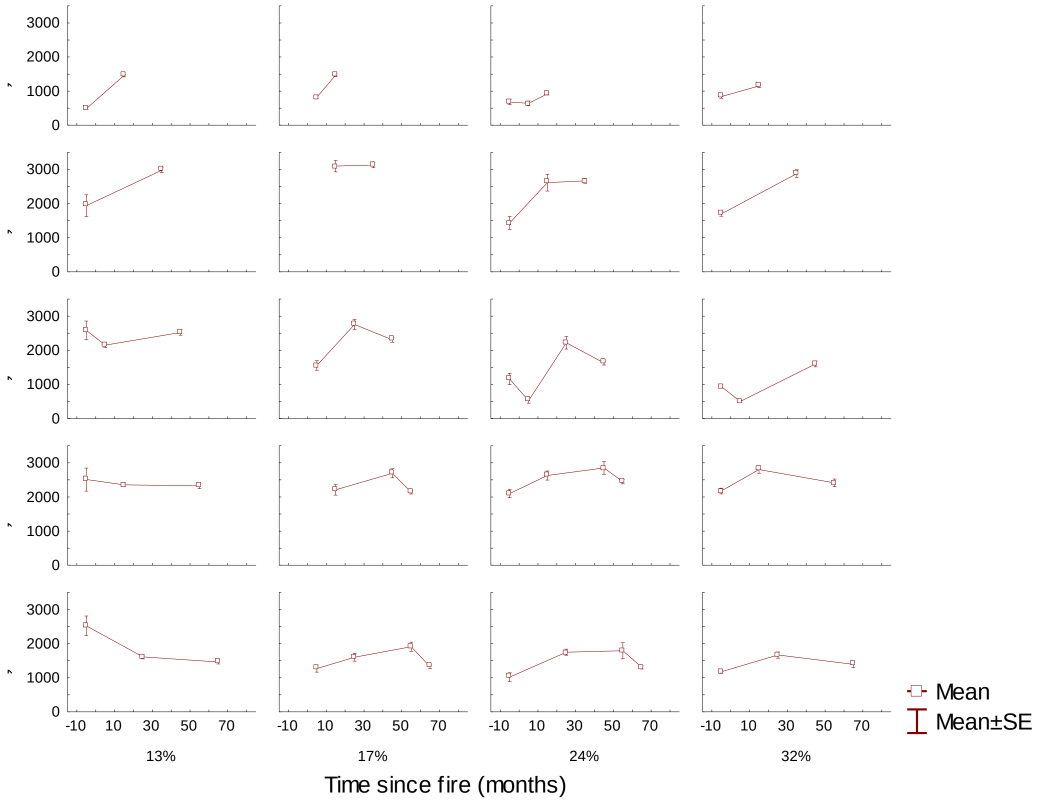

Figure C.2. Effect of time since fire on yield in utilisation paddocks at Pigeon Hole station.

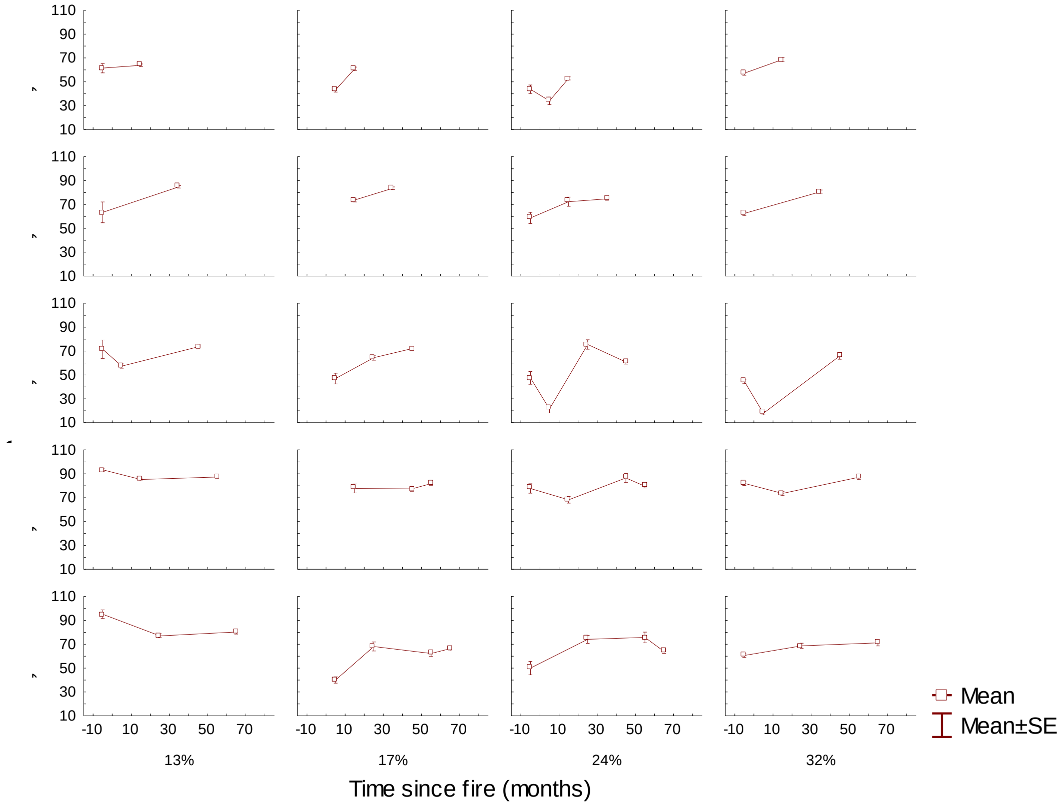

Figure C.3. Effect of time since fire on cover in utilisation paddocks at Pigeon Hole station.

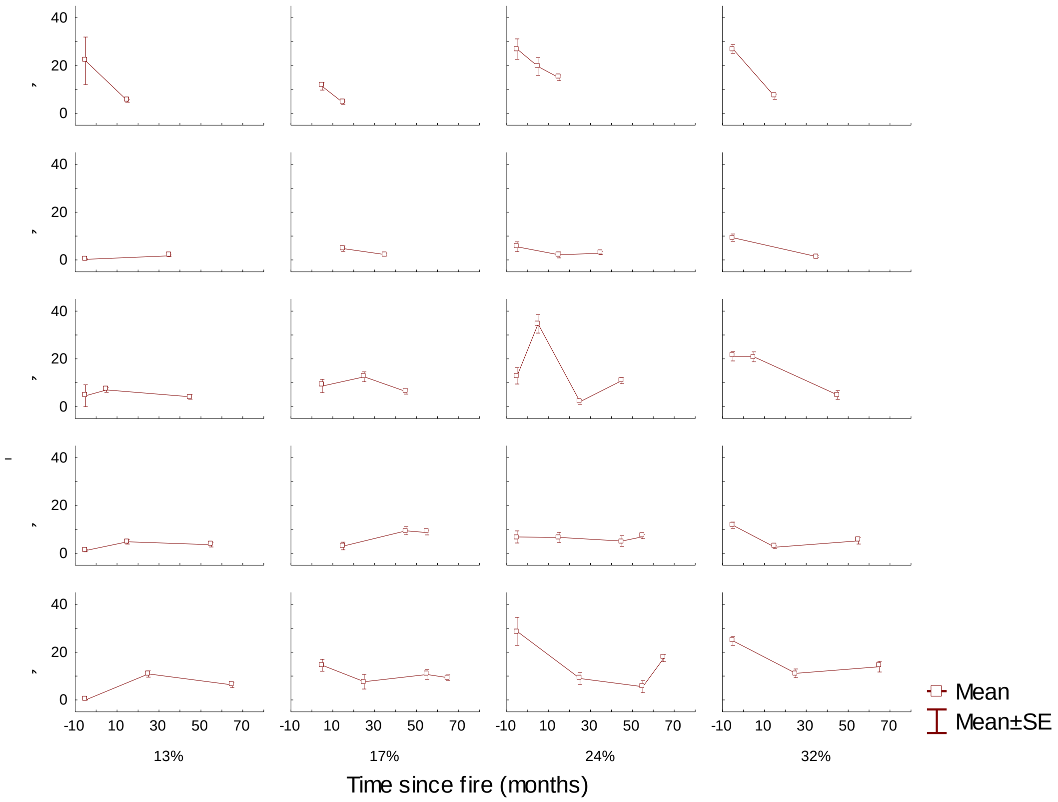

Figure C.4. Effect of time since fire on defoliation in utilisation paddocks.

Woody cover in utilisation paddocks was lower in areas where there had been more fires Kruskal-Wallis ANOVA H $_{(3,\ N=\ 4398)}$ = 80.7 p <0.0001, (Figure C.5).

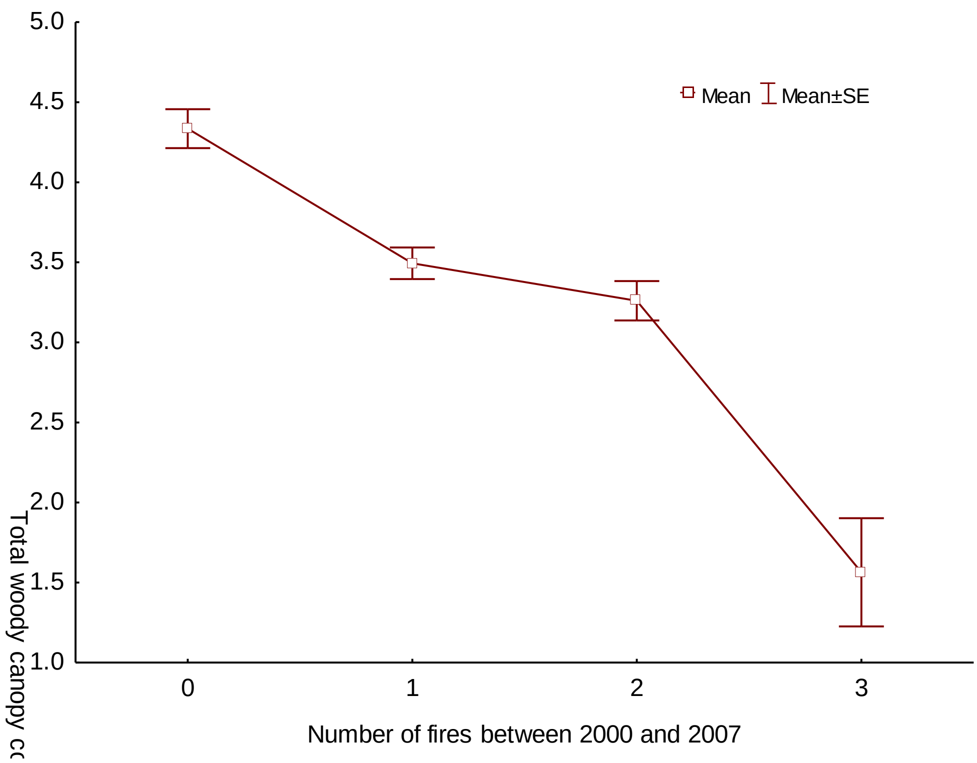

Figure C.5. Woody cover versus number of fires in the years between 2000 and 2007 in utilisation paddocks at Pigeon Hole station.

In 2005 areas that were burned during the previous wet season in 24% and 32% treatments had significantly higher defoliation (Mann-Whitney U test, P<0.0001 and P<0.0001, in 24% and 32% respectively), lower yield (Mann-Whitney U test, P<0.0001 and P<0.0001), lower cover (Mann-Whitney U test, P<0.0001 and P<0.0001) than unburned areas in both May and October (Table C.1).

Table C.1. Median yield, defoliation and ground cover in May and October 2005 in burned and unburned parts of 24% and 32%, treatments at Pigeon Hole station.

Season		Utilisation treatment	n	Yield (kg/ha)	Defoliation (%)	Cover (%)
May	no burn	24	359	1614	0	67
	burn	24	66	259	32	10
	no burn	32	243	974	2	52
	burn	32	141	411	13	13
October	no burn	24	360	946	15	64
	burn	24	66	16	63	2
	no burn	32	244	377	59	36
	burn	32	137	139	71	4

Varying fire timing, frequency and extent in different treatments may have confounded the response of *Sorghum* through time at Pigeon Hole. This is because fire can both promote *Sorghum spp.* (Scott *et al.* 2009, Bowman *et al.* 2007, Russell-Smith *et al.* 2003) by reducing litter effects on germination and reducing overstorey shading; and reduce *Sorghum* if burnt prior to seed set (reviewed in Lazarides *et al.* 1991). However, several points tend to discount fire impacts on *Sorghum* in utilisation paddocks at Pigeon Hole. The 19% treatment had no fire during the trial but responded similarly to the highest utilisation treatments. Also the greatest increase in *Sorghum* occurred in the 32% utilisation paddock which had the largest wet season fire, which should have lead to a decline in *Sorghum*.

C.3 Growth estimate

Growth estimate (intake + TSDM in May) declined above 17% in 2005 and was lower above 17% in 2003 and 2005 (Figure C.6). However, in 2005, ‘lower growth’ may have been partly due to reduced TSDM following fires in part of in 24 and 32% utilisation paddocks in January 2005, which would lead to an underestimate of growth by this method.

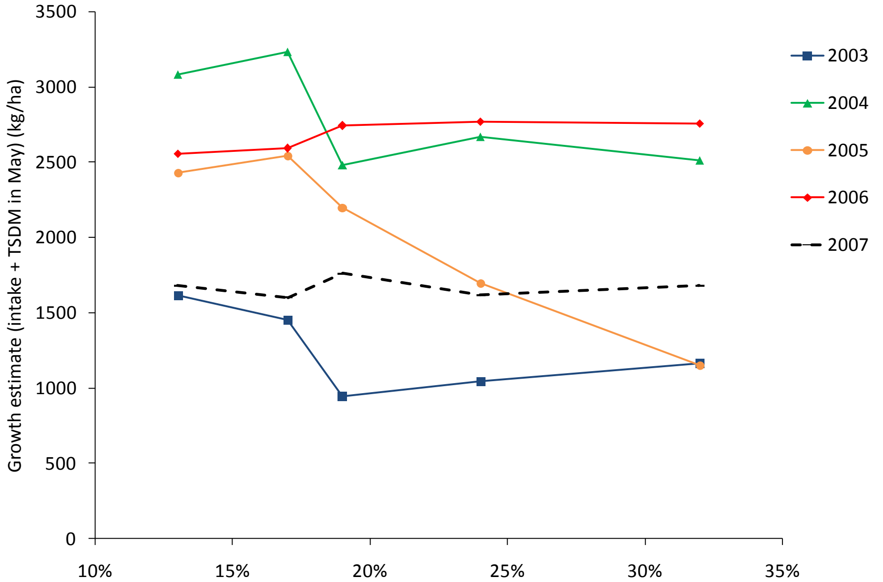

Figure C.6. Estimated growth versus average annual utilisation for different years at Pigeon Hole station.

C.4 Species yield

Table C.2. Plant functional groups repeated measures ANOVA results for utilisation treatments at Pigeon Hole Station. *** = P<0.001, ** = P<0.01, * = P<0.05, ns = not significant.

Functional group yield	Utilisation	Year	Utilisation*Year
Perennial	***	***	***
Palatable perennial	ns	***	***
% Palatable perennial	ns	***	*

Perennial yield was consistently highest in 17% utilisation (Figure C.8).

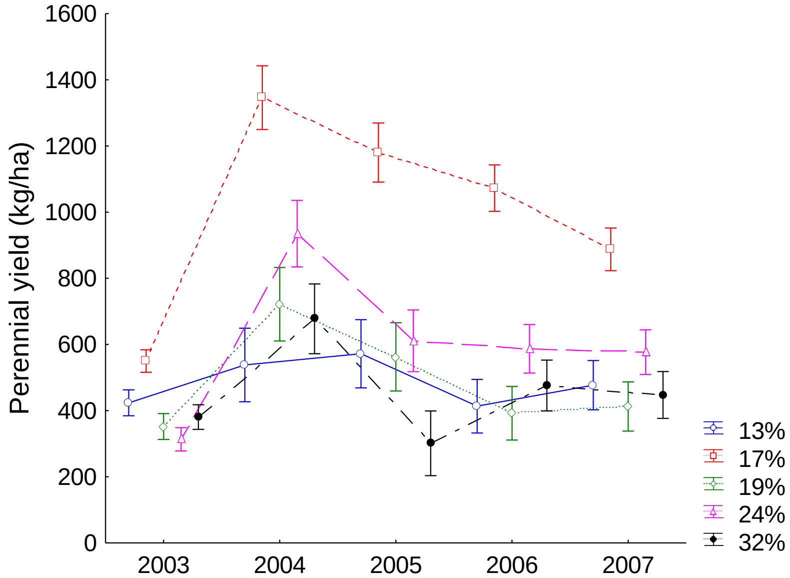

Figure C.7. Perennial yield in May in utilisation treatments at Pigeon Hole Station. Means ± standard errors.

Palatable perennial yield showed no evidence of treatment related shifts through time (Figure C.8). The large increase in 24% in 2004 was due to *Chrysopogon fallax* increasing following very low stocking rates from the trial start to September 2004 (Figure 3.34).

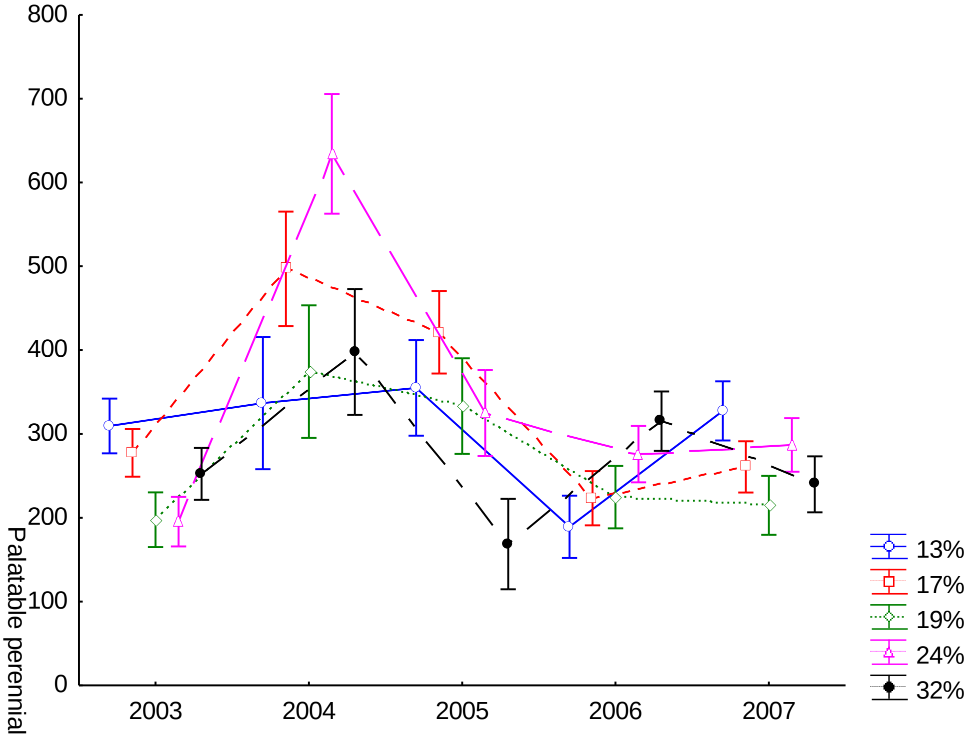

Figure C.8. Palatable perennial yield in May in utilisation treatments at Pigeon Hole Station. Means ± standard errors.

Percent palatable perennial yield significantly decreased between 2003 and 2007 at all utilisations (Figure C.9), but only significantly at 19 and 32% (Duncan's critical range test P<0.05). Given the stable palatable perennial yield, this must have been due to an increase in other functional groups.

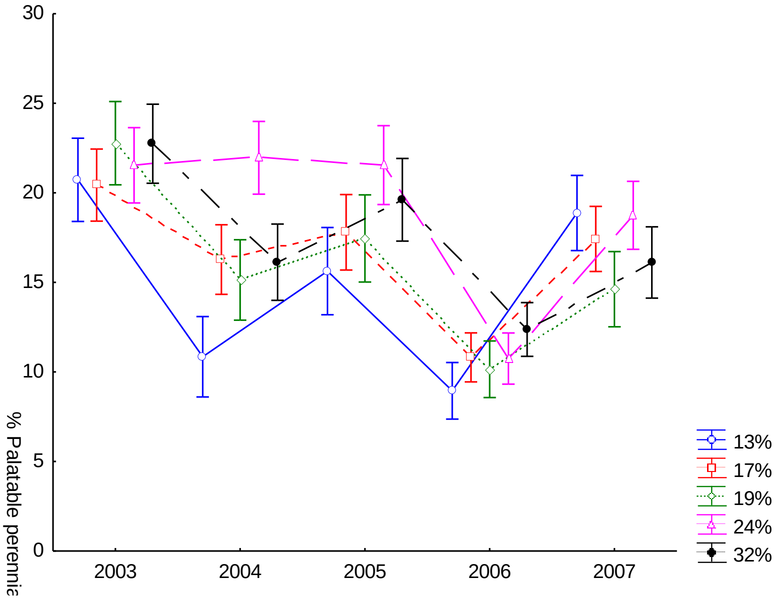

Figure C.9. Percent palatable perennial yield through time for different utilisations at Pigeon Hole station. Means ± standard errors.

Table C.3. Grass species repeated measures ANOVA results for utilisation treatments at Pigeon Hole station. *** = P<0.001, ** = P<0.01, * = P<0.05, ns = not significant.

Grass species yield	Utilisation	Year	Utilisation*Year
√ *Aristida latifolia*	***	**	ns
% *Aristida latifolia*	***	***	***
√ *Chrysopogon fallax*	ns	***	***
√ *Dichanthium fecundum*	***	ns	*
Log 10 *Dichanthium sericeum*	ns	***	ns
Log 10 *Iseilema spp.*.	***	***	***

There was no trend in *Aristida* through time that suggested treatment related effects (Figure C.10).

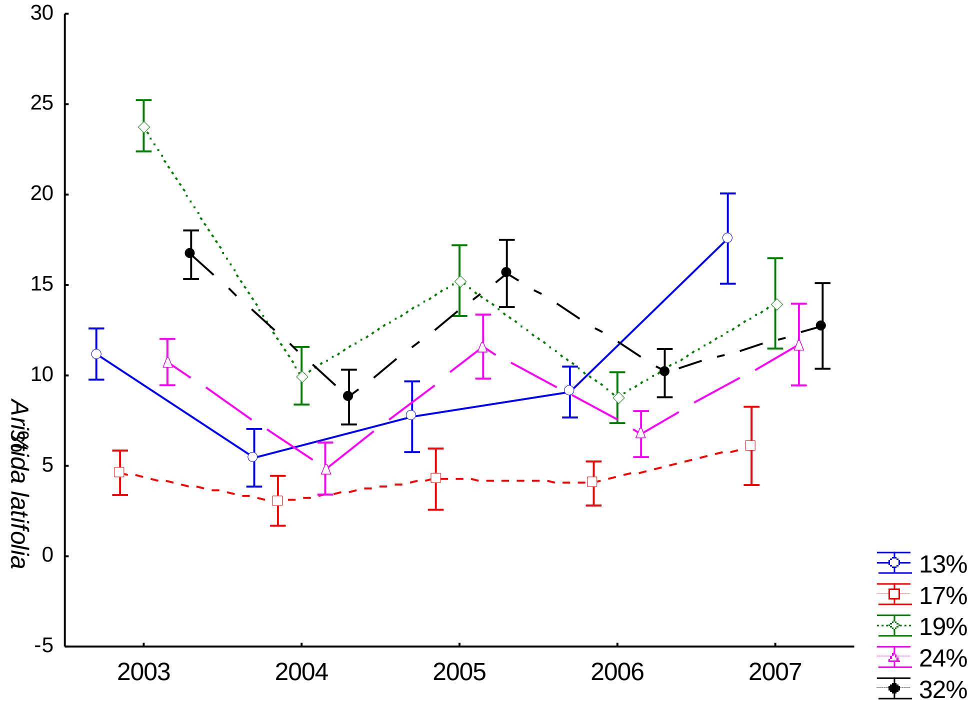

Figure C.10. % *Aristida latifolia* yield in May in utilisation treatments at Pigeon Hole Station. Means ± standard errors.

All utilisation treatments ended with similar *Chrysopogon fallax* yield to 2003, although the seasonal fluctuations were greater for 24 and 32% utilisation paddocks (Figure C.11).

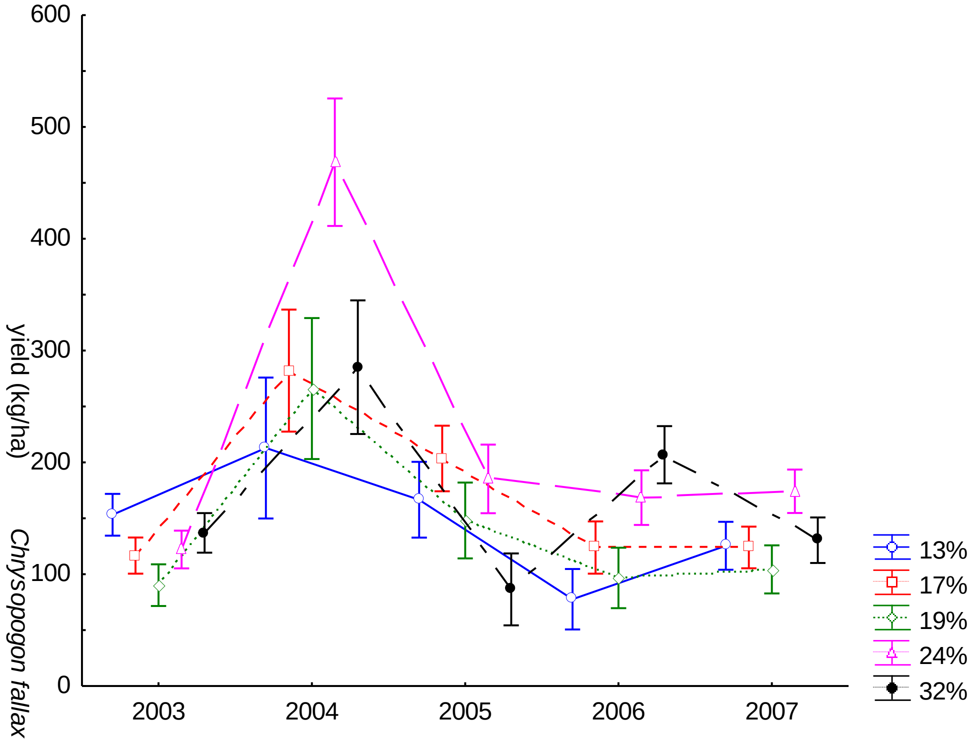

Figure C.11. *Chrysopogon fallax* yield in May in utilisation treatments at Pigeon Hole Station. Means ± standard errors.

Dichanthium fecundum fluctuated differently through time for different utilisation rates; in particular between 2003 and 2005 *Dichanthium fecundum* declined most at 32% utilisation. This was following the combination of extensive wet season fire for this paddock combined with a particularly high utilisation rate (43% for that year). This suggests the combination of wet season fire and high utilisation rates may be detrimental to this species. However, *D. fecundum* had recovered to its pre-trial rates of 2003 by 2007 (Figure C.12).

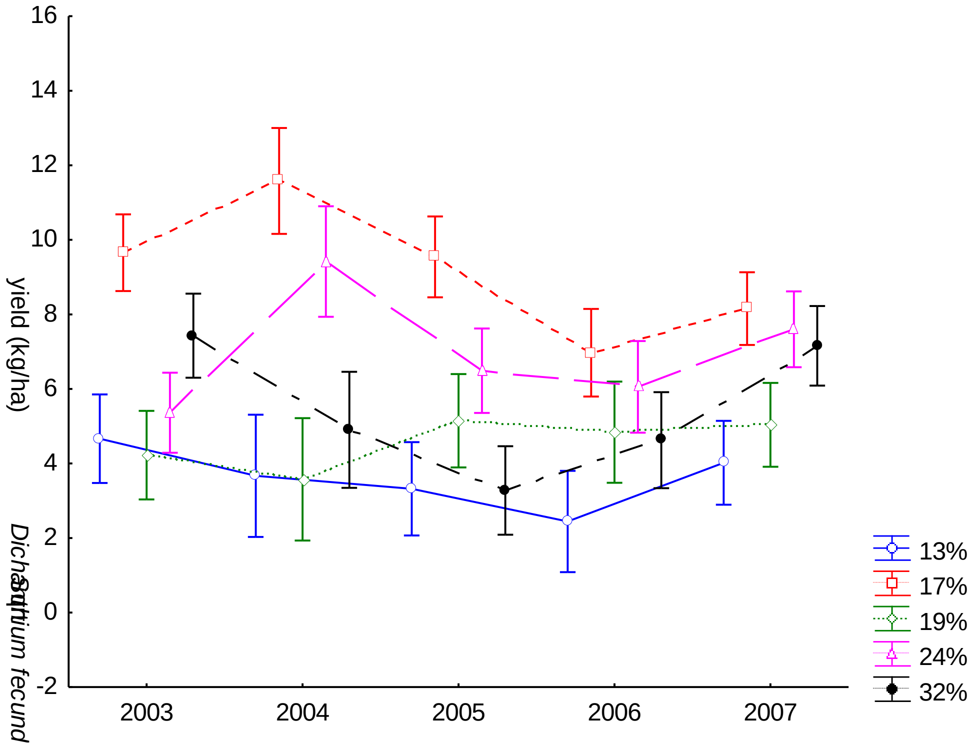

Figure C.12. Square root *Dichanthium fecundum* yield in May in utilisation treatments at Pigeon Hole Station. Means ± standard errors.

Iseilema spp. varied between paddocks and time, and decreased most in 17% utilisation, mirroring the increase in perennial yield during that period (Figure C.13).

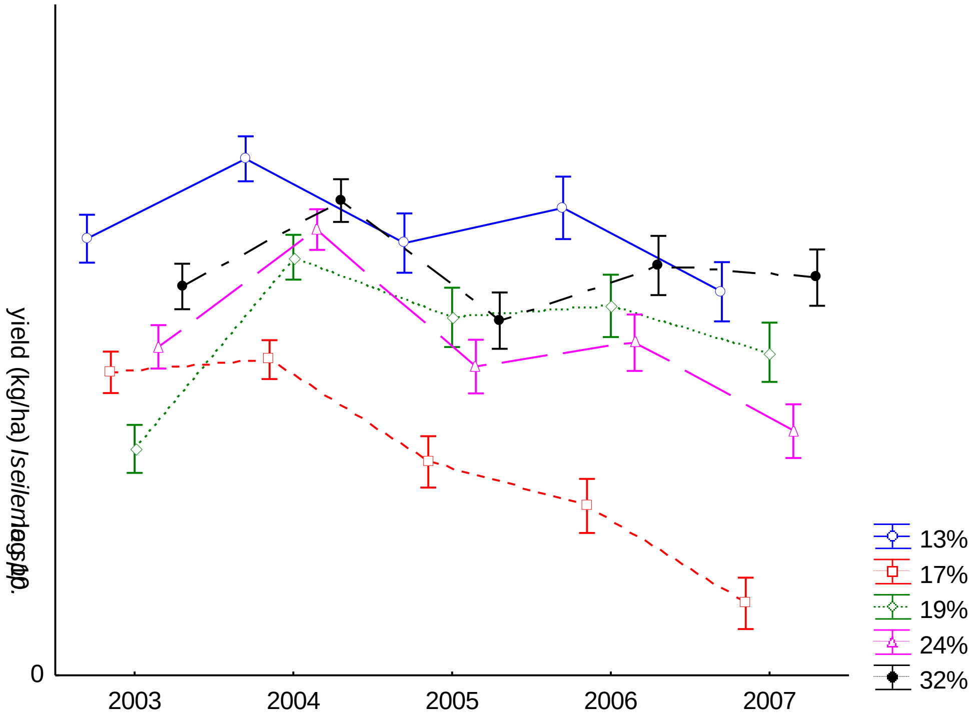

Figure C.13. Log 10 *Iseilema spp.* yield in May in utilisation treatments at Pigeon Hole Station. Means ± standard errors.

C.5 Species defoliation

Defoliation of annual grass species was not always correlated with utilisation (Figure C.14 - Figure C.15).

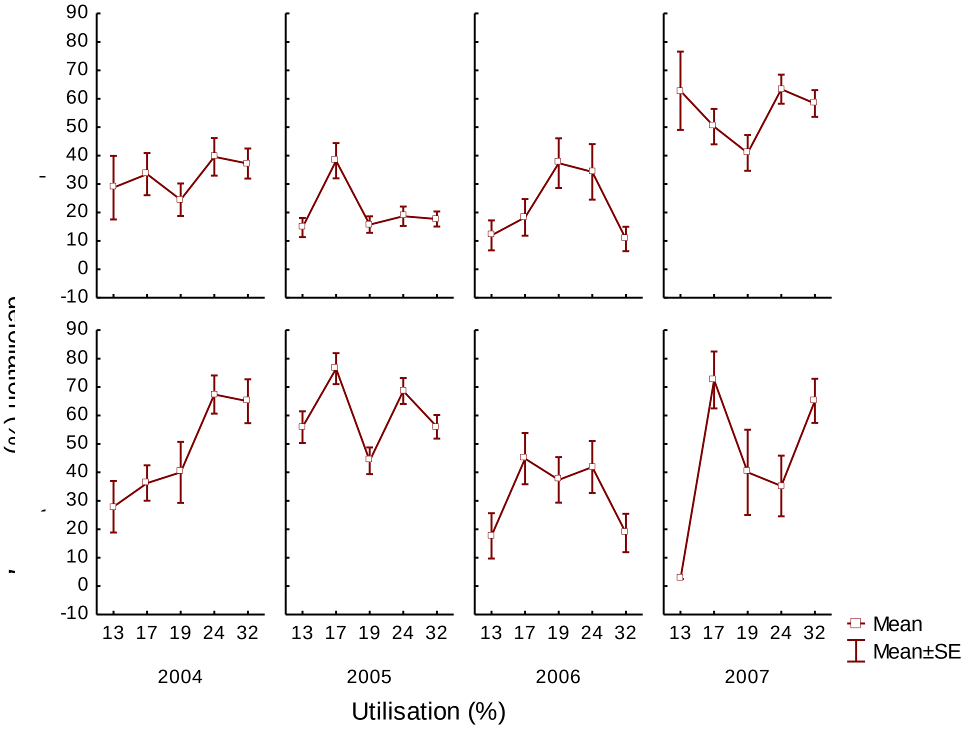

Figure C.14. Defoliation of *Brachyachne convergens* yield through time with utilisation at Pigeon Hole station.

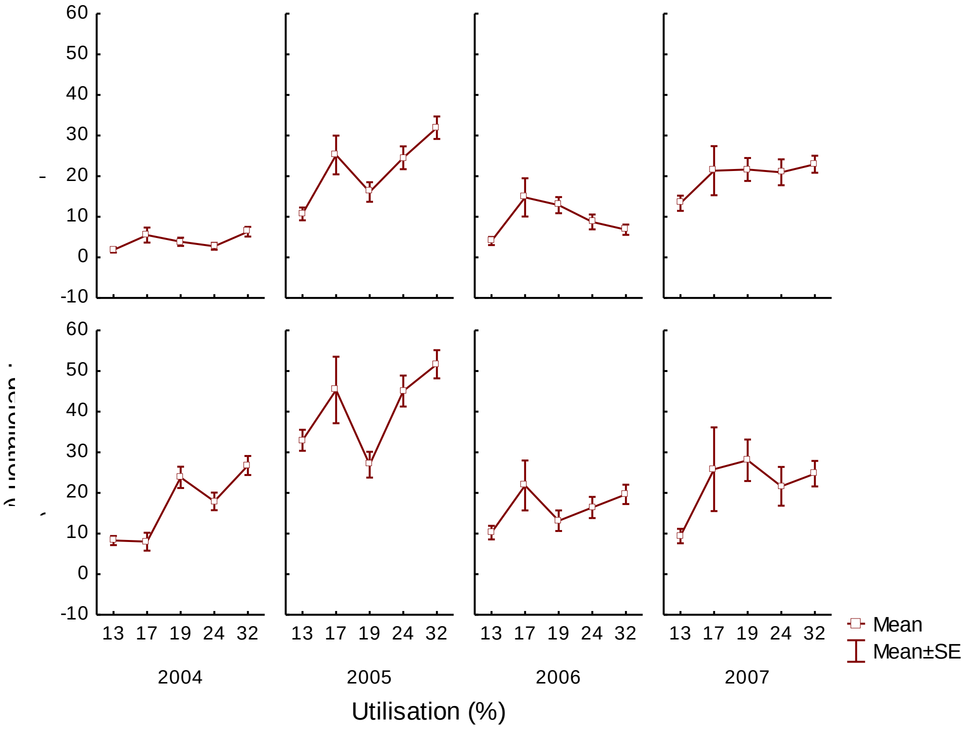

Figure C.15. Defoliation of *Iseilema spp.* yield through time with utilisation at Pigeon Hole station.

C.6 Species selection index

Selection index of the main species at Pigeon Hole is shown in Figure C.16 - Figure C.19.

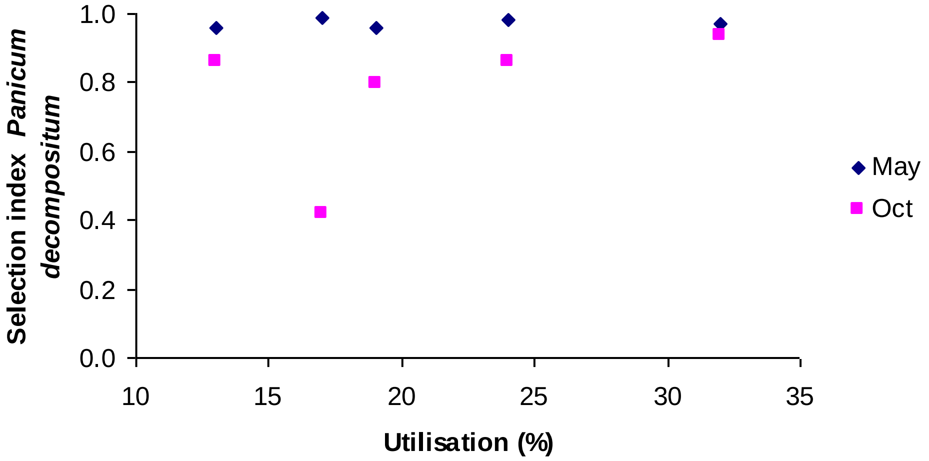

Figure C.16. Selection index of *Panicum decompositum* at Pigeon Hole Station.

Sehima was least selected for in 17% utilisation, where it had the highest % yield at 11% compared with only 2-6% of the yield in the other utilisation paddocks.

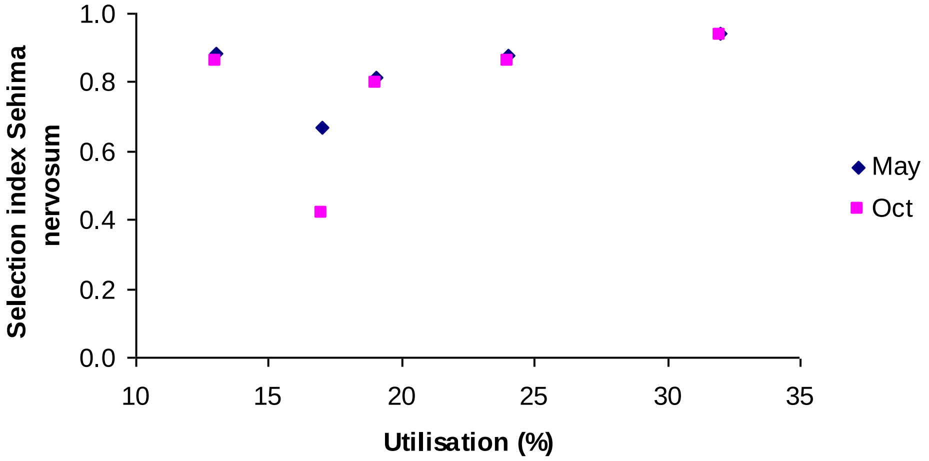

Figure C.17. Selection index of Sehima nervosum at Pigeon Hole Station.

The annual grasses Brachyachne and Iseilema were strongly selected for (Figure C.14, Figure C.15).

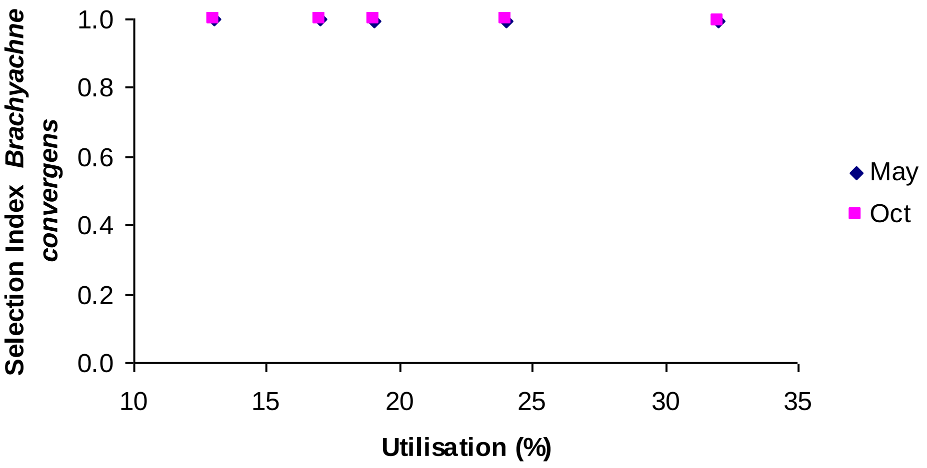

Figure C.18. Selection index of *Brachyachne convergens* at Pigeon Hole Station.

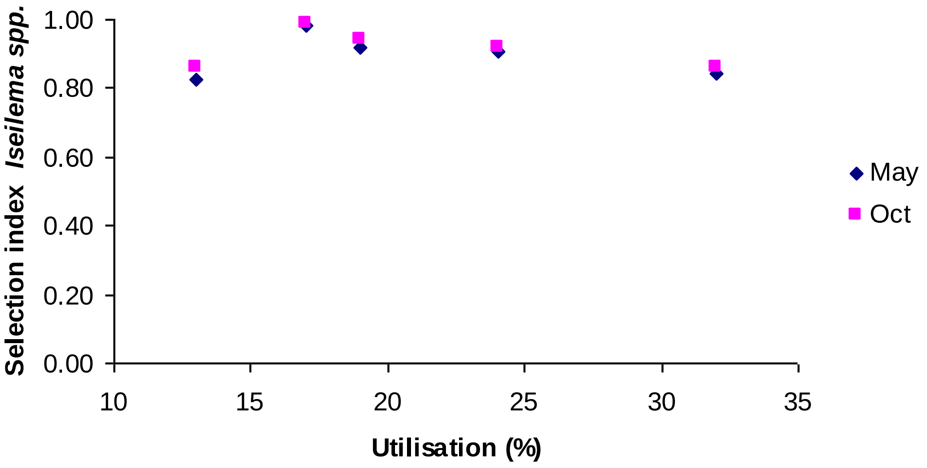

Figure C.19. Selection index of *Iseilema spp.* at Pigeon Hole Station.

Appendix D: Modelling pasture growth at Pigeon Hole

D.1 Introduction

Pasture growth is known to be limited by rainfall and nitrogen in northern Australia (Mott *et al.* 1985). Modelling pasture growth provides insight into the seasonal conditions experienced during a grazing trial in the context of the longer term range of seasons likely to be experienced in the region. GRASP can also be used to simulate grazing trials, allowing extrapolation of trial results to longer time series and different seasonal conditions.

Previous work at Mt Sanford (Cobiac 2006a) enabled pasture growth to be modelled for the Wave Hill land system using the GRASP pasture growth model (Littleboy and McKeon 1997). However, the soil and vegetation at Pigeon Hole appeared to be substantially different to that found at Mt Sanford, with poorer land condition, the large contribution of annual sorghum to yield, and considerably rockier soil. Hence, pasture growth was measured at sites at Pigeon Hole to develop a locally specific GRASP parameter set that would better represent conditions found at the Pigeon Hole research site.

D.2 Methods

D.2.1 Site description

Sites were selected based on wet season access (hence the location on the northern end of the trial site) and land condition. Sites that were representative of B and C condition were selected. In 2004 the C condition site was initially covered in weedy dicots, with very little grass, following extensive late dry season fires in 2002 and a late wet season in 2003. However, following the 2004/05 wet season, annual sorghum dominated the site. The sites were both situated on the Wave Hill land system, but varied slightly in available soil water and species composition, sward structure and dilution of nitrogen.

The perennial grass site (Figure D.1) was dominated by the perennial grasses *Dichanthium fecundum* and *Chrysopogon fallax* and the annual grass site (Figure D.2) was dominated by *Sorghum timorense*.

Figure D.1. Perennial grass SWIFTSYND site at Pigeon Hole Station in April 2005 and August 2006.

Figure D.2. Annual Sorghum dominated SWIFTSYND site at Pigeon Hole Station in April 2005 and August 2006.

The sites were located at the northern end of the Pigeon Hole research trial site (Figure D.3, Table D.1).

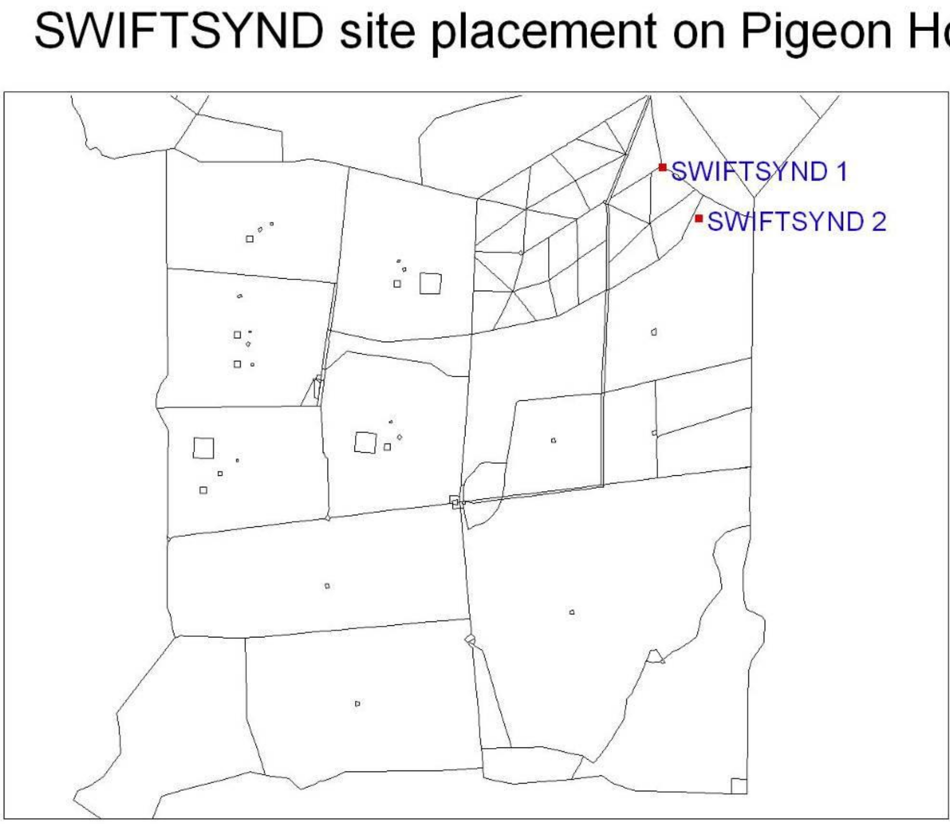

Figure D.3. Location of SWIFTSYND sites on the Pigeon Hole research trial site. Site 1 is the perennial grass site, and site 2 is the annual grass site.

Table D.1. SWIFTSYND site description at Pigeon Hole station.

Site	Geographic Coordinates (UTM, GDA 94)	Paddock	Land system	Land condition	Soil description
Mixed perennial grass	Easting 725046, Northing 8130127	Cell graze	Wave Hill	B	Basalt derived black cracking clay, very rocky. Lots of smaller red and yellow surface rocks. Quite undulating, with melon holes at the scale of around 1m.
Annual sorghum	Easting 726151, Northing 8128361	Set Stocked	Wave Hill	C	Basalt derived black cracking clay, very rocky

D.2.2 Data collection

Data to calibrate GRASP was collected following Day and Philp (1997). Sites were reset with fire at the end of each dry season. See Table D.2 for data collection timing.

Table D.2. Schedule of data collected at Pigeon Hole SWIFTSYND sites.

Mixed perennial grass		Annual sorghum	
Date	Activity	Date	Activity
04/11/2004	Burn	04/11/2004	Burn
05/11/2004	Initial	05/11/2004	Initial
28/01/2005	Harvest* 1	28/01/2005	Harvest 1
06/04/2005	Harvest 2, full species composition	06/04/2005	Harvest 2, full species composition
03/06/2005	Harvest 3	02/06/2005	Harvest 3
19/10/2005	Harvest 4	18/10/2005	Harvest 4
20/10/2005	Burn	19/10/2005	Burn
20/10/2005	Initial	20/10/2005	Initial
06/01/2006	Harvest 5	05/01/2006	Harvest 5
12/04/2006	Harvest 6	11/04/2006	Harvest 6
11/08/2006	Harvest 7	10/08/2006	Harvest 7
11/10/2006	Harvest 8	13/10/2006	Harvest 8

*Harvest – both soil moisture and pasture TSDM collected

D.2.3 Calibration of GRASP

SWIFTSYND data were used to calibrate GRASP in GRASP Calibrator following standardised calibration procedures (Scanlan *et al.* 2008).

D.3 Results

D.3.1 Rainfall

The 50 year median rainfall for the sites is 623mm (from interpolated SILO datadrill records 1957/58 – 2007/08). However there has been an increasing trend in rainfall over the last 50 years in the region (CSIRO and BOM 2007). The two years that pasture growth was monitored were the median and the highest ever recorded rainfall (Table D.3). Figure D.4 shows the distribution of rainfall throughout the growing seasons of 2004-05 and 2005-06.

Table D.3: Rainfall at Pigeon Hole SWIFTSYND sites over the study period.

Median	2004-05 rainfall (mm)	Deviation from median	Percentile	2005-06 rainfall (mm)	Deviation from median	Percentile
623	623	0%	50th	1069	+71%	100th

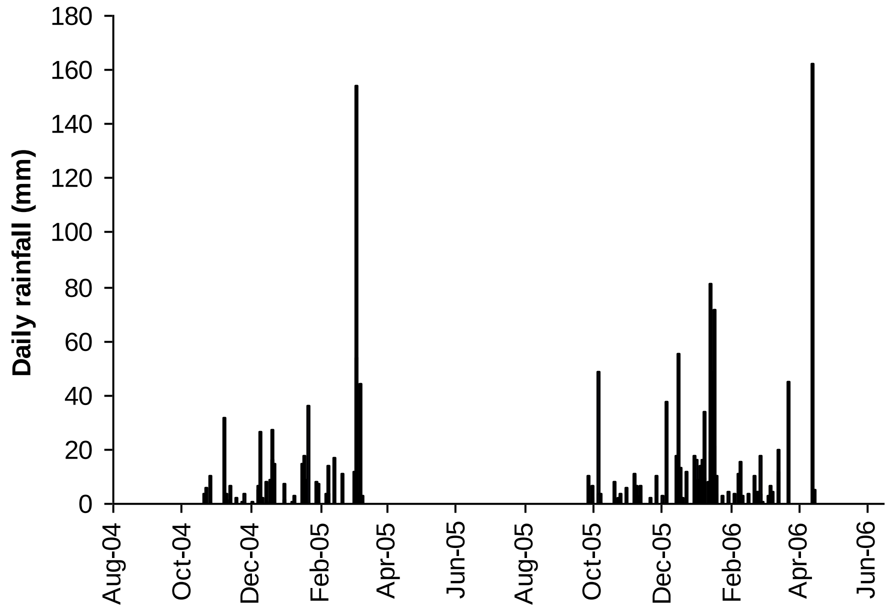

Figure D.4. Daily rainfall at the Pigeon Hole SWIFTSYND sites in 2004-05 and 2005-06 wet seasons.

D.3.2 Soils

D.3.2.1 Soil description

The soils were basalt derived cracking clays (Table D.4 - Table D.5). Both sites were very rocky, particularly the perennial grass site with 60-80% rock by volume to 42cm depth. This compares with the annual grass site with 50-60% rock to 10cm, and 25% rock to 25cm.

Table D.4: Soil description for mixed perennial grass SWIFTSYND site at Pigeon Hole station.

Site	Mixed perennial grass	
Landform	Gently undulating plain (gilgai micro relief)	
Australian Soil Classification	Haplic, Brown Dermosol	
Depth	Horizon	Description
Surface		25%, 20mm, sub angular, sandstone and 35%, 50mm, sub rounded quartz and 10%, 200mm, sub rounded quartz and 10%, 20mm sub angular chert
1-5cm	A1	Brown (10YR5/3); clay loam; massive; earthy; dry, firm consistence; 40%, 20mm angular quartz and 5%, 40mm angular basalt and 15%, 8mm angular platy quartz; pH 6.5
5-42cm	B1	Dark yellowish brown (10YR4/4); light clay; strong smooth-ped structure; moist; moderately sticky; 25%, 20mm, sub rounded, quartz and 25%, 20mm, sub angular tabular chert and 20%, 5mm, sub angular chert and 10%, 20mm sub angular quartz; pH 6.5
42-65cm	B1	Olive brown (2.5Y4/3); medium heavy clay; strong smooth-ped structure; moist; very sticky; 2%, 3mm, sub angular tabular, quartz and 8%, 40mm, sub angular quartz

Table D.5. Soil description for annual sorghum SWIFTSYND site at Pigeon Hole station.

Site	Annual sorghum	
Landform	Gently undulating plain	
Australian Soil Classification	Self-mulching, Grey Vertosol	
Depth	Horizon	Description
Surface		10%, 20mm, sub angular tabular, basalt and 30%, 200mm, sub angular tabular basalt and 20%, 300mm, sub angular tabular basalt
0-10cm	A1	Dark greyish brown (2.5YR4/2); medium clay; strong 3mm and 20mm, sub angular blocky; smooth-ped structure; dry, rigid consistence; very sticky; common, distinct, slickensides; 40%, 60mm, sub angular tabular, sandstone and 5%, 15mm, sub rounded chert and 5%, 15mm, sub angular tabular basalt; pH 7.0
10-25cm	B21	Dark greyish brown (2.5YR4/2); medium heavy clay; strong 5mm and 15mm, sub angular blocky; smooth-ped structure; moist, rigid consistence; very sticky; common, distinct, slickensides; 20%, 60mm, sub rounded basalt and 5%, 8mm, rounded chert; pH 7.0
25-65cm	B22	Dark greyish brown (2.5YR4/2); heavy clay; strong 5mm and 15mm, sub angular blocky; smooth-ped structure; moist, rigid consistence; very sticky; common, distinct, slickensides; 10%, 25mm, sub rounded chert; pH 7.5
65+cm	C	basalt

D.3.2.2 Soil moisture

Total water holding capacity was slightly lower at the perennial grass site (Table D.6).

Table D.6. Physical properties of soils at Pigeon Hole SWIFTSYND sites.

Site	Air dry moisture content (%)		Bulk density (g/cm^3)					Water holding capacity (mm)			
	0-10cm	10-20cm	0-10cm	10-20cm	20-30cm	50-60cm	80-100cm	0-10cm	10-50cm	50+ cm	Total
Mixed perennial grass	2.6	3.7	0.98*	0.98	0.98	0.98	0.98	21	52	71	144
Annual sorghum	6.8	9.0	1.46	1.57	1.62	1.57	1.57	25	50	79	154

*Only one bulk density reading was obtained due to high volume from rocks in the soil profile.

Water holding capacity (estimated as the difference between field capacity and wilting point, maximum – minimum soil water) declined with depth, despite the higher volume of soil (Figure D.5 - Figure D.6). It is likely that maximum water holding capacity was not able to be measured in the field due to difficulties accessing the sites following rain.

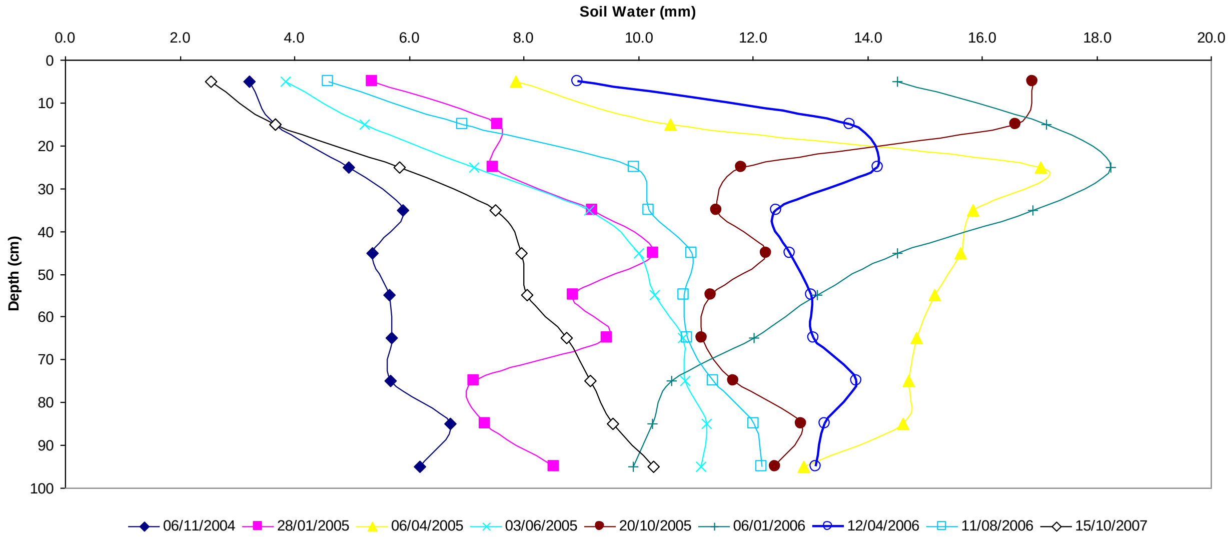

Figure D.5. Soil water holding capacity by depth (mm/10cm) for mixed perennial grass site at Pigeon Hole Station.

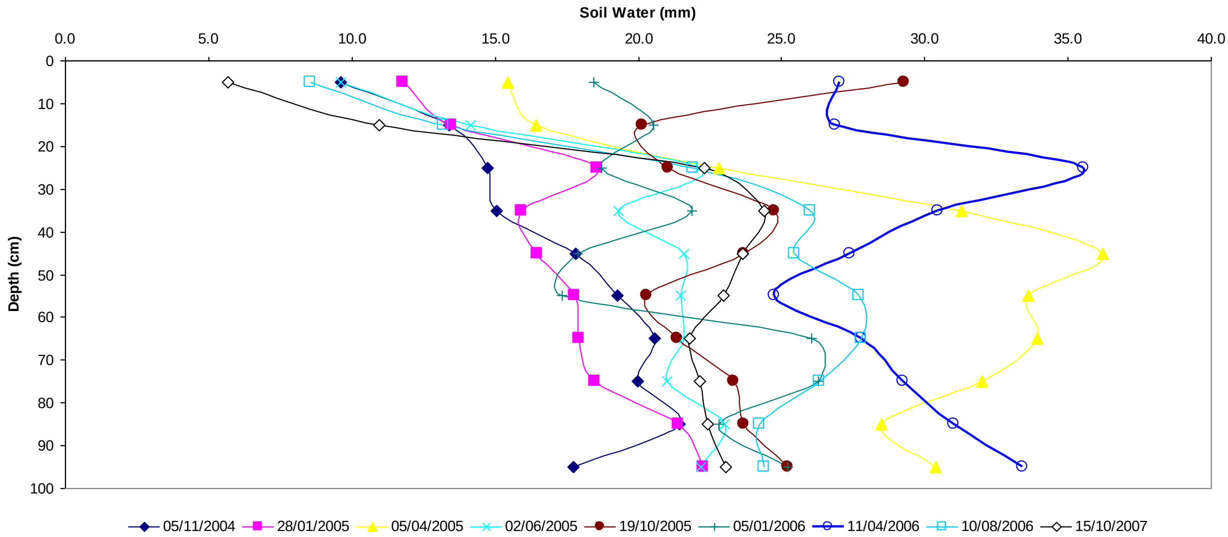

Figure D.6. Soil water holding capacity by depth for annual sorghum site at Pigeon Hole Station.

D.3.3 Pasture

D.3.3.1 Species composition

Species composition by weight and a full list of species present at sites are shown in Table D.7 - Table D.8. The average of the combined composition of the two SWIFTSYND sites in April and June 2005 was similar to the average composition of the Pigeon Hole research site in May 2005.

Table D.7. Species composition of SWIFTSYND sites at Pigeon Hole Station. Average of end of season harvests.

Site	Main species groups contributing to yield	% composition
Perennial grass 2005 and 2006 combined	*Dichanthium fecundum*	30
	Chrysopogon fallax	23
	Brachyachne convergens and *Aristida latifolia*	34
	Dicots	13
Annual sorghum 2005 and 2006 combined	*Sorghum timorense*	85
	Chrysopogon fallax, Panicum decompositum, Brachyachne convergens, Iseilema spp.	9
	Dicots	6
Average of April and June 2005 SWIFTSYND sites combined	*Sorghum timorense*	37
	Chrysopogon fallax, *Aristida latifolia*, *Panicum decompositum*, *Brachyachne convergens, Iseilema spp.*	38
	Dichanthium fecundum	12
	Dicots	13
May 2005 Average across larger Pigeon Hole Research site	*Sorghum timorense*	32
	Chrysopogon fallax, *Aristida latifolia*, *Panicum decompositum*, *Brachyachne convergens, Iseilema spp.*	39
	Dichanthium fecundum	5
	Dicots	14

Table D.8. Main species present at SWIFTSYND sites at Pigeon Hole station.

Latin Name	Common Name	Mixed perennial grass	Annual sorghum
Abutilon andrewsianum	Andrews Lantern		Scattered
Aristida latifolia	Wiregrass	Common	
Astrebla elymoidies	Mitchell Grass	Scarce	
Brachyachne convergens	Native Couch	Very Abundant	Abundant
Bulbostylus barbarta	Sedge	Common	
Chrysopogon fallax	Ribbon Grass	Sub-Dominant	Common
Commelina ciliata	Slender Commelina	Common	
Commelina ensifolia	Succulent Commelina		Not Common
Desmodium muelleri	Trifoliate Leaf	Not Common	
Dichanthium fecundum	Queensland Blue Grass	Dominant	Not Common
Eriachne ciliata	Wanderrie Grass	Patchy	
Euphorbia schizolepis	Caustic Weed		Scattered
Flemingia pauciflora	Fleming's Bush		Abundant
Goodenia byrnesii	Byrne's Goodenia	Scattered	
Heliotropium plumosum	Heliotrope	Common	
Iseilema fragile	Flinders Grass		Sub-Dominant
Iseilema vaginiflorum	Flinders Grass	Scattered	
Jacquemontia browniana	Jacquemontia		Common
Panicum decompositum	Native Millet	Not Common	Common
Phyllanthus maderaspatensis	Spurge		Scattered
Polymeria ambigua	Creeping Polymeria		Scattered
Rhynchosia minima	Rhynchosia		Common
Sesbania chippendalei	Sesbania Pea	Common	Not Common
Sorghum timorense	Annual Sorghum	Scattered	Dominant
Tephrosia rosea	Composite Leaf Herb		Scattered

Growth of pasture components through the two growing seasons is shown in Figure D.7 - Figure D.8. *Iseilema* was only present in the first growing season on the annual grass site.

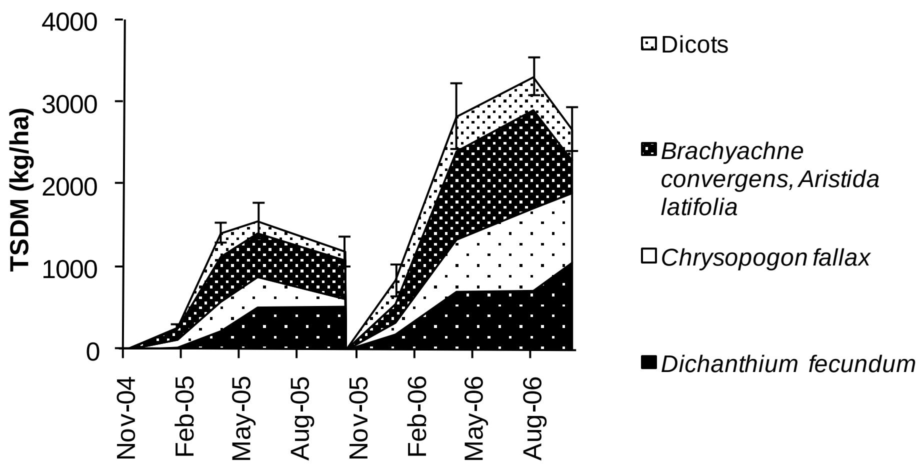

Figure D.7. Change in species yield through time at the perennial grass SWIFTSYND site at Pigeon Hole Station. Means ± standard errors.

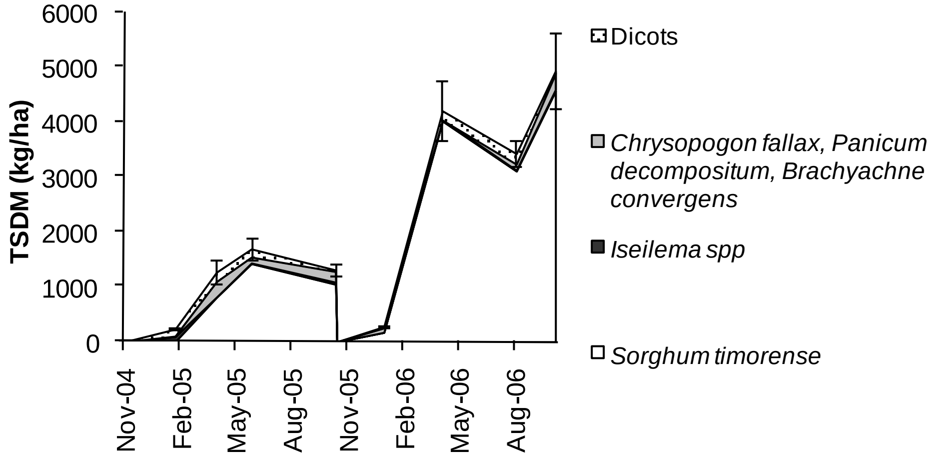

Figure D.8. Change in species yield through time at the annual sorghum site at Pigeon Hole station. Means ± standard errors.

D.3.3.2 Nitrogen

Maximum nitrogen uptake was similar between the sites, but the sorghum site had a greater dilution of N (Table D.9). N% for individual species or species groups was able to be expressed as a function of days since the initiation of the growing season following Scanlan (cited in Jacobsen 1981) (Figure D.9 - Figure D.14). The peak N% for the perennial grass site may be lower than what occurs earlier in the growing season, as it was sampled 78 days into the growing season (e.g. Figure D.9).

Table D.9. N status of SWIFTSYND sites at Pigeon Hole station.

Site	Max uptake (kg/ha)	Max content (%)	Min content (%)
Perennial grass	17.1	1.52	0.39
Annual sorghum	16.2	2.19	0.29

Change in N% as the growing season progresses is shown for the different pasture components in (Figure D.10-Figure D.14). Data are shown for both SWIFTSYND sites and years combined.

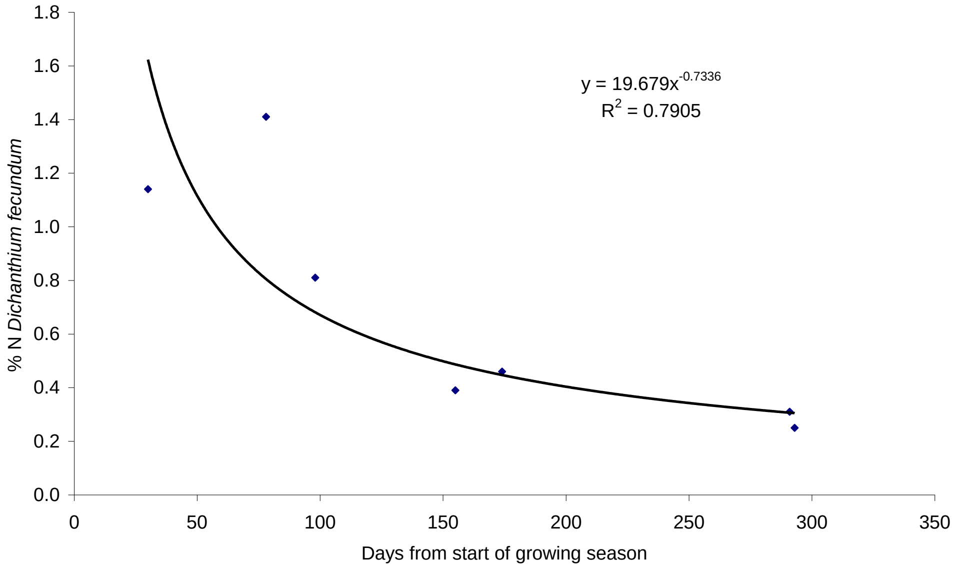

Figure D.9. Change in N concentration of *Dichanthium fecundum* with time since the start of the wet season at Pigeon Hole station.

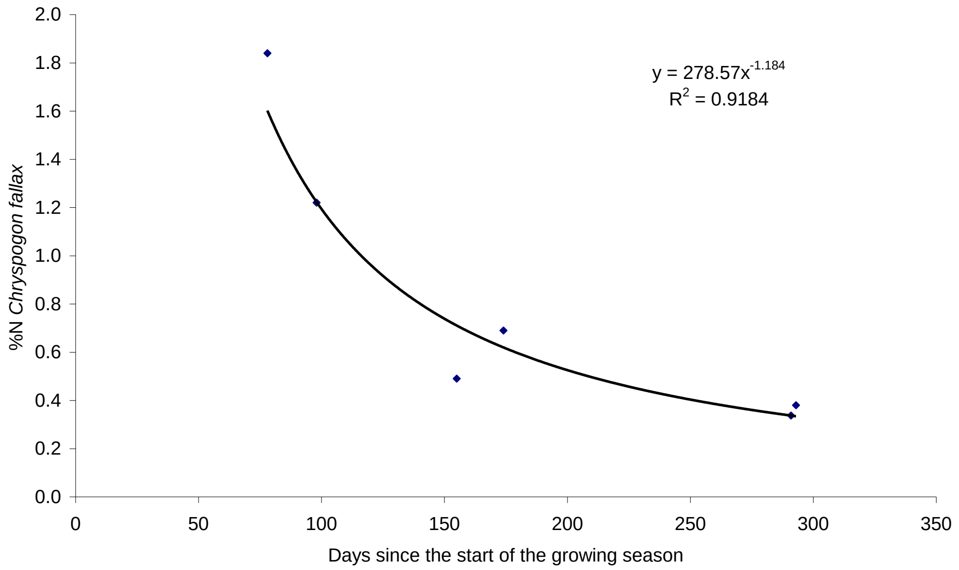

Figure D.10. Change in N concentration of *Chrysopogon fallax* with time since the start of the wet season at Pigeon Hole station.

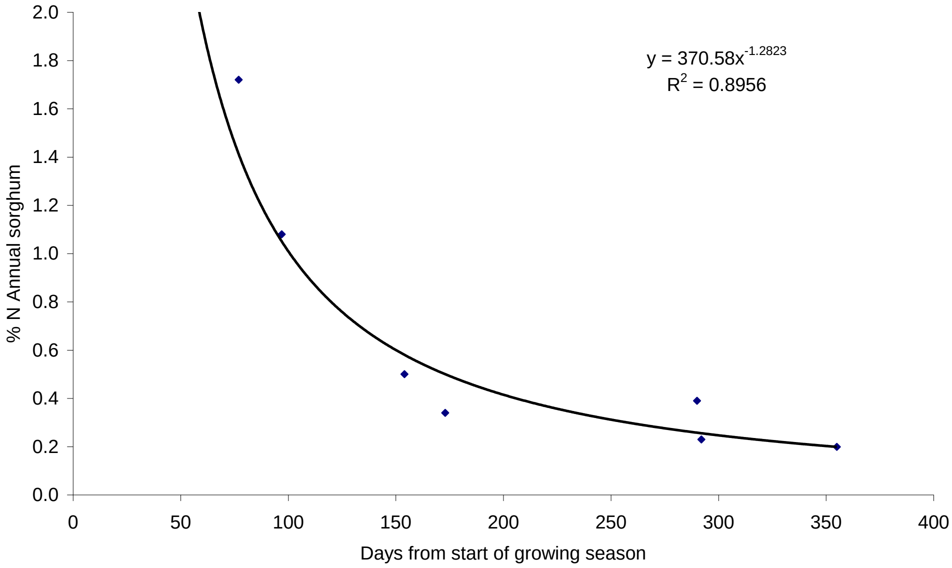

Figure D.11. Change in N concentration of annual sorghum with time since the start of the wet season at Pigeon Hole station.

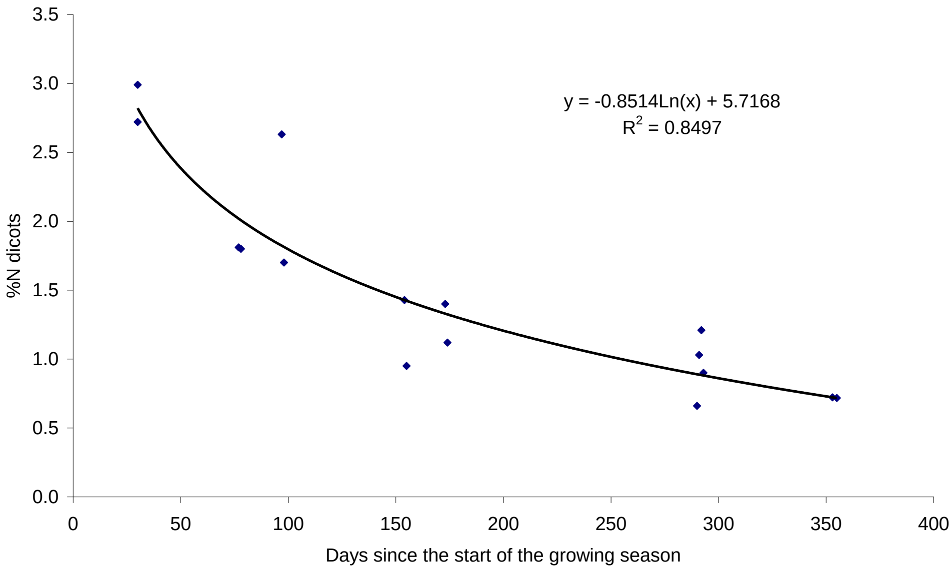

Figure D.12. Change in N concentration of dicots with time since the start of the wet season at Pigeon Hole station.

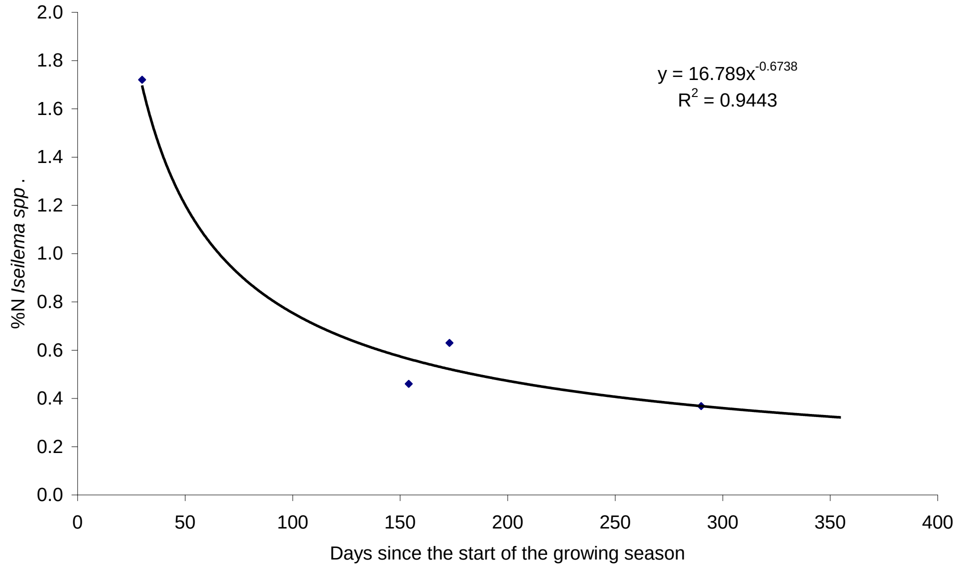

Figure D.13. Change in N concentration of *Iseilema spp.* with time since the start of the wet season at Pigeon Hole station.

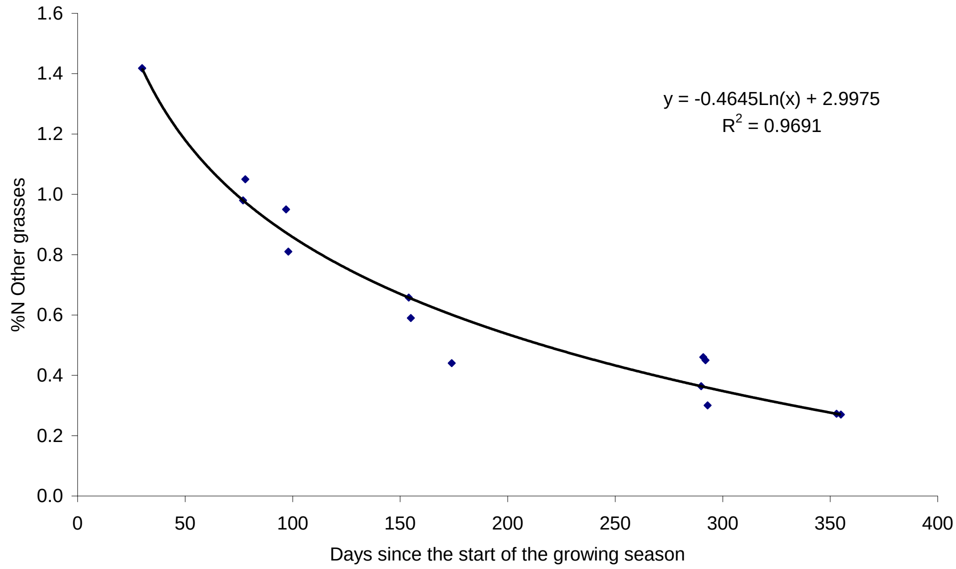

Figure D.14. Change in N concentration of other grasses with time since the start of the wet season at Pigeon Hole station.

D.3.3.3 Pasture structure and growth

Pasture growth rates were similar between the sites in the first median rainfall year, but were much higher for the annual sorghum site in 2005-06 (Table D.10).

Table D.10. Pasture variables at Pigeon Hole SWIFTSYND sites.

Site	Year	Tree basal area	Perennial grass basal area (%)	Peak total standing dry matter	Growth rate (kg/ha/yr)
Perennial grass	2004/05	0	1.6	1570 ± 223	10.1
	2005/06	0	2.2	3327 ± 395	16.4
Annual sorghum	2004/05	0	0.44	1696 ± 192	11.0
	2005/06	0	0.33	4217 ± 560	24.2

The two sites differed structurally (Figure D.15 - Figure D.17). The annual sorghum site had higher cover and lower height per yield.

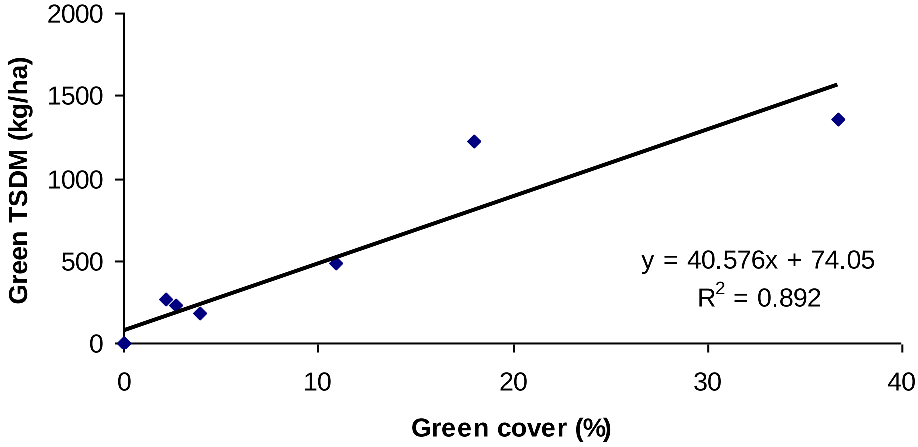

Figure D.15. Relationship between total standing dry matter and green yield at Pigeon Hole Station (perennial grass and annual sorghum sites pooled).

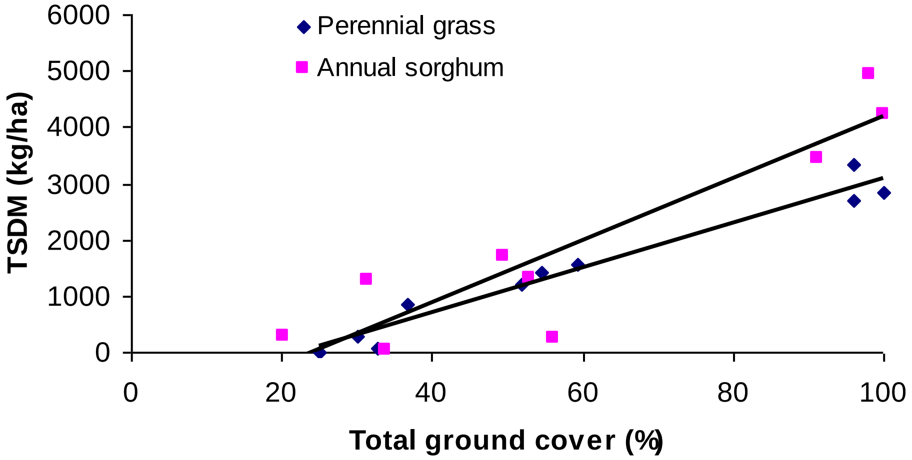

Figure D.16. Relationship between total standing dry matter and total ground cover for SWIFTSYND sites at Pigeon Hole station.

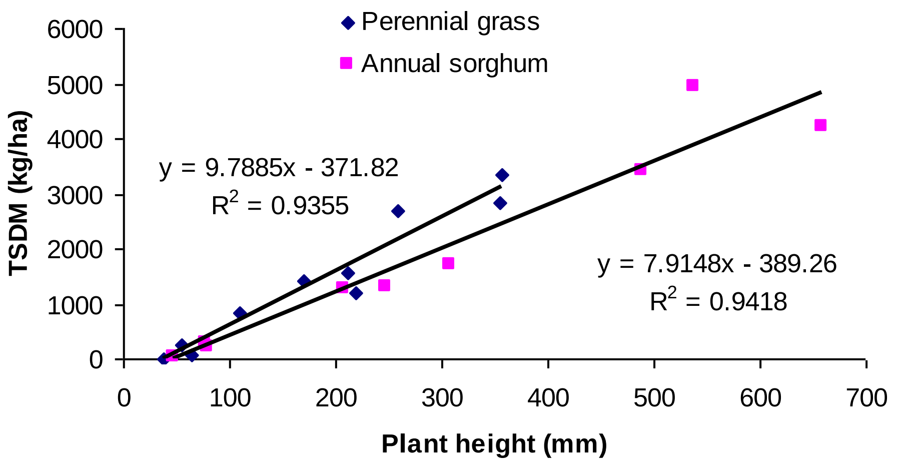

Figure D.17. Plant height versus TSDM at Pigeon Hole station SWIFTSYND sites.

D.3.4 Modelled pasture growth

GRASP was able to simulate pasture growth well (r^2=0.95 and 0.93 for the perennial and annual grass sites respectively) at the SWIFTSYND sites. See Figure D.18 and for model calibration of the *Dichanthium* and *Sorghum* sites and Table D.11 for GRASP parameter values for the different sites.

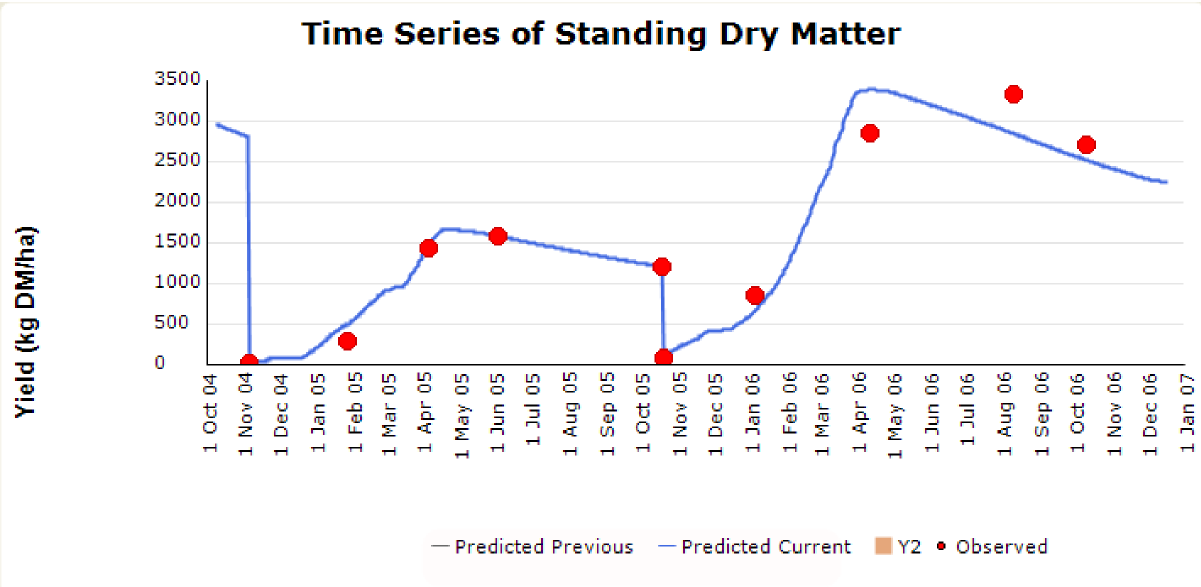

Figure D.18. Model fit of simulated Total Standing Dry Matter for *Dichanthium fecundum* SWIFTSYND site at Pigeon Hole Station. r^2 = 0.95, rmse = 255.

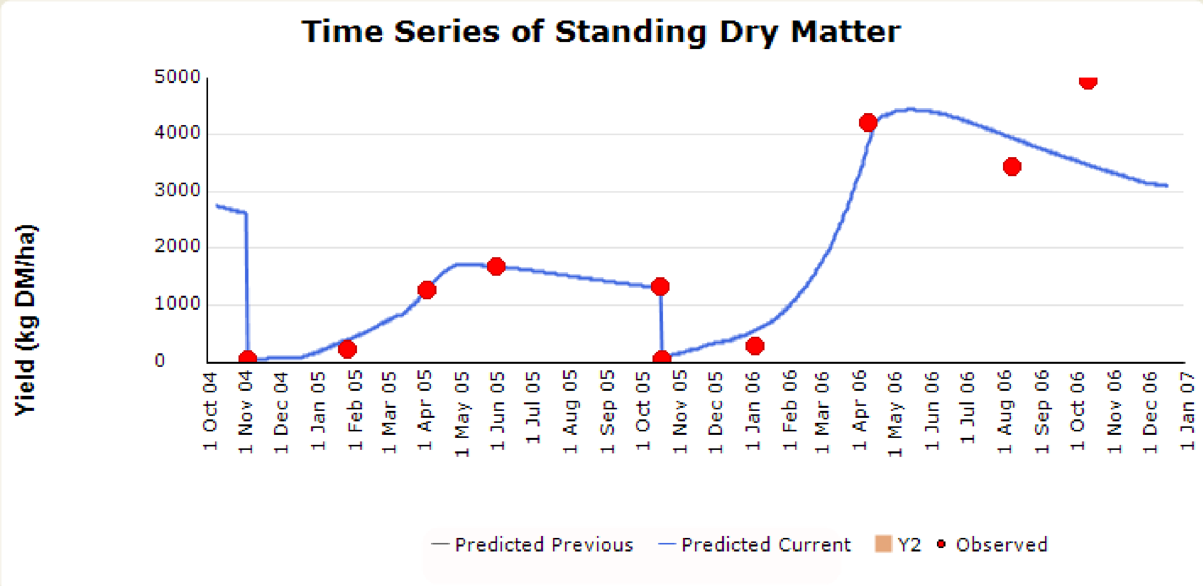

Figure D.19. Model fit of simulated Total Standing Dry Matter for annual sorghum SWIFTSYND site at Pigeon Hole Station. r^2 = 0.93, rmse = 517. When the last TSDM point is excluded r^2 = 0.98, rmse = 232.

Median pasture growth was very similar for the two sites (2043 kg/ha for the perennial grass site and 2028 kg/ha for the annual sorghum site). But in the wettest years the annual sorghum site grows more than the perennial grass site (Figure D.20 - Figure D.21).

Table D.11. GRASP parameter values for SWIFTSYND sites at Pigeon Hole.

Parameter	Parameter No.	Perennial grass site	Annual sorghum site
Soil parameters			
Depth of layer 1 (mm)	020	100	100
Depth of layer 2 (mm)	021	400	400
Depth of layer 3 (mm)	022	500	500
Air dry layer 1 (mm)	019	2	7
Air dry layer 2 (mm)	389	25	77
Air dry layer 3 (mm)	390	40	92
Wilting point layer 1 (mm)	029	5	10
Wilting point layer 2 (mm)	030	28	80
Wilting point layer 3 (mm)	031	44	96
Field capacity layer 1 (mm)	026	26	35
Field capacity layer 2 (mm)	027	80	130
Field capacity layer 3 (mm)	028	115	175
Cracking / deep soil evaporation (Yes/No)	035	Yes	Yes
Maximum soil evaporation (mm/day)	033	4	4
Rate of deep soil evaporation (mm/day)	036	0.6	0.6
Runoff (Yes/No)	270	No	No
PAWC (fc-wp) layer 1 (mm)		21	25
PAWC (fc-wp) layer 2 (mm)		52	50
PAWC (fc-wp) layer 3 (mm)		71	79
PAWC (fc-wp) layers 1-3 (mm)		144	154
PAWC (fc-wp) layers 1-3 average (mm/10cm)		14.4	15.4
Tree parameters			
Mature tree basal area	291	0	0
Layer 1 minimum soil moisture (mm) with trees	292	5	10
Layer 2 minimum soil moisture (mm) with trees	293	28	80
Layer 3 minimum soil moisture (mm) with trees	294	44	96
Layer 4 available water (trees only)	295	0	0
Maximum rooting depth of trees in cm	296	100	100

Parameter	Parameter No.	Perennial grass site	Annual sorghum site
Starting value for soil moisture layer 4 (mm) trees	299	0	0
Sward structure parameters			
Green standing dry matter at 50% green cover (kg/ha)	045, 046, 271	1876	3074
Height of 1000kg/ha standing dry matter (cm)	096	14	17.5
Plant growth parameters			
Perennial grass basal area (%)	005	1.6	1
Potential regrowth rate / unit PGBA (kg/ha/day/basal%)	006	9	11
Potential regrowth rate (kg/ha/day)		14.4	11
Transpiration-use-efficiency (kg/ha/mm transpired)	007	15	22
Soil water index at which growth stops	149	0.35	0.3
Soil water index at which cover is restricted	009	0.45	0.4
Nitrogen parameters			
N uptake at 0 mm of transpiration (kg/ha)	097	4	4
N uptake per 100mm of transpiration (kg/ha/100mmT)	098	8	8
Maximum nitrogen uptake (kg/ha)	099	17	18
Maximum nitrogen content in plants (%)	100	2.5	2.5
N content at which growth stops (%)	101	0.5	0.4
N content at which growth is restricted (%)	102	0.6	0.5
Minimum N content in dead (%)	111	0.4	0.3
Detachment parameters			
Leaf detachment – wet season (kg/kg/day)	128	0.001	0.001
Stem detachment – wet season (kg/kg/day)	129	0.001	0.001
Leaf detachment – dry season (kg/kg/day)	130	0.002	0.002
Stem detachment – dry season (kg/kg/day)	131	0.002	0.002

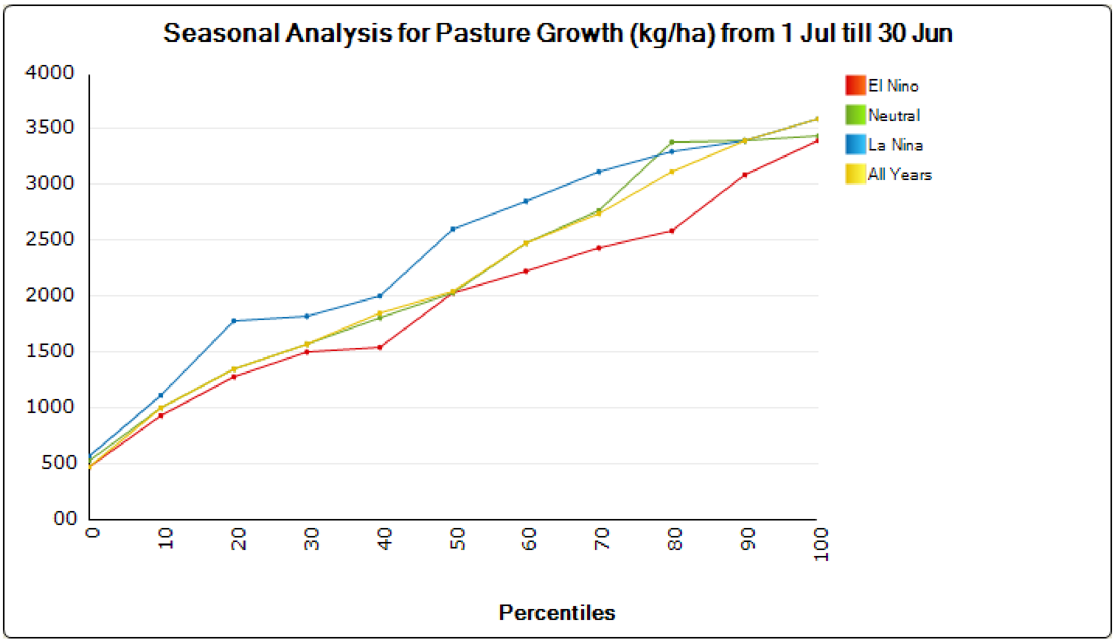

Figure D.20. Simulated historical percentile pasture growth at *Dichanthium fecundum* site at Pigeon Hole Station.

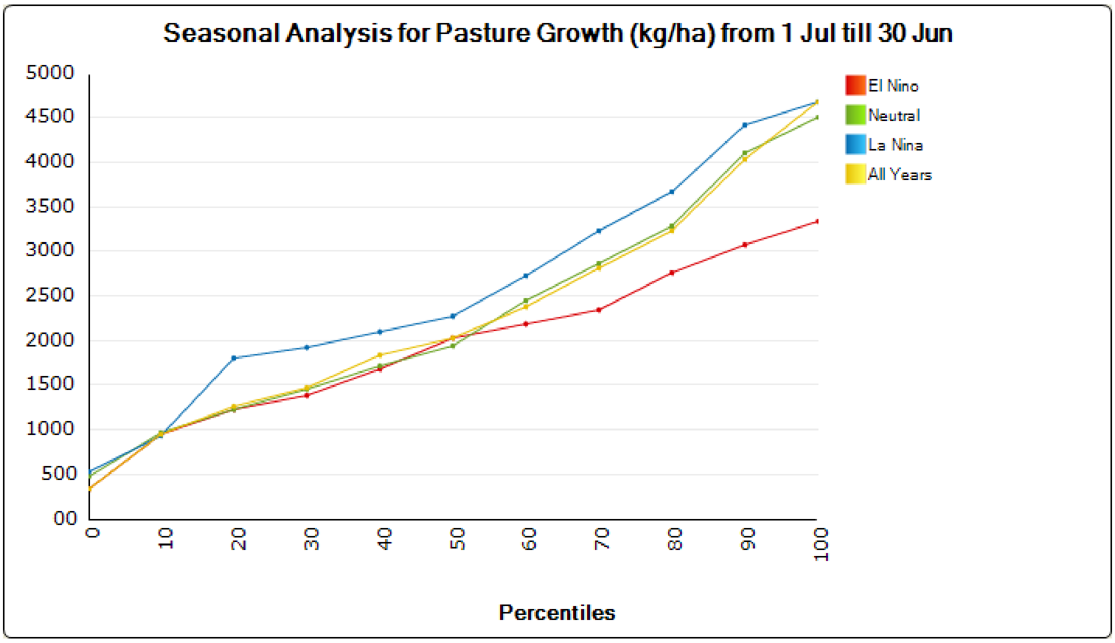

Figure D.21. Simulated historical percentile pasture growth at annual sorghum site at Pigeon Hole Station.

D.3.5 Start date and duration of the wet season

The start date of the wet season was calculated as when the first 50 mm of rain fell within a 14 day period (first day of = start of wet). The start date by this method was sometimes different to the start date of growth as modelled by GRASP (Table D.12). When differences were in the order of a month, this occurred when there was only a small growth event. For this reason, the 50mm start date was used as this better represented wet season start.

The duration of the wet season (the number of days with pasture growth) ranged from 4 to 5 months. There were two growth events in 2007. The dry season growth event of 2007 only produced an estimated 296 kg/ha, due to the suboptimal temperatures for growth at this time.

Table D.12. Start and end dates for the wet season based on 50 mm within 14 days and GRASP modelled first and last day of growth.

Wet Season	50mm in 14 days	Modelled grass growth start	Modelled grass growth end *Dichanthium* model	Modelled grass growth end sorghum model	Estimated growing season (days)
2002-2003	03-Dec-02	01-Dec-02	09-Apr-03	09-Apr-03	129
2003-2004	12-Dec-03	07-Dec-03	13-Apr-04	13-Apr-04	128
2004-2005	24-Dec-04	20-Nov-04	18-Apr-05	18-Apr-05	149
2005-2006	18-Oct-05	18-Oct-05	27-Mar-06	30-Apr-06	160
2006-2007	13-Jan-07	20-Dec-06	28-Apr-07	28-Apr-07	129
	20-Jun-07	23-Jun-07	08-Aug-07	08-Aug-07	46

D.4 Discussion

Representativeness of SWIFTSYND sites to the larger trial area

The composition of the combined SWIFTSYND sites was very similar to that found across the research site. However the individual SWIFTSYND sites were generally less representative, due to their very small scale, although the perennial grass site was similar to GR1 in the lack of Sorghum. This suggests that a combination of both sites would suit the larger research site for simulation purposes.

The seasons experienced covered a good range of possible conditions, from median to highest on record rainfall. The ability of the model to simulate both wet seasons increases confidence in the reliability of the model to predict growth over a range of seasons, and therefore the long term median.

Water holding capacity

The water holding capacity of the perennial grass site was limited by a higher volume of basalt rocks compared to the annual grass site. Water holding capacity at both sites was lower than previously recorded values for the Wave Hill land system (Cobiac 2006a). Again, this was probably due to the high volume of large basalt rocks at Pigeon Hole Station compared with Mt Sanford Wave Hill SWIFTSYND sites.

Nitrogen

The maximum N uptake was much lower than for midgrass on clay soils (29 kg/ha reported in Mott *et al.* 1985), the Mt Sanford sites on the Wave Hill land system, which had maximum N uptakes ranging between 26.5 to 36.4 kg/ha (Cobiac 2006a) and alluvial cracking clays in the VRD which averaged 27 kg/ha (Cobiac 2006a). Like the water holding capacity, the lower maximum N uptake may reflect the lower soil volume per m^3 at Pigeon Hole due to the high rock volume.

Maximum N Uptake was similar to that reported for the Wave Hill land system at Rosewood station (18 kg/ha, Cobiac 2006a), for tussock grassland (17 kg/ha, Christie 1981); for the red earths of the VRD (averaging 18kg/ha, Cobiac 2006a) and higher than found for pastures on less fertile soils such as *Sorghum intrans* swards south of Darwin (8-12 kg/ha, Cook and Andrew

1991) and native perennial grass pasture near Katherine (7-11 kg/ha Smith 1960, 8-9 kg/ha Dyer *et al.* 2003).

The N concentration of *Chrysopogon fallax* showed a similar range and seasonal decline to that found elsewhere at Townsville (McIvor 1981) and Katherine (Arndt and Norman 1959).

The peak N% for the perennial grass site was similar to that reported for Tippera pastures at Katherine (1.6%, Norman 1963), but lower than found on Wave Hill land system soils in the VRD (2.04-3.11%, Cobiac 2006a). It is possible this is due to sample timing, as the peak value at the Pigeon Hole site was collected relatively late in the growing season (78 days) due to difficulties gaining access on the heavy clays when wet.

The minimum N% measured at the sites was similar to that reported elsewhere (ranging from 0.2-0.4% Norman 1963, McIvor 1981), but lower than found at Mt Sanford (0.36-0.5%, Cobiac 2006a).

The N% measured at the *Dichanthium* – *Chrysopogon* site is similar to that found in *Dichanthium-Eulalia* grasslands in north west Queensland (Hall 1981) where the N% of *Chrysopogon* and *Dichanthium* at the end of the dry season was around 0.4 and 0.45% respectively.

At the sorghum dominated site minimum N% of sorghum (0.23-0.39%) was similar to that found for *S. timorense* in north west Queensland (<0.3%N, Hall 1981). The minimum and the maximum N% of sorghum at Pigeon Hole (1.5%) are both higher than reported for *S. intrans* and *S. stipoideum* which ranged from 0.91-0.12 %N at 60 days and at maturity (Cook and Andrew 1991). This may reflect the different *Sorghum* species and more fertile soils at Pigeon Hole.

Pasture growth

The pasture growth at these sites was comparable to that found by Cobiac (2006a) in 1994-5 at Mt Sanford SWIFTSYND sites on the Wave Hill Land system (2058-3471 kg/ha in average to above average rainfall years). Growth was also similar to *Sorghum intrans* swards south of Darwin (3000 kg/ha, Cook and Andrew 1991).

Growth rates were similar to those reported for the Wave Hill land system (9-25kg/ha/day, Cobiac 2006a) and for midgrass on clay soils and tussock grasslands (12-14 kg/ha/day respectively, reviewed in Mott *et al.* 1985).

The higher pasture growth on the annual sorghum site was due to a slightly higher water holding capacity, higher TUE and a greater capacity to dilute nutrients. Hence it could produce more biomass per nutrient availability. This is contrary to the previous findings where a decline in land condition resulted in lower pasture growth (Ash *et al.* 1995, McIvor *et al.* 1995). Land condition change to annual dominated pastures has been previously observed to and been represented in GRASP by: reducing the soil water index at which growth stops and declines; reducing maximum N Uptake; and increasing minimum N concentration (McKeon *et al.* 2000). However at Pigeon Hole minimum N concentration and was lower and maximum N uptake was very similar for the annual vs. perennial dominated pastures, which facilitated greater pasture growth in annual sorghum in high rainfall years, due to the ability of Sorghum to dilute N.

GRASP calibration

The annual sorghum was somewhat problematic to calibrate using GRASP. Calibration methods for annual dominated sites recommend setting perennial grass basal area to 1% regardless of actual PGBA (here only 0.3-0.4%) and running the model on potential regrowth (Scanlan *et al.* 2008). The potential regrowth model is usually only used for early regrowth of perennial pastures, before green cover increases enough to run the model based on transpiration use efficiency. To avoid using the TUE model, the TUE parameter value is assigned a very low number, so growth is always based on potential regrowth. However, the potential regrowth rate required to fit the early growth of the sorghum site did not grow biomass fast enough to reach the final measured yields at the site. So to accurately model measured growth at the sorghum site, it was not only run on potential regrowth rate, as is recommended for annual pastures, but TUE was also used and was set at quite a high rate of 22kg/ha/mm transpired. This was based on best fit, and the relatively high value may reflect annual sorghum directing most of its photosynthate to above ground growth, compared to perennial swards (Greg McKeon pers. comm.). Setting the PGBA to 1% also fits with Cobiac's (2006a) method of using both annual and perennial grass basal area for calibration of annual dominated sites. The annual plus perennial basal area of the sorghum site was 0.8-0.9%, which is close to 1%.

Modelled pasture growth

Despite differences between the sites, the modelled *median* pasture growth was the same. The ability of the annual sorghum site to produce much higher yields in high rainfall years further separates it from the perennial grass site, as the sorghum site can grow up to 4500 kg/ha when water is unlimited, whereas the perennial grass site can only grow up to 3500kg/ha. This is due to a slightly higher maximum N uptake in the annual grass site, but probably mostly because sorghum can dilute nutrients more, allowing more biomass per N.

The implications of this are that in high rainfall years sorghum dominated areas will have a large bulk, but very low quality pasture (total dry sward N% was only 0.3% in the late dry, versus 0.4% N for total sward at the perennial grass site). The increase in grass growth with increasing rainfall suggests the growth of these pastures is predominantly water limited. This was despite the modest fertility of the sites, but enabled through high dilution of N. This is perhaps not surprising given the average rainfall of 623 mm.

Equations developed to predict growth for Eulalia – Dichanthium swards in north west Queensland (Scanlan cited in Jacobsen 1981) overestimate growth for the Pigeon Hole sites in the drier year of 2004-05, by 1000 kg/ha, but are closer for the wetter year, predicting yield to within 300 kg/ha of the measured 2005-06 growth.

Other

It is possible that the disappearance of *Iseilema* from the annual sorghum site was due to the reset fires, as fire reduces *Iseilema* germination, by burning the seeds (Scanlan and O'Rourke 1982). Conversely Sorghum seeds are adapted to fire with higher germination rates after fire (Mott (1978) and here is evidence that fire may promote Sorghum frequency in northern Australia (e.g. Scott *et al.* 2009, Bowman *et al.* 2007, Russell-Smith *et al.* 2003).

Appendix E: Assumptions for economic comparison of grazing systems

Background financial details and assumptions used in the economic comparison of the different grazing systems presented in Table 5.6. Actual Pigeon Hole project figures were used where possible e.g. livestock numbers, branding percentage, stocking rates for the subsequent calculations of return on invested capital (ROIC) or earnings before income tax (EBIT). The commercial comparison was from a 100 km^2 paddock managed as a set stocked system typical for the district.

		Commercial	**Set stocked**	**Set Util 20%**	**Set Util 25%**	**Wet season spell**	**Cell grazing**
Financial Data	Replacement Capital ($)	60,962	70,567	70,567	70,567	70,567	70,567
	Total Operating ($)	891,100	941,874	969,628	973-,865	938,998	1,542,547
	Total Revenue ($)	1,961,569	2,932,034	2,606,137	3,036,833	3,007,871	3,452,608
	EBIT ($)	941,243	1,796,314	1,423,796	1,821,216	1,845,939	1,680,878
	Capital value ($)	17,542,946	22,283,168	20,731,600	20,914,399	27,008,756	31,778,771
	ROIC	5.4%	8.1%	6.9%	8.7%	6.8%	5.3%
Herd Data	Area (km^2)	100	21	21	21	15	31
	Stocking rate (AE/km^2)	10.0	14.7	13.9	14.7	14.5	18.1
	Branding Percentage	79%	80%	73%	86%	78%	75%
	Herd Mortality	2.0%	1.3%	1.3%	1.3%	1.3%	1.3%
	Breeders	4,843	7,111	6,965	6,807	7,084	8,975
	Total Herd (AEs)	13,063	19,317	18,020	19,266	18,983	23,561
	Sale Cows	591	889	870	851	885	1,122
	Sale Steers	1,820	2,706	2,420	2,789	2,629	3,205
	Sale heifers	1,110	1,693	1,427	1,819	1,619	1,926
	Total sale kg	1,255,520	1,884,707	1,684,970	1,942,834	1,929,408	2,232,078

Assumptions

- The stocking rates are the average of the monthly stocking rates from Oct 2003 to Oct 2007, the period when the paddocks were fully stocked (different from the stocking rates presented for the complete trial period). For Cell grazing the stocking rates were only calculated until October 2006 due to the cell system being closed in December 2006. These are not considered the optimum or recommended stocking rates for these grazing systems but are simply the stocking rates used as a result of the proposed utilisation rate and run of seasons during the trial period. The stocking rates drive the economic data, therefore the economics presented are also an approximation of the returns etc given the stocking rates used in the trial.
- With both set utilisation paddocks 20% and 25%, it was assumed cattle needed to be added or removed in 2 out of 3 years, which involved walking cattle to and from the paddocks (20 additional stock camp days @ $2,000/day). It was also assumed in 1 out of 3 years the station had to pay agistment ($1.50/animal/week) and 1 out of 3 years they offered others agistment ($1.50/animal/week). The net cost was the freight to send 20% of the cattle for agistment in 1 out of 3 years, i.e. 3,920 cattle @ $1.1/deck/km x 300 km =$42,900. They

send grower cattle and sell them off the agistment block so there is no return freight. There is also a 5% decline in branding due to the movement of breeders.

- For WSS there was no additional operating costs in the dry season relative to set stocked as the moves were done during the musters. During the wet season there was 1 extra muster to move cattle out of the late wet season spell treatment. Assumed we moved 30% of the paddocks and cattle @ $5/hd for the chopper.
- With cell grazing it was assumed another person was needed for every 4,000 head to manage the moves, animal behaviour and the paddocks (5 people).
- The herd fertility was kept the same as the branding percentage achieved in the paddocks over the 2004 to 2007 period. The branding percentage was different to that from Table 5.5 as those were based on 2004 and 2005 data due to requirements for statistical analysis.
- Mortality assumed to be equal across the trial systems and less than the commercial herd
- Stabilised static herd with no growth or decline in numbers
- Sale of steers and heifers to live export at 18 m old
- Cows culled at 10 to 12 yr old
- Bulls culled at 8 yr old
- Bull percentage of 4% for cows and 5% for heifers
- Cull for type for breeders of 2%
- Sale price for steers of $1.70/kg ex station
- Sale price for heifers of $1.60/kg ex station
- Sale price of cull cows of $1.20/kg ex station
- Average breeder value of $300

Appendix F: Plant taxa recorded at biodiversity sites at Pigeon Hole

List of plant taxa recorded from sample sites, showing the frequency (number of sites) for each sample year. Taxa used in analyses are shown in this table (see Appendix F).

	Year	2003	2004	2005	2006	2007	All
	Number of sites	*62*	*100*	*100*	*100*	*100*	*100*
FAMILY	**Species**						
ACANTHACEAE	*Rostellularia adscendens*	7	12	11	7	11	15
AIZOACEAE	*Zaleya galericulata*	1	1	1		1	2
AMARANTHACEAE	*Achyranthes aspera*	16	32	30	35	26	46
AMARANTHACEAE	*Alternanthera angustifolia*		1			2	3
AMARANTHACEAE	*Alternanthera nana*	5	14	8	9	5	21
AMARANTHACEAE	*Alternanthera nodiflora*		2			1	2
AMARANTHACEAE	*Alternanthera pungens*	2	3	3	7	3	7
AMARANTHACEAE	*Gomphrena affinis*	14	33	31	23	23	49
AMARANTHACEAE	*Gomphrena canescens*	1			5		6
AMARANTHACEAE	*Ptilotus exaltatus*	1	1	2	1	2	4
AMARANTHACEAE	*Ptilotus fusiformis*		1	1	1		1
AMARANTHACEAE	*Ptilotus spicatus*	31	59	47	47	45	72
AMARANTHACEAE	*Salsola tragus*		1		1	1	3
APOCYNACEAE	*Carissa lanceolata*	8	12	8	13	13	19
ASCLEPIADACEAE	*Calotropis procera*	27	27	27	44	38	53
ASTERACEAE	*Bidens pilosa*			1		1	1
ASTERACEAE	*Blumea tenella*	32	39	2	47	27	70
ASTERACEAE	*Flaveria australasica*	1	7		3	2	9
ASTERACEAE	*Pentalepis ecliptoides*	36	63	31	46	52	80
ASTERACEAE	*Pterocaulon serrulatum*	2	14	1	1	7	18
ASTERACEAE	*Pterocaulon sphacelatum*	1	1		1		3
ASTERACEAE	*Streptoglossa bubakii*	17	37	20	26	37	58
ASTERACEAE	*Streptoglossa odora*		1			2	3
ASTERACEAE	*Wedelia asperrima*	51	77	70	69	80	87
BIGNONIACEAE	*Dolichandrone heterophylla*	2		1	2		5
BORAGINACEAE	*Ehretia saligna*		1		2		3
BORAGINACEAE	*Heliotropium combined*	21	24	28	38	20	69
BORAGINACEAE	*Heliotropium foveolatum*		3	1	4	7	11
BORAGINACEAE	*Heliotropium sp. affin tenuifolium*	3	9	9	8	6	17
BORAGINACEAE	*Trichodesma zeylanicum*	57	94	80	76	95	99
CAESALPINIACEAE	*Bauhinia cunninghamii*	18	20	20	28	31	34
CAESALPINIACEAE	*Parkinsonia aculeata*					1	1
CAESALPINIACEAE	*Senna notabilis*	1				1	1
CAESALPINIACEAE	*Senna obtusifolia*		1			2	2
CAESALPINIACEAE	*Senna planitiicola*	3	6	3	3	7	15
CAPPARACEAE	*Capparis lasiantha*	1			1	2	4
CAPPARACEAE	*Cleome viscosa*	11	17	14	9	5	33
CARYOPHYLLACEAE	*Polycarpaea breviflora*		6	6	5	6	9

	Year	2003	2004	2005	2006	2007	All
	Number of sites	*62*	*100*	*100*	*100*	*100*	*100*
COMBRETACEAE	*Terminalia arostrata*	47	50	49	77	69	83
COMBRETACEAE	*Terminalia bursarina*	3	1	3	2	3	3
COMBRETACEAE	*Terminalia volucris*	33	31	31	47	48	61
COMMELINACEAE	*Commelina ciliata*	11	19	11	11	13	30
COMMELINACEAE	*Commelina ensifolia*	52	64	77	53	51	90
CONVOLVULACEAE	*Bonamia media*		3	1	1	2	4
CONVOLVULACEAE	*Bonamia pannosa*	3	4	4	3	1	6
CONVOLVULACEAE	*Evolvulus alsinoides*	13	28	25	23	23	42
CONVOLVULACEAE	*Ipomoea diamantinensis*	1	1			1	1
CONVOLVULACEAE	*Ipomoea diversifolia*	5	14	6	10	6	16
CONVOLVULACEAE	*Ipomoea eriocarpa*	1			2		3
CONVOLVULACEAE	*Ipomoea lonchophylla*	10	26	11	18	3	40
CONVOLVULACEAE	*Ipomoea nil*	2	7	4	7	3	16
CONVOLVULACEAE	*Ipomoea plebeia*	1	1		2	1	4
CONVOLVULACEAE	*Ipomoea polymorpha*	3	8	2	2	5	13
CONVOLVULACEAE	*Ipomoea sp.*					1	1
CONVOLVULACEAE	*Jacquemontia browniana*	53	92	93	96	94	100
CONVOLVULACEAE	*Operculina aequisepala*	1	15	1	3	1	18
CONVOLVULACEAE	*Polymeria ambigua*	54	92	70	90	86	99
CONVOLVULACEAE	*Polymeria longifolia*	6	3	2	1	3	9
CUCURBITACEAE	*Cucumis melo*	48	75	43	56	28	91
CYPERACEAE	*Bulbostylis barbata*	16	30	4	11	3	34
CYPERACEAE	*Cyperus bifax*	35	52	50	51	54	69
CYPERACEAE	*Cyperus difformis*			1		1	1
CYPERACEAE	*Cyperus sp.*			1			1
CYPERACEAE	*Eleocharis brassii*					1	1
CYPERACEAE	*Fimbristylis cardiocarpa*	4	10	9	9	3	12
CYPERACEAE	*Fimbristylis dichotoma*	2	4	8	6	7	11
CYPERACEAE	*Fimbristylis miliacea*			1			1
CYPERACEAE	*Fimbristylis phaeoleuca*		2	1	2		2
CYPERACEAE	*Fimbristylis schultzii*	22	55	16	29	31	63
CYPERACEAE	*Rhynchospora exserta*				2	2	2
CYPERACEAE	*Schoenoplectus dissachanthus*		1	1		1	1
ELATINACEAE	*Bergia pedicellaris*	6	4		2	1	11
EUPHORBIACEAE	*Euphorbia alsiniflora*	20	19	22	21	31	51
EUPHORBIACEAE	*Euphorbia maconochieana*	45	47	47	38	31	70
EUPHORBIACEAE	*Euphorbia schizolepis*	25	50	47	48	42	58
EUPHORBIACEAE	*Euphorbia stevenii*	11	4	27	19		36
EUPHORBIACEAE	*Excoecaria parvifolia*	1	1	3	1	2	3
EUPHORBIACEAE	*Leptopus decaisnei*	1		1			2
EUPHORBIACEAE	*Phyllanthus exilis*		3	2	5	3	7
EUPHORBIACEAE	*Phyllanthus maderaspatensis*	60	89	79	88	94	99
EUPHORBIACEAE	*Sauropus hubbardii*	8	13	16	5	13	30
FABACEAE	*Aeschynomene indica*	1	1	1	1	1	1

	Year	2003	2004	2005	2006	2007	All
	Number of sites	*62*	*100*	*100*	*100*	*100*	*100*
FABACEAE	*Alysicarpus muelleri*	41	83	74	62	74	99
FABACEAE	*Crotalaria medicaginea*	34	60	55	36	47	83
FABACEAE	*Crotalaria montana*	16	37	21	33	40	51
FABACEAE	*Cullen balsamicum*	3	7	3	7	9	16
FABACEAE	*Desmodium muelleri*	26	60	38	54	47	82
FABACEAE	*Flemingia pauciflora*	55	92	90	90	84	97
FABACEAE	*Galactia tenuiflora*	1	3	2	3	2	4
FABACEAE	*Glycine falcata*	6	10	8	8	10	16
FABACEAE	*Indigastrum parviflorum*	4	3	6	6	4	15
FABACEAE	*Indigofera colutea*	1	1		3	2	5
FABACEAE	*Indigofera linifolia*	37	49	48	64	54	84
FABACEAE	*Indigofera linnaei*	1	4	1			6
FABACEAE	*Indigofera trita*	13	23	26	30	20	50
FABACEAE	*Rhynchosia minima*	56	93	91	91	91	95
FABACEAE	*Sesbania cannabina*	3	4	1	3	3	5
FABACEAE	*Sesbania simpliciuscula*	59	95	93	98	94	100
FABACEAE	*Tephrosia brachyodon*	3	6	5	3	5	6
FABACEAE	*Tephrosia filipes*		7	3	8	7	12
FABACEAE	*Tephrosia rosea*	35	51	56	56	54	67
FABACEAE	*Tephrosia supina*				1		1
FABACEAE	*Vigna lanceolata*	1	1	3	2	1	3
GOODENIACEAE	*Goodenia byrnesii*	39	64	35	43	54	79
GOODENIACEAE	*Goodenia sepalosa*	2	5	1	1	2	6
LAMIACEAE	*Basilicum polystachyon*		1				1
LAMIACEAE	*Ocimum tenuiflorum*	1	2	1	2	4	5
LAMIACEAE	*Teucrium integrifolium*	2	2	2	1	2	3
LILIACEAE	*Caesia chlorantha*			4	4		6
LYTHRACEAE	*Ammannia multiflora*	14	10	2	3	1	19
MALVACEAE	*Abelmoschus ficulneus*	26	45	18	16	23	56
MALVACEAE	*Abutilon hannii*	40	68	72	75	70	92
MALVACEAE	*Gossypium australe*		1		1		1
MALVACEAE	*Hibiscus pentaphyllus*	1	1	1		1	3
MALVACEAE	*Hibiscus trionum*			2		2	3
MALVACEAE	*Malvastrum americanum*	7	24	23	24	29	41
MALVACEAE	*Sida fibulifera*	14	30	25	24	24	41
MALVACEAE	*Sida sp.*		1				1
MALVACEAE	*Sida spinosa*	28	55	48	57	42	77
MARSILEACEAE	*Marsdenia sp.*					2	2
MARSILEACEAE	*Marsilea hirsuta*	3	3	3	3	2	4
MENISPERMACEAE	*Tinospora smilacina*		2	3	3	3	10
MIMOSACEAE	*Acacia acradenia*		1	2		1	2
MIMOSACEAE	*Acacia ampliceps*	1		1	1	1	1
MIMOSACEAE	*Acacia farnesiana*		2	1	3	1	4
MIMOSACEAE	*Acacia holosericea*	1					1

	Year	2003	2004	2005	2006	2007	All
	Number of sites	*62*	*100*	*100*	*100*	*100*	*100*
MIMOSACEAE	*Acacia leptophleba*		1	2	3	2	3
MIMOSACEAE	*Acacia victoriae*	4	2	8	2	4	10
MIMOSACEAE	*Dichrostachys spicata*	1		2		3	4
MIMOSACEAE	*Neptunia dimorphantha*	15	37	32	24	30	55
MIMOSACEAE	*Neptunia gracilis*	8	19	28	34	26	51
MIMOSACEAE	*Neptunia monosperma*	3	2	4	3	3	6
MIMOSACEAE	*Neptunia sp.*	5	1			1	7
MYRTACEAE	*Corymbia terminalis*	22	20	20	36	35	47
MYRTACEAE	*Eucalyptus camaldulensis*	1			1	1	1
MYRTACEAE	*Lophostemon grandiflorus*	2	1	2	1	2	2
MYRTACEAE	*Melaleuca bracteata*	1	1	1	1	1	1
NYCTAGINACEAE	*Boerhavia spp*	43	42	60	64	57	92
ONAGRACEAE	*Ludwigia perennis*	4	2	1	3	2	5
PASSIFLORACEAE	*Passiflora foetida*				1		1
PEDALIACEAE	*Josephinia eugeniae*	1	7	4	2	7	15
POACEAE	*Aristida holathera*	1	4	2	6	2	8
POACEAE	*Aristida latifolia*	61	90	95	98	97	100
POACEAE	*Astrebla elymoides*	19	33	53	35	28	68
POACEAE	*Astrebla pectinata*	5	5	10	3	8	16
POACEAE	*Astrebla squarrosa*		1	1		2	4
POACEAE	*Bothriochloa ewartiana*	1	2		1		3
POACEAE	*Brachyachne convergens*	55	77	82	61	59	96
POACEAE	*Chionachne hubbardiana*	24	49	25	17	28	56
POACEAE	*Chrysopogon fallax*	54	92	89	84	84	99
POACEAE	*Dactyloctenium radulans*					1	1
POACEAE	*Dichanthium fecundum*	29	56	55	47	44	69
POACEAE	*Dichanthium sericeum*	28	57	51	60	47	72
POACEAE	*Digitaria bicornis*				1	1	1
POACEAE	*Echinochloa colona*	6	8	11	9	13	22
POACEAE	*Elytrophorus spicatus*		4	2	2	1	4
POACEAE	*Enneapogon polyphyllus*	3	9	8	6	9	16
POACEAE	*Enneapogon purpurascens*	2	4	1	4	1	9
POACEAE	*Eragrostis tenellula*	36	50	3	33	15	64
POACEAE	*Eriachne ciliata*		1	1	1		1
POACEAE	*Eriachne fastigiata*	4	5	5	4	3	6
POACEAE	*Eriachne obtusa*	9	16	18	13	15	21
POACEAE	*Eulalia aurea*	15	29	32	21	31	38
POACEAE	*Heteropogon contortus*		3	1	2	4	6
POACEAE	*Iseilema ciliatum*	20	26	30	16	13	54
POACEAE	*Iseilema fragile*	42	83	80	67	70	97
POACEAE	*Iseilema macvag*	51	96	93	91	89	100
POACEAE	*Iseilema membranaceum*	1	1				1
POACEAE	*Iseilema trichopus*	4	14	18	7	9	24
POACEAE	*Mnesithea formosa*		3	2	3	1	4

	Year	2003	2004	2005	2006	2007	All
	Number of sites	*62*	*100*	*100*	*100*	*100*	*100*
POACEAE	*Ophiuros exaltatus*		3	2	4	2	5
POACEAE	*Oryza australiensis*		1		1	1	1
POACEAE	*Panicum decompositum*	54	92	93	87	93	99
POACEAE	*Paspalidium retiglume*	5	7	7	2	1	16
POACEAE	*Pseudoraphis spinescens*	1	1	1	1	1	1
POACEAE	*Sehima nervosum*	14	28	31	26	32	39
POACEAE	*Sorghum interjectum*	1	1	1	4	1	4
POACEAE	*Sorghum timorense*	44	82	82	82	87	91
POACEAE	*Sporobolus australasicus*	10	27	11	9	5	32
POACEAE	*Themeda triandra*	1				1	1
POACEAE	*Tragus australianus*	1		1			1
POACEAE	*Urochloa piligera*			1	1		1
POACEAE	*Urochloa reptans*	3	10	9	8	4	17
POLYGALACEAE	*Polygala crassitesta ms.*	43	62	51	28	59	79
PORTULACACEAE	*Portulaca digyna*	3	5	1	7	2	8
PORTULACACEAE	*Portulaca oleracea*		1	3	4	1	9
PORTULACACEAE	*Portulaca sp.*		2				2
PORTULACACEAE	*Portulaca sp. Elliott*	5	2				7
PORTULACACEAE	*Portulaca sp. finely echinate*			1			1
PROTEACEAE	*Grevillea dimidiata*	3	4	2	7	3	8
PROTEACEAE	*Grevillea striata*	1		2	2	3	4
PROTEACEAE	*Hakea arborescens*	3	5	8	11	12	15
RHAMNACEAE	*Ventilago viminalis*	1	1	1			1
RUBIACEAE	*Oldenlandia argillacea*	19	13	4	22	10	36
RUBIACEAE	*Spermacoce auriculata*	1	1	1			2
RUBIACEAE	*Spermacoce pogostoma*	46	69	41	36	51	81
SAPINDACEAE	*Atalaya hemiglauca*	13	11	14	16	20	25
SAPINDACEAE	*Cardiospermum halicacabum*	5	8	11	13	10	13
SCROPHULARIACEAE	*Buchnera asperata*	2	17		11	13	28
SCROPHULARIACEAE	*Stemodia glabella*	9	9	10	9	17	25
SCROPHULARIACEAE	*Stemodia tephropelina*	13	26	6	9	6	36
SCROPHULARIACEAE	*Striga curviflora*	2	22	10	22	14	47
SCROPHULARIACEAE	*Striga squamigera*	1		1		2	4
SOLANACEAE	*Physalis angulata*		1				1
SOLANACEAE	*Solanum esuriale*			1	1		2
STERCULIACEAE	*Melochia pyramidata*	3	6	7	7	6	13
TILIACEAE	*Corchorus aestuans*	7	6	5	5	7	21
TILIACEAE	*Corchorus combined*	32	27	50	26	40	84
TILIACEAE	*Corchorus macropetalus*	29	16	30	19	17	45
TILIACEAE	*Corchorus olitorius*	13	30	17	34	7	55
TILIACEAE	*Corchorus sidoides*	3	3	5	3	5	8
VERBENACEAE	*Stachytarpheta sp.*	1					1
VIOLACEAE	*Hybanthus enneaspermus*	18	28	25	30	22	41
ZYGOPHYLLACEAE	*Tribulopis pentandra*	1	3	8	3	2	10

	Year	**2003**	**2004**	**2005**	**2006**	**2007**	**All**
	Number of sites	*62*	*100*	*100*	*100*	*100*	*100*
ZYGOPHYLLACEAE	*Tribulopis sessilis*	1		4	1	3	7

Appendix G: Plant taxa combinations used in the biodiversity analyses

Table showing how plant species were combined to give taxa used in analyses. Species were combined because they could not be reliably distinguished in the field or (in some cases) distinct forms were recognised in the field that are not supported taxonomically.

FAMILY	'Field name' or recognised species	Analysed taxa name
BORAGINACEAE	*Heliotropium conocarpum*	*Heliotropium* combined
BORAGINACEAE	*Heliotropium plumosum*	*Heliotropium* combined
BORAGINACEAE	*Heliotropium sp.*	*Heliotropium* combined
EUPHORBIACEAE	*Phyllanthus lacerosus*	*Phyllanthus maderaspatensis*
FABACEAE	*Desmodium muelleri* (narrow leaf)	*Desmodium muelleri*
FABACEAE	*Desmodium muelleri* (round leaf)	*Desmodium muelleri*
MALVACEAE	*Abutilon hannii* subsp. Erect (previously known as *A. andrewsianum*)	*Abutilon hannii*
MALVACEAE	*Abutilon hannii* subsp. Prostrate	*Abutilon hannii*
NYCTAGINACEAE	*Boerhavia paludosa*	*Boerhavia* spp
NYCTAGINACEAE	*Boerhavia sp.1*	*Boerhavia* spp
NYCTAGINACEAE	*Boerhavia sp.2*	*Boerhavia* spp
POACEAE	*Brachyachne tenella*	*Brachyachne convergens*
POACEAE	*Iseilema macratherum*	*Iseilema* macvag
POACEAE	*Iseilema vaginiflorum*	*Iseilema* macvag
POACEAE	*Iseilema sp.*	*Iseilema* macvag
POLYGALACEAE	*Polygala crassitesta* ms. (previously known as *P. gabrielae*)	*Polygala sp.* Thickened Testa
POLYGALACEAE	*Polygala pterocarpa* ms. (previously known as *P. rhinanthoides*)	*Polygala sp.* Thickened Testa
TILIACEAE	*Corchorus fascicularis*	*Corchorus* combined
TILIACEAE	*Corchorus tridens*	*Corchorus* combined
TILIACEAE	*Corchorus trilocularis*	*Corchorus* combined
TILIACEAE	*Corchorus sp.*	*Corchorus* combined
EUPHORBIACEAE	*Sauropus hubbardii*	*Sauropus trachyspermus*

Appendix H: Bird species recorded at Pigeon Hole

List of bird species recorded from sample sites, showing the frequency (number of sites) for each sample period.

	Early Dry Season				Late Dry Season					All years
	2003	**2005**	**2006**	**2007**	**2003**	**2004**	**2005**	**2006**	**2007**	
Number of sites	*62*	*100*	*100*	*91*	*99*	*100*	*100*	*100*	*84*	*100*
Emu			2	1	2	1			2	8
Stubble Quail	1					5				6
Brown Quail	7	7	8	6	6	24	17	16	17	54
Wandering Whistling-Duck			1							1
Australian Wood Duck		1								1
Pacific Black Duck		1								1
Australasian Grebe				1						1
Flock Bronzewing	4	8				4	1		1	17
Crested Pigeon	30	50	60	42	39	63	53	43	56	90
Spinifex Pigeon					1				1	2
Diamond Dove	4	30	14	9	66	43	47	45	43	89
Peaceful Dove	12	17	30	15	18	26	10	28	35	64
Bar-shouldered Dove				1						1
Tawny Frogmouth							1	1	1	2
Australian Owlet-nightjar						1	3	1	1	5
Fork-tailed Swift					2	2				4
Black-necked Stork		1								1
White-necked Heron	2		1							3
White-faced Heron	1	1	1	1						2
Australian White Ibis				1						1
Straw-necked Ibis			1							1
Black-shouldered Kite	1			1					1	3
Black-breasted Buzzard	1	2	1	1		3	3	3		12
White-bellied Sea-Eagle				1					1	2
Whistling Kite	4	1	4	8	1	3	2	2	1	23
Black Kite	5	14	17	17	2	23	1			60
Goshawk/Sparrowhawk	2	3	2	8		2		1	1	19
Spotted Harrier	6	33	6	16	3	7	5	5	8	61
Wedge-tailed Eagle	3	8		1	3	6	1	1	6	27
Little Eagle		1		2	1					4
Nankeen Kestrel	4	48	7	8	2		4		1	59
Brown Falcon	14	45	8	12	13	11	3	13	12	77
Australian Hobby	4	13	3	9		1				25
Peregrine Falcon			1							1
Brolga	3	9	15	6	4	2		3	1	31
Australian Bustard	9	30	21	17	12	12	18	18	14	77
Bush Stone-curlew		2	1	1						4
Oriental Plover					2	1		2	1	6

	Early Dry Season				Late Dry Season					All years
	2003	2005	2006	2007	2003	2004	2005	2006	2007	
Number of sites	*62*	*100*	*100*	*91*	*99*	*100*	*100*	*100*	*84*	*100*
Masked Lapwing	3		3							6
Button-quail spp.	12	41	6	28	10	20	19	2	21	75
Australian Pratincole									1	1
Red-tailed Black-Cockatoo	5	23	5	7	1		1	1		38
Galah	27	32	37	18	14	19	12	29	27	82
Little Corella	4			3	4	3		5	7	18
Sulphur-crested Cockatoo							1			1
Cockatiel	5	13	7	6	2	5	15	6	16	48
Rainbow Lorikeet			1							1
Varied Lorikeet	9	2	4	3		3	3		2	23
Budgerigar	20	61		6	24	2	66	2	20	94
Pheasant Coucal	1		2		4	7		3		13
Channel-billed Cuckoo					1					1
Horsfield's Bronze-Cuckoo		5	2	4	3	2	2	5	1	16
Black-eared Cuckoo			1							1
Pallid Cuckoo		1	1		1	1		1		5
Brush Cuckoo			1							1
Red-backed Kingfisher	9	20	12	11		1		1	2	40
Sacred Kingfisher			2							2
Rainbow Bee-eater			3	5			1	1		9
Dollarbird									2	2
Great Bowerbird						1				1
Red-backed Fairy-wren	46	80	85	84	67	93	68	93	68	99
Weebill	5	7	12	3	2	5	7	3	3	24
Western Gerygone		3		1						4
Red-browed Pardalote		2								2
Striated Pardalote				1						1
Singing Honeyeater	21	15	15	7	17	22	11	18	11	51
Grey-headed Honeyeater		1								1
Grey-fronted Honeyeater		1		8						8
Yellow-tinted Honeyeater	1	5	2	3			1		1	8
Yellow-throated Miner	29	35	29	32	34	50	23	49	39	81
Rufous-throated Honeyeater	13	13	15	29	26	50	32	48	33	81
Crimson Chat		8								8
Dusky Honeyeater			2							2
Banded Honeyeater	5		9			2	1			13
Brown Honeyeater	15	4	20	23	1	1	17		1	39
Black-chinned Honeyeater			1	1						2
Blue-faced Honeyeater						1	1			1
Silver-crowned Friarbird			1							1
Little Friarbird	3	4	4	19		20	8	5	19	45
Grey-crowned Babbler	7	6	5	3	5	11	2	3	2	23
Ground Cuckoo-shrike		2	3	3	2		1	2	2	11

	Early Dry Season				Late Dry Season					All years
	2003	**2005**	**2006**	**2007**	**2003**	**2004**	**2005**	**2006**	**2007**	
Number of sites	*62*	*100*	*100*	*91*	*99*	*100*	*100*	*100*	*84*	*100*
Black-faced Cuckoo-shrike	27	38	44	25	27	51	12	28	31	93
White-bellied Cuckoo-shrike		1			1	4				6
White-winged Triller	16	38	24	40	9	12		23	18	74
Varied Triller			2						1	3
Rufous Whistler	3	8	3	2			1	1	1	11
Grey Shrike-thrush							1			1
Crested Bellbird			1					3	2	6
White-breasted Woodswallow			1			1				2
Masked Woodswallow	12	3	4							39
White-browed Woodswallow	1	4								5
Black-faced Woodswallow	34	69	58	60	63	87	67	69	74	100
Pied Butcherbird	44	61	67	50	48	60	54	49	48	97
Australian Magpie					1					1
Willie Wagtail	13	74	29	24	12	17	25	17	23	89
Torresian Crow	29	24	20	5	21	33	28	23	15	82
Leaden Flycatcher								2		2
Restless Flycatcher	6	3	5	1	5	3	3	3	2	16
Magpie-lark	25	43	48	37	16	12	2	24	20	84
Jacky Winter				4	1					5
Hooded Robin						1				1
Singing Bushlark	46	93	82	78	88	94	89	91	74	100
Golden-headed Cisticola	25	24	38	34	2	47	7	49	16	77
Rufous Songlark	7	4	8	13			2	1		31
Brown Songlark	5	37	5	16	6	1	1	1	4	61
Spinifexbird			3		2					5
Martin spp.	6	73	21	2	9	4	1	1	8	84
Mistletoebird	1	3		2		1	3	2	11	16
Zebra Finch	16	63	13	21	61	37	53	23	28	93
Double-barred Finch			4	3						5
Long-tailed Finch		1								1
Masked Finch		2	1			1			3	6
Star Finch		1	2							3
Yellow-rumped Mannikin			1	2						3
Pictorella Mannikin	8	40	24	31	7	7	1	9	6	67
Richard's Pipit		1			1					2

Appendix I: Frog, reptile and native mammal species recorded at Pigeon Hole

List of frog, reptile and native mammal species recorded from sample sites, showing the frequency (number of sites) for each sample year.

		Year	2003	2004	2005	2006	2007	All
		Number of sites	*99*	*100*	*100*	*100*	*71*	*100*
Family	**Species**	**Common name**						
FROGS								
Myobatrachidae	*Uperoleia sp.*	Toadlet	5		6			11
Hylidae	*Litoria australis*	Giant Frog	1					1
REPTILES								
Gekkonidae	*Lucasium stenodactylum*	Crowned Gecko	8	2		1	4	12
Gekkonidae	*Lucasium immaculatum*	Pale-striped Ground Gecko			1			1
Gekkonidae	*Gehyra australis*	Northern Dtella	1					1
Gekkonidae	*Gehyra nana*	Northern Spotted Rock Dtella		1				1
Gekkonidae	*Heteronotia binoei*	Bynoe's Gecko	51	57	64	57	32	91
Gekkonidae	*Oedura rhombifer*	Zig-zag Gecko	2					2
Pygopodidae	*Delma borea*	Rusty-topped Delma	3		1	1	1	6
Pygopodidae	*Delma tincta*	Black-necked Snake-lizard	16	26	26	30	19	69
Agamidae	*Lophognathus gilberti*	Gilbert's Dragon	2	1		2		4
Agamidae	*Tympanocryptis lineata*	Lined Earless Dragon	6	13	11	11	4	31
Agamidae	*Tympanocryptis uniformis*	Even-scaled Earless Dragon	1					1
Varanidae	*Varanus acanthurus*	Ridge-tailed Monitor			2			2
Varanidae	*Varanus storri*	Storr's Monitor	5	11	10	8	8	22
Scincidae	*Cryptoblepharus megastictus*	Spotted Snake-Eyed Skink					1	1
Scincidae	*Cryptoblepharus plagiocephalus*	Aboreal Snake-Eyed Skink	11	9	7	12	5	32
Scincidae	*Ctenotus inornatus*	Plain Ctenotus			1			1
Scincidae	*Ctenotus rimacola*	VRD Blacksoil Ctenotus	30	33	14	38	22	70
Scincidae	*Ctenotus robustus*	Robust Ctenotus	2			2	1	5
Scincidae	*Menetia greyii*	Grey's Menetia		5	1	4	3	11
Scincidae	*Menetia maini*	Main's Menetia	8	5	8	17	4	34
Scincidae	*Proablepharus naranjicaudus*	Fire-tailed Snake-Eyed Skink	28	20	9	18	6	41
Scincidae	*Proablepharus tenuis*	Slender Snake-Eyed Skink	50	33	58	50	41	85
Scincidae	*Tiliqua scincoides*	Common Blue-Tongued Lizard	1	1	2		1	5
Typhlopidae	*Ramphotyphlops ligatus*	Robust Blind Snake	8	4	8	7	5	28
Elapidae	*Demansia torquata*	Collared Whip Snake	3	11	3	6	4	27
Elapidae	*Pseudechis australis*	King Brown Snake			1			1
Elapidae	*Brachyurophis semifasciatus*	Half-girdled Snake				1		1
Elapidae	*Suta punctata*	Little Spotted Snake				1		1

		Year	2003	2004	2005	2006	2007	All
		Number of sites	*99*	*100*	*100*	*100*	*71*	*100*
Elapidae	*Suta suta*	Curl Snake	2	3	1			6
Elapidae	*Vermicella multifasciata*	Northern Bandy-bandy	1				1	2
MAMMALS								
Dasyuridae	*Planigale ingrami*	Long-tailed Planigale	50	60	31	54	33	92
Dasyuridae	*Sminthopsis macroura*	Stripe-faced Dunnart	6	1	2		1	10
Macropodidae	*Macropus antilopinus*	Antilopine Wallaroo				1	2	3
Macropodidae	*Macropus robustus*	Common Wallaroo	1		4	7	9	17
Macropodidae	*Macropus rufus*	Red Kangaroo			1			1
Macropodidae	*Onychogalea unguifera*	Northern Nailtail Wallaby	8	4	3	14	16	33
Pteropodidae	*Pteropus scapulatus*	Little Red Flying-fox	2					2
Muridae	*Leggadina lakedownensis*	Northern Short-tailed Mouse	1	1		2	1	5
Muridae	*Rattus villosissimus*	Long-haired Rat	4*					4*

*This species was captured in Elliott traps, which were only set in 2003.

Appendix J: Ant taxa recorded at Pigeon Hole

List of ant taxa recorded from sample sites, showing the frequency (number of sites) for each sample year. Many ant taxa are undescribed – the codes used her correspond to voucher specimens maintained at CSIRO Sustainable Ecosystems, Darwin.

	Year	2003	2005	2007	All
	Number of sites	*62*	*100*	*91*	*100*
Family	**Species**				
Aenictinae	*Aenictus* sp3		1	1	2
Ponerinae	*Anochetus* sp2		3	2	5
Ponerinae	*Leptogenys adlerzi*	11	26	14	34
Ponerinae	*Leptogenys fallax*			1	1
Ponerinae	*Odontomachus* spA	7	16	15	20
Ponerinae	*Platythyrea* nr_*parva*		1	2	2
Ponerinae	*Rhytidoponera* spA	40	73	56	79
Ponerinae	*Rhytidoponera* spB	11	15	9	25
Cerapachyinae	*Cerapachys clarki*	3			3
Cerapachyinae	*Cerapachys* nr_*edentatus*	1			1
Myrmicine	*Carebara* spA		2		2
Myrmicine	*Cardiocondyla* spA	4	10	14	21
Myrmicine	*Crematogaster queenslandica*	24	46	13	59
Myrmicine	*Meranoplus ajax*	2	2	2	4
Myrmicine	*Meranoplus pubescens*	29	48	40	65
Myrmicine	*Meranoplus mjobergi*	7	11	5	15
Myrmicine	*Meranoplus oxleyi*	36	32	19	57
Myrmicine	*Meranoplus* spK	3	8	5	14
Myrmicine	*Meranoplus* spE	1	2	4	4
Myrmicine	*Meranoplus* spD			4	4
Myrmicine	*Meranoplus* spI			1	1
Myrmicine	*Monomorium anderseni*	8	40	14	43
Myrmicine	*Monomorium fieldi*	46	81	73	90
Myrmicine	*Monomorium silaceum*			2	2
Myrmicine	*Monomorium* sp24	44	90	67	99
Myrmicine	*Monomorium* spE	14	27	26	43
Myrmicine	*Monomorium* spL		1	3	4
Myrmicine	*Monomorium destructor*			1	1
Myrmicine	*Pheidole impressiceps*	45	80	55	90
Myrmicine	*Pheidole* spD	3	13	15	22
Myrmicine	*Pheidole* spB	3	5	9	13
Myrmicine	*Pheidole* spC	25	40	30	53
Myrmicine	*Pheidole* spE		2	1	3
Myrmicine	*Pheidole* sp13			4	4
Myrmicine	*Podomyrma adelaidae*	2	2		4
Myrmicine	*Solenopsis* spA	1			1
Myrmicine	*Tetramorium* spA	7	31	18	43
Myrmicine	*Tetramorium* spB	21	47	47	76

	Year	2003	2005	2007	All
	Number of sites	*62*	*100*	*91*	*100*
Myrmicine	*Tetramorium* spC		2		2
Dolichoderinae	*Doleromyrma* spA	13	35	33	55
Dolichoderinae	*Iridomyrmex hartmeyeri*		4		4
Dolichoderinae	*Iridomyrmex pallidus*		3		3
Dolichoderinae	*Iridomyrmex sanguineus*	14	25	16	37
Dolichoderinae	*Iridomyrmex* sp2	2	43	18	54
Dolichoderinae	*Iridomyrmex* spD	37	18	39	66
Dolichoderinae	*Iridomyrmex* sp1	27	37	18	58
Dolichoderinae	*Iridomyrmex* spE	59	78	64	89
Dolichoderinae	*Iridomyrmex* sp23			4	4
Dolichoderinae	*Tapinoma* spA	20	65	54	84
Formicinae	*Camponotus* spA	33	55	63	75
Formicinae	*Camponotus* spC	16	42	42	65
Formicinae	*Camponotus* sp9	39	85	79	89
Formicinae	*Camponotus* sp18		1	2	3
Formicinae	*Camponotus* sp11			3	3
Formicinae	*Camponotus* spG			4	4
Formicinae	*Melophorus bagoti*		1		1
Formicinae	*Melophorus* spA	11	16	6	29
Formicinae	*Melophorus* spB	14	22	10	30
Formicinae	*Melophorus* spC	39	61	29	73
Formicinae	*Melophorus* spH	6		3	9
Formicinae	*Melophorus* spE	32	53	30	67
Formicinae	*Melophorus* spF	2	6	3	11
Formicinae	*Melophorus* sp20		2		2
Formicinae	*Melophorus* spI			7	7
Formicinae	*Opisthopsis haddoni*	1			1
Formicinae	*Opisthopsis rufoniger*	7	14	14	24
Formicinae	*Paratrechina longicornis*		2		2
Formicinae	*Paratrechina* spA	2	3	5	7
Formicinae	*Paratrechina* spD	1	1	3	5
Formicinae	*Paratrechina* spC		1		1
Formicinae	*Polyrhachis crawleyi*	2	10	21	25
Formicinae	*Polyrhachis inconspicua*	2	5	9	12
Formicinae	*Polyrhachis senilis*			1	1
Formicinae	*Polyrhachis* spC	7	3	11	19
Formicinae	*Polyrhachis* spD	2	17	19	30
Formicinae	*Polyrhachis* sp3	1	1		2