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FOREWORD

"If we don't know where we are going then we are likely to end up somewhere else" – Anonymous

Research is one of the fundamental cornerstones of agricultural production. To ignore the need for research is to accept a slow decline in competitiveness, sustainability, profitability and social wellbeing. Too often the results of research are not communicated to the production sector -and in some cases to fellow researchers- in spite of extensive efforts through a variety of means

This Conference is one medium whereby researchers can come together to communicate in a northern beef industry update forum. The North Australian Beef Research Council is pleased to support this program in keeping with its mandate to enhance the relevance of research, development, extension, education and training to northern beef producers.

Your attendance at this Conference indicates you will not "end up somewhere else".

I wish you every success in your endeavors.

J.R.Cox
Chairman. NABRC.

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Meat and Livestock Australia

The drought and competition from US beef in North Asian markets are the two key - and unpredictable - factors that will shape Australia's cattle and beef industries over the next few years

While much of Northern Australia is enjoying favourable seasons, the impact of drought on southern Australia will continue to have nationwide repercussions for the beef industry. Australia's cattle producers have become a lot better at managing drought and this has improved the nation's production capacity during extended dry periods. The industry continues to set records amid this challenging environment.

The current severe drought, is expected to lower the herd by around 2.4 percent, or 700,000 head, in 2006-07, to 27.9 million head. This is a smaller reduction than in the 2002-03 drought year, which saw a 1.2 million head decline in the herd. The decline in numbers in southern states (around 1 million) is expected to be partially offset by herd rebuilding in Queensland, the NT and WA (estimated 300,000).

Australia's global beef market is now worth nearly $11 billion. The dominant markets for Australian beef exports are likely to remain Japan, Korea and North America, as competition from South America and India in other markets is expected to remain fierce. A 4.6 percent fall in beef exports is forecast for 2007 from the record set in 2006, to 910,000 tonnes shipped.

In the live export market, Australia earned over $400 million from cattle. After recovering 9 per cent in 2006, to an estimated 627,000 head, live cattle exports are forecast to rise a further 4 per cent in 2007, to 655,000 head in 2007. Livestock exports continue to face a number of major challenges; the high cost of Australian cattle, a rising Australian dollar and animal welfare lobbies and regulations.

Consumer expenditure on beef has risen by 50 percent since 1999 and is estimated to have risen by around 5 percent last year. This is expected to be at least maintained in 2007. The '*Red Meat. Feel Good*' nutritional campaign and CSIRO diet continue to have positive impacts on the health and nutrition image of beef. Key factors likely to impact on consumption over coming years are the rate of economic growth in Australia, beef's relative health and safety image, progress in beef quality and marketing and competition from other proteins.

Beef producers also face the challenge of the ever increasing demands of consumers. Today's consumer demands quality, consistency and convenience across all red meat products, with guaranteed product safety standards being non-negotiable. Community trust is vital to Australia's beef industry, resulting in investments in food safety, traceability, eating quality, environmental stewardship and improved animal welfare while also ensuring reduced cost of production to maintain profitability.

The industry is in good shape, beef producers should be proud of it, and have the confident that Australia can keep ahead of our rivals and can successfully respond to the challenges the industry faces.

Why do beef genomics in Australia?

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Abstract. Animal genomics has developed in Australia over the last decade through targeted investments of public and red meat levy funds, and supported by significant "in-kind" contributions from industry and the academic community. It has not been an inexpensive enterprise and hence it is reasonable to ask why the investments were made, and what have been the returns. Because there has been considerable spillover of benefits from the global human genomics enterprise, simple estimates of benefit vs cost have limited value, so this article describes some qualitative features of investments in beef genomics in order to raise awareness amongst the beneficiaries, and to provide a general framework for evaluation of current research priorities. The accompanying presentation will focus more on the methods of genomics, as appropriate for the audience.

Introduction

"Genomics" really hit Australian animal production research in 1997. Animal genetics has a long and well-respected tradition in Australia and has produced some notable achievements (Nicholas 2005). The global effort to sequence the human genome led directly to an increase in the rate of discovery of genetic information about production animals, through the availability of technological innovations and targeted support from the Federal government, State governments and the Rural Research and Development Corporations. As we approach the tenth year since the expansion of effort, it is timely to reflect on the outcomes from these investments so far, and the priorities for work in the future. This paper sets out to discuss the drivers and the implications of investment in genomics. It is not intended to be an in-depth description of genomic technologies or genomic science, as there are many other worthy sources of this information. Where the jargon of genomics impedes understanding of the issues, I have made reference to a glossary of terms included as an Appendix.

Animal genomics in Australia

"Genomics" is the study of all of the genetic material of an organism, in an integrated way, and utilising industrial-scale machinery and automated technologies. It differs from classical genetics in terms of scale and scope – in the same way that macroeconomics, which deals with entire economies, differs from accountancy, which can be focussed on individual accounts. Whilst genetics and genomics share the goal of unravelling the roles of genes in determination of the appearance, structure or biochemical properties of an organism (the "phenotype"), genomic technologies allow the researcher to study many of the genes of the organism simultaneously.

Because genomics was a significant change in direction for Australian animal science, a change in structure and technology was required. Funding encouraged the collection of larger collaborative teams, and focussed their work around shared animal resources. This can be appreciated through an example of the "marbling" phenotype in cattle.

"Marbling" is the term used to describe the seams of fat that appear within high quality cuts of beef. It can also be used as a verb to describe the biological processes leading up to its appearance in the slaughtered carcass. Prior to 1993, Australian public and levy-funded research into marbling focussed on nutritional strategies to make all cattle marble, independent of breed or production system (Harper and Pethick 2004; Pethick *et al.* 2004). Experiments tended to use randomly selected animals from particular breeds. By 1997 it was clear that marbling resulted from both the animal's nature (the genetic component) as well as its nurture (the environmental component). Through studies carried out in the Cattle and Beef Quality Cooperative Research Centre and by CSIRO, Bill Barendse and his colleagues were able to demonstrate that a single sequence variant in DNA (a "SNP") could account for some of the genetic effect on marbling observed within experimental herds of cattle. This was a breakthrough and represented the first time a DNA polymorphism had been associated with an animal production trait (Barendse 2005). In subsequent years, significant research effort has focussed on understanding how this SNP induces the development of marbling and whether it works in all

circumstances: nutritional, climatic, and breed background. That particular SNP has also been commercialised as a diagnostic test:
(http://www.geneticsolutions.com.au/content/v4_standard.asp?name=New_Genestar; 12/2006).
Barendse's approach to SNP discovery can be classified as a genetic, or more specifically quantitative genetic approach, reflecting the fact that the marbling trait can be measured in terms of amount in each animal, the frequency in the population, and the effect of multiple genes. A genomic approach to the same trait is illustrated below, and the consensus view is that this approach is now more likely to yield value for the investment dollar (Nicholas 2006).

Experience from sequencing the human, mouse and fruit fly genomes, has told us that SNPs are relatively common in all individuals of a particular species. Many of these SNPs are however "silent", meaning that they cause no apparent effect (positive or negative) on the individual in terms of its appearance, performance or health. However SNPs are heritable and can be used to establish genetic relationships within and amongst herds of cattle i.e. they can be used to establish pedigrees. Sequencing the bovine genome (http://www.livestockgenomics.csiro.au/ibiss; Jan 2007) has enabled the international animal science community to study a large number of these SNPs in cattle, and their relationship with traits of interest. Gene Chip technologies already enable researchers and service providers to assess the SNP genotypes for any particular individual at as many as 10,000 sites within the genome in one experiment. Coupled with information about the animal's phenotype, these technologies unlock breeding options that were unimaginable a decade ago. An extension of this approach, called Whole Genome Selection, is already being used as a basis for determining breed values in dairy cattle, 10,000 DNA markers at a time, rather than one or ten as is happening now (http://www.hg.nl; Jan 2007). Animal genomics has allowed us to significantly accelerate the processes of discovery, and is challenging us to think again about the structures we use to describe, assess and market cattle as members of breed groups rather than individuals with unique genetics.

Targets for Australian beef genomics

At the base level, genomics techniques are being used to accelerate discovery for the benefit of animal breed improvement. In Australia we already have breeding systems like BREEDPLAN: the beef genetic evaluation system that estimates breeding values for economically important traits in progeny from information about pedigrees, breed averages and measurements of the performance of closely related animals. Whilst genomics can be used to improve the accuracy of EBVs for traits like growth rate and hide colour, this is not an efficient use of capacity because these traits can be measured directly. Genomics technologies (such as DNA markers) come into their own when applied to hard to measure traits. Marbling for example, is a trait that is hard to measure with any certainty. Firstly, marbling doesn't develop until the animal is near mature size, weight and body composition, which makes genetic selection a drawn-out process. A newborn calf with a high genetic potential to marble does show some signs of the trait, but these can only be measured with sophisticated laboratory techniques. Secondly, marbling traits are not expressed in the same way in the parents of a particular animal: the bull is unlikely to be slaughtered and have its carcass assessed, and likewise the cow is managed in a very different way from the steer or heifer progeny which are destined for slaughter. Finally, marbling is often sought in multi-sire breeding systems, where the pedigree can not be deduced with certainty. For these reasons a DNA marker for marbling would be very convenient for use as a selection tool. Indeed the industry is fortunate that a number of DNA markers are now commercially available and they will deliver most value to the industry when integrated into the existing EBV-based system. Some limitations to the use of this technology that will be outlined below. In this context, other examples of hard to measure traits include: meat eating quality; feed efficiency; reproductive potential; polledness; parasite resistance; nutritional resilience.

At a higher level of sophistication, genomics will accelerate our discovery and validation of selectable gene markers through comparisons with other mammalian species. I will use the example of feed efficiency (or Net Feed Intake as feed efficiency is measured) here, because it is a hard to measure trait that is known to have a genetic component. Across the globe mammalian researchers are investigating the basis of feed efficiency in humans, mice, dogs and cattle, though in the case of humans, the target is addressing the obesity epidemic rather than increasing the industrial efficiency of animal growth and development. Human medical research has the benefit of huge populations for which much is known about pedigree, nutritional history and environment. Research in the mouse also has the benefit of large populations and known nutritional environment, along with the availability of gene modification technologies, where genes can be turned off or on for the benefit of the researchers goals. Research in the dog has the benefit of large populations that have been selected by man over many thousands of years, and which demonstrate remarkable diversity. The genetic relationships amongst the human, mouse, dog and cow are becoming better understood than ever before, and the new field of bioinformatics helps us cope with unprecedented amounts of disparate information, and to capitalise on it to deliver novel technologies for cattle breeding. Hypothetically it is now possible to discover an important SNP variation in mouse that accounts for feed efficiency, understand its biology in the human and the dog, and deliver it as an experimental DNA marker for cattle, all within 12 months. Importantly, much of the research underpinning this approach to discovery came from public funds that were not directed towards animal science and started more than 50 years ago (Fig. 1).

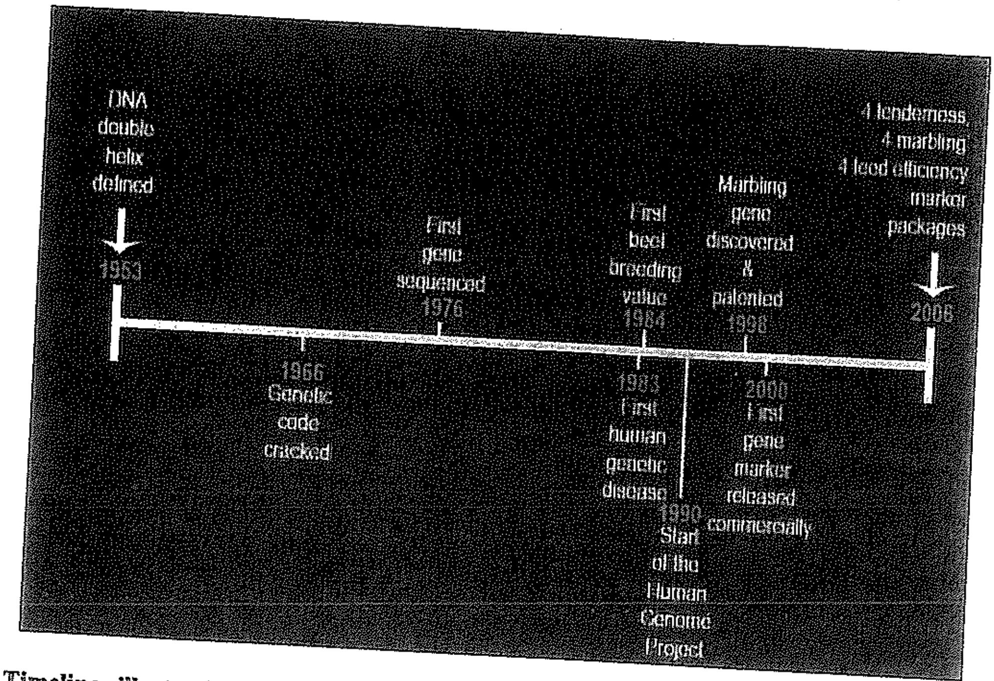

Fig. 1. Timeline illustrating the development of enabling technologies that were essential to the development of DNA markers for various traits in cattle.

At the highest level of sophistication, genomics should deliver solutions to intractable problems of animal production, though this cannot be guaranteed. A good example is bovine ephemeral fever (BEF). BEF is caused by a virus carried by mosquitoes and biting midges (culicoides), and currently costs the northern beef industry about $100 million per annum (Holmes and Sackett 2006). The standard approaches to the problem include: synthetic vaccines to enhance the animal's and the herd's immunity; genetic selection to increase the herd's innate immunity to the virus; pharmaceuticals to discourage the vectors from biting the host; or chemicals to manage the populations of the vectors themselves. None of them works well enough to be relied upon alone. Global genomics activities make it possible for researchers to strategically assess the best options for approaching the problem of BEF. From human and domestic animal genomics, we can assess the best targets for development of a one-shot vaccine against the virus. From genomics in all the domestic and agricultural species, we can assess the most productive approaches to development of heritable resistance to the either the virus or the vector that delivers the virus, and through insect genomics we can target the vector more accurately through application of specific chemicals with minimal environmental toxicity. Investments in genomics are not certainties, but the potential rewards can be significant, as are the potential costs of not making the investment.

Current investments in beef and sheep genomics

The Australian animal science community has been very fortunate to enjoy the support of the Australian tax payer, the red meat levy payer and other industrial supporters in their efforts to explore animal genomics. Through internet research I have estimated the global public investment in the bovine and ovine genomes to be in the order of $US500M since 2000, with significant contributions coming from the United States, the UK, the EU, Canada, New Zealand, Japan and Australia. In Australia, Meat and Livestock Australia has invested in the order of $US14M, and other significant investments have come from the Federal govt including CSIRO, the State governments, and the university sector. So the Australian effort in production animal genomics (about $30M since 2000) is large in comparison to many Australian animal science investments, and some programs needed to be relatively under funded (e.g. ruminant nutrition) in order to secure these resources for this period of time. Nonetheless our total investment is less than 5% of the global public investment in bovine and ovine genomics. It is unclear how large the purely private investments have been, but given the involvement of several large global corporations (Merial and Metamorphix Inc.), the sums of money are unlikely to be small.

Notwithstanding the size of these investments, it is interesting to compare it to estimates of the total global, public investment in mammalian genomics: $US10,000M since 2000. Relative to this sum, MLA's investment is less than 0.2%. Despite how it seems, this is very good news. Global, public investments in the genomics of man, mouse and moulds tend to work together to facilitate research in the agriculturally-important animal species. This results from a couple of facts. Firstly, the mammalian species share many common characteristics. Obviously at the very basic level, they share the same genetic material (DNA), the same structural materials (proteins, carbohydrates and fats) and many of the same functional molecules (hormones, signalling molecules). At the higher level, they share many of the same biochemical pathways and regulatory systems. So some of the issues we seek to understand in production animals may well be resolved by researchers working on completely different scientific problems in species that are of no agricultural interest. Finally, the reader needs to appreciate that the US Government's decision to drive a public and international effort to sequence the bovine genome was largely motivated by the value of the cow as a model for human diversity, and for its value as a well-characterised mammalian species, not primarily for agricultural benefit.

So why not just rely on spillover of information from well-funded international programs? Increased research funding in the developed world has generally been accompanied by increased pressure to commercialise, so whilst the information might be available for research purposes, once Australian commercialisation is envisaged the price for Australian companies to access it may be restrictively high. Relying on spillovers is also a risky strategy because much of the discovery work done in northern hemisphere labs, is unlikely to be directly applicable to Australian field conditions – particularly in northern Australia. So we need to repeat and adapt work done elsewhere. A strategy that relies on spillovers also has the disadvantage of making no contribution to the innovation capacity of the Australian industry, which without active inputs will decline over time.

Limitations of the genomics approach

As was noted above, there are some limitations to the current applications of DNA technology. Some of these come about through overly optimistic projections by the scientific community. Others arise through the lack of understanding amongst producers of the nature of the technology. Some examples are discussed here, and others certainly exist.

Traits with low heritability

DNA markers will not overcome the reality of genetics. Traits that are largely environmental (or nutritional) in origin will not appear in the progeny with any reliability. A good example is fat colour in beef, which is largely determined by the diet the animal has recently eaten. The corollary of this is that gene markers cannot overcome the influence of the environment on the development of a trait: if you don't feed an animal properly, it will never reach its full growth potential no matter how favourable its genetics might be.

DNA markers as an end in themselves

Complex animal traits like marbling or feed efficiency are influenced by many genes (perhaps between 50 and 500). When one uses breeding index to estimate the value of progeny from a particular bull-cow union, many genetic effects are accounted for and optimised in the prediction. In particular, the relative value of one trait versus another can be balanced off in the calculations. If one chooses to select only on the basis of a small number of gene markers, then all the other components of the profitability story are ignored or allowed to vary randomly. Whilst there is a chance that these other components will be irrelevant to the final performance of the herd, it is much more likely that there will be an effect of selection, and we can't we sure what the direction of that effect might be: valuable to profitability or destructive to it. This comes about because DNA markers tend to be near genes that have a significant physiological effect on the growing animal, and these genes rarely affect just one body system e.g. fatness can rarely be dissociated from muscling or reproductive performance. So until we have access to hundreds of DNA markers each of known effect, it is unwise to base breeding decisions solely on small numbers of DNA markers. When the technology becomes available, a merger of gene marker and estimated breeding value technologies will be much more reliable as a long term breeding strategy.

DNA markers as absolute determinants of phenotype

Breeding, growing, finishing and processing cattle for beef is an inherently variable process. All current systems for managing the beef value chain rely on a statistical approach to predict the most likely, and average outcome. No technology can predict meat yield or quality outcomes with anything like the reliability we have come to expect of manufactured products like cars, paints or electronic goods. DNA markers and other genetic selection tools will lead to changes in the average for the selected population of animals relative to unselected animals of similar age, but variation around this average will continue, particularly when one starts to consider all the different stresses the animal encounters on the way to the slaughterhouse, the many different muscles within its body, and the myriad of other processing factors that influence the carcass once processing is initiated. DNA marker technologies are not silver bullets with which to overcome slaughter chain variation.

Deliverables over the next five years

We can expect acceleration in the rate of appearance of DNA markers in the market place, and these are likely to be marketed as packages of markers focussed on particular traits. We can expect to see DNA marker technologies integrated with the other methods for animal selection (e.g. marker-enhanced estimated breed values) so that each technology can be used to maximise its particular strength. We can also expect to see marker-enhanced breeding values for some of the traits that are impossible to measure currently. We can also expect to see steady improvements in the accuracy of the tools used to assist genetic selection decisions.

In addition we can expect to see the products of our joint investments in genomics and optimised for other challenges of the animal production enterprise. Likely examples include novel approaches to the management of ecto- and endoparasites in cattle, novel feed additives, and innovative tools with which to address environmental contamination with man-made chemicals.

Conclusion

There is no question that genomics research has been a costly investment by MLA, CSIRO, the State Departments of Agriculture, the university sector and the Federal Government, using our tax and levy dollars. Whilst the outcomes have been slow to arrive, they are now coming at a rate that will challenge our existing capacity to absorb and implement them. Delayed delivery does not reflect badly on the decision to invest a decade ago, because the failure to take the risk back then, would have left us with fewer options for the future, going forward from 2007. Nonetheless slow rates of adoption of technology remain a challenge to us in the business of R&D, to target our work more accurately, and communicate its benefits more realistically and persuasively.

Acknowledgements

The author is grateful to the Cooperative Research Centre for Beef Genetic Technologies for assistance with the compilation of the glossary.

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Appendix - Glossary of terms

Bioinformatics	The computational and mathematical methodologies that underpin modern biology, and especially genomics.
BREEDPLAN	Australia's beef genetic evaluation system that estimates breeding values for economically important traits in progeny from information about pedigrees, breed averages and measurements of the performance of closely related animals.
Chromosome	A single large macromolecule of DNA that is the packaged form of DNA in a cell. It contains many genes, regulatory elements and other intervening nucleotide sequences. It also includes the DNA-bound proteins which serve to package and manage the DNA. It is the form of genetic material that is passed from one cell to its daughter as an animal grows.
DNA	Deoxyribonucleic acid, the chemical polymer that constitutes the heritable genetic material in all cellular forms of life. In cattle, there are two strands of the DNA polymer for each gene and it consists of the nucleotides G, A, T and C.
DNA marker	A known sequence of DNA that can be identified with great accuracy by a laboratory assay. It is used to detect different forms of genes and to test their relationship with particular animal characteristics. The tests can be carried out on a wide range of tissue samples such as blood, skin, hair or muscle collected at any age after conception. Many DNA markers are SNPs.
EBV	Estimated Breeding Value, an estimate of an animal's genetic value for economically important traits such as growth rate that is calculated from the measured performance of closely related animals, pedigrees and breed averages.
Gene	The basic unit of heredity in every living organism that is made up of DNA and wound into chromosomes. Whilst each gene might have many subtle sequence variations (polymorphisms), those with measurable effect are important in the context of selective breeding.
Gene Chip technologies	Biotechnologies that utilise a solid surface to mount DNA fragments for the purpose of determining nucleotide sequence or quantifying the amount of a particular sequence present in a solution. DNA microarrays are an example that utilises glass slides as the surface.
Genetics	The branch of science concerned with the means and consequences of transmission and generation of the components of biological inheritance. "Structural" genetics deals with the sequence of DNA and genes within chromosomes. "Molecular" genetics focuses more on variations within particular genes, whilst "biochemical" genetics focuses on the impact of DNA sequence variation on the biochemical processes of the organism.

Genomics	The molecular characterisation of all of the genetic material of a particular organism (its "genome"), and by necessity utilises high throughput technologies.
Genotype	The genetic makeup of an animal.
Heritability	Proportion of variation for a measurable trait attributable to genetic variation and therefore potentially passed on to offspring. Heritabilities range from 0.0 to 1.0. An heritability of 0 means the trait is not controlled by genetic factors and of 1 means the trait is under total genetic control. In general, traits that have heritabilities greater than 0.4 are considered to be highly heritable.
Net Feed Intake (NFI)	A measure of feed efficiency that refers to variation in feed intake between animals remaining after differences due to weight and growth rate have been accounted for. Low (more negative) NFI is desirable.
Phenotype	The appearance, structure or biochemical characteristics of an organism, contrasted against genotype, which refers to sequences within the DNA.
Polymorphism	Multiple forms of some biological characteristic within a population. Used in the context of a SNP, to indicate that a nucleotide at this particular position in the genome can take one of four different chemical forms in the population, with various correlated effects on phenotype.
Probe	In molecular genetics, many copies of a tagged nucleotide sequence, denatured into single stranded nucleic acids and available for nucleotide hybridisation in order to quantify a complementary segment of DNA (the "target").
SNP	A Single Nucleotide Polymorphism is a variation in the chemical sequence that makes up the DNA of individual cattle (or other organism), and that may contribute to the individual phenotype of that animal. These sequence variations are heritable, and were previously called mutations. For instance, at some specific point in the DNA sequence one individual might have an "A", whilst another might have a "T".
Trait	Attribute or characteristic of animals that can be improved genetically (for example, growth rate, fertility, carcass or meat quality etc).

Gene markers and their impact on the Northern Beef Industry

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Abstract. Gene marker technology offers two major opportunities to the Northern Beef Industry. Firstly, it provides additional genetic information that will enable accelerated improvement in selecting high performance bulls and cows for traits that have been difficult to make change in. Amongst others these include tenderness, marbling, feed efficiency, tick resistance and reproduction. These changes will need to be kept in context with the constraints of beef production systems that operate in this region but gene marker technology provides the precision to do so. Secondly, the technology offers the opportunity to indicate the suitability of animals to particular finishing production systems and markets. Such information can be determined early in life and enable efficient use of animal, feed and finishing resources.

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Beef CRC - Links between genetics of beef quality and components of herd profitability in northern Australia - genetics results update

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Abstract. Data from 4,445 steers and heifers were used to characterise the genetics of numerous traits associated with whole herd profitability in northern Australia. Genotypes included Brahman and a composite genotype derived from approximately 50% tropically adapted breeds. Steers were measured for traits associated with growth, body composition, feed efficiency, carcase and meat quality. These traits were found generally to be moderate to highly heritable. Heifers were retained for breeding and age a first *corpus luteum* (CL) was determined using regular ultrasound scanning on all heifers. Age at first CL (i.e. a measure of age at puberty) was heritable in both genotypes and was highly genetically related to first calving performance in Brahmans. Calving performance traits were lowly heritable however significant differences existed between sires for their daughter's calving performance. These early genetics results show opportunities exist to change many of these traits through selection however knowledge of genetic relationships between traits will be critical in ensuring the changes made are favourable.

Project aims

The stated mission of Project 2.3 of the CRC for Cattle and Beef Quality was "to increase the knowledge of genetic relationships between components of herd profitability in northern Australian environments, in order to improve efficiency and product quality without unduly compromising breeder herd performance or adaptability". This project was designed to study the genetics of female fertility in northern Australia and its links with carcase, meat quality and feed efficiency. The aim was to generate sufficient animals of known pedigree and management to enable the estimation of genetic effects (heritabilities, variances and correlations among traits) for various measures of female fertility and adaptability traits along with the carcase and meat quality traits of their half-sib steers. The project was also designed to allow benchmarking of EBVs, validation and detection of gene markers, and provide valuable progeny test data on over 100 sires. Importantly, non-genetic treatments and management strategies were recorded (and costed), and will serve as critical data, in conjunction with the genetic outcomes, to develop improved management and selection practices for northern Australia.

Key experimental design features

In brief, a total of 4,445 generation 1 animals, representing 105 sires from two genotypes, were bred from the mating of industry and CRC-nominated sires to base cows in cooperating herds of the Northern Pastoral Group of companies (see Burrow *et al.* 2003). The female progeny produced by the project were grown out at 4 locations and mated each year to produce "generation 2" progeny. Listed below are some of the key features of the design:

- Use of two tropically adapted genotypes (Brahman and Tropical Composites), representing large differences amongst tropically adapted breeds for carcase and beef quality, adaptation and male and female fertility traits.
- Tropical Composites were represented by Belmont Reds and animals from Industry/Pastoral company composite programs. On average the genotypes comprised ½ tropically adapted genes (Brahman, Africander or Senepol) and ½ unadapted genes (mainly British breeds and some Charolais).
- Approximately 2,200 progeny (original target of 2,400) per genotype were generated from about 50 sires (i.e. 20-30 progeny per sire and sex). These numbers were required to enable accurate estimates of the genetic relationships between traits, particularly between (lowly heritable) female fertility traits.

* AGBU is a joint venture of NSW DPI and the University of New England

- The sires used included a mix of those nominated by the collaborating breeders and sires nominated by the CRC (mainly used through AI). Most sires nominated by the collaborators were young, unproven bulls from their nucleus breeding herds. The CRC-nominated sires were selected primarily on the availability of moderate to high accuracy BREEDPLAN estimated breeding values (EBVs) for retail beef yield percent (RBY%) and intramuscular fat percent (IMF%). Sires representing a range in EBVs for the two traits were used. Additional selection criteria included known heterozygosity for gene markers identified in CRCI, or the ability of a sire to genetically link to other genetics projects (e.g. CRC I straightbreeding and crossbreeding projects) and to industry data (e.g. Brahman BREEDPLAN herds). Sires with BREEDPLAN EBVs prior to the project data will allow analyses of the ability of EBVs to predict progeny differences in a range of production systems.
- At each property a proportion of the herd were mated by AI followed by natural service joining in large multiple sire groups. AI was used to generate genetic linkage across co-operator breeding herds and years.
- DNA was collected from all animals generated in the project, as well as from all sires and many of the base dams. This allowed sire parentage assignment for animals, and in conjunction with the phenotypic measures, the DNA forms an extremely value resource for gene marker mapping and marker validation studies.
- Calves were generated by 8 co-operators across 4 years. At weaning, all calves were delivered to the control of the CRC and ownership remained with the companies.
- Steers and heifers were allocated to post weaning groups on the basis of property of origin and sire. The allocation was carefully done to ensure genetic linkage was maintained across post weaning cohorts.
- Steers were backgrounded at one of 5 grow out properties and when the average live weight of the group was 400-440 kg they were transferred to the CRC research feedlot near Armidale northern NSW ("Tullimba") for 120 day finishing.
- Heifers were relocated post weaning to one of 4 Queensland research stations (QDPI and CSIRO) where they were grown out and entered the breeding herd at 2 years of age. This phase of the project was designed to assess the lifetime reproductive performance of the females. Male progeny (generation 2) from these cows are being retained for a study of male fertility. Generation 2 heifers are currently sold or returned to their owners after weaning. All generation 2 calves are parentage identified using DNA fingerprinting and are fully recorded for all weaning traits.
- Environments for measuring heifer and cow performance traits were chosen to represent the range encountered by each breed, also recognising that this range included harsher (e.g. greater tick and worm prevalence) environments for Brahmans than for Tropical Composites.

Measurements

Animal details

For each animal produced by the project (generation 1 and 2) records included: property of origin, date of birth, sex, birth weight (not all properties or locations), dam id, dam age (days or year), sire id (by DNA), breed composition (for Tropical Composites), DNA sample, Breed Society registration number, generation number (1 or 2), and post weaning cohort. Current BREEDPLAN EBVs are also available for those animals recorded with Brahman or Belmont Red breed societies.

Pre weaning & post weaning measures

Numerous traits were recorded on both sexes and many of the traits were repeatedly measured over time. The date of measurement and location of the animal were recorded for each record. Traits included: weaning weight, post weaning weight (usually taken monthly), hip height, ultrasound scans (eye muscle area, P8 fat, rib fat and intramuscular fat %), body condition score, insulin-like growth factor-I concentration (IGF-I) and flight time. For steers, traits measured at 3 distinct stages (post weaning, feedlot entry and feedlot exit) were identified and used to assess changes in steer performance over time. For heifers, the end of the 1st post weaning wet season (approx. 18 months) and end of the 2nd post weaning dry season (i.e. approx. 24 months) were identified as 2 stages of interest for assessing heifer development.

Steer traits

Steers were backgrounded at one of 5 grow out properties and when the average live weight of the group was 400-440 kg they were transferred to the feedlot. A subset of the steers (N=1500) were individually feed intake tested for 70 days using automatic feeders with approximately 12 animals per pen. All steers were feedlot finished for approximately 120 days and slaughtered when the average live weight of the cohort was 550 kg (320 kg carcase). In total there were 26 slaughter groups. For each body the left side was conventionally hung (i.e. Achilles tendon) and the right side was tender stretched (i.e. aitch bone hung). A meat sample was removed from both sides and frozen for subsequent meat quality assessment.

Traits measured specifically on steers included those associated with feedlot finishing, carcase and meat quality.

Feedlot traits. Individual daily feed intake (and feeding time and duration) for a 70 d test, live weights and gains, net feed intake (NFI), ultrasound scans, body condition score, flight time, feet score, coat score, sheath score and IGF-I (traits measured at feedlot entry and exit).

Carcase traits. Hot carcase weight, hot P8 fat depth, dentition, AUSMEAT, MSA and VIA chiller assessments, and retail yield % (whole side bone out or VIA whole body scan).

Meat quality. Shear force, compression, cooking loss, Minolta meat colour (all for each hanging method), and intramuscular fat%.

Female traits

Traits measured only on heifers and cows included ovarian scanning, full breeding and calving history, tropical adaptation, calf performance and death/disposal information. At each location, all heifers from the same year of birth were managed as a single group (defined as a cohort). Heifers commence ovarian ultrasound scanning at 200kg live weight and were regularly scanned on a 4-6 week basis using real-time ultrasound to determine their age at the occurrence of a first *corpus luteum* (CL). Live weight and measures of body composition (scan P8 fat depth and body condition score) were also recorded at this time. The occurrence of a CL prior to, and on the day of, the commencement of their first (i.e. maiden) mating was also derived.

At each location heifers and cows are mated (by genotype) in large multiple sire groups for 12 weeks to the same breed of bull sourced from industry herds. The average age of the heifers at the commencement of first joining was approximately 25 months (i.e. to first calve as 3 year olds). At each location, the females are run in large mixed aged groups and mated annually. Any female failing to wean a calf in 2 consecutive years has been culled.

Ovarian scanning traits (left and right ovary). Primary follicle size, secondary follicle size, ovarian activity score, ovary shape score, ovary size, CL presence, CL size, uterine tract size and tone scores, pregnancy status and foetal age.

Mating details. Start of joining date, mating paddock, bull syndicate, IGF-I into mating, and end of joining date.

Calving details. Date of birth, sex, birth weight, weaning records (weight, IGF-I, flight time, coat score and colour, scrotal size and sire).

Tropical adaptation and *cow traits.* Faecal egg count, tick score and count, buffalo fly lesion score, rectal temperature, coat colour, coat score, navel score, teat and udder scores, death and disposal codes.

Quantitative genetics analysis overview

A very large number of genetic analyses have been completed and the results are currently being collated in a series of scientific publications. Analyses were conducted on a trait-by-trait basis both within and pooled across the 2 genotypes. For each trait, analyses involved first determining the appropriate fixed effects model and then using these effects in a univariate REML analysis for the estimation of variance components. Genetic and phenotypic correlations within and across the trait complexes were computed for all pair wise trait combinations.

Analyses of the female mating and re-breeding data are ongoing as each year generates further data on individual cow reproductive performance. Numerous non-genetic analyses (e.g. follicular development, heifer growth curves and carcase tenderstretch) have also commenced.

Results

The project is generating new knowledge on the underlying quantitative genetic mechanisms controlling a wide range of traits important for beef production in tropical and sub-tropical production environments and relationships between these traits, particular those associated with female reproductive performance. The heritability of each trait has been estimated as well the genetic correlation between all combinations of traits. These estimates are being used to quantify the magnitude of genetic differences in these populations. Knowledge of genetic correlations allows us to determine the existence of early in life (or easier to measure) indicator traits, possible genetic antagonisms between traits and any genotype x environment interactions.

Summary of key results to date

Steer traits

- Most traits were moderate to highly heritable
- Some differences exist in the genetics of Brahmans and Tropical Composites
- Early weights and scans were good genetic predictors of carcase performance
- Large genetic differences for the feed intake traits
- Generally high correlations of measures over time
- Carcase traits moderate to highly heritable (range 20- 50%)
- Large genetic differences for meat quality traits (for both genotypes)
- Tender stretch reduced the genetic differences in tenderness
- Few traits genetically correlated with tenderness (except flight time for Brahmans and IMF for Tropical Composites)

Heifer growth and adaptive traits

- Most growth traits moderate to highly heritable
- Wet season growth can be changed genetically more than dry season growth
- Adaptive traits were low to moderately heritable (but generally benign years), except coat score (heritability = 60%)
- Corresponding traits of heifers and steers are very similar genetically. Differences are likely to be more due to their environments than to their sex

Heifer puberty and reproductive performance

- Age at puberty under large degree of genetic control (heritability=0.50)
- Weight, eye muscle area, P8 fat depth and IGF-I were all modest genetic predictors of age at puberty
- Age at puberty highly related to calving output from 1st mating in Brahmans
- Large differences between sires for daughter calving performance
- Ranking of sires may change for daughter's calving performance from 1st (maiden) and 2nd matings

Next analyses

Analyses are underway to finalise the estimation of genetic correlations for traits across the various blocks with a particular focus on relationships with the adaptive traits. For the female reproductive data the aim is to complete all analyses involving calving data from the 2nd mating (with latest data coming from calving of 03's) and then commence preliminary analyses of the calving data from the 3rd mating. Analyses of each successive year's mating/calving data will then continue to attain an understanding of the genetics of lifetime reproductive performance and its relationship with other traits, particularly early in life indicators (e.g. age at puberty).

Along with this quantitative genetics work; analyses are underway to determine associations between gene markers and the numerous traits recorded. This process involves estimation of the size of the effect of markers in this population and also provides the opportunity to discover new genes/markers (with new whole genome scan technology).

Future release of results

Only limited release of these results has occurred to date. Key early results were released to co-operators in October and November of 2006, including trial EBVs for several new traits measured in the project for each of the co-operator's bulls.

The new knowledge of genetic effects along with many of the non-genetic outcomes (e.g. location/year effects) on female fertility in tropical breeds will provide opportunities to improve reproductive rates in northern Australia and have spin-offs for Southern Australian production systems. The key relationships between female fertility traits and steer traits, including feed efficiency, will be pivotal in allowing more accurate targeting of breeding, particularly for self replacing production systems. In conjunction with other projects (including those in CRC3), the effect of commercially available gene markers on the primary trait (and also all correlated traits) will provide extremely valuable information on the utility of these markers in the 2 genotypes and production systems used in this study. These results will assist greatly in progressing the development of marker assisted EBVs and marker assisted selection. However, extensive efforts, through both existing and new avenues, will be required for maximum use to be made of the outputs by seedstock breeders, commercial producers and other sectors of the Australian beef industry.

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Bullpower and Beyond - Maximising the Calf Output of Bulls

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Abstract. Factors interfering with the calf production of bulls in northern Australia were examined. These included sperm morphology, the impact of relocation on bull reproductive traits and the effect of bull percentages at different levels of herd dispersion on pregnancy rates. The repeatability of percent normal sperm in an ejaculate was collated from 8 studies. Repeatabilities for yearling bulls (1 to 2 years of age) ranged from 0.09 to 0.33. In bulls 2 years or older, repeatabilities of percent normal sperm ranged from 0.41 to 0.78. A survey of 927 bulls relocated to northern Queensland found that approximately 50% failed a breeding soundness examination 3 months post-relocation. Most failures were due to low levels of normal sperm and appeared independent of breed, age, and region of source. Detailed studies on relocating bulls found that there were minimal effects of breed, the feeding of concentrates prior to relocation or relocation *per se* on semen traits or sperm morphology either in the short-term (1.5-3 months) or long-term (12 months) post-relocation. Seven studies in north and north-west Queensland determined the effect of different bull mating percentages under different herd dispersion conditions. In 4 of these studies, pregnancy rates were either the same or higher in herds with lower bull percentages. The data provided further support that bull percentages of 2.5% reproductively-sound bulls are adequate under most north Australian conditions.

Introduction

Multiple-sire mating accounts for more than 95% of all matings that occur in northern Australia. Earlier studies established that the calf output of individual bulls in multiple-sire herds was extremely variable with 14% of the bulls individually siring over 30% of calves, 58% sired 10% or less and a further 6% of bulls did not sire any calves (Holroyd *et al.* 2002). All of these bulls had passed a bull breeding soundness examination (BBSE). Further studies relating pre-mating measures of physical, seminal and behavioural traits of bulls to calf output found that the strongest associations occurred with measures of sperm morphology, where percent normal sperm was positively related to calf output (Holroyd *et al.* 2002). As sperm morphology is one of the criteria for bulls passing a BBSE, it is important to know how repeatable the measurement is and conditions that modify it.

The delivery of adequate normal sperm to the site of fertilisation is critical to maximise the calf output of bulls. There are a number of reasons why bulls cannot provide adequate normal sperm at the site of fertilisation (reviewed by Barth and Oko 1989). Firstly, bulls may have low levels of normal sperm and this may be permanent or temporary. In bulls with permanently low normal sperm, the condition may be innate or acquired. In the majority of cases, the reason for the condition is not apparent but could be an inability to adapt to the environment. Temporary reductions in semen quality may be from stress as a result of relocation, lack of environmental adaptation, obesity and disease. Secondly, bulls with adequate normal sperm may not be able to deliver it to the site of fertilisation. This may be due to suppressed mating ability through behavioural influences such as social dominance or lack of sexual motivation or through impaired mating ability due to physical defects such as lameness, penile and sheath problems which can interfere with serving ability. Thirdly, herd dispersion effects may limit bulls accessing females in oestrus.

Many bulls originate from herds in environments different to that of their property of use. In the course of relocation, bulls may be transported many hundreds of kilometres and through extremes of hot and cold weather. During transport, they may experience irregular feed and water supply, crowding and physical trauma and on the property of destination, they may experience different forage quantity and quality, water quality and climate. There may be intense competition from existing bulls, different mustering and handling procedures and new pathogens. McCool and Holroyd (1993) reported that up to 40% of bulls were sub-fertile in their first season after being relocated and this was generally not recognised for 12 months or more after relocation. Fertility failure of relocated bulls was an issue identified by producers in a series of "Breeding Better Bulls' days in north Queensland (JD Bertram, pers coms).

Reducing bull mating percentages will reduce the bull costs per calf. Traditionally bulls have been mated at 5% (1 bull to 20 females). Evidence from both single-(Pexton *et al.* 1990) and multiple-sire (McCosker *et al.* 1989) herds suggest that bull percentages can be lowered below 5% without compromising herd fertility. This needed to be tested under different levels of herd dispersion. In northern Australia, the majority of cattle graze at stocking rates of 1 adult to 5-30 ha. Cattle can be widely dispersed which may limit bulls finding females in oestrus. Alternatively with controlled waters such as dams and bores being the only supply, high concentrations of cattle can occur.

This paper reports on issues that could interfere with the calf production of bulls in northern Australia. These include the repeatability of sperm morphology in both yearling and adult bulls, the impact of relocation on bull reproductive traits and the effect of bull percentages under different herd dispersions on herd pregnancy rates.

General materials and methods

The data presented in this paper is drawn from a number of experiments reported in MLA Final Report NAP3.117 (Holroyd et al. 2005). Location of experimental sites is summarised in Table 1. Bulls underwent a BBSE based on McGowan *et al.* (2002). Semen was collected mainly by electroejaculation (Entwistle and Fordyce 2003) and was evaluated based on the procedures of Fitzpatrick *et al.* (2002) and Entwistle and Fordyce (2003). The morphology of 100 sperm was determined in the laboratory by examining a thin cover-slip preparation of semen preserved in 0.2% glutaraldehyde in phosphate buffered saline using phase contrast microscopy (x1000) (Entwistle and Fordyce 2003; Barth and Oko 1989).

Table 1. Location of experimental sites.

Property	Nearest centre	Location	Native pasture community (Weston and Harbison 1980)
Belmont Research Station	Rockhampton	23°S, 150°E	Black spear grass
Bow Park	Julia Creek	20°S, 141°E	Mitchell grass
Brigalow Research Station	Theodore	24°S, 149°E	Brigalow pastures
Canobie	Cloncurry	19°S, 140°E	Blue grass - Browntop
Dilga	Glenmorgan	28°S, 149°E	Brigalow pastures & feedlot
Gyranda	Theodore	25°S, 150°E	Brigalow pastures
Kamilaroi	Cloncurry	19°S, 140°E	Blue grass - Browntop
Narayen	Mundubbera	25°S, 150°E	Brigalow pastures
Swan's Lagoon Research Station	Ayr	20°S, 147°E	Black spear grass
Toorak Research Station	Julia Creek	21°S, 141°E	Mitchell grass

Results and discussion

Repeatability of sperm morphology

Data were collated from experiments conducted between September 1998 and November 2002 (Table 2). Semen was collected from 379 bulls and collections were repeated between 3 and 9 times depending upon the cohort. Mean bull ages at the initial semen collection ranged from 1 to 5 years.

In 4 studies of various breeds of bulls (Table 2), where the initial age was about 1 year, the repeatabilities of percent normal sperm over the following 8 to 12 months were low and ranged from 0.09 to 0.33. However in one group of Brahman bulls where the initial age was 1.75 years, repeatabilities (0.75) over the following 3 months were high. In bulls older than 2 years of age, repeatabilities of percent normal sperm ranged from 0.41 to 0.78. The repeatability data from Belmont

Research Station (0.41) is of dubious value as the bull population was not stable as a result of a number of additions and sales of bulls during the study period.

Table 2. Repeatabilities of percent normal sperm.

Location	Bulls (n)	Breed#	Mean age or range (y) at start of study	Measures (n)	Study period (m) and dates	Repeatability ± se
Belmont	70	B & C	1	8	(8) Jan-Aug 00	0.09 ± 0.04
Gyranda	39	SG	1	8	(11) Sep 00-Aug 01	0.29 ± 0.08
Dilga	40	DM	1	5	(9) Nov 00-Aug 01	0.25 ± 0.08
Narayen	24	BR	1	5	(12) Sep 98-Aug 99	0.33 ± 0.11
Brigalow	80	B	1.75	3	(6) May-Nov 01	0.75 ± 0.04
Brigalow - Toorak	80	B	2	9	(12) Nov 01-Nov 02	0.78 ± 0.03
Belmont - Swans Lagoon	80	B & C	2	9	(12) Nov 01-Nov 02	0.69 ± 0.04
Belmont	12-46	B&C	2-5	9	(23) Oct 99-Nov 01	0.41 ± 0.08

#B Brahman; BR Belmont Red; C Composite; DM Droughtmaster; SG Santa Gertrudis

Overall, percent normal sperm was poorly repeatable in bulls that were sexually maturing (1 through to 1.75 years of age) suggesting the selection of bulls at a young age for sperm morphology is not feasible. The generally high repeatabilities for normal sperm once bulls have reached 2 years of age indicate that normal sperm levels are relatively stable in bulls that have reached sexual maturity. As there are variations in percent normal sperm due to either transient or permanent effects (Barth and Oko 1989) then an annual BBSE is desirable to ensure that all mated bulls are reproductively sound.

The effect of relocation on bull reproductive traits

Breeding soundness of sale bulls after relocation. BBSEs (n = 927) were conducted from June 2000 to June 2002 on bulls after they had been sold and relocated to north or north-west Queensland. The bulls were *Bos indicus, Bos taurus*, or crossbred; grain- or paddock-fed; and sourced mainly from southern and central Queensland. The study occurred during a period of below-average rainfall. Approximately 50% of the bulls failed a BBSE up to 3 months after sale and relocation. Most failures were related to low levels of normal sperm and were independent of breed, age, and source. Providing bulls then experienced favourable nutritional and managerial conditions over the next 6 months, about 80% of bulls passed a BBSE

The effect of feeding and relocation on reproductive traits of Brahman bulls. At Brigalow Research Station, 80 yearling Brahman bulls (18 months of age and mean weight 355 kg) were allocated to 2 treatments, G - grazing pasture or F – grazing pasture and supplemented with a commercial pellet mix (CP 15%, ME 10.4 MJ/kg) through self-feeders at 1-1.5% body weight (about 6 kg/bull/day) for 150 days. At the end of feeding, bulls were further allocated within each feeding treatment thus creating 4 relocation treatments: NRG (not relocated, grazing pasture only prior to relocation), NRF (not relocated, grazing pasture and supplemented prior to relocation), RG (relocated, grazing pasture only prior to relocation) and RF (relocated, grazing pasture and supplemented prior to relocation). Relocated bulls were transported by truck 1100 km (16 h) to Toorak Research Station. Bulls were subjected to a BBSE at 6-8 weekly intervals from the commencement of the experiment (16 May 2001) until 12 months after relocation (04 November 2002). During the feeding period, G bulls lost, on average, 4 kg (-0.03 kg/day) whilst the F bulls gained, on average, 143 kg (1.03 kg/day). Liveweights and scrotal circumferences at the end of feeding were 362 kg and 517 kg and 31.8 cm and 36.1 cm for G and F bulls respectively. There was no effect of feeding on semen traits such as motility or on either normal sperm or on any sperm abnormality categories either in the short term (1.5-3 months) or long term (12 months) post-relocation although both semen and sperm traits improved over time. Liveweight gains post-relocation and final liveweights were respectively NRG 149 and 526 kg, NRF 52 and 565 kg, RG 225 and 593 kg and RF 128 and 633 kg. Scrotal circumference changes post-relocation and final sizes were respectively NRG 3.4 and 36.6 cm, NRF 1.2 and 37.1 cm, RG 4.4 and 37.3 cm and RF 2.2 and 37.7 cm. There was a significant ($P<0.001$) effect of time on semen motility with motility decreasing until August 2002 and then increasing back to the value at time of relocation

The effect of relocation on reproductive traits of Brahman and Composite bulls. At Belmont Research Station, 38 Brahman (B) and 42 Composite (C) bulls (24 months of age, mean weight 381 kg) were allocated within breed to 2 treatments: Non–relocated (NR) with bulls remaining at Belmont and Relocated (R). These relocated bulls were trucked to Swan's Lagoon a distance of 630 km (11 h). Bulls were subjected to a BBSE 6 weekly from the commencement of the experiment (7 November 2001) until 12 months after relocation (28 October 2002). There was a general increase in liveweight over time in both breeds. The pattern of liveweight gain for B and C bulls was similar in NR bulls but in the R bulls, liveweights plateaued after 6 months with B bulls heavier than C bulls in the latter part of the experiment. Twelve-month gains and final liveweights were 239.5 kg and 619.6 kg for NRB; 237.5 kg and 618.1 kg for NRC; 144.1 kg and 527.6 kg for RB and 108.1 kg and 486.2 kg for RC. There was no significant effect of breed on scrotal circumference, but there was a more rapid increase in circumference for NR than R bulls. Relocation had only minor effects on semen traits and there was no effect of either relocation or breed on normal sperm or the various sperm abnormality categories.

The detailed experimental studies found that there were minimal effects of breed, concentrate feeding prior to relocation or relocation *per se* on bull semen traits or sperm morphology either in the short or long term post-relocation. In these experimental studies bulls were relocated under favourable conditions. Bulls were yarded overnight prior to relocation; the transport time was minimised; bulls were familiar with each other and then grazed good pasture post-relocation. However the survey on the breeding soundness of the 972 sale bulls after relocation could not establish the cause of the 50% failure rate but appeared unrelated to breed, age, property of origin or prior nutrition. Our inference is that many bulls in the industry are being relocated and managed post-relocation under less than ideal conditions. Any depressions in bull fertility associated with relocation are therefore likely to be from factors other than changes in semen quality, or that occur in bulls that undergo a more stressful relocation process than that experienced by the bulls in these experiments.

The effect of different bull mating percentages and herd dispersion on herd fertility

Seven studies were conducted in north and north-west Queensland to determine the effect of reducing bull mating percentages under different dispersion conditions (Table 3). Each of the studies was unreplicated because of the size of the herds and properties. As well, it was not possible to allocate cows to their treatments based on their oestrous cycle status. In 4 studies, pregnancy rates of cows mated at the lower bull percentage were either the same or higher (11-18%) than that of cows mated at higher percentages. At Bow Park results were influenced by heifers in the lower bull percentages being heavier. The 3 cases where pregnancy rates were reduced in the lower bull percentages ranged from 6 to 8%. In the case of the 2 studies at Kamilaroi (Fordyce *et al.* 2002), the higher bull percentage group was considered to have better nutritional conditions than the lower bull percentage group.

In almost all cases where differences in pregnancy rates occurred, these differences were generated during a short peak-conception period early in mating and the differences remained relatively constant for the rest of mating. The differences could possibly be related to confounding nutritional conditions between paddocks. In the one observation conducted under high-dispersion conditions, the specific reason for the difference between mating groups was not apparent, but given the very low mating loads on bulls during peak mating, the difference was not obviously attributable to the differences in bull percentages.

There were several other significant findings in the studies by Fordyce *et al.* (2002). Firstly, the variation between bulls in calf output, measured by DNA typing, was substantially lower when fewer bulls were used in the herd. Secondly, there was less bull loss due to fighting and injury with lower bull percentages, and thirdly, the data refuted the perception that bulls with greater calf output ("harder–working") finished the mating season in poorer body condition, as there was no relationship between calf output and bull body condition.

Table 3. Summary of studies of different bull mating percentages.

Location	Herd dispersion	Breed	Bull:female matings (%)	Bulls (n)	Females (n)	Difference#
Kamilaroi (1994-95)	Low	Brahman	2.4	10	411 heifers	-8%
			5.8	24	411 heifers	
Kamilaroi (1995-96)	Low	Brahman	2.5		350 heifers and cows	-6%
			6.0		350 heifers and cows	
Canobie (2001)	High	Brahman	2.0	150	3766 heifers	-8%
			4.0	10	500 heifers	
Bow Park (2001)	Low	Brahman cross	1.4	3	120 heifers	0%
			2.7	5	183 heifers	
Bow Park (2002)	Low	Brahman cross	1.2	2	170 heifers	11%
			2.3	4	175 heifers	
Swan's Lagoon	Moderate	Brahman cross	1.1	3	276 heifers	0%
			2.4	11	462 heifers	
Swan's Lagoon	Moderate	Brahman cross	1.5	2	137 cows	18%
			2.4	11	462 cows	

#Percent unit advantage in pregnancy rate of lower bull percentage herd

These studies showed that pregnancy rates were not reduced as a direct result of reducing bull percentages from high to moderate under high dispersion grazing management in north Australia, or from moderate to low under low or moderate herd dispersion. This provides further support to the recommendation that mating percentages of 2.5% reproductively-sound bulls (a moderate bull percentage) are adequate under most north Australian cattle management conditions.

Current studies

Except for scrotal size, there is little information on the degree of genetic variation in male reproductive traits and their association with female fertility. Traits such as sperm morphology have been related to calf output in multiple-sire matings in extensive herds (Holroyd *et al.* 2002). However there is a lack of information on the heritabilities of and genetic correlations between such traits and with female traits. The CRC for Beef Genetic Technologies has some 2500 Brahman and Composite females that have a detailed reproductive history including age at puberty, pregnancy rates and post-partum anoestrous intervals. Weaner bulls produced from these herds are transferred to either Brigalow Research Station or retained on Belmont Research Station. These bulls undergo a BBSE including collection of semen for morphology at 12, 18 and 24 months of age. Seminal fluid is collected to assess various proteins and enzymes. As well blood is collected from prepubertal bulls to measure LH, inhibin, leptin and IGF-1. To establish with confidence, the genetic relationships between male and female reproductive traits, there will be a requirement to examine about 3500 bulls from weaning to 2 years of age. The work commenced in April 2005 and will be completed in November 2011. If this project can identify bulls that produce more fertile daughters then the identification of gene markers could be explored to commercialise these results. Early life predictors of fertility in the male will greatly improve the efficiency of selection of sires for improving reproductive performance of beef herds.

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Calf wastage - how big an issue is it?

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What is calf wastage

Breeding female cattle in north Australia contribute best to business success by producing a heavy weaner each year at the first weaning round. This maximises increase in value by the cow unit over the year, generally from mid-year to mid-year. The ability to cycle in both maiden heifers and lactating cows is the primary limitation to achieving this. Wastage of a calf at any stage between conception and weaning also substantially limits fertility and value increase at a herd level. Embryo loss may result in later calves as cows re-conceive; the calves produced are smaller at weaning and have to be weaned later into the dry season. Late calf wastage usually results in breeders missing a calf for the year. Late calving often also results in failure to cycle, thus cows rear a calf in the subsequent year.

Prevalence and causes

Embryonic mortality is loss between fertilisation and Day 45 of pregnancy. Foetal mortality occurs from the 45th day of pregnancy to the commencement of birth/parturition. Neo-natal mortality occurs when calves die or exhibit illness within 2 days of birth resulting in death within one week of birth. Post-natal mortality occurs between the neo-natal period and weaning. It is difficult to define prevalence or incidence of losses at various stages, as well as causes, and reports of losses are often simply between confirmed pregnancy and weaning.

Burns *et al.* (2007) reviewed reports from the mid-1960's to 2005 of prevalence of pregnancy to weaning losses ranging from 2% to 61% for extensively-managed north Australian herds. Recent anecdotal evidence is that losses from first-lactation females are typically 20% with no cause identified. For example, in a recent NW Queensland study, unexplained losses in this period averaged 17% in a well-managed herd.

Pre-natal loss

Embryo mortality rates of 25% are considered normal in extensively-managed beef cattle. At least 80% of embryonic mortality occurs between Day 8 and Day 18 after fertilisation Burns *et al.* (2007), which usually results in seamless transition to the subsequent oestrus cycle. Combined with fertilisation failure rates of 85-90%, a pregnancy rate per cycle of 65-70% is expected in healthy cattle. Foetal loss averages no more than 3% in healthy cattle. However, the Burns *et al.* (2007) review reported foetal losses in north Australia, ranging from 1% to 17% between the mid-1960's and 2005.

In north Australian herds, Burns *et al.* (2007) reported that primary causes of pre-natal loss include:

- *Campylobacter foetus* subspecies *veneralis* (vibrio) and *Tritrichomonas foetus*. The primary evidence of these diseases is delayed conception patterns, resulting in smaller weaners. Prevalence of vibrio is suspected to be high across north Australia, but probably low for trichomoniasis.
- Bovine pestivirus. This disease appears to be endemic in the majority of large north Australian herds. Its impact in causing embryo and foetal loss, and mortalities in animals born as persistently-infected (PI) may be highest in herds where animal management is better, (ie, create small-herd situations) and naïve age groups are often created. It is within these naïve groups that significant pre-natal loss occurs when exposed to PI cattle.
- *Neospora caninum.* Has been suggested as a significant cause of losses, but despite it being present in most herds with a prevalence level of 20% not unusual, and it clearly being a cause of loss in specific intensively-managed herds, there is no evidence to date that it causes significant loss in extensive north Australian herds.

- Stress may be the most significant cause of non-infectious prenatal loss. Causes of stress include handling, heat, and mal-nutrition. Stress-related losses may be prevalent in most herds, but incidence is only likely to be significant where specific conditions are created.
- Impaired female reproductive tract environment and function related to endocrine (hormonal) and immunological dysfunction may also cause losses that could be related to diet, the environment, and genetic predisposition. The prevalence and incidence of these losses have not been quantified.

Neonatal loss

Burns et al. (2007) reviewed reports from the mid-1960's to 2005 of neo-natal losses in north Australia ranging from 2% to 12%. Significant causes of losses included:

- Stress due to nutrition or heat, eg, heatstroke/hyperthermic shock in non-adapted genotypes
- Predators, especially wild dogs. Losses can exceed 20% and are proportional to the dog population.
- Lack of milk to the calf because of either poor milk production, teat and udder abnormalities, or accidental mismothering. These problems may be caused by malnutrition, genetic predisposition (eg, bottle teats or very large udders), environmental conditions, handling/mustering, immaturity of the dam, and twins where usually only one survives.
- Calf abnormality or weakness associated with abandonment by the dam. Affected calves are often of low birthweight.
- *Leptospira spp* are known to cause late abortions and weak calves. A minority of species are considered a problem. Though the organisms are ubiquitous, the incidence of significant loss confirmed as due to leptospirosis in extensive areas is low. Vaccination also prevents zoonoses.
- Dystocia occurs in all breeds, including Brahmans, and primarily in 2-year-olds. The primary problem is foeto-pelvic disproportion (Norman 2006). Control measures include avoiding matings that cause big calves, preventing heifer obesity at calving and most importantly, keeping heifers growing at all times, especially during the first half of pregnancy. Under-nutrition at any stage can retard pelvic growth. Under-nutrition in early pregnancy may increase size and efficiency of the placenta, which disproportionately increases foetal growth when adequate nutrition is restored. In a recent north Queensland study, dystocia did not occur when preventative management was implemented; however, 5-10% of heifers experienced dystocia when positive action was not taken.
- Misadventure, which is sporadic.
- Unknown causes. Unfortunately this is consistently the primary cause given for loss, even in detailed studies.

Post-natal loss

Burns et al. (2007) reviewed reports from the mid-1960's to 2005 of post-natal losses in north Australia ranging from 0% to 53%. Main causes of losses included:

- Bovine pestivirus as discussed earlier.
- Botulism. There are many anecdotal reports of suckling calf botulism deaths, usually where cows were unvaccinated.
- Arboviruses. The primary viruses are Akabane and Bovine ephemeral fever. Both are ubiquitous and potentially have greatest effect following a series of dry years when heifers do not gain exposure, thus immunity. The effect of BEF on calf wastage in north Australia remains unquantified.
- Malnutrition, including deficiency of diet components such as Vitamin A, which was identified as the primary cause of calf loss exceeding 40% in one NW Queensland herd following a series of dry years.
- Predators, misadventure and environmental stresses as for neo-natal losses.

Benchmarks

From the above, and other reported data for north Australia, benchmark levels for reproductive wastage elements are proposed as: 25% of embryos, 3% of foetuses, 5% of neonates, and 1% of the remaining calves.

The review of Burns *et al.* (2007), reinforced by recent observations, indicates that many herds are not achieving the benchmark levels indicated above. Though specific incidence of losses has not been quantified for north Australian beef herds, all indicators are that they are not low. It highlights substantial opportunities in north Australian herds to reduce reproductive wastage, with the most significant opportunities being to:

- increase the rate of established pregnancy per cycle in breeding female cattle, with specific emphasis on early embryonic mortality, and
- reduce neo-natal mortality.

Financial impact

Foetal and calf wastage affects business efficiency by reducing the number and size of calves at weaning as a function of the number of breeding females retained in the previous year, i.e., it reduces or eliminates the increase in value achieved by a breeding animal over a year.

Foetal, neo-natal, and post-natal losses all generally result in failure to rear a calf to weaning within the year. Cows may re-conceive after embryo or early foetal loss, and still raise a calf, though it will be a small weaner and the delayed calving results in the cow having little chance of rearing a calf in the next year. Figure 1 provides an example of how weanings may be affected in this way.

Figure 1. Predicted calves/100 heifers after 3 months mating to *Campylobacter*-infected bulls (grey columns; ~40% pregnant per cycle and weaning 79% at 203 kg) in a north Queensland herd compared to potential calves in the absence of disease (black columns; ~70% pregnant per cycle and weaning 84% at 214 kg).

Table 1 shows estimates of the financial effect of reproductive disease and calf losses in a representative NW Queensland cattle herd using BREEDCOW modelling. Model input was generated by detailed analysis of available data on reproductive function in breeding herds. Vibrio was estimated to reduce weaning rates in heifers by 5% and their progeny weights by 11kg. Mid-pregnancy to weaning losses were taken to increase from 10% to 18% in heifers where high calf loss is occurring. The effect in cows was taken as 20% of that in heifers. The effects were taken as additive when they occurred together. Steers were sold at weaning. Surplus heifers are sold at 2.5 years of age.

Table 1. BREEDCOW estimates of the financial effect of vibrio and/or high calf loss in a representative NW Queensland 3,000 adult equivalent beef herd.

	No vibrio & normal calf loss	Vibrio present	High calf loss	Vibrio & high calf loss
2-year-old heifers mated	646	640	632	625
Total females mated & kept	1570	1592	1603	1627
Heifer weaning rate	84%	79%	76%	71%
Heifer pregnancy-weaning loss	10%	10%	18%	18%
Cow weaning rate	84%	83%	82%	81%
Cow pregnancy-weaning loss	10%	10%	12%	12%
Total calves weaned	1318	1306	1290	1276
Weaner size (kg)	214	203	214	203
Reproductive efficiency[a]	180	167	172	159
Capital value of herd	$1,522,655	$1,521,379	$1,523,600	$1,522,367
Net cattle sales	$621,713	$610,637	$613,263	$601,935
Direct costs	$53,000	$52,796	$52,606	$52,372
Gross margin for herd	$568,713	$557,841	$560,657	$549,563
GM per adult equivalent	$190	$186	$187	$183

[a] kg weaned/cow retained

This analysis indicates that for every 1,000 cows mated and retained, business profit is reduced by:

- >$600 for each percentage unit in pregnancy-weaning loss incurred.
- >$200 for each percentage unit in embryo loss incurred.

In both scenarios presented in Table 1, the gross margin was reduced by $3-$4 per Adult Equivalent.

This estimate does not account for other substantial secondary benefits that may also accrue from reducing calf wastage, eg the opportunity to implement more effective genetic improvement programs.

Table 2 shows suggested impacts of vibriosis and trichomoniasis in when it is assumed that one third of the north Australian herds is affected, and of pregnancy to weaning loss when possibly 20% of cattle are in herds that experience high losses.

Table 2. Possible impact of reproductive disease and pregnancy to weaning loss in the north Australian cattle herd.

Parameter	Derivation	Value
North Australian herd	AE	12M adult equivalents
Cows mated and kept	AE*0.5	6M
Impact of vibrio & trichomoniasis		
Percent of cattle in affected herds	Assumption	33%
Loss within a herd	Embryo loss +30%*200/1000	$6/cow mated & kept
Cost to north Australian herd	$6*0.5/3	$1/cow mated and kept
		$6M
Impact of high pregnancy-weaning losses		
Percent of cattle in affected herds	Assumption	20%
Loss within a herd	Foetal and calf loss +8%*600/1000	$5/cow mated & kept
Cost to north Australian herd	$5*0.5*20%	$0.50/cow mated and kept
		$3M

Estimates in Table 2 indicate that there is significant opportunity to improve business performance by identifying and implementing solutions to the causes of embryo, foetal and calf wastage. Modelling developed by the CRC for Cattle and Beef Quality indicates that the benefit to the community of improving beef business performance is three times that accruing to producers (Farquharson *et al.* 2003).

Current recommendations to minimise losses

There are currently many recommendations which may significantly reduce embryo, foetal and calf wastage. These are summarised as follows:

1. Cow selection

- Select female cattle for future breeding at all ages if they rear calves to weaning, and do not have attributes that may contribute to calf loss, eg, bottle teats, poor maternal temperament

2. Mating management

- Use bulls identified as fertile by a breeding soundness evaluation prior to initial mating at least.
- Manage time of mating to achieve calving when nutrition is adequate, and when cows and calves are able to tolerate prevailing climatic stresses (temperature extremes, inclement weather).

3. Metabolic status management

- Nutrition
  - Ensure adequate feed and water quality, quantity and access.
  - Prevent hypovitaminosis A. Specific practical strategies are yet to be developed and tested, but may include targeted supplementation over the latter half of the usual growing season in years when availability of green feed is limited.
- Minimise handling stress, especially in the latter half of pregnancy.

4. Disease management

- Use ultrasound examination of ovaries in conjunction with pregnancy diagnosis and animal description to differentiate malnutrition and infectious disease as the primary potential causes of delayed pregnancy or low pregnancy rates, especially in heifers.
- Diagnose prevailing reproductive disease. Basic sampling for infectious disease if this is considered a probability includes:
  - Vaginal mucus for a *Campylobacter foetus* subsp. *venerealis* ELISA antibody test.
  - Preputial secretions for a real-time-PCR test of both *Campylobacter foetus* subsp. *venerialis* (McMillen *et al.* 2006) and *Tritrichomonas foetus* (Lew *et al.* 2006) from up to 20 bulls.
  - Serum from up to 20 heifers for pestivirus antibody.
- Use vaccination or allied strategies where significant loss due to a specific disease may occur
  - Pestivirus. Use strategic sampling of management groups to assess previous exposure or potential presence of persistently-infected (PI) carriers in a herd. Vaccinate naïve groups of females prior to mating if there is any chance of exposure to a PI during mating.
  - Campylobacteriosis. Vaccinate heifers prior to first mating. Vaccinate bulls, starting early in life to establish immunity before homosexual transmission occurs.
  - Leptospirosis. Implement the recommended vaccination program where this disease is known to cause reproductive wastage, or there is a high probability that it may. Commence vaccination in calves at the earliest practical time.
  - Clostridial diseases. At marking, 5-in1 (especially to prevent tetanus) and botulism vaccines should be given to suckling calves in areas where these diseases are endemic.

5. Dystocia management

- If possible, only mate yearlings that have reached a target mating weight (Fordyce 2006).
- Select sires and females with traits indicative of calving ease; eg: when available, use EBVs for calving ease and short gestation length; mate older heifers; avoid cross-breeding of yearlings.

- Ideally, maintain growth and forward body condition in pregnant yearlings, especially during the first half of pregnancy; however, avoid obesity at calving.
- Supervise calving and provide early assistance if required, especially of 2-year-olds.

6. Predator management

- Control predators where there is a risk that these may cause significant calf loss.

The future through R&D

There are a number of recent, current, and planned projects in north Australia that will provide outcomes to limit embryo, foetal and calf loss. They include the following:

- *Sperm chromatin (DNA) instability and reproductive wastage.* Imperfect condensation of DNA into the head of sperm has been shown to cause significant embryo mortality in other species and there is some suggestion that a similar problem occurs in cattle. A recent study in Queensland showed there is a relatively low prevalence in bulls of levels of sperm chromatin instability that may be of concern.
- *Improved diagnosis of reproductive disease in cattle.* Highly-sensitive and highly-specific PCR tests were developed to detect the infectious agent in vibriosis and trichmoniasis. This will greatly enhance future investigation of these diseases. In the short term they are useful for herd diagnoses, to prevent potential impact of these diseases in single-sire mated herds, and ensuring the infectious agents do not contaminate frozen semen (Lew *et al* 2006).
- *Impact of pestivirus and Neospora on beef herds.* This is a current study where the disease impacts are being monitored in small, medium and large herds primarily in Queensland and NSW. A project report will be prepared in 2007.
- *CRC for Beef Genetic Technologies.* Female selection strategies will be more targeted when the repeatability and genetics of calf wastage is determined as part of current herd studies. The inheritance of sperm attributes that may affect embryo survival may extend from other parallel studies.
- *Impact of BEF on north beef herds.* A current study is attempting to measure the effect of BEF vaccination on fertility of heifers, including calf wastage, in north Australian herds.
- *Diagnosis and prevention of hypovitaminosis A.* This is an on-going study within the DPI&F in Queensland following recent diagnosis of substantial calf losses caused by this condition. There is a linked investigation of a newly-described condition which presents as neo-natal haemolysis.
- *Levels and causes of foetal and calf loss in north Australian herds.* A four-year prospective epidemiological study of region-, property-, mob-, and animal-level factors affecting selected measures of fertility is in the planning stages. Using selected representative herds, achievable levels of reproductive performance and the primary influencing factors will be defined and quantified to form the basis of decision support tools to profitably improve fertility of north Australian breeding herds. Methods to monitor reproductive performance will also be determined.

Basic studies have been proposed that may also lead to practical solutions to high embryo, foetal and calf loss. These include study of the mode of action of nutritional, environmental and genetic factors that influence ova and embryo viability and acceptance by the uterus, and development of remedial strategies for negative factors where possible.

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Northern Australian collaborative heifer fertility projects

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Introduction

The low fertility of lactating first calf heifers is generally regarded as the biggest area of inefficiency in northern Australian breeding herds and two projects are currently running on commercial properties in the NT and northern WA to address this problem. The projects were designed and are being run in collaboration by NT DPIFM and DAF WA staff and have been underway since late 2004.

Current levels of heifer fertility on commercial properties are being documented and demonstration sites have been set up on commercial properties where improved management practises are being researched and demonstrated. Cattle managers are also being surveyed on their estimates of current heifer performance, their management practises and their attitudes towards changing the way they manage heifers. The aim is to increase the awareness of cattle managers about the problems with heifer fertility in their regions, and of practises that can be used to improve it. At the end of the projects (in 2009) a best practise manual for heifer management will be produced.

The purpose of this paper is to give an outline of these projects and report on the preliminary findings.

1. North western WA heifer project: "Industry initiatives to improve young breeder performance in the Pilbara and Kimberley of WA"

Introduction

The profitability of pastoral leases in the Pilbara and Kimberley is determined by the number, weight and value of cattle produced and sold, less the input costs. Limited information available indicates that, in common with many extensive northern Australia cattle enterprises, female sales as a percentage of total sales in the Pilbara and Kimberley seldom exceeds 35% with a range of 15 – 40%. This indicates that at least one half of the females bred in these enterprises do not leave the property. Similarly long term average reproductive rates (progeny weaned/breeding age females exposed to bulls in the previous season) range from 45 – 75%. While some enterprises are certainly more productive than these figures suggest, there is opportunity to improve productivity by improving the efficiency of reproduction and increasing female sales.

In common with producers across northern Australia, pastoralists in the northern rangelands of WA have identified young breeders (defined as young females in the breeding herd until they conceive their second calf) as a high survival risk group in the breeding herd with often less than optimal reproductive performance.

Pastoralists project management groups

An expression of interest for pastoralists to be involved in a group to oversee and contribute to project development and management was advertised in the Department of Agriculture and Food (DAFWA) Northern Pastoral Memo. In the Pilbara this resulted in the formation of a group which included co-operators in the site activities and pastoralists responding to the expression of interest. The Kimberley management group is made up of the pastoralists on the RBRC and other cooperating managers.

Survey of current practises and attitudes

A survey was developed and conducted to provide a background of current practises and pastoralists' attitude to adopting alternative management practises. A 40% sample of pastoralists was surveyed to represent all herd sizes and major land systems of the Pilbara. Survey information was collected during personal interviews. All participants were advised that they would again be asked to participate in a similar survey towards the end of the project in 2008/09 as part of project evaluation.

Results

A sample of the results of a survey of 40% (n=22) of Pilbara pastoralists conducted during 2004/05 are included in Table 1.

Table 1. Summary of Pilbara survey results.

Herd information:	
Average herd size	6,800
Average number calves marked/weaned 2003/04	2,300
Average number females sold 2003/04	880
Enterprises using botulism vaccine (%)	83
Enterprises segregating heifers following weaning (%)	78
Enterprises mustering breeders more than once a year (%)	40
Enterprises vaccinating bulls for Campylobacter (%)	28
Enterprises control mating heifers – (bulls actually removed) (%)	5
Attitude towards changing heifer management:	*Agree/strongly agree*
"Would change if new techniques are demonstrated to be better" (%)	67
"Are definitely thinking of changing what we do" (%)	56

While this information has not yet been statistically analysed it provides an overview of cattle management practises currently in operation in the Pilbara and shows an encouraging attitude of pastoralists to change.

Performance recording on commercial properties

Four performance recording sites were established in the Pilbara to document the performance of young breeders under current management systems. The management aim at two sites was to intentionally mate heifers in the second year following weaning as 'two year olds'. At the other two sites heifers were intentionally mated in the year following weaning as 'yearlings'.

Groups of heifers were individually identified on each of four properties with liveweight, body condition score (BCS), and reproductive information recorded as convenient for co-operating pastoralists. Individual animal performance of these young breeding females will be monitored until they have the opportunity to conceive their second calf.

Results

Information recorded at these sites during the project is summarised in Table 2. It should be noted that the reproduction information is not yet complete for some of these sites as two of the sites do not intentionally mate heifers until they are 'two year olds'. Mating in the year following weaning as 'yearlings' was intentional at Pilbara 1 and Pilbara 2 with mating in the second year following mating as 'two year olds' being the aim at Pilbara 3 and Pilbara 4.

Table 2. Summary reproduction information collected from the Pilbara 'data collection' sites.

Site	n	Weaning wt.	Yearling wt.	2 y.o. wt.	Yearling Preg. %	2 y.o. Preg. % Lactating	Calf loss %	Missing 2 yrs %
Pilbara 1	250	208 kg	332 kg		64		16	6
Pilbara 2	229	218 kg	297 kg	382 kg	37	64 (13)	16	2
Pilbara 3	162	143 kg	261 kg	341 kg	22			5
Pilbara 4	200				60		22	18
Kimberley 1 (no.3s)	302		303 kg		8	(85)**	18	
Kimberley 1 (no. 4s)	477		306 kg		51*			

*Mating period reduced from 6 to 2 months for mating of No4 maiden heifers.

** Recorded in 2006 following a good 2005/06 season.

Discussion
The information recorded at these and additional sites in the Kimberley has identified a number of management practises likely to improve young breeder productivity. Issues identified for consideration for inclusion in best practise systems to be demonstrated/evaluated at different locations during the next phase of the project include:

- The relatively high conception rate achievable by heifers in the year following weaning in average to better years - ~60% conceptions recorded at two sites in the Pilbara and ~ 80% recorded at one Kimberley site.
- The difficulty in controlling bulls in extensive areas – pregnancy rates up to 60% recorded before heifers intentionally mated at one site in the Pilbara.
- The need to run young breeders as a separate group until they wean their first calf to provide the opportunity for preferential management, e.g. supplementation or earlier weaning should seasonal conditions deteriorate. At one Pilbara site 24% of heifers pregnant to calve early in 2005 during a failed growing season have failed to turn up at musters in the following 2 years.
- The potential role of supplements to improve the relatively low growth rates of cattle between weaning and mating to improve maiden and 1st calf mating outcomes.
- The effect of the highly variable seasonal conditions experienced in the Pilbara and Kimberley on heifer and young breeder growth and reproductive performance highlights the importance of management to optimise growth rates of heifers. Opportunities include grazing management to ensure quantity and quality of feed is available for heifers and the role of supplements.
- The need to match the nutritional requirements of the different classes of breeders to the available supply is especially important in 1st calf heifers.

Future activities – Pilbara and Kimberley
The project is currently in its third phase of trialling and demonstrating best practise management practises on three co-operator properties. An additional site in the Kimberley is investigating and demonstrating the effects of supplementation to improve the growth rates of heifers following weaning and prior to mating on maiden and first calf reproductive performance.

The project is demonstrating active co-operation between pastoralists and agency staff in WA and across northern Australia in identifying and addressing a production issue.

2. NT heifer project: "Industry initiatives to improve young breeder performance in the Northern Territory."

Introduction
This project is being implemented right across the Northern Territory (NT). While it is a broad generalisation a brief description of the typical cattle enterprises in each of the different regions of the NT is as follows;

- Darwin region: Mostly privately owned properties running cattle with high *Bos indicus* content.
- Katherine region: A mix of private and company owned properties running cattle with high *Bos indicus* content.
- Barkly region: A higher proportion of company owned properties mostly running *Bos indicus x Bos taurus* cattle.
- Alice Springs region: Mostly privately owned properties running *Bos taurus* cattle.

Survey of current practises and attitudes
In late 2004 an extensive survey of the NT pastoral industry was undertaken (Oxley *et al.* 2004). A total of 169 station managers were surveyed from the Darwin (D), Katherine (K), Barkly (B) and Alice Springs (AS) districts. Extension officers sat down with managers and went through a detailed survey which aimed to document their management practises and record their estimates of production statistics at that point in time. A section on heifer management and performance was included in the survey.

Results

One of the main findings of the survey was that most managers don't seem to be aware of the extent of the problem of low fertility in lactating first calf heifers. The average of the estimates of the re-conception in lactating first calf heifers for the managers in the different regions were D = 56%, K = 61%, B = 62% and AS = 71%. These estimates are considerably higher than the actual figures that have been recorded from performance recording on commercial properties so far, where most properties have had re-conception rates of below 10% in lactating first calf heifers and none have been more than 20%.

Other interesting findings from the survey were;

- Most stations join their heifers for the first time at 2 years of age and most try to segregate them from the rest of the herd at least until their first joining (D = 65%, K = 78%, B = 82% and AS = 58%).
- Few properties practise controlled mating (D = 46%, K = 25%, B = 6% and AS = 16%).
- Few properties (< 20%) vaccinate for any diseases other than Botulism.
- The average of managers estimates for several production parameters are shown in Table 3.

Table 3. Averages of NT manager's estimates of branding and mortality rates.

	Estimated branding %			Estimated mortality rate		
District	Maiden heifers	Lactating 1st calvers	Breeders	Maiden heifers	Lactating 1st calvers	Breeders
Darwin	61%	56%	71%	2.7%	2.2%	2.7%
Katherine	68%	61%	72%	2.9%	3.0%	3.0%
Barkly	70%	62%	73%	4.2%	3.8%	3.5%
Alice Sp.	70%	71%	77%	4.0%	3.8%	3.0%

Performance recording on commercial properties

One of the aims of the project is to document current levels of heifer fertility on commercial cattle properties. Unless heifers are individually identified and records kept of their performance it is very difficult to know how they are performing with any accuracy. So far the performance recording has shown that actual re-conception rates in lactating first calf heifers are much lower than what most managers estimate them to be (see Tables 3 and 4).

Method

Groups of 300 to 400 heifers on three properties in each of the Katherine, Barkly and Alice Springs districts were individually identified and weighed prior to their first joining. They were then mustered again after joining and their weight, pregnancy status, lactation status and condition score were recorded. These measurements were then recorded twice a year (usually around May and September) until most heifers had re-conceived with their second calf.

Preliminary results

The performance recording is at different stages on different properties depending on when recording commenced. A brief summary of results to date is shown in table 4 for properties where work is sufficiently advanced to report.

Discussion

These results show that while maiden heifer fertility is usually quite high on most NT commercial properties, re-conception rates in lactating first calf heifers recorded so far have been low. There have been anecdotal reports of much higher re-conception rates on properties especially in the Barkly and Sturt Plateau regions but we have not been able to document these so far.

Table 4. Preliminary results from commercial performance recording.

Property location	Breed	Maiden heifer conception rates	Lactating 1st calf heifer re-conception rates	Calf loss
Central VRD	Brahman	84%	1% (2006)	14%
Northern VRD	Brahman	59%	4% (2006)	24%
Southern VRD	Brahman & Brahman cross	72%	19% (2006)	11%
North East Barkly	Brahman & Brahman cross	85%	3% (2006)	31%
Western Barkly	Santa		7%* (2005)	
Northern Alice Springs	Shorthorn	84%		
Southern Alice Springs	Angus	81%	17% (2005)	4%

* It should be noted that 2004/5 was a very poor season on the Barkly due to drought conditions.

Another feature of the results so far has been that calf losses in first calf heifers can be quite high (eg. 31%). This is something that often goes un-noticed as when the first calf heifers are mustered at the first round, they are nearly all either lactating (wet) and not pregnant, or not lactating (dry) and pregnant, so it seems that there are no "passengers" in the herd. However when heifers are individually identified and records kept, it becomes evident that many of the dry and pregnant heifers should actually be wet but have lost a calf and re-conceived.

Demonstration sites

Demonstration sites have been established in the different regions but only the work at Newry is reported on here (due to space restrictions).

Newry (Katherine District)

A heifer demonstration site commenced in late 2004 at Newry station, (about 440 km west of Katherine in the northern Victoria River District). Traditionally, heifers at Newry are put in a heifer paddock at weaning, and kept there (separate from bulls) until they are ready for their first joining (usually at around two years of age). They are then 'let go' into the main breeder herd. This is a common management system in the region. Supplementation is only considered in "bad" years.

This traditional management system is being compared to one which involves a limited joining period (Nov-April/May) and supplementation of heifers from the dry season prior to their first calf until their second joining. Both groups are segregated from the breeding herd until they are pregnant with their 2nd calf. Within these treatments the effectiveness of a single injection of vibriosis vaccine prior to the first joining is being tested.

Method.. 700 heifers were individually identified, weighed and preg-tested to confirm that they were not pregnant prior to their first joining. 300 of these heifers were also given a vaccination against vibriosis at that time. The heifers were all joined for the 1st time in the same paddock and then at the 1st round muster after joining the heifers were allocated to one of two paddocks. The bulls were removed from one of the paddocks (so that they were control mated) and this paddock was also supplemented with mineral supplement blocks. The bulls remained with the heifers year round in the other paddock and they were not supplemented. This protocol was followed with two year groups of heifers. The first group was mated in the 2004/5 wet season (starting in December) and the next group in the year after.

The heifers are mustered in April/May (1st round) and September/October (2nd round) every year for the next 3 years. At each muster they are weighed, preg tested, and their lactational status (wet/dry) and condition score are recorded.

Results. Some of the main findings so far are;

- a strong relationship between joining weight and fertility was seen in both year groups.
- re-conception rates in lactating first calf heifers are low but improved by supplementation with lick blocks (see Table 5).

- lactating heifers that re-conceived were on average 40 kg heavier than those that did not.
- control mating is very hard to implement successfully as bull control in large paddocks with flood fences is difficult.
- one injection of Vibrovax prior to joining increased conception rates by 11% at the first round. By the second round (September) the benefit of vibrio vaccination had been reduced to 6% as more heifers conceived later in the control group (Schatz *et al.* 2006).
- Growth can be extremely variable. There was 140kg difference in growth between the highest and lowest gaining heifers over the wet season in which they were first joined (maximum growth = 138 kg, minimum growth = -2 kg, average growth = 86 kg).

Table 5. Effect of supplementation on re-conception rates in first calf heifers.

	May 2006 Re-conception rate	Oct 2006 Re-conception rate
Control	1%	20%*
Supplemented	8%	36%*

*All heifers that re-conceived between May and October had been weaned in May.

Conclusion

Both projects will continue through until the end of 2009 when they will culminate with the production of a best practise manual for heifer management in northern Australia. The work is already raising awareness of the problems of low heifer performance in northern Australia and follow up surveys will be done at the end of the projects to assess how heifer management has changed on properties over that time.

Acknowledgements

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Optimal pasture utilisation rates for sustainable cattle production with a commercial Brahman herd in the Victoria River Downs region of the Northern Territory

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Abstract. Variable cattle stocking rates were trialled in the Victoria River Downs to achieve utilisation rates ranging from 12-43% over six years. Individual animal reproduction indices declined with increasing utilisation rate, although differences were not always significant. However, animal production per unit area increased on average with utilisation rate, although above 21% utilisation production per unit area was more sensitive to seasonal fluctuations, and varied more between seasons. There was little evidence of deteriorating species composition at even the highest utilisation rates. However, low ground cover leading into the wet season at utilisation rates above 21% suggest increased environmental risk so these levels are not recommended. Utilisation rates up to 21% were sustainable in small, evenly grazed paddocks.

Introduction

Cattle properties in Australia's north-western rangelands are extensive, with large areas unfenced and undeveloped. A 2006 survey found the proportion of a property grazed varied from 76% in the more developed parts of the Katherine region, to 70% in the Victoria River District (VRD) and Roper districts to just 44% in the Gulf region (Oxley 2006). Many properties still have large areas that are relatively unwatered. A 2001 study found 40% of the VRD was greater than 4km from water (Fisher 2001). Consequently, pastoral development is still at an early stage, with resource development, subdivision and internal property development still a major focus of industry. This is evident through current Northern Territory (NT) government strategic direction to increase production on pastoral lands through sustainable development. Internal departmental business plans refer to 'encouraging infrastructure development through subdivision, improving efficiency of production and assisting indigenous landowners to increase pastoral production from their lands'. The NT government subsidises the cost of new pastoral waters as part of this approach.

Cattle producers in the region recognise the potential for further development. In a recent survey of cattle producers in the Katherine region producers estimated that carrying capacity could be increased by 25% in the next five years and 42% in the next 10 years with current development plans, with 80% of producers having immediate plans to develop further water points and subdivide paddocks (Oxley 2006).

However, during this phase of development there is the risk of overestimating the potential productive capacity of the land as historically occurred in many parts of eastern Australia. This led to enterprises being too small to be viable, with subsequent land degradation and loss of productive capacity (as reviewed in Stokes *et al.* 2006).

This paper presents results from the Mt Sanford grazing trial which aimed to provide objective estimates of sustainable levels of utilisation for the VRD region. Prior to this study there was little local information on sustainable carrying capacity in the region. The results from this study will facilitate infrastructure development based on realistic production capacity estimates, which should help avoid the over-development of rangelands.

Materials and Methods

Site

The trial was on black cracking clays at Mt. Sanford Station, approximately 500km 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*. Canopy cover of trees and shrubs averaged 2%. Annual rainfall averages 630mm and is strongly seasonal with

80% of rain falling between December and March.

Treatments

The grazing system examined was set utilisation with variable stocking. Six paddocks were allocated target utilisation rates (12, 16, 22, 28, 35 and 45%) which were applied for the duration of the trial. The paddocks ranged in size from 4-8 square km and were roughly square or rectangular in shape. Animal numbers were adjusted each May according to the amount of pasture available to achieve the target utilisation rate (the proportion of the pasture that grows each year that is consumed by cattle) for the paddock.

Animals and their management

Initially 482 high grade Brahman breeders (average weight 436 kg, 45% pregnant and 67% lactating) of varying age were sourced from existing breeder herds at the station. The animals were allocated to one of the six experimental groups so that initial herd statistics were similar between treatments. During the trial replacement breeders were sourced from breeding herds in surrounding paddocks. Spayed breeders were added to breeding herds when additional animals were required to achieve the required utilisation rates.

Breeding herd management. Breeders were mustered twice annually, during the months of May (WR1) and October (WR2). Breeders were culled on infertility (non-pregnant and non-lactating) at WR1 or temperament, injury or age (10 years) at either muster. Breeders were continuously mated to 4% bulls and vaccinated against C & D botulism strains at WR1. Bulls were vaccinated against vibriosis at WR2.

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

Supplementation was provided all year round to all paddocks via NPN in water medicators. The supplementation regime was based on the principle that nitrogen is the limiting nutrient in the dry season and phosphorus (P) during the wet season.

Measurements

Utilisation rates. Utilisation rates were calculated as estimated consumption divided by estimated pasture growth. Pasture growth was calculated as the standing dry matter (DM) at the end of the wet, plus estimated intake over the wet. Intake was assumed to be 7.21kg DM/AE/day, where an AE is a 450kg non-lactating non-pregnant Brahman Breeder at maintenance. The average of calculated utilisation rates across all years for each treatment paddock was used for analysis and are referred to in the text.

Pasture composition. Pasture was assessed using the BOTANAL technique at the end of the wet season in April/early May and the end of dry season in October each year, with 12 datasets from 2001-2006. Percent bare ground, total standing dry matter, the top 6 species contributing to biomass and percent composition of the top four species were recorded. A previous paper reported species yield (Cowley *et al.* 2006). Species frequency results are reported here, except for palatable yield, which is the sum of dry matter yields of all palatable species.

Animals. Month of pregnancy, lactation status, body condition and liveweight were recorded for all breeders at WR1 and WR2. Liveweight and sex were recorded for all progeny.

Breeders were pregnancy tested by rectal palpation and stage of gestation of pregnant animals estimated to the nearest month. The lactational status of all breeders was assessed by external observation of the udder and attempted expression of milk. The body condition of the animal was visually assessed and scored accordingly against a nine point system where 1 is emaciated and 9 over-fat (Holroyd 1978).

Liveweights were recorded for all animals at the time of processing after being held overnight without feed, but with unlimited access to water. Progeny remained on their mothers prior to their liveweights being recorded.

Diet. The relative planes of nutrition of herds were estimated by near infrared reflectance spectroscopy (NIRS). Fresh faeces samples were collected from each paddock at various times throughout the year and analysed via NIRS to estimate crude protein (CP) content and dry matter digestibility (DMD).

Statistical analyses
All analysis were performed using STATISTICA (StatSoft Inc. 2005).

Pasture. Each utilisation treatment was usually 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 often of interest as a way of differentiating utilisation effects. This was detected through repeated measures analysis of variance of the April/May datasets with the significance of the time x utilisation rate interactions being of prime interest. The relationships between variables and the average adjusted utilisation rate were examined by fitting linear regressions.

Animal. Both single factor and interaction treatment effects for all variables (kg weaned / area / year, breeding herd efficiency, empty liveweight of breeders, mean intercalving interval and mean weaning rate) were analysed using least squares ANOVA with type 1 error rate (significance level) set at 0.05. Year was used as a main effect blocking variable in all models. Model fits were checked and where necessary an appropriate transformation was used.

Where significant effects were detected for groups of three or more means, pairwise comparisons were done using Tukey's test for unequal N to determine homogeneous groups. Means within treatment interactions were tested using planned comparisons by specifying the appropriate contrast vector for the levels of interest. Type 1 experiment–wise error rate for these tests were corrected to 0.05 using the Dunn-Sidak adjustment for multiple comparisons. Correlations between variables were tested using Pearson's correlation statistic (r). Data for 2001 was excluded from all analyses because there had not been time for treatment effects to develop.

Results

Rainfall
Rainfall was average to well above average during the trial (Table 1). However pasture growth in 2002-2003 was below average, due to most of the rain falling in February. This combined with a late start for the following wet season, with no rain until December 2003, resulted in very high utilisations for 2003.

Table 1. Rainfall at Mt Sanford 2001-2006.

July to June	2000-2001	2001-2002	2002-2003	2003-2004	2004-2005	2005-2006	Long term Average
Rainfall (mm)	1134	700	673	1436	634	1277	628

Utilisation rates
Utilisation rates and stocking rates are shown in Table 2. The average utilisation rates over the trial were equal or close to targeted utilisations, except for in 2003. The upper range shown in Table 2 corresponds to 2003, while for all other years utilisation levels were below or close to the targeted utilisation rate. In 2006 utilisation rates were all at the lower range, except for Pigeon Paddock, which had a higher than average utilisation rate.

Table 2. Treatment stocking rates and utilisations at Mt Sanford, VRD.

Target utilisation rate (%)	12	16	22	28	35	45
Actual average utilisation rate (%)	12	19	21	28	36	43
Range in utilisation rate (%)	9-18	14-27	14-31	21-39	28-54	35-59
Average stocking rate (AE/km^2)	11.8	17.3	17.5	21.9	26.5	37.8
Range in stocking rate (AE/km^2)	8-16	11-25	12-22	15-26	18-33	29-43

Ground Cover
Percent bare ground was higher in both May and October with higher utilisation (P<0.001 for both seasons). From 2003 to 2005 the average percent ground cover in October was less than 40% in paddocks with greater than 21% average utilisation (Fig. 1, Table 3). Bare ground peaked in 2003 when utilisation rates were at their highest, and tended to improve thereafter.

Species composition

Species frequency generally fluctuated significantly through time, following seasonal variations, but rarely with any trend upwards or downwards. There was little evidence of an effect of utilisation on plant species composition at the site. *Iseilema spp.* were consistently most abundant at 12% and 36% utilisation, but trends through time were similar for all utilisations, suggesting individual paddock differences rather than a utilisation effect. 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* which was lowest and fluctuated least at 12% utilisation. Conversely *B. convergens* increased more through time at the highest 2 utilisation levels (Fig. 2, Table 3).

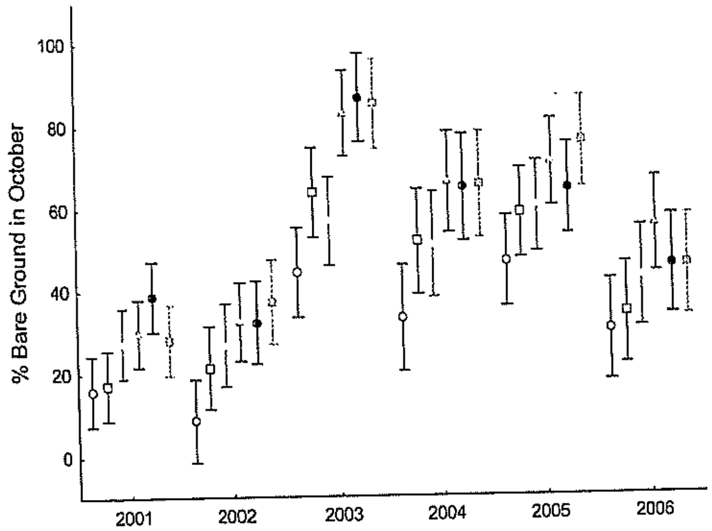

Fig. 1. Ground cover with utilisation rate and time at Mt Sanford 2001-2006. Average utilisation level 13% 19% 21% 28% 36% 43%. Bars denote 95% confidence intervals.

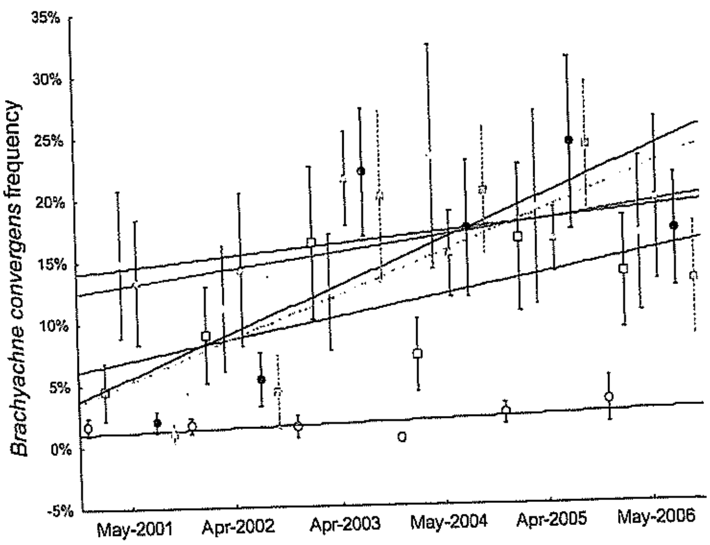

Fig. 2. Change in frequency of *Brachyachne convergens* through time with utilisation at Mt Sanford 2001-2006. Average utilisation level 12% 19% 21% 28% 36% 43%. Bars denote standard errors.

Table 3. Effect of utilisation on % bare ground and *Brachyachne convergens* frequency. Repeated Measures Analysis of Variance Sigma-restricted parameterization.

Variable	F		P
% bare ground in May			
Utilisation %	$F_{5,55}$	4.87	0.0009
TIME	$F_{5,275}$	139.85	<0.0001
TIME*Utilisation %	$F_{25,55}$	2.70	<0.0001
% bare ground in October			
Utilisation %	$F_{5,55}$	5.53	0.0003
TIME	$F_{5,275}$	222.35	<0.0001
TIME*Utilisation %	$F_{25,275}$	2.98	<0.0001
Brachyachne convergens frequency in May			
Utilisation %	$F_{5,55}$	2.69	0.03
TIME	$F_{5,275}$	17.96	<0.0001
TIME*Utilisation %	$F_{25,275}$	3.05	<0.0001

Diet

The crude protein content and dry matter digestibility were not different between utilisation rates, P=0.34 and P=0.34 respectively.

Average palatable yield was significantly lower at higher utilisation rates (r^2 = 0.83, P=0.01, n=6). The difference in palatable yield between paddocks was equivalent to estimated intake for each paddock, so was probably due to recent grazing of palatable forage rather than an effect on growth of palatable species. By October palatable yield was on average only 400kg DM/ha at 43% utilisation (Fig. 3).

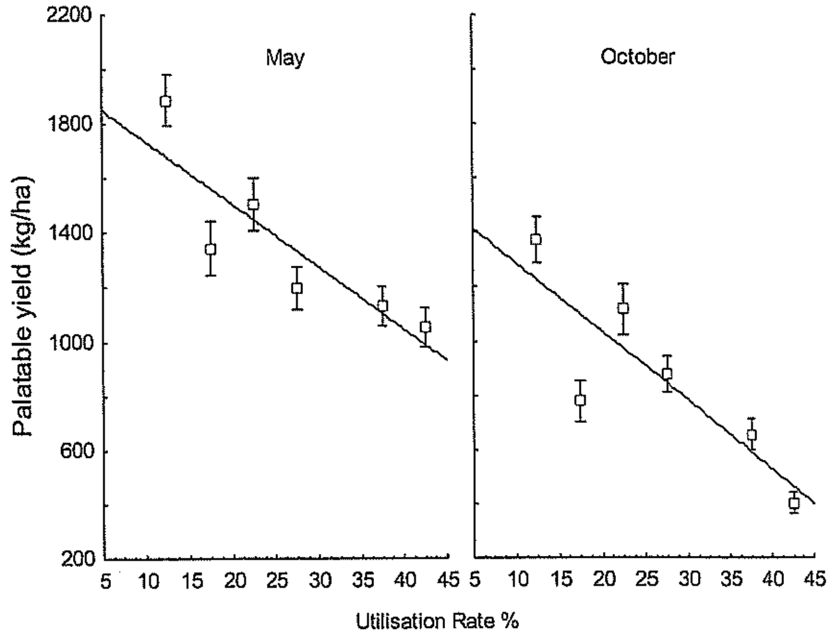

Fig. 3. Average palatable yield with utilisation at Mt Sanford 2001-2006. Mean through time. Bars denote standard errors.

Weight of weaner produced per unit area per year

The weight weaned each year per unit area (kg/km^2) was influenced by utilisation rate (%) (P<0.05, n=24) and year (P<0.05, n=24) (Fig. 4). Kilograms of weaner produced per unit area was positively correlated to average utilisation rate (r^2=0.33, P<0.01, n=24). Production was more variable through time at higher utilisation rates.

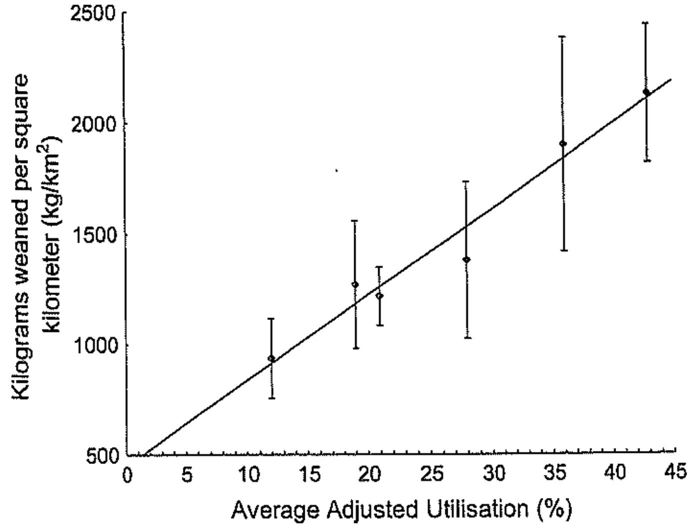

Fig. 4. Effect of utilisation rate on average kilograms of weaner produced per square kilometer (kg/km^2) 2003-2006. Bars denote standard errors.

Breeding Herd Efficiency

There were no significant differences in breeding herd efficiency (BHE, kg of weaner weaned per 100 kg of breeder mated), between utilisation rates (P=0.93, n=24) or between years (P=0.38, n=24), although BHE tended to decline as utilisation rate increased (Fig. 5). Utilisation was not significantly correlated to BHE (r^2=0.05, P=0.29, n=24).

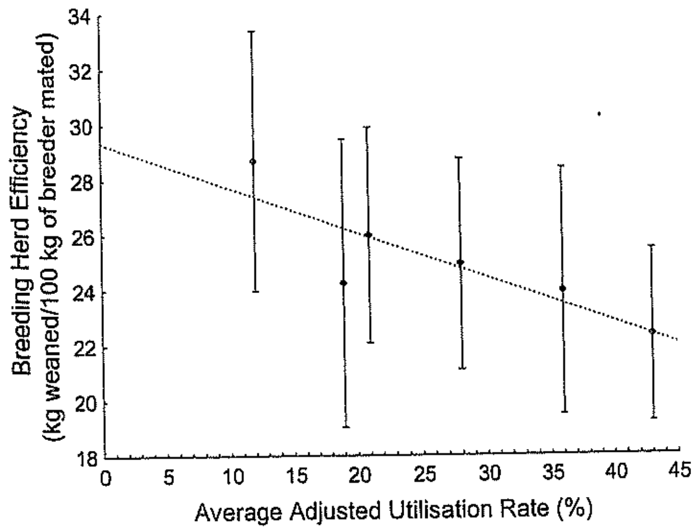

Fig. 5. Effect of utilisation rate on average breeding herd efficiency (kg weaned/100 kg breeder mated) 2002-2005. Bars denote standard errors.

Breeder Liveweight

The average empty liveweight (ELW; liveweight corrected for pregnancy, O'Rourke *et al.* 1991) was negatively correlated to average utilisation rate (r^2=0.02, P<0.0001, n=4472) (Fig. 6). Breeders were significantly heavier at WR1 than WR2, 450.2 ± 1.4 kg *v.* 386.0 ± 1.3 kg s.e. (P<0.0001, n=4472). Average ELW of breeders was not different across years (P=0.07, n=4472).

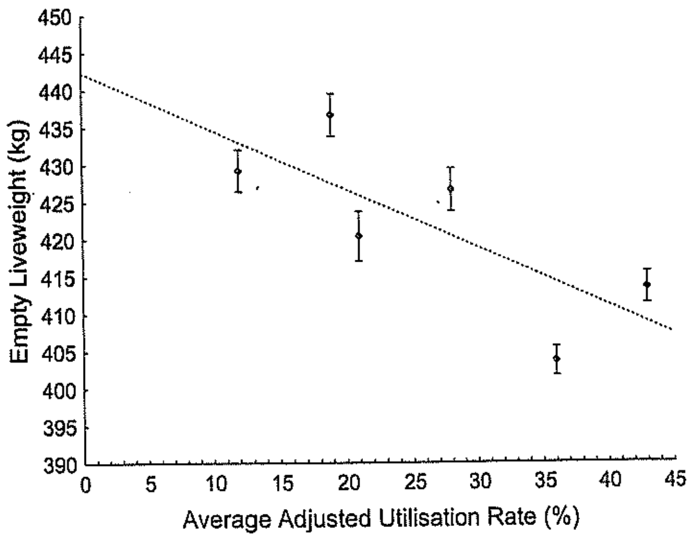

Fig. 6. Effect of utilisation rate on average breeder liveweight (kg) 2002-2006. Bars denote s.e.

Inter-calving Interval

The inter-calving interval (ICI; months to calving since parturition) was estimated using pregnancy diagnosis information collected at WR1 and WR2. The ICI of breeders was positively correlated to average adjusted utilisation rate (r^2=0.02, *P*>0.0001, n=899) (Fig. 7) indicating pregnancy was delayed at higher utilisation rates. A difference in ICI was detected between years (*P*<0.01, n=899).

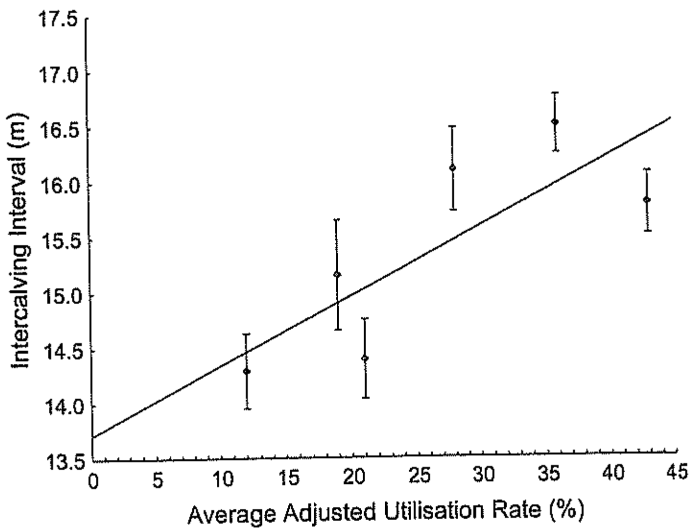

Fig. 7. Effect of utilisation rate on average inter-calving interval (m), months to calving since parturition, 2002-2005. Bars denote standard errors.

Weaning Rate

Utilisation rate had no significant effect on weaning rate (*P*=0.39, n=24) (Fig. 8), although weaning rate tended to be higher at lower utilisation rates than higher utilisation rates (eg. mean ±se: 71 ± 12% at 12% *v.* 58 ± 10% at 43%).

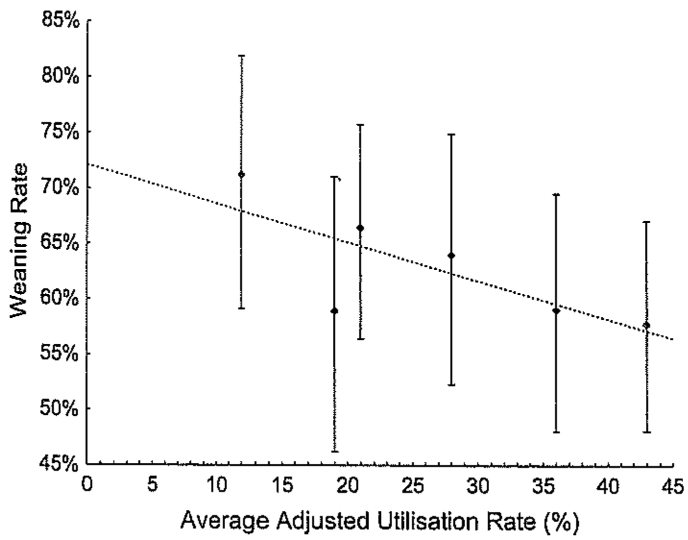

Fig. 8. Effect of utilisation rate on average weaning rate (%) 2002-2005. Bars denote standard errors.

Weaner Liveweight

Calves weaned from breeders grazed at lower utilisation rates were generally heavier than those weaned from breeders grazing at higher utilisation rates (Fig. 9) (r^2=0.01, P<0.001, n=1139). At both rounds, calves weaned from breeders which grazed at lower utilisation rates were heavier than those from high utilisation rates. (WR1, r^2=0.01, P<0.05, n=1139 and WR2, r^2=0.02, P<0.01, n=1139).

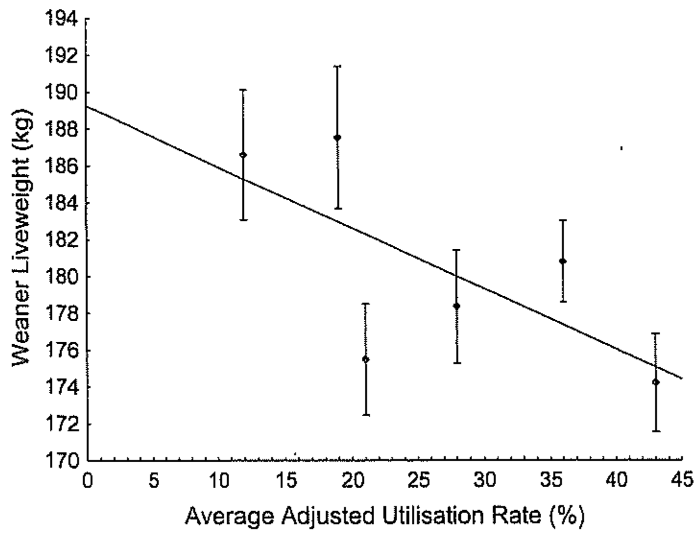

Figure 9. Effect of average adjusted utilisation rate (%) on average weaning weight (kg) 2003-2006. Bars denote standard errors.

Discussion

The actual utilisation rates in 2006 were generally lower than targeted, which combined with the excellent season may have had a dampening effect on the impact of the higher utilisation rates, ameliorating the impact of the treatments towards the end of the study, as was evidenced in improving % bare ground in 2006. This combined with the short duration of the study may have influenced our ability to detect a threshold utilisation beyond which species composition alters and pasture productivity declines. Even so, it is possible to make some recommendations regarding optimum utilisation rates for the region.

Cover levels of less than 40% lead to accelerated soil and water loss in northern Queensland (McIvor *et al.* 1995, Scanlan *et al.* 1996). Given this, the low cover levels in October in paddocks with

28% and higher utilisation levels suggests that these rates of utilisation rates may not be sustainable in the longer term.

A previous paper looking at species *yields* at the site (Cowley *et al.* 2006) concluded there was some evidence of an effect of utilisation rate at the site. However species *frequency* data is less influenced by recent grazing and better reflects species composition at the site. Nevertheless, as only the top 6 species contributing to yield were recorded, the species frequency data here are limited in their ability to fully explore grazing effects. A comparison with full plant diversity data at the site indicated that only 8 species abundances were accurately reflected in botanal frequency data (Cowley unpublished data). Even so, for those 8 species, the botanal frequency data suggest that while species composition fluctuated seasonally, it has not generally been influenced by utilisation. The exception to this was the increase in the annual *Brachyachne convergens* at higher utilisation rates through time, which is consistent with previous studies and its status as an increaser (reviewed in Fisher 2001).

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 with increasing utilisation rate. This may be a function of the short time frame of the study. On a per animal basis production is thought to remain constant below a critical threshold stocking rate and decrease past this threshold (Ash and Stafford Smith. 1996). Our data suggests that 12% utilisation and higher are all above this threshold on a per animal basis. The two fold increase in utilisation rate did not result in a doubling of kilograms weaned, probably due to a loss of production per breeder as utilisation rates increased.

Differences in BHE were recorded, however, they were not significant largely due to the small sample size. The higher variability in kilograms weaned per unit area at utilisations above 21% reflects the increasing sensitivity of animal production to seasons at higher utilisations. The BHE results across all average utilisation rates were below the stated 31.0 kg weaned/100 kg breeder mated for Brahman herds grazing the VRD by Cobiac (2006), which can be accounted for with Cobiac (2006) utilising a weaning weight that was 20 kg lower than the present study. Earlier weaning of calves has been shown to reduce the inter-calving interval (Sullivan *et al.* 1997, Jolly *et al.* 1996), and ultimately increasing the weaning rate (Braithwaite *et al.* 1999), a driver of BHE.

Differences between BHE at different average utilisation rates were further masked by a decreasing average ELW of breeders as utilisation rate increased. This reduction in average breeder ELW 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 ELW is consistent with stocking rate trials grazed by breeding animals (Langlands *et al.* 1984).

Declining average ELW of breeders with increasing utilisation rate possibly reflects the available palatable yield (kg DM/km^2) at higher utilisation rates during the late dry/early wet season when breeders nutritional requirements are not being met, resulting in a loss of body condition and liveweight. Over the longer term this will likely result in lower weaning rates since body condition is one of the main factors effecting fertility.

A loss of breeder liveweight/body condition has been shown to have significant impacts on herd productivity, especially if losses occur during late gestation or early lactation. Breeders under nutritional stress display increased ICIs as a result of prolonged periods of anoestrous (Jolly *et al.* 1996, Randel 1990, Rudder *et al.* 1976 and Short *et al.* 1990), conceive later in the season (Rudder *et al.* 1976), increases in the proportion of out of season calves and reduced weaning rates (Braithwaite *et al.* 1999). The results from this study are consistent with this as ICI increased as utilisation rate increased. However, the effect of utilisation rate on ICI may not have been fully expressed in the above study as breeders were culled for sub-fertility if their ICI was greater than 24 months (ie. non-pregnant and non-lactating at WR1). This particularly may have favoured better results in the case of breeders at higher utilisation rates.

The average ICI of herds was greater than 12 months at all utilisation rates. Therefore, all herds were drifting away from the optimal calving time in the late dry/early wet season (Braithwaite *et al.* 1999) resulting in breeders either not conceiving or calving out of season under sub-optimal nutritional conditions. The ICIs of herds grazing at greater than 21% utilisation rate had on average a 1 month longer ICI than those less than those at 21% or lower utilisation rate. A month longer inter-calving corresponds to a loss of 4% weaning rate (Braithwaite *et al.* 1999). A significant difference in average weaning rate was not detected between utilisation rates in the present study. However, the study probably had not been going long enough for this to be expressed as the lengthening of ICIs and loss of breeder condition (measured as ELW in this study) at the higher utilisation rates should eventually reduce weaning rates. Other evidence pointing towards this occurring is the average weaning weight decreasing as utilisation rate increases.

Conclusions

Grazing across a variety of seasons has demonstrated that land condition can be maintained (for at least the short term) at stocking rates considerably higher than the industry average of 11 AE/km^2 (Dyer *et al.* 2003). The 21% utilisation rate (achieved with an average stocking rate of 17.5 AE/km^2 during the time of the current trial) appears sustainable in terms of animal production and land condition. However the reported stocking rates in Dyer *et al.* (2003) were averaged across all land types, and do not compare that well with this study which was conducted on the most fertile land type in the NT and with watering points considerably closer together than on most properties. It may be that current utilisation of black soil is at this level already. There is a paucity of data on actual utilisation rates of the region for different land types to compare with this study's results.

While species composition and animal production were maintained even up to the highest utilisations during the six years of the trial, over the longer term, low cover levels and more variable animal production at utilisation rates above 21% suggest greater environmental and management risk.

Due to the cyclic nature of breeding herd performance it is felt that 4 years of weaner data is not enough to define an optimal utilisation rate. However, differences in the key drivers of productivity, ICI and weaning rate, were detected around utilisation rates of 21-28%, suggesting that this range is optimal for sustainable pasture utilisation by cattle in the VRD region.

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The Burdekin Catchment: an R&D hotspot for the environmental impact of the Northern Australian beef industry

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Abstract. Extensive beef production is one of the major land uses of the Great Barrier Reef (GBR) catchments. It brings in over A$3B to the national economy annually and employs nearly 9000 people, many of them in rural communities. As well as being the major industry supporting economic activities and urban centres in remote rural Queensland, over 80% of terrestrial sediments and nutrients deposited in the GBR World Heritage Area, affecting the health of vulnerable reef ecosystems, originate from the extensive grazing lands of Queensland's interior. Recent research in the Burdekin Catchment on Queensland's east coast indicates that the quantity of sediments and nutrients lost from these grazing lands is strongly dependent upon grazing management practices which lead to degradation of soil and water resources, reduced infiltration and vegetation production. This has led to growing public concern about the environmental performance of the beef industry and increasing pressures on graziers to change their management practices to decrease off-property impacts. There is now an opportunity to assess options scientifically and provide guidance for the development of new on-property actions, that would allow an increase in profit from adopting sustainable grazing practices while reducing the off-property impacts of sediment and nutrient loss. I argue that improvements in the quality of water draining into the GBR Lagoon can best be achieved by demonstrating the productivity and economic benefits of science-based improved grazing management practices for graziers, leading to 'Win-Win' outcomes for all concerned.

Introduction

The rangelands of Northern Australia have had a short relationship with the beef industry. The relationship has not been an equal one; the rangelands have provided the resources for the development and growth of the beef industry, however, in many cases this has been to the detriment of the health the rangelands themselves. Whilst this imbalance may not affect the beef industry in the short term, the erosion of the natural capital of the rangelands (e.g. soils, organic matter, nutrients) will lead to a decline in productivity, a reduction in the capacity to recover from droughts and ultimately the loss of the economic, social and cultural capital in much of the rangelands regions of northern Australia. Graziers, through the Meat and Livestock Australia, have become aware of this challenge to the sustainability of the northern beef industry and, along with research agencies in the region, have put in place a series of research projects to assess the impacts of grazing strategies on rangeland health. The outputs of these research projects will help develop means by which grazing management can be improved to reduce its environmental impact and improve the long term prospects for the industry. With the latest stage of the programme coming to an end it time to assess the findings and outline the management implications of the research.

Much of the research in the MLA Improving Environmental Health programme is focused on the Burdekin Catchment, and this will form the basis of this review. I will also draw upon other pertinent research funded through other programme such as the CSIRO Water for a Healthy Country flagship programme, the Burdekin Dry Tropics NRM (BDTNRM) Coastal Catchment Initiative (CCI) (Coughlin et al. 2006) and Regional Investment Strategy (RIS) (www.burdekindrytropics.org.au). However, firstly I will give a brief overview of the biophysical and economic characteristic of the Burdekin Catchment itself; for a more extensive description see McCullough & Musso (2004).

Description of the Burdekin

Covering an area of 133,000km^2, on the eastern seaboard of Queensland, from Bowen north to Ingham and west to Hughenden, the Burdekin River has the largest catchment in Queensland and empties into the Great Barrier Reef (GBR) Lagoon at Upstart lagoon, just south of Ayr. Running a total length of 720km the Burdekin River has 9 major tributaries, including the Belyando, Bowen, Clarke, and Suttor Rivers. The topography goes from the coastal plains up a steep set of ranges (up to 900m) and then onto a gently rolling and flat terrain between 200 and 650m in elevation. The soils are varied but dominated by basalt, sandstone and sedimentary formations. The vegetation in the region is dominated by eucalypt (*Eucalyptus xanthoclada*) savannas with smaller areas of acacia (*Acacia argyrodendron*) scub, semi-deciduous vine thickets, wetlands and natural grasslands.

The rangelands of the upper part of the Burdekin Catchment are characterised by a warm, sub-humid climate with distinct wet (December – March) and dry seasons (May – October). Whilst the average rainfall is just over 650mm, there is a large annual variation (coefficient of variation in annual mean is over 40%) with extended dry periods (e.g. early 1990s and 2000s) broken by short, above average rainfall conditions (e.g. 1970s and late 1990s).

The major industries in the upper catchment are mining and beef production; grazing lands cover over 90% of the area and most beef is produced under extensive systems on large properties that have relatively low levels of infrastructure (dams and fencing). Stocking rates generally range between one animal unit per 5-10ha (Quirk *et al.*, 2004; Bortolussi *et al.*, 2005), although these can vary with rainfall. Within the extensive systems livestock productivity is primarily determined by rainfall and its interaction with soil characteristics (nutrients and hydrological properties), although supplementation is extensively used during the dry season and in dry years.

The catchment has been extensively modified since European settlement through forestry, urbanisation and agriculture (Lukas *et al.*, 1997; Furnas, 2003). At the end of the 19th Century a much smaller proportion of the rangelands were grazed compared with today, mainly because of the constraints on animal movement by the position of watering points and rivers. However, with the sinking of bores and the replacement of the European breeds (*Bos taurus*) with hardier, drought and tick resistant (Frisch and O'Neill, 1998) Brahman breeds (*Bos indicus*), the proportion of the landscape that remains ungrazed is now small as most water-points are now within 10km of each other (Abbott and McAllister; 2004).

This modification of the landscape to meet the needs of the extensive beef production system has also had negative downstream (off-property) environmental consequences; the grazing industry of the catchments feeding into the GBR Lagoon accounts for the majority (over 80%) of terrestrial sediments and nutrients deposited in the GBR (Gilbert *et al.*, 2003). The Burdekin Catchment, where the primary land use is grazing, delivers on average 3.77 million tonnes of fine sediments, 8,633 tonnes of nitrogen and 1,338 tonnes of phosphorous per annum into the lagoon of the reef (Brodie *et al.*, 2003). Present day export of sediments and phosphorus from these catchments is six times, and nitrogen four times, greater than pre-European levels (Brodie *et al.*, 2003).

The reductions in vegetation cover, both ground and upper storey, through grazing and tree clearing, changes in vegetation composition (loss of native perennial grasses, introduction of new pasture species and invasion by weeds), and loss of riparian vegetation and wetlands has also resulted in a substantial loose of biodiversity in the region. Currently, less than 1.5% of the catchment is within areas protected for conservation (as compared to over 4% for Queensland as a whole) (Queensland Government 2006), which means that the majority of the area in which wildlife and flora that does exist is within grazing properties.

Issues and research and development

O'Reagain's paper (2007; see also O'Reagain *et al.*, 2005) in this issue describe the results of research from the Wambiana trial, in which he applied a range of stocking treatments based upon utilisation levels, forage budgeting and weather forecasting. I will not cover this trial here but will focus on the research conducted by CSIRO in collaboration with QDPI&F based at the Virginia Park Station in the Dalrymple Shire of the Burdekin. Firstly, however, I will describe the centrality of ground vegetation cover management in the development of sustainable outcomes (e.g. economic and environmental) for the rangelands of northern Australia.

The dominant native ground vegetation in the rangelands of the catchments of the GBR is characterised by an open woodland layer over an understorey of perennial tussock grasses such as *Heteropogon contortus* (black spear grass), *Triodia* spp (spinifex), *Bothriochloa* spp, *Dichanthium* spp and mixtures of *Chrysopogon* spp, *Aristida* spp and *Themeda* spp with a few herbs (Tohill and Gillies 1992). The primary source of forage for cattle in extensive grazing systems is this native vegetation. The composition, biomass and cover of the vegetation, therefore, determines the productivity of the cattle and through that the economic viability of the property (Fig. 1). Ground cover is also the primary determinant of the degree of infiltration of rainfall into the soil (macroinvertebrates also play a role; Eldridge 1994); when ground cover is high any overland flow of water is slowed down by the vegetation, giving it time to infiltrate. Because the productivity of grasses in rangelands is primarily limited by soil moisture, increased ground cover increases productivity because of the increased soil moisture content. Increased ground cover also contributes to increase biodiversity, particularly ground dwelling invertebrates and reptiles (Woinarski & Ash 2002; James 2003).

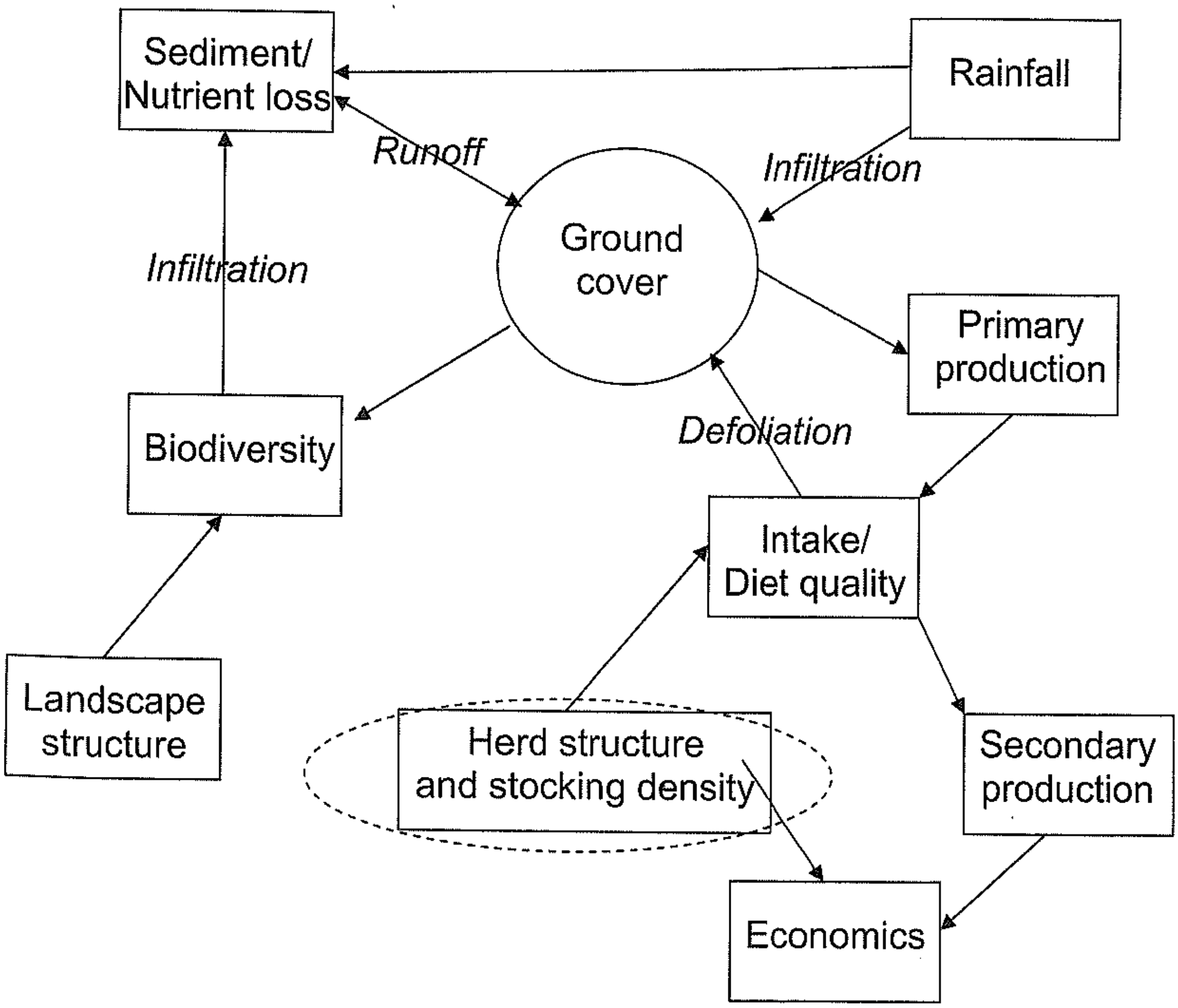

Fig 1. Relationship between vegetation biomass/cover and economic and environmental outcomes for the Australian rangelands. The dashed ellipse indicates the major point of management intervention.

This recognition of the key role of ground cover in the sustainable grazing management of the rangelands is central to the ABCD Land Condition monitoring system developed by the DPI&F and the Grazing Land Management extension workshops provided by the DPI&F (Chilcott et al. 2003; Gordon & Nelson 2007). The success of this approach has meant that the BDTNRM and QNRM&W are using these to assess the areas that NHT funding should be targeted, monitoring the outcomes of SIP implementation (http://www.burdekindrytropics.org.au/index.html) and guiding future property leases (Neldner 2006).

Our research has shown the relationship between the ABCD Land Condition classes and hydrological function and hopefully, ongoing research on the relationship between the Land Condition classification and biodiversity will allow us to use this framework to assess the environmental as well as the production/economic benefits of improved grazing land management practices in the rangelands of northern Australia (Post *et al.*, 2007). We have also shown that it is not only the degree of cover that is important but also its distribution; if cover is evenly spread over the hill slope is will have a greater effect on reducing run-off of sediments and nutrients than if it is concentrated at the top of the hill slope. Although it was not modelled, this has implications for the investment that Natural Resource Management (NRM) bodies are putting into riparian fencing; if improvements in cover do not occur on the hill slopes in conjunction with the fencing of riparian zones then there will be little benefit in terms of water quality, running-off into the creeks and rivers (see also Coughlin *et al.*, 2006).

Research in the 1990s showed that resting paddock from grazing during the wet season (wet season spelling) allows vegetation to recover in terms of both cover and composition (increasing perennial grass species proportion in the ground layer) (Ash *et al.*, 2001). Ash *et al.* (2001) also found that this improvement lead to increased primary production and consequently economic return to the property. Whilst this early research was conducted on the plot scale, our work has shown that it is possible to scale up these conclusions to the property scale, even during drought years (the original research was conducted during a period of above average rainfall) (Post *et al.*, 2007).

Future research needs/requirements

Past unsustainable grazing practices have lead to a substantial reduction in the ground cover of many areas in the Burdekin Catchment region. There have also been detrimental changes in grass species composition, moving from perennial species to annual species, which have high growth rates but provide little forage resource over the dry season or in a drought. As described above, wet season spelling can improve the ground cover and species composition of the pasture, however, care should be taken when stocking paddocks after spelling as our results also demonstrate that it restoration of vegetation cover (Land Condition) is not necessarily even across the whole of the paddock; the C condition land is preferred by cattle (Fig. 2), whose focus on these areas can lead to degradation of these hotspots even though the overall condition of the paddock is improving. This clearly demonstrates the importance of both monitoring the key indicators of paddock condition (e.g. the proportion of C condition patches) but also the need to assess techniques for changing the spatial distribution of cattle in the paddock (e.g. water points, supplementary feeding sites, movable fences; see Coughlin *et al.*, 2006). Given the amount of research that has been conducted on the spatial distribution of cattle at the paddock scale (MacDonald 2007; O'Reagain 2007; Tomkins & O'Reagain in press), it is now an ideal time to draw this information together within a modelling framework to help graziers make predictions about the consequences of management actions for pasture restoration and environmental benefits.

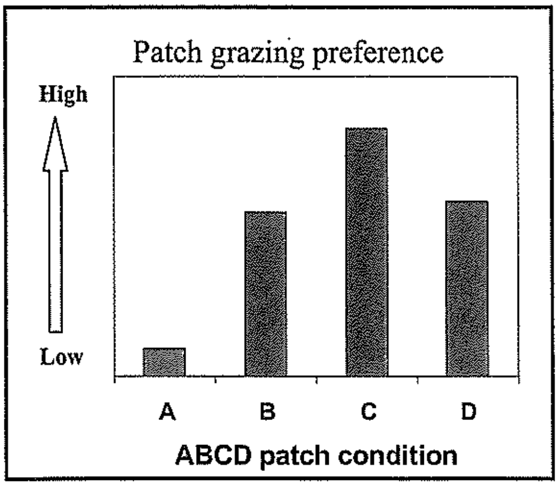

Fig. 2. Selection for patches of different Land Condition by cattle at the Virginia Park Station, Burdekin Catchment.

One of the key limitations of implementing changes in grazing management practices is a fear of graziers that short term destocking will cost money and may not improve long-term economic and off-property impacts. This requires two things:

1) a scenario modelling framework that allows graziers to see the benefits of changes in ground cover and vegetation composition (Fig. 1) that lead to Win-Win outcomes (Gordon & Nelson 2007);
2) a series of properties that demonstrate the triple-bottom-line benefits of implementing best management practices. By monitoring the economic, social and environmental gains of improved ground cover and vegetation composition, that are region specific, these properties will show, at first hand, the benefits of adopting sustainable grazing management practices.

Sustainable grazing practices for the rangelands of northern Queensland need to be based upon management of vegetation composition, cover and distribution, resulting in improved livestock performance and reduced off-property impacts (Ash, 2004). It is my belief that the knowledge exists to achieve this objective, with the beef industry in northern Queensland, showing the way to the rest of the grazing industry in the tropics as to how livestock production and achieve its goals while also maintaining landscapes and habitats of conservation importance.

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Effects of different grazing strategies on sustainability and profitability in a variable environment

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Abstract. The Wambiana grazing trial is testing the ability of heavy stocking (HSR), light stocking (LSR), variable stocking (VAR), a Southern Oscillation Index (SOI)–variable strategy and rotational wet season spelling (R/Spell) to cope with rainfall variability. Over nine years individual animal production was consistently better under light- than under heavy-stocking giving higher meat works grades and prices. Live weight gain/hectare was highest under heavy stocking but this difference narrowed sharply in later, drier years. Drought feeding was required in the HSR in three different years and stocking rates had to be cut in May 2005. Economic performance was penalised under heavy stocking due to high costs and reduced product value. After nine years, accumulated cash surplus was highest in the LSR and VAR ($17, 410 /100 ha) and lowest in the HSR ($10, 112 /100 ha). Pasture condition and composition were best in the LSR and R/Spell, intermediate in the SOI and VAR strategies, and poorest in the HSR. These results provide preliminary quantitative evidence to showing that strategies like light and variable stocking are not only more sustainable but provide better economic returns than traditional heavy stocking strategies.

Introduction

Rainfall variability is a major challenge to sustainable and profitable grazing management in the tropical savannas. Sustainable management strategies do exist to manage for climate variability e.g. variable stocking, but need testing at the paddock scale, particularly regarding their relative economic performance. In this paper we present data collected over the last nine years quantifying the effects of a range of different grazing strategies on animal production, economic performance, pasture condition and runoff.

Materials and methods

The Wambiana trial is located 60 km SW of Charters Towers, north Queensland (mean annual rainfall = 650 mm; C.V. = 40%). The vegetation is an open savanna on relatively infertile tertiary sediments in the *Aristida-Bothriochloa* pasture community (Tothill and Gillies 1992). Soils on the trial include low fertility kandosols, medium fertility sodosols and chromosols, and higher fertility vertosols (Isbell 1996).

Ten *c.* 100 ha paddocks were established in 1997 in a randomised block design of 5 treatments, replicated twice. Paddocks were laid out so as to include similar proportions of the different soil types present. Five stocking strategies were selected for testing: (i) *light stocking* (LSR) run at 8 ha/large stock unit (LSU= 450 kg steer), (ii) *heavy stocking* (HSR) run at 4 ha/LSU, (iii) *variable stocking* (VAR) - stock numbers adjusted annually in May (range: 3-10 ha/LSU) according to available pasture, (iv) a *Southern Oscillation Index* (SOI)-variable strategy with stock numbers adjusted in November according to available pasture and SOI-based rainfall predictions (range: 3-10 ha/LSU) and (v) *rotational spelling* (R/Spell) – moderately stocked (6 ha/LSU) with a third of the paddock receiving an annual wet season spell. In 2000 and 2001, the spelled section was burnt after the first rains before being locked up.

Live weight gain (LWG) was quantified with Brahman-X steers (18 and 24 month) with cattle remaining for two years on the trial. Animals were initially unsupplemented but received dry-season lick (32 % urea), wet season P (14.76 % P, 21.87% urea) and *Compudose* implants from May 2003 onwards. Molasses and urea drought feeding was required in the HSR in the 2003, 2004 and 2005 dry seasons due to very low pasture yields (<200 kg/DM/ha). One HSR paddock also had to be temporarily destocked and animals agisted from December 2004 to February 2005. All major trial management decisions were made following close consultation with the Grazier Advisory Committee.

Accumulated cash surplus (ACS) was calculated from annual gross margins (GM) i.e. the value of beef produced minus variable and interest (10%) costs. Animals were valued at $1.80/kg at the start - and at $1.80/kg or $1.60/kg (depending upon condition score) at the end of the season. Variable costs were derived from the costs of supplements and drought feeding. Agistment costs of $2.20 per animal/week were used for the period when the HSR animals were absent from their paddock.

Total standing dry matter (TSDM) and species contribution to yield were assessed annually in May using BOTANAL (Tothill *et al.* 1992). Species data was grouped into 8 functional groups i.e. 3-P and 2-P (palatable, productive and/or perennial) grasses, wire grasses (*Aristida* and *Eriachne* spp.), annual grasses, 'other grasses', forbs, legumes and sedges. 3-P tussock densities were derived from tussock counts in 0.25 m^2 quadrats (200 quadrats per soil type) during frequency sampling in May 2006 – although all soils were sampled, density data is only presented for the sodosols. Runoff and soil loss was measured in a single paddock in each treatment using San-Dimas flumes (O'Reagain *et al.* 2005).

Results

General

Good rainfall in the first 4 years was followed by 5 consecutive below-average rainfall years (Fig. 1). Pasture mass varied 5-fold from *c.* 5000 kg/ha in 1999 to < 1000 kg/ha in 2006 (O'Reagain 2007). Stocking rates in the VAR and SOI were very high in the early wetter years (*c.* 4 ha/LSU) but were progressively reduced to *c.* 10 ha/LSU as rainfall declined (Table 1). In the HSR strategy, stocking rates were cut by 30 % in May 2005 due to an obvious drop in carrying capacity.

Table 1 Average stocking rates (ha/LSU) in the different grazing strategies at the Wambiana trial between 1997 and 2006. (LSU=450 kg steer).

Strategy	*Season*								
	97/98	98/99	99/00	00/01	01/02	02/03	03/04	04/05	05/06
Var	12.45	5.18	5.70	3.92	4.11	8.55	9.50	10.84	9.49
R/Spell	9.11	6.97	8.03	7.32	6.97	6.89	7.90	9.54	8.58
SOI	12.31	6.21	5.80	4.40	5.93	8.17	8.60	8.74	8.21
HSR	6.51	5.03	5.74	5.22	4.91	4.82	4.12	4.04	5.75
LSR	12.47	9.43	11.65	10.42	9.49	9.41	7.74	7.60	7.39

Live weight gain

Individual live weight gain (LWG) varied between years due to rainfall variability (Fig. 1). Overall, annual LWG was greatest in the LSR (mean: 123 kg) and least in the HSR (mean: 96 kg). LWG in the R/Spell, VAR and SOI was intermediate between the latter strategies and largely depended upon the stocking rate applied. After 2 years on the trial, animals from lighter stocked treatments were usually 50 - 100 kg heavier with a larger frame and in markedly better condition than those from more heavily stocked paddocks. These animals accordingly received a higher meatworks price due to superior carcass mass and grades (O'Reagain 2007).

LWG per hectare (LWG/ha) also varied markedly between years due to rainfall and, for the SOI and VAR, changes in stocking rate (Fig 1). Overall, the highest LWG/ha occurred in heavier stocked strategies but treatment differences narrowed in later years due to lower rainfall and, for the HSR, a possible reduction in productive potential of the pasture.

Economic performance

The heavier stocked strategies made rapid initial gains in accumulated cash surplus (ACS) due to higher gross margins (GM) in the earlier wetter years (Fig. 2). However, ACS in the HSR declined in the drier years post-2000/01 due to consistently negative GMs that arose from the high costs associated with drought feeding and interest on livestock capital, and reduced product value at the meatworks. In contrast, ACS increased consistently across all years in the LSR and R/Spell due to low costs and a higher product value. Consequently, by 2004/05 ACS in the latter strategies had surpassed that in the HSR.

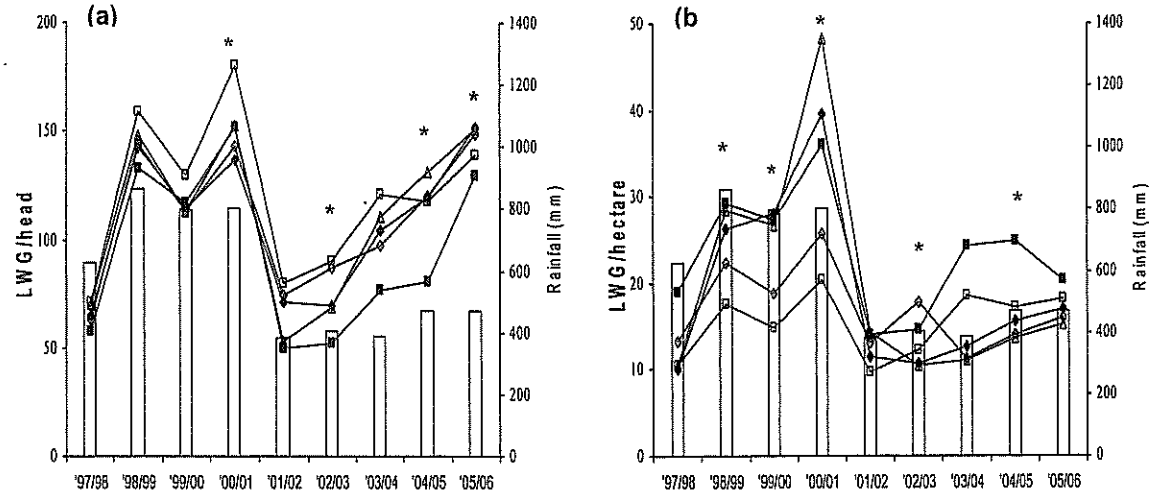

Fig. 1. Annual rainfall and live weight gain (LWG) per animal (a) and annual rainfall and LWG per hectare (b) for the VAR (△), (R/Spell (◇), SOI (◆), HSR (■) and LSR (□) strategies at Wambiana over 9 years. Years marked with a (*) indicate a significant *(P<0.05)* treatment effect. See text for treatment abbreviations.

In the VAR and SOI, the initially high ACS was eroded by GM losses from forced sales of relatively poor condition cattle and/or the reduced LWG with the start of the dry years going into 2001/02. Nevertheless, in contrast to the HSR, the rapid reduction in stocking rates in the SOI and VAR allowed ACS in these strategies to recover in subsequent years. By May 2006, ACS was highest in the LSR and VAR but lowest in the HSR: for a property size of 20 000 ha, this equates to a gross income advantage for the LSR over the HSR of $140 000 over 9 years.

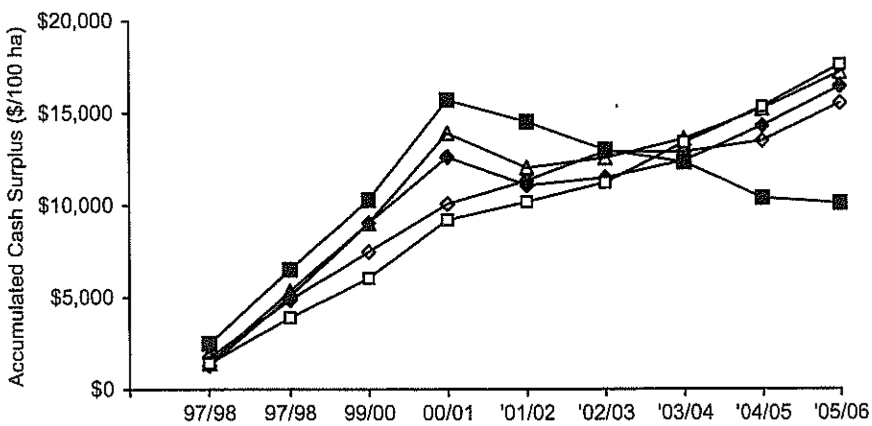

Fig. 2. Accumulated cash surplus (ACS) over nine years for the VAR (△), (R/Spell (◇), SOI(◆), HSR (■) and LSR (□) strategies at the Wambiana trial. See text for details and treatment abbreviations.

Pasture composition

After nine years of treatment application, major differences in TSDM and % species contribution to yield exist between the different strategies. In May 2006, 3-P species made up 52% of the total yield in the LSR compared to only 21% in the HSR (Fig. 3). Total 3-P grass yield was also 7- fold greater under light- than under heavy-stocking (384 vs. 51 kg/ha). The % contribution of annual- and wire-grasses to yield in the HSR was conversely almost double that in the LSR. 3-P % contribution to yield was similar in the LSR and R/Spell (52 vs. 47 %) but both were higher than the SOI and VAR (35 %). In terms of pasture condition, 3-P tussock density was highest in the LSR and R/Spell, lowest in the HSR and intermediate in the VAR and SOI. Overall, these results show that pasture condition, composition and yield are greatest in the LSR and R/Spell, lowest in the HSR and intermediate in the VAR and SOI strategies.

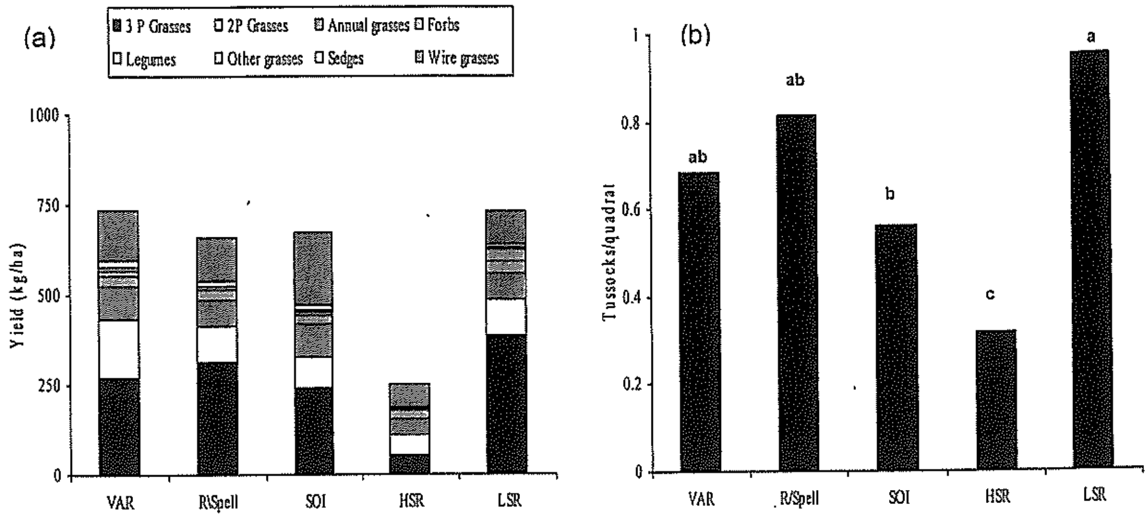

Fig. 3. Contribution of different species groups to yield across all soils (a) and 3-P tussock density/quadrat (b) across 5 grazing strategies in May 2006 at Wambiana. For tussock density bars with the same letter are not significantly different (P<0.05).

Runoff and soil loss

There were few initial treatment differences in runoff due to the high cover levels in early, high rainfall years. However in later years the number and intensity of runoff events was greater in the HSR compared to the LSR, particularly with late dry season storms leading to increased sediment and nutrient loss in the HSR (O'Reagain 2007).

Discussion and conclusion

After 9 years the relative performance of the different grazing strategies may be summarised as follows:

Light stocking gave good LWG and economic returns, largely maintained pasture condition and minimised runoff despite below average rainfall years.

Heavy stocking performed well in early, wetter years but economic returns dropped later due to high feeding costs and poor animal performance. Pasture condition and cover also declined sharply leading to an increase in runoff and a drop in carrying capacity. It remains to be seen however, whether this treatment will recover with the return of better seasons.

Variable stocking (VAR and SOI) shows potential but carries a greater degree of environmental and economic risk than light stocking, particularly when a sudden change from good to poor rainfall years occurs. Climate forecasting appears to add some value if used in integrated management decisions.

Rotational wet season spelling appeared to improve pasture condition and gave good LWG but was difficult to objectively assess due to fire effects (O'Reagain 2007). Importantly, spelling did not appear to completely buffer the effects of increased utilisation rates, particularly in dry years.

In conclusion, the data presented here provide preliminary quantitative evidence to show that strategies like light and variable stocking are not only more sustainable but provide better economic returns, at least with steers, than traditional strategies like constant heavy stocking. It is important that the present results be consolidated and extended to breeder enterprises at the property level through a combination of continued research, modelling and on-property adaptive management.

Acknowledgements

We thank the Lyons family of 'Wambiana', the Grazier Advisory Committee for their continued support and guidance and DPI&F, NRM and CSIRO colleagues for assistance and advice. The trial is co-funded by Meat and Livestock Australia and the DPI&F. We are also extremely grateful to other, previous funding bodies including the Natural Heritage Trust, The Drought Regional Initiative, The Great Barrier Reef Marine Park Authority and the CRC for Tropical Savanna Management.

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Investigating cell grazing and other grazing management systems in northern Australia

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Abstract. A four-year, producer-inspired research project jointly-funded by Queensland DPIF, CSIRO and MLA has commenced to investigate inputs and outcomes from different grazing systems across the northern beef industry. Nine commercial beef properties (primary sites) with 2 or 3 planned grazing systems were selected covering heavy (higher fertility) and light soils (lower fertility) in northern and southern Queensland. From three to eleven paddocks have been selected on each property for measurements of pasture and soil ecology, cattle production, management and financial performance There are a total of 72 paddocks, covering 21 grazing systems, and an area of 12500 ha,. Other properties (secondary sites) with a planned grazing system have been selected to broaden the range of environments being studied. The first year's data has been recorded, providing a baseline to measure trends between grazing systems and sites over the next three years. There were drought or below average rainfall conditions in the south, and near average in the north, with the autumn rainfall above the long-term means at the northern sites.

Introduction

Declining cattle productivity and deterioration of condition of grazing lands is a concern for some northern beef producers. A survey by Tothill and Gillies (1992) suggested that 42% of Queensland was in A condition (no soil deterioration, vegetation dominated by desirable species), 41% in B condition and 17% in C condition (severe soil deterioration, predominance of undesirable species). Producers have reported that their traditional management practises are not improving, and are often not even maintaining, pasture and land condition. Recognising this, some producers and their industry organisations are looking for grazing management solutions to arrest the declines and to improve pasture condition and beef production profitability.

The number of animals is the broadest driver of animal performance, profitability and sustainability and considerable effort has been directed towards developing sustainable carrying capacities and pasture utilisation rates. More recently, attention has shifted to the spatial and temporal distribution of grazing pressure and this has led to interest amongst producers in different grazing methods or systems for controlling the location, duration and timing of grazing.

Intensive grazing systems, such as cell grazing, are promoted by private consultants (e.g. Resource Consulting Services, Holistic Management Group) and have been adopted by an increasing number of producers. This has attracted interest from other producers who are eager to improve their management performance. They are interested in the concepts of cell and other rotational grazing systems, but are unsure of the costs and benefits of such systems and whether they are suited to their environment, climate, property infrastructure, management capacity and desired lifestyle.

This interest from producers and their industry organisations prompted a joint research project by a team from Queensland DPIF, CSIRO and MLA, to investigate the inputs and outcomes from the main grazing systems used in northern Australia. The team developed a research approach with commercial producers to measure and monitor the environmental, productivity and social aspects of a range of grazing systems across the main land types on commercial beef properties. This project aims to determine the advantages and disadvantages, and costs and benefits of grazing systems to assist producers to decide the most appropriate grazing system for their purposes. This paper outlines the research hypotheses and methodology, defines the grazing systems and locations of nine primary sites, and reports on preliminary results from the first year of the 4-year study.

Philosophy behind the methodology

The project considers some of the common questions raised by producers such as: What will the benefits be for me? What aspect or aspects of the management system confer benefits? Will cell or intensive rotational grazing work in my environment? If not, what are the limits to its successful use?

Is it possible to achieve the benefits of sound grazing management with other approaches and grazing methods? What will I have to learn and change to achieve benefits? Will it suit my lifestyle? To provide the required information, the project needed to identify the key questions to be addressed, and to develop a scientifically sound and rigorous approach that would yield credible and robust results that are also commercially relevant.

This project relies largely on data obtained from existing commercial management systems along the continuum of increasing management intensity from set stocking to rotational systems to cell systems. This approach aids credibility, but causes problems for scientific rigour and the ability to answer key questions in an unambiguous and statistically significant manner. However, this approach is necessary as (a) the property owners and/or managers are integral parts of the management systems, (b) there were insufficient resources to establish trials at large enough scale, and (c) we are able to assess grazing systems that have already been in place for a number of years.

Cell grazing and other intensive grazing management systems have been around for over 30 years, especially in South Africa and the USA, where more deliberate and planned approaches to rangeland management have a longer tradition than in northern Australia. There have been many studies of grazing systems, especially cell grazing, in both these countries. This information will be collated and synthesised to support results gathered in our field studies.

Research hypotheses and objectives

Issues and hypotheses

In addition to describing the performance of different grazing systems we are studying a number of issues to determine reasons for differences in performance.

- *Issue 1.* Many factors influence animal production in addition to grazing system (e.g. breed, age, gender, land type, climate, etc). Since it is impossible to control all these other factors in the comparisons, it will be difficult to detect and be able to accurately and confidently ascribe reasons for differences between grazing systems. *Hypothesis:* animal production will vary as much within a grazing system (continuous, rotational, cell) as it will between grazing systems.
- *Issue 2.* Different grazing systems can be considered to lie along a spectrum of increasing management intensity from continuous set-stocking at low stock densities in large paddocks, to cell grazing at high stock densities with large numbers of paddocks and frequent movement of cattle. *Hypothesis:* as grazing system intensity increases, spatial uniformity of grazing will increase; soil and pasture condition/health will improve due to longer rest periods, animal impact and higher stock densities; diet quality and liveweight gain per head will decrease; and pasture growth, carrying capacity and animal production per hectare will increase.
- *Issue 3.* Frequent and severe defoliation has deleterious impacts on plants. Resting/spelling pastures can minimise these impacts and rotational and cell grazing systems include periods of rest of varying lengths. Spelling may also be incorporated into other grazing systems. *Hypothesis:* timing and duration of rest is the key factor for land condition rather than grazing method *per se*.
- *Issue 4.* Changing from a continuous to a rotational to a cell grazing system will involve more active management, monitoring and decision making, and differences in pastures and animal performance between systems could reflect this rather than differences due to the system *per se*. *Hypothesis:* The more "active" grazing management there is, the more likely that desirable land condition and animal production outcomes will occur.
- *Issue 5.* Some grazing systems attempt to maintain the pasture in phase 2 (well developed leaf canopy, pre-flowering) during the growing season. In seasonal environments such as northern Australia this will require more cattle than can be carried during the dry season. Also, reserves of herbage need to be accumulated during the growing season to support animals through the dry season. These greater numbers will make it difficult to accumulate sufficient reserves. When growing seasons are short (either in arid areas or during drought years) it may be impossible or difficult to balance these competing goals. *Hypothesis:* The shorter the growing season, the less likely that benefits will be derived from more intensive grazing systems.
- *Issue 6.* During the dry season when there is little or no pasture growth and animals must select their diet from aging or old dry material, allowing maximum selection will enable them

to maximise their diet quality. *Hypothesis:* Lower diet quality under short duration "mob" grazing, compared with continuous grazing, will be most evident during the dormant or dry season.

- *Issue 7.* Large mob sizes which are characteristic of cell grazing systems may increase animal behaviour issues that reduce animal performance. *Hypothesis:* Animal performance will decrease due to animal behaviour issues as mob size and herd density increase.

Each of these issues and corresponding hypothesis has been considered in selecting the properties and in developing the methodologies.

Objectives

The project has 4 main objectives:

1. Identify the key principles that define productive and sustainable cell and other grazing systems in northern Australia.
2. Produce a technical compendium (including case studies), which will describe the structure, management and performance aspects of cattle production and associated resource condition of cell and other grazing systems under review in northern Australia.
3. Produce a package containing guidelines and decision aids for producers to use in assessing the potential performance, profitability and sustainability of cell and other grazing management systems.
4. Incorporate the information and guidelines into training and extension references and materials including, for example, the EDGE*network* Grazing Land Management (GLM) package.

The philosophy of this project is not to strictly compare various systems to conclude that one system is "better" than another, because of the over-riding influence that management and extent of infrastructure development can have on the outputs of any grazing system. Rather, the results from individual properties will be analysed and synthesised to identify key attributes, and costs and benefits associated with the different systems. This information will then be used to develop guidelines to better inform producers faced with a wide array of information and opinion on grazing systems. Producers will, ultimately, adopt and adapt systems to suit their unique circumstances, armed with credible, current, commercial information from across Queensland.

Methods

Sites

All measurements are conducted on grazing properties under commercial conditions managed by the owners/managers. Properties were selected to include continuous grazing (larger paddock areas, low management intensity), rotational grazing (moderate intensity) and cell grazing (smaller paddocks, high intensity). There are two levels of sites.

Primary sites. Nine properties have been selected in Queensland (Fig. 1) where there is a comparison of two or three grazing systems, total of 21, and most of the measurements are recorded by the project team. Eight sites have cells, 6 have a rotation and 7 have a set stocked system. These sites cover both northern and southern areas, and two important pasture types, brigalow and eucalypt woodlands (including both black speargrass and *Aristida-Bothriochloa* native pasture communities), and a range of land fragility/resilience. The sites cover a range of growing seasons due to differences in total rainfall and its distribution through the year and temperature. To provide greater confidence in the results, the sites are duplicated in the two vegetation types in both the north and south regions. Whole properties are not being monitored, so on each property, paddocks in the different grazing systems (e.g. 1 in a continuous system, 2-3 in a rotation and 5-10 paddocks in a cell system) with similar characteristics (soil type, pasture, tree cover, topography, etc) were selected for monitoring. In total there are 72 paddocks covering 12528 ha in 52 cell (2907 ha), 13 rotation (5697 ha) and 7 set stocked paddocks (3924 ha).

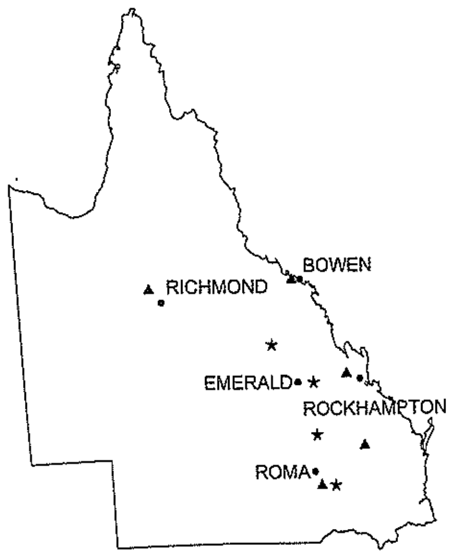

Fig. 1. Location of nine primary sites in Queensland. with main towns (stars are heavy soil brigalow/gidgee and triangles are light soil Eucalypt country)

There is limited capacity to statistically compare systems at one site. While there is no system replication at any site, there are multiple paddocks being recorded in the rotation and cell systems at all sites, and repeating these comparisons over 4 years at a number of sites should permit general inferences to be made.

Secondary sites. Additional properties are being selected where there is a planned grazing system and good records, and preferably a comparison of grazing systems. Many of the measurements are taken by the producer with the project team taking fewer complementary measurements. These sites are located in regions or landtypes not covered in the primary sites (e.g. Mitchell grass, wet coast). They also provide additional comparisons (systems) not available at the primary sites, the opportunity to obtain information on specific topics, and additional numbers to increase confidence in, and verification of, results obtained at primary sites.

Procedures and measurements at primary sites

Background information. This includes: people (visions, goals, motivations, objectives and attitudes of producers, levels of understanding), land (property history, pasture communities, current condition), livestock (types, numbers and breeds), level of monitoring, and capital and operating finance.

Description of grazing systems. The 21 grazing systems at the nine site have been defined (numbers and classes of animals, changes to numbers, periods of rest and grazing, supplementation programs, record keeping, labour and infrastructure requirements).

Field measurements. Data are being collected from the 72 paddocks to allow inferences about sustainability, productivity and profitability to be made. Data is collected annually on biophysical (cattle, pasture, soil health), financial and management inputs and outcomes for the different systems.

Quadrat and point data being collected includes: pasture yield, botanical composition, species frequency, basal area of perennial grasses, degree of utilisation, cover, tree regrowth, and soil surface condition to provide LFA (Landscape Function Analysis) (Tongway and Hindley 2005) indices of stability, infiltration and nutrient cycling (at approximately 8230 sampling locations across all paddocks located by GPS reference). From 5-20 LFA transects (each 50 m) are recorded every 1-2 years in each paddock with permanent photo points established at the upper-slope position of each transect (a total of 484 locations). Annual estimates are made of land condition using the ABCD framework of the Grazing Land Management package. Faecal samples (one bulked sample from 10 animals from each system) are collected monthly for NIRS analysis to assess diet quality, crude protein, digestibility, faecal nitrogen, grass to non-grass proportions, and predicted liveweight gain. Animal performance (numbers, classes, grazing days, liveweights and condition scores (scale 1-5) to calculate LSU's and financial values) is being monitored and financial information collected for both partial analyses (direct comparisons of treatments) and whole property analyses.

Pasture modelling. The pasture growth model GRASP will be used to relate the growing seasons experienced during the trial period to long-term values, and to predict the likely variability in pasture and economic performance.

Decision making information. The project is interested in the decision making processes used in determining and conducting the various grazing systems successfully. This will help our understanding of the management, as shown by the actions/behaviour of what was actually done and the responses in the physical (pasture and soil ecology, and cattle performance) measurements we are recording.

An MS Access database has been established to maintain and manipulate the data.

Results

Pasture and soil surface conditions (year 1)

The project has completed the first years recording of the primary sites, setting the base line for measuring any future trends. The pasture and soil surface condition results (Table 1) show no consistently large differences between the grazing systems at the nine sites at this stage.

Table 1. Pasture and Landscape Function Analysis indices for stability, infiltration and nutrient cycling of grazing systems at nine sites at the end of the 2005-06 growing season.

Primary site	Grazing system	Pasture			LFA indices		
		Yield (kg/ha)	Perennial grass (%)	Cover (%)	Stability	Infiltration	Nutrient cycling
Condamine	Cell	1750	99	55	62.0	34.0	27.8
	Continuous	910	93	51	59.0	40.0	30.8
Emerald	Cell	3470	99	62	62.7	35.2	29.1
	Rotation	3190	97	62	61.5	37.3	29.8
	Cont	1700	98	46	59.7	34.2	27.8
Clermont	Cell	1500	95	37	56.3	36.2	27.9
	Rotation	2270	84	67	58.2	43.7	33.1
	Continuous	1800	92	50	56.7	44.2	30.2
Rockhampton	Cell	1780	89	51	60.8	32.8	27.5
	Rotation	1920	83	62	61.8	32.2	26.3
	Continuous	1780	87	65	61.3	32.4	27.1
Mundubbera	Rotation	2450	98	75	67.5	34.7	30.5
	Continuous	2820	99	84	66.1	36.9	30.5
Bowen	Cell	4100	61	74	63.7	36.9	29.0
	Continuous	5300	68	80	62.1	37.6	29.9
Richmond	Cell	1800	89	39	54.8	43.2	25.4
	Rotation	1560	65	45	54.7	43.5	27.2
Injune	Cell	3290	98	61	58.5	37.4	27.8
	Continuous	3180	99	60	60.3	36.4	29.5
Surat	Cell	2620	98	63	62.4	36.7	27.0
	Rotation	1950	97	58	62.0	35.9	28.0

Diet quality
Table 2 shows the means of all data from each grazing system across the primary sites over 6 months. There is insufficient data to draw any conclusions yet.

Table 2. Mean diet quality predictions from NIRS analysis for the grazing systems at the primary sites (means of all data for January-June 2006).

Grazing System	Crude protein %	Faecal N %	Digestibility %	Non-grass %	LWG kg/day
Cell	7.34	1.38	55.6	18	0.64
Rotation	8.18	1.52	57.6	22	0.74
Continuous	8.73	1.55	57.9	18	0.74
Primary sites mean	8.08	1.48	57.0	20	0.70

An example of the diet quality, crude protein and digestibility, selected in three grazing systems is shown for the Rockhampton site (Fig. 2).

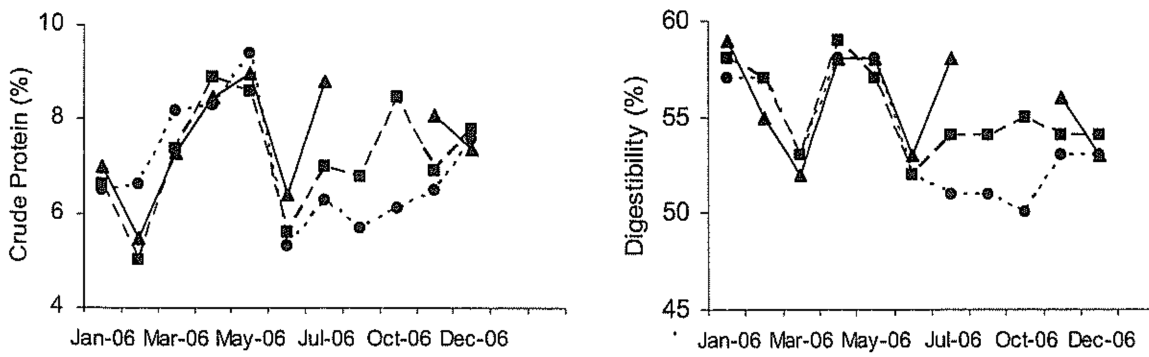

Fig. 2. Monthly crude protein and digestibility prediction by NIRS analysis for three grazing systems at the Rockhampton site. (circles = cell; squares = rotation; triangles = continuous grazing systems)

Discussion

The first year results show little difference between grazing systems but set the baseline to quantify future trends. The annual data will be analysed to quantify production, financial performance, pasture and soil resource impacts and management requirements of the different grazing systems on the primary properties and any trends within or between the grazing systems over time will be identified.

Each of the grazing systems at the primary sites can be considered as a case study. Over time the performance of each of these will build up a picture of how systems perform. By combining these case studies with the comparative data from the different grazing systems, the results from the secondary sites, and published results from other studies we will produce a final set of principles for grazing systems in northern Australia and guidelines for their implementation. The first years' results are too early in the project to draw firm conclusions.

Acknowledgments

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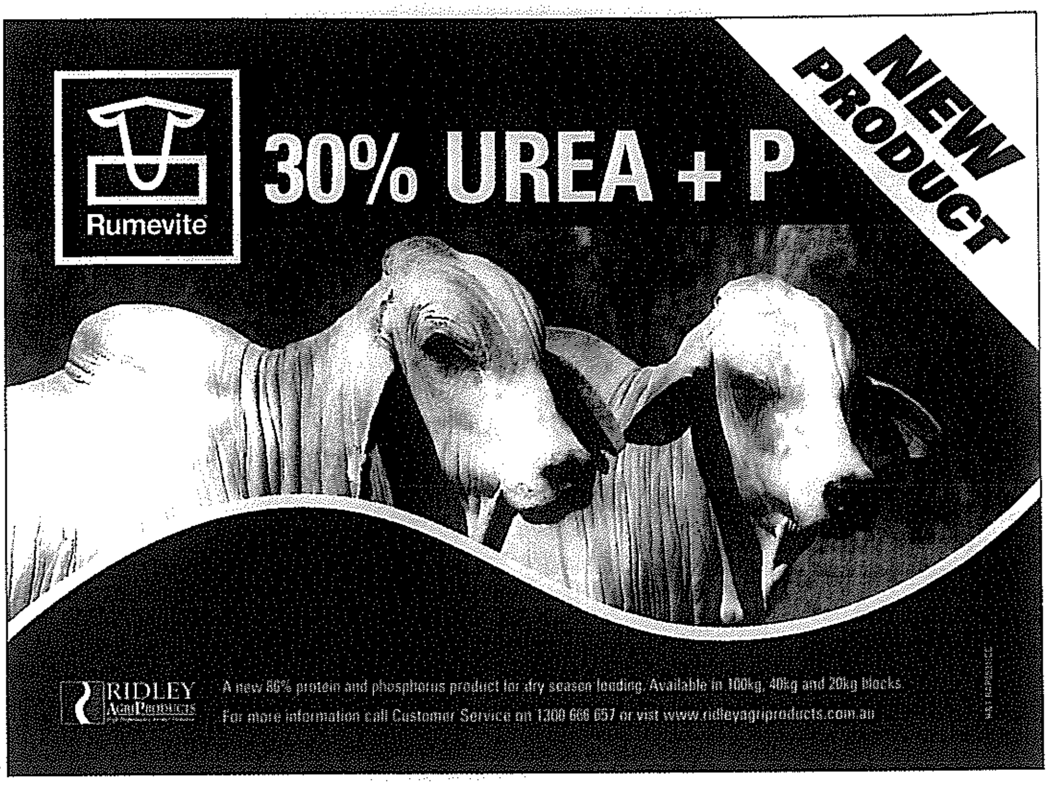
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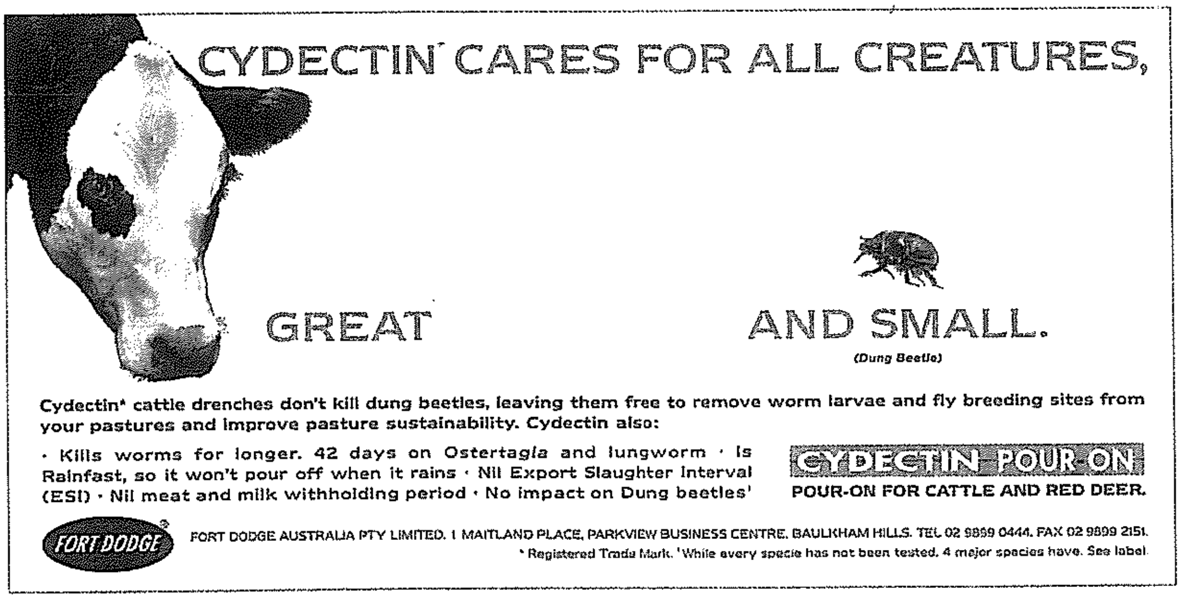
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Land monitoring information for grazing management

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Abstract. Monitoring grazing land condition in Australian rangelands is complex because of vast areas and difficulties in quantifying condition variables consistently over time and space. Yet condition is a significant factor in setting stock carrying capacities that are appropriate for profitable and sustainable grazing enterprises. In this paper we propose an integrated grazing land monitoring framework. We discuss the components necessary of a monitoring system and a delivery approach for using system outputs in property-scale decision-making. Time-series remote sensing data is the key component for interpreting land condition in a spatially continuous manner. Combined with site assessments, the local experiences of land managers and systems analysis, our ability to monitor with respect to climate variability is greatly improved. However, the benefits of the monitoring system are not fully realised if system outputs are not used in grazing management. A delivery approach where consideration is given to profitability and sustainability across the whole grazing enterprise is needed. Those land managers equipped with better monitoring information can optimise the use of pastures through proactive management suited to prevailing and predicted land condition, thus, contribute towards the goal of reaching environmental outcomes set for the broader catchments and regions.

Introduction

A considerable effort has gone into monitoring the rangelands of Australia. Commencing in the 1960s, much of the early work was spent identifying rangeland condition and developing methods of how to measure it (e.g. Holm 1984; Friedel and Shaw 1987). Clearly the focus of rangeland monitoring has been on grazing lands – as opposed less 'productive' landscapes (see Smyth *et al.* 2003) – with an aim to improve the sustainable use of natural resources and the profitability of the grazing enterprise.

Friedel *et al.* (2000) *cited in* Bastin and Ludwig (2006:71), describe rangeland condition as the assumed potential of specific indicators, such as vegetation cover, production and composition, in one locality compared to other locations. Under this definition, benchmarking condition states is necessary (i.e. defining the best to worst). However, without the full range of benchmark sites extrapolating condition consistently over time and space is difficult, as sites only represent limited spatial areas. Remote sensing provides the quantitative means to view temporal changes in vegetation consistently at the paddock, property, catchment and national scales. Yet the identification of vegetation species with respect to groundcover is typically beyond sensor resolution, so remotely sensed condition statements are often generalised, and in need of field verification. Bastin and Ludwig (2006) stated that the major challenges associated with mapping condition include separating management from seasonal effects, along with system efficiencies and deriving universal condition classes. A result of these challenges is that there is still no definitive map of rangeland condition across the grazing lands of Australia, even though monitoring methods and analyses are continually improving towards realising this goal (see Bastin *et al.* 2005).

Aside from the issues with developing and testing the science of rangeland monitoring, another challenge remains. That is, how to package complex monitoring information into formats that demonstrate value to grazing land managers – to help make decisions that improve productivity while maintaining or improving condition. For addressing this challenge, we propose an integrated grazing land monitoring framework. We describe the components (or data needs) for a monitoring system and a delivery approach to maximise the benefit from system outputs in decision-making (Fig. 1).

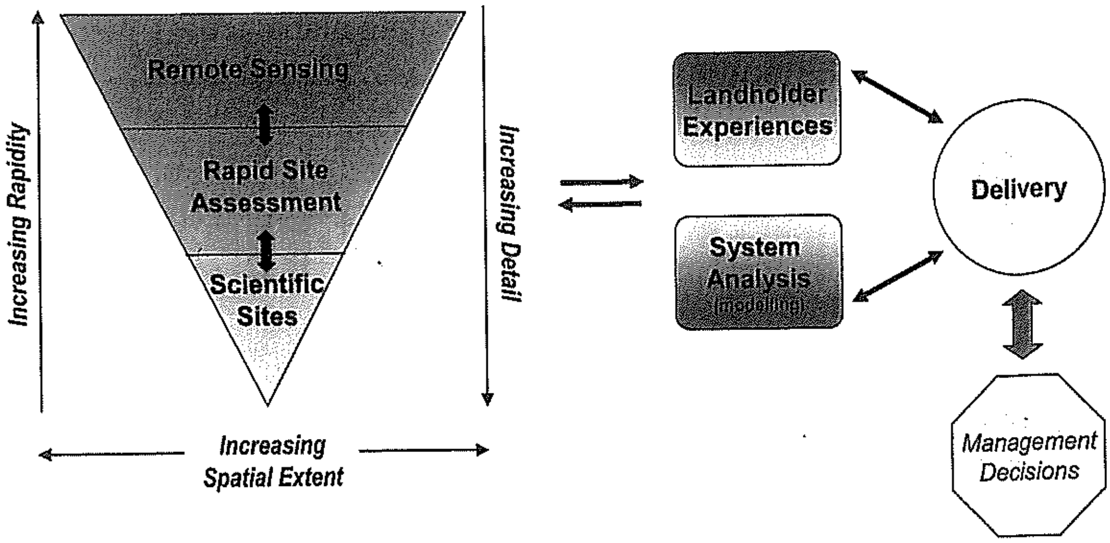

Fig. 1. A grazing land monitoring framework.

Components of a grazing land monitoring system – data needs

For monitoring grazing land in Australian rangelands, we consider five components in an integrated monitoring system: remote sensing, scientific sites, rapid site assessment, landholder experiences and systems analysis (or simulation modelling). The former three components are part of a hierarchical structure; the most extensive measurements come from the remote sensing and provide the data basis that is verified through site investigation. But the ground "intelligence" (i.e. interpretation of the signal and management impacts) comes from interrogating landholders and the systems analysis.

Remote sensing

Knowledge of where and when changes in vegetation have occurred is fundamental to monitoring grazing land and management impacts in rangelands (Wallace *et al.* 2006). The Landsat series of Earth observation satellites provides this capability. The value of Landsat data lies in its repetitive medium spatial resolution, multispectral measurements over 30+ years that are unmatched in quality, detail and coverage (Williams *et al.* 2006). In Australia's rangelands, where climate variability affecting groundcover condition often operates over periods of a decade or more (Pickup *et al.* 1998), the Landsat archive is especially important. Landsat time-series assessments of groundcover are further enhanced through integrating ancillary GIS layers such as: geology, topography, woody plant density, infrastructure, rainfall and fire histories.

In the foreseeable future, the use of new high spatial resolution (less than 10 meters) and hyperspectral (imaging spectroscopy) airborne and space-based systems for monitoring rangelands appears to be of a complementary nature, rather than a replacement of the Landsat-class satellites (see Green 2006; Hill *et al.* 2006; Irons and Masek 2006). Concern over the operational but ageing Landsat-5 and technically compromised Landsat-7 satellites was reassured in December 2005 by Presidential (White House) memorandum, dictating the continuation of this important earth observation system (Irons and Masek 2006).

The most comprehensive Landsat archive of any State/Territory jurisdiction in Australia is in Queensland. The Statewide Landcover and Trees Study (http://www.nrm.qld.gov.au/slats/), has complied annual coverage of geometrically and radiometrically corrected Landsat TM and ETM+ images providing the ability to assess groundcover trends over 20 years anywhere in the State. In related work, Scarth *et al.* (2006) report on trialling a sophisticated new groundcover index (Bare Ground Index – BGI) that is based on multiple regression statistics. This cover index does not require stratification of areas into similar land type units, minimising the need for local adjustments in the remote sensing data across different soil types. Development of this general cover index is viewed as a significant improvement over previous Landsat cover indices used in Australia.

However, one limitation to the broadscale application of satellite-based groundcover monitoring techniques is where dense woody vegetation occurs. Generally, groundcover in areas having greater than 20% woody Foliage Projected Cover (FPC) cannot be measured by optical remote sensing systems such as Landsat. Typically though rangelands are lightly forested, and in some States like Queensland only around one-quarter of its area has woody foliage cover greater than 20%; where a reliance on ground monitoring is needed.

Scientific sites

Detailed collections of vegetation and soil characteristics at scientific monitoring sites are required for defining condition states and understanding grazing land ecology over time, as well as calibrating remote sensing data. A number of site-based monitoring programs have evolved in Australia, employing a range of approaches to suit a particular environment, program objective or operator capability (e.g. Holm *et al.* 1984, Green *et al.* 1994; Lynch and Karfs 2001). One of the primary concerns with site-based monitoring systems has been the selection and distribution of sites, and their limited representation of the landscape (Wilson *et al.* 1984; Pickup *et al.* 1998), leading to biased results. Despite these concerns however, ground monitoring systems have been shown to 'mature' over time, providing the reference necessary for improving our knowledge of condition trend and grazing land ecology (e.g. see Watson *et al.* 2005). Ground sites are also used to calibrate and refine remote sensing cover indices (e.g. Scarth *et al.* 2006); increasing our ability to provide this key land condition parameter in a spatially continuous and sequential manner across vast areas.

Rapid site assessment

Rapid site assessment refers to the visual appraisal of a series of biophysical attributes over a specified area (usually no more than a few hectares). Site locations are permanently recorded using GPS with the stream of data providing spatial detail over a wide area, helping to fill the knowledge gaps between scientific site locations. Rapid site assessment is not intended to replace detailed scientific investigation, yet the advantage of collecting 100s of sites per day compared with a handful of scientific sites is clear. Hassett *et al.* (2000) have lead the way in mobile rapid assessment in Australia, that is, recording observations from a moving vehicle, and demonstrated its important role in validating groundcover estimates from Landsat and the AussieGrass model (see Scarth *et al.* 2006). With technological advances in data recorders, laptops and in GPS software tracking programs, this form of ground monitoring is now accessible by many..

Another notable approach, albeit aimed at the paddock and property level, is the Stocktake Monitoring Package (Aisthorpe and Paton 2004) procedure. It was developed for estimating land condition using visual standards (i.e. 'ABCD' described in the following section) collected at a number of sites relative to the livestock carrying capacity for different land types within different property paddocks.

Landholder experiences

Landholder experiences in managing daily grazing impacts while coping with climate variability provides valuable context for interpreting monitoring results. For example, an increase in Landsat groundcover index values (representing increases in ground vegetation) over a series of median rainfall years might be related to a management decision to reduce stock numbers. Alternatively, stock numbers might have remained the same, but the increase in index values attributed to more rain falling in places undetected by sparsely located rainfall gauging stations. Landholders are often aware of these details and are often willing to share their experiences. Local knowledge is a resource for helping make sure we are getting the maximum benefit from a rangeland monitoring system through linking biophysical responses with management actions.

Systems analysis (modelling)

The purpose of a system analysis approach in grazing land monitoring is to provide objective and reproducible information for discriminating the effects of grazing management against climate variability. Models enable prediction of future scenarios (e.g. the impacts of climate change), as well as providing a rationale test on the internal consistency of monitoring data over time and space. AussieGrass (Carter *et al.* 2000) and SedNet (Prosser *et al.* 2001) are two models that have gained prominence in Australia for understanding ecosystem processes at catchment scales. AussieGRASS is a spatial pasture growth/water balance model that provides additional information on the simulation of seasonal and inter-annual variability in vegetation cover. The SedNet model provides spatial information indicating soil loss potential, for identifying hazard areas in the landscape where greater management effort might be needed to reduce rates of erosion.

Delivery approach

An important step in our integrated monitoring framework is the consideration of how to deliver condition monitoring information to land managers in useful formats – allowing those landholders to 'feed back' their local experience and knowledge to the interpretation of the data. A delivery approach is outlined below.

Group based and one-to-one learning programs

The Grazing Land Management (GLM) package (Chilcott *et al.* 2003) was developed in response to identification by industry (Meat and Livestock Australia – MLA) of the need for a 'product' that would enhance management of grazing lands in northern Australia by transfer of information to graziers. The objective of the workshop is to provide practical tools and information to land managers to maximise productive potential, while maintaining or improving the health of the land. Given the major regional differences in land types and production systems, the workshop has been developed for different catchments or unique pastoral zones across northern Australia, with 13 different versions available. Exposure to a diversity of views and peer networking underlie the group format where typically up to ten graziers participate in any one workshop. Follow-up agency support is provided.

An alternative to the group approach is one-to-one extension such as GLM+ (Rolfe and Shaw 2006). GLM+ uses the same concepts and tools from the GLM workshop, but is delivered on-property to individual management teams. GLM+ has an advantage in that materials can be tailored to address the specific issues on a particular enterprise. In regions where grazing properties are large (e.g. 100,000 ha), the one-to-one approach has proven most successful.

ABCD land condition assessment

One of the core principles in GLM and GLM+ is the concept of land condition, defined as '*The ability of land to respond to rain and produce useful forage*'. Understanding land condition is therefore a critical component in understanding the productive potential of a property, and a basis for deciding when to alter stocking rates, introduce spelling practices and/or modify infrastructure to minimise damage in degraded areas. To assist land managers in identifying condition, the 'ABCD' condition framework was devised as part of the GLM package. The framework was constructed from existing knowledge of grazing land ecology and relies on data from long-term grazing trials such as Ecograze (Ash *et al.* 2002) and Wambiana (O'Reagain *et al.* 2003). Implicit in the definition of good condition (A) is the maintenance of ecosystem processes such as water and nutrient cycling, resulting in stable pasture production responses across seasons relative to the livestock carrying capacity (Chilcott *et al.* 2003; Quirk and McIvor 2003). To guide this process a site assessment procedure was developed, where the productivity value of B condition is only 75% of the optimum A condition. C condition is only 45% and D condition only 25%. Perennial, palatable and productive pasture species, percentage groundcover, presence of weed species and soil condition are all important attributes for assigning a condition class to a particular site. The transferability of land condition concepts to workshop participants via the ABCD framework has been high.

Monitoring products from time-series remote sensing

In both GLM and GLM+, property maps are the basis for which land managers assign land condition values across the property. Time-sequential groundcover change maps from remote sensing could significantly aid this interpretation. For example, information quantifying the extent of less productive bare ground or the spread of weed infestation provides feedback which land managers rarely receive, and generally appreciate (e.g. see MLA VegMachine project, Beutel *et al.* 2005).

In Fig.2, an example of a property-scale remotely sensed monitoring map is shown, comparing Landsat groundcover BGI averaged over five years (2001-05) with a single-date (2005) Landsat colour composite image (RGB = 347). Areas of woody density greater than 20% FPC (dark green) and cropping (gold) have been masked. BGI values were divided into five categories ranging from low 0-

10% (red) to high 80-100% (dark blue). During median rainfall years from 2001-05, most of the property area (outlined) had BGI values in the 40-80% range (green/light blue). Rapid site assessment conducted in 2006 agreed with the relatively high mean BGI values, and these areas were found mostly in good condition. Areas of low BGI values (0-10%) in the centre of the image were associated with low groundcover and poor condition on small weathered hillocks rising above surrounding plains. The summed area of these less productive landscapes is minimal, about 1.5% of the property area.

A current issue complicating remotely sensed condition assessments in rangelands is the inability of sensors to resolve species composition in groundcover, which is often critical for adjusting sustainable carrying capacities (e.g. Indian couch is less productive than Blackspear grass). At this time there is no explicit quantitative relationship between remote sensing groundcover indices and condition (i.e. as described by ABCD above); hence the need for interpreting remote sensing information with respect to knowledge of condition. To this end, remote measurements of groundcover change are more likely to be coupled with landscape function (Ludwig *et al.* 1997; 2006). Although the emphasis in landscape function is more on the spatial organisation of perennial plants and less on their forage value, functional landscapes are those where soil and vegetation patterns

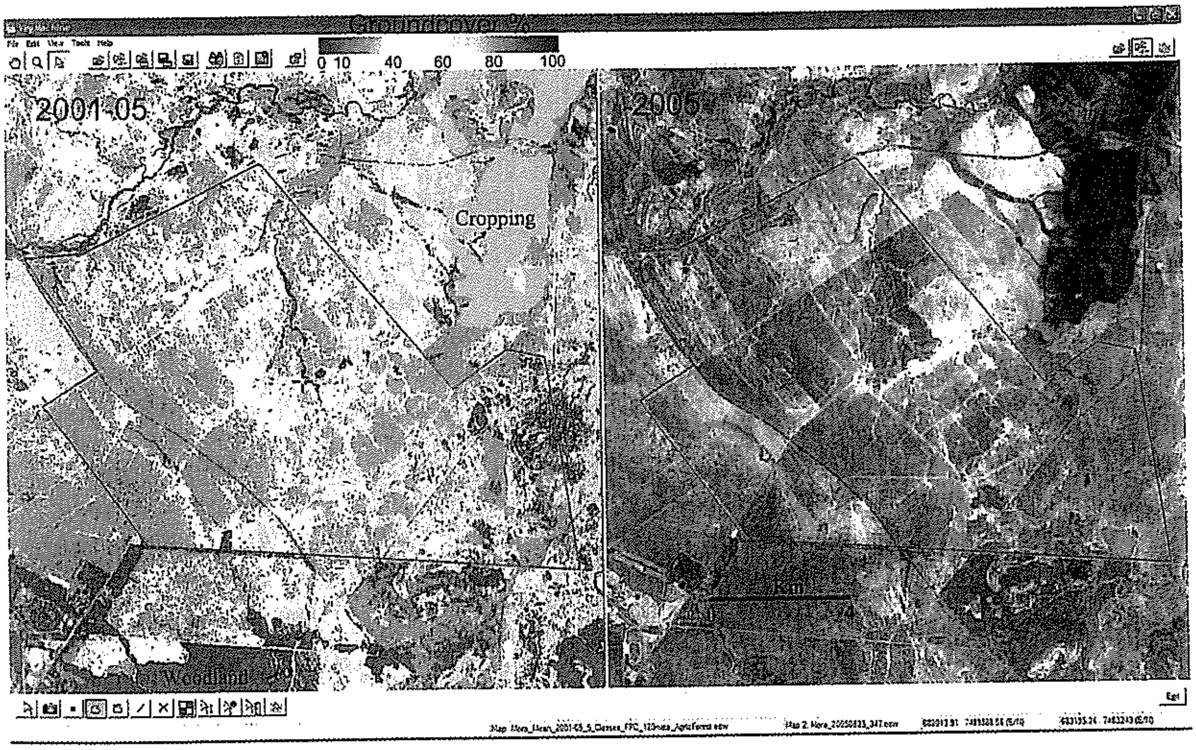

Fig. 2. Property-scale map comparing Landsat groundcover BGI (left) averaged over five years (2001-05) with a single-date (2005) Landsat image (right). BGI preliminary product ver. Apr 2006.

ensure high levels of resource control, and are thus optimal for primary production. Consequently, landscape function provides a more complementary basis for estimating rangeland condition. In the future, indices of landscape function should provide improved means for mapping rangeland condition using remote sensing (Bastin and Ludwig 2006).

A need for monitoring information

Over the past decade or so, there has been an increased recognition of the relationship between poor land management and negative off-site environmental impacts, such as soil erosion and a decline in the condition of rivers and adjacent near shore coastal areas from sediment transport. These concerns have led to encouraging the uptake of management practices that improve both productivity and land condition. However, until land managers have specific property-scale information on land condition, it will be difficult for them to see how they are contributing towards broad-scale catchment issues.

Until recently the tools for decision-making have been limited to a grazier's intuition and memory of pasture condition transposed onto a static map or satellite image. What has been missing is the link between management actions and graphical information that tracks condition changes through variable climatic sequences. This information is now becoming increasingly available through the interpretation of time-series remote sensing data. In an era where external drivers are increasing the need to improve the efficiency of production (Ash and Stafford-Smith 2003), objective monitoring information that helps in optimising the use of pastures could become commercially advantageous. A significant challenge then will be in helping land mangers recognise the value of monitoring information, in making proactive decisions that are suited to prevailing and predicted land condition. One way to do this is through group-based and one-to-one delivery such as GLM and GLM+, providing the setting which to establish rapport for open discussion on the grazing business, as well as land management and condition issues.

Conclusions

In this paper we have proposed a grazing land monitoring framework that integrates a monitoring system with a delivery approach for guiding management decisions at the property-scale. The monitoring system is based on the unique Landsat image archive combined with ground assessments over a range of site densities. Monitoring system outputs are enhanced from observations by landholders, while ecosystem modelling provides objective results for data validation and scenario forecasting. The importance of land condition to a grazing enterprise is significant. Therefore, discussion on land condition issues and management solutions should be discussed in parallel. This can be achieved under the successful extension approach of GLM and GLM+, where consideration is given to the whole grazing enterprise. In the face of climatic change and the need to improve efficiencies, a better understanding of land condition by beef producers will allow opportunities for improved profitability and sustainability.

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Comparison of woody vegetation change datasets from the grazed woodlands of central Queensland

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Abstract. Vegetation change in central Queensland remnant woodlands has been measured and predicted using five techniques which span different temporal periods, have different spatial and temporal resolution and are based on independent sources of data. How do these datasets compare? Are they consistent? Five datasets; model output from a simulation model, $\delta^{13}C$ assessment of soil organic matter, sediment pollen analysis, tree cover assessed from aerial photography and on-ground monitoring of woody vegetation are presented on a common temporal axis. We explore similarities and differences in the vegetation trend over time and discuss how the relatively short term record from on-ground monitoring fits within the longer term trend. In general, the datasets indicate a trend for thickening of woody vegetation over the last few decades and over the last century. The recent drought (2001-2006) however has resulted in woodland thinning negating some of the previous increase in tree basal area.

Introduction

An understanding of historic vegetation change provides insight into landscape variability and whether current trends in vegetation change are outside the bounds or at the extremes of historical fluctuations. Major changes in the abundance of woody vegetation may impact on landscape function including carbon storage, stream flow, subsurface hydrology, forage production and habitat abundance.

In Queensland, ~91 Mha are still classed as remnant/uncleared woodland despite the clearing of ~30 Mha of woodland vegetation since the early 1900s (Accad *et al.* 2003). The area of clearing and rate of clearing is well documented (Accad *et al.* 2003; NRM 2005). In this paper, we focus on the large areas of remnant/uncleared woodland vegetation and the changes that have occurred which may be due to natural climate cycles or modern imposed impacts such as fire suppression, domestic livestock grazing, higher carbon dioxide concentrations in the atmosphere or a combination of these factors (Burrows *et al.* 2002; Bond *et al.* 2003b; Bond *et al.* 2003a; Sharp and Whittaker 2003; Fensham *et al.* 2005; Berry and Roderick 2006). If the modern imposed changes are 'pushing' the woody vegetation to the bounds of natural variability we need to consider proactive management of woodlands to minimise the impact of adverse changes on landscape function particularly in relation to landscape hydrology on which many ecosystems rely (Murray *et al.* 2003; Wilcox and Kreuter 2003).

In Queensland, many of the modern imposed impacts such as domestic livestock grazing began in the mid to late 1800s. Therefore we need to assess historic change over at least the last two hundred years. There are a number of techniques which can be used to assess changes in woody vegetation over time (Fig. 1), however all the techniques have limitations in spatial and temporal distribution and resolution. Any one dataset is unable to provide a comprehensive picture of past vegetation history across the landscape.

In this paper we compare five independent vegetation change datasets generated for the semi-arid woodlands of central Queensland. The five datasets include:

- On-ground woodland monitoring
- Aerial photography assessment
- Sediment pollen analysis
- $\delta^{13}C$ analyses of soil organic carbon
- Simulation modelling

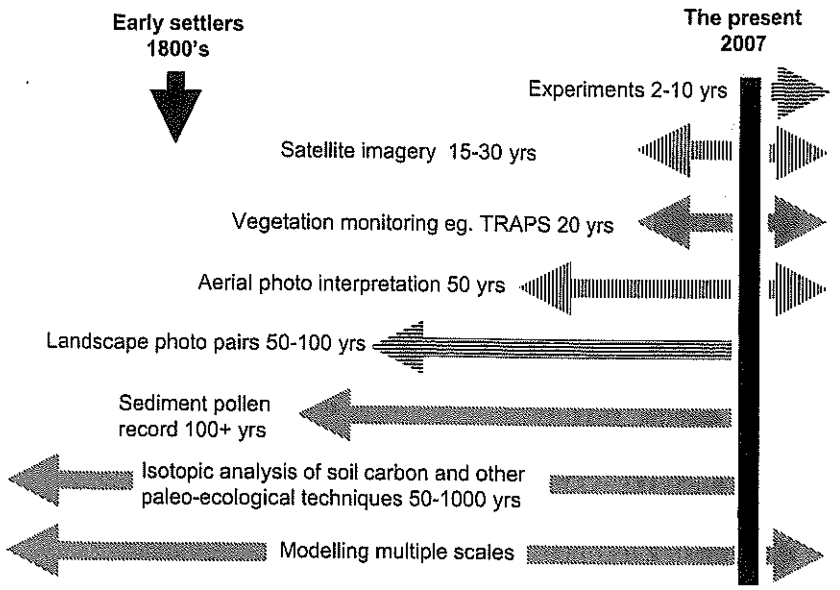

Fig. 1. Techniques used to investigate and understand vegetation change and its relationship to temporal and spatial scales. Note the solid arrow indicates the 1800s and the solid bar represents the present. The horizontal hashed arrows indicate the technique is site specific or restricted to a local region, the vertical hashed arrows indicate the technique is good for regional assessments and the diagonal hashed arrows indicate the technique can be used to assess specific sites and for regional assessments.

By presenting the datasets on a common temporal axis, we check for similarities and differences between the datasets and discuss how the relatively short-term (23 years) on-ground woodland monitoring dataset fits within the likely long-term woodland change history for the central Queensland region.

Materials and Methods

The five datasets used in this comparison have been extracted from different sources, but have been derived to assess woodland vegetation change in the central Queensland region. A brief summary of the methods used to generate each dataset is now provided.

On-ground monitoring of woody vegetation

The TRAPS (Transect Recording And Processing System) woodland monitoring network began in the early 1980s to monitor changes in tree population dynamics (Back *et al.* 1997). The results of the network up until the year 2000 were reported for eucalypt woodlands in (Burrows *et al.* 2002). The network is based on permanent sites with the standard site configuration of 5 parallel belt transects 100x4 m in a 1 ha area. All woody plants within the transect are individually located, the species recorded and their height and basal circumference measured (Back *et al.* 1997). In this paper we have used sites not cleared during the monitoring period (remnant vegetation) and have been resampled in the period 2003-2006. Due to differences in site establishment date, sites have been categorised into three groups:

- 'Long-term' sites (average establishment date June 1984, 24 sites)
- 'Short-term' sites (average establishment date September 1997, 26 sites)
- 'New' sites (average establishment date September 1999, 20 sites)

Change was assessed from the establishment date until an average date of September 1999 for the 'long-term' and 'short-term' sites and for all sites from an average date of September 1999 until October 2004.

Stand basal area (BA) was converted from being assessed at a height of 0.3 m to 1.3 m (breast height) using the equation $BA_{0.3m} = 1.5294\ BA_{1.3m}$ (Krull and Bray 2005).

Aerial photography assessment

Aerial photography was assessed over a study area of 121,200 km^2 in central Queensland (Fensham *et al.* 2003). Randomly generated remnant sites (108) were assessed with the average initial photography date in 1951 and final photography date in 1995. At each site, a graticule grid covering a ~25 ha area was used to assess cover at 100 points. Cover was categorised into tree, shrub and ground and calibrated against ground sampling (Fensham *et al.* 2002; Fensham *et al.* 2003). Regional trends were generated from individual site trends within broad land types. We have extracted the average trend for uncleared overstorey cover for Eucalypts on texture contrast soils (Fig. 2c. in (Fensham *et al.* 2003)).

Sediment pollen record

Sediment was sampled from Lake Dunn, a semi-permanent lake in the Desert Uplands bioregion of central western Queensland surrounded predominately by semi-arid woodland. The pollen record in the sediment was assessed. Specifically, the amounts of Poaceae (grass) and Myrtaceae (includes *Eucalyptus* spp. and *Melaleuca* spp.) pollen were used as indicators of temporal change in the tree/grass balance.

The sediment core, 135 mm in depth, was obtained from centre of Lake Dunn using a gravity corer (Sim 2004). The penetration of the corer was restricted by the heavy clay sediment. The core was sliced at 2.5 mm intervals from 0-50 mm and at 5 mm intervals to the end of the core at 135 mm. Analyses were conducted on 10 slices down the profile. Analyses included ^{210}Pb-dating, pollen abundance, grainsize characterisation, charcoal, bulk density and moisture content.

The ^{210}Pb analysis used the 'wet chemistry' method as described by (Goldberg 1963; Krishnaswami and Lal 1971). The constant initial concentration model was used to produce a chronology of the sediment core (Oldfield and Appleby 1984) and was successfully cross referenced with grainsize, moisture content and macrosopic charcoal analyses (Sim 2004).

Pollen preparation followed the standard procedure used by the ANSTO Environmental Division (Harle 2005). Sample masses of 2 to 4 g were used. *Lycopodium* spores were added to each sample to allow quantitative pollen number calculation. In this paper we have extracted the measurement of Poaceae and Myrtaceae pollen numbers down the dated sediment profile (Fig. 5.5g in (Sim 2004)).

$\delta^{13}C$ analyses of soil organic matter

The $\delta^{13}C$ technique utilises the distinct difference between the isotopic $\delta^{13}C$ signature of C4 photosynthetic pathway grass carbon and C3 tree, shrub and forb carbon. The ratio of non-grass (mostly trees and shrubs) and grass carbon in different soil organic mater size fractions and different soil layers down the soil profile was assessed (Krull *et al.* 2005). Different soil organic matter size fractions and soil depths have different carbon ages therefore trends in the ratio of 'tree' and grass carbon can be assessed over time (Krull and Bray 2005; Krull *et al.* 2005; Krull *et al.* in review). A regional survey was conducted using the technique at 44 remnant vegetation sites in the Burdekin River catchment spanning central and the lower part of north Queensland (Bray *et al.* in prep; Krull *et al.* in review). The change in tree basal area was estimated by developing a relationship between current tree basal area and the particulate organic carbon $\delta^{13}C$ value (Krull *et al.* in review) and then applying this relationship to older carbon fractions with corrections for isotopic fractionation (Bray *et al.* in prep). Dating using this method has low resolution and the older carbon fraction has an age range of 50-150 years.

In this paper we have extracted the estimates of current and historical (50-150 years ago) tree basal area (Bray *et al.* in prep).

Simulation modelling of woodland dynamics

The FLAMES fire and vegetation model (Liedloff and Cook 2006) was used to generate possible change scenarios for a woodland in central Queensland against which to compare measured datasets. The model was parameterised for infertile red tableland country dominated by narrow leafed ironbark (*Eucalyptus crebra*) woodland. Clermont historical climate data (1886 to 2003) ((Clewett *et al.* 2003)) was used in the model and represents a typical summer dominant semi-arid rainfall pattern for the region. Initial tree populations were based on data collected from a remnant TRAPS woodland monitoring site in the region after converting individual tree circumference (C) at 0.3 m height to 1.3 m height using the equation $C_{1.3m} = 0.789\ C_{0.3m}$ (Burrows *et al.* 2002).

Four scenarios are presented with each scenario a mean of three iterations of the model. The scenarios are:

1. 100% initial tree population and 1 fire every 10 years (high tree population, low fire)
2. 100% initial tree population and 1 fire every 2 years (high tree population, high fire)
3. 33% initial tree population and 1 fire every 10 years (low tree population, low fire)
4. 33% initial tree population and 1 fire every 2 years (low tree population, high fire)

The 33% initial population was generated by selecting every third tree down the list. A low initial population was included as there is evidence that the woodlands were more sparse and open 100-200 years ago (eg. (Berry and Roderick 2006; Krull *et al.* in review)).

The model included sustainable grazing, removing on average 25% of the grass biomass which is a modification of the original model (Cook *et al.* in-prep). Fire only occurred if sufficient fuel was present in a 'fire year' with the fire occurring in October (late dry season). If in-sufficient fuel was available in the 'fire year', subsequent years were tested until a fire occurred. The model was run from 1886 until 2003.

Results

Figure 2 presents the 3-year average historical rainfall for Clermont and the five woodland vegetation change datasets on a common temporal axis. The response for individual datasets is presented followed by a discussion on the similarities and differences between the datasets.

On-ground monitoring of woody vegetation

Tree basal area of the 24 'long-term' sites increased between the early 1980s until the late 1990s (from a mean 8.58 m^2/ha to 9.73 m^2/ha))(Fig. 2B)(Burrows *et al.* 2002), however basal area declined between the late 1990s and 2004 (to a mean 9.2 m^2/ha). Over the total monitoring period (early 1980s to 2004) basal area increased by an average 0.032 m^2/ha.yr. The 26 'short-term' sites increased in basal area in the first two years in the late 1990s (Burrows *et al.* 2002), however in the subsequent period to 2004 the live tree basal area declined to less than the establishment date tree basal area (from a mean 7.09 m^2/ha to 6.72 m^2/ha). The 20 'new' sites with an average establishment date of late 1999 maintained a relatively stable tree basal area up until 2004.

Aerial photography assessment

Overstorey tree cover of uncleared woodland as estimated by aerial photography across all land types increased from the early 1950s to mid 1990s, although the change at the start and end of the period was slower (Fig. 2C)(Fensham *et al.* 2003). This increase in overstorey cover is equivalent to an average basal area (at 1.3 m) across all land types increasing from 7.74 m^2/ha in 1951 to 9.22 m^2/ha in 1995 and a basal area change rate of 0.034 m^2/ha.yr over the full period. However the change rate from the early 1980s until mid 1990s was about one quarter of the full period change rate (Fensham *et al.* 2003; Fensham *et al.* in-press).

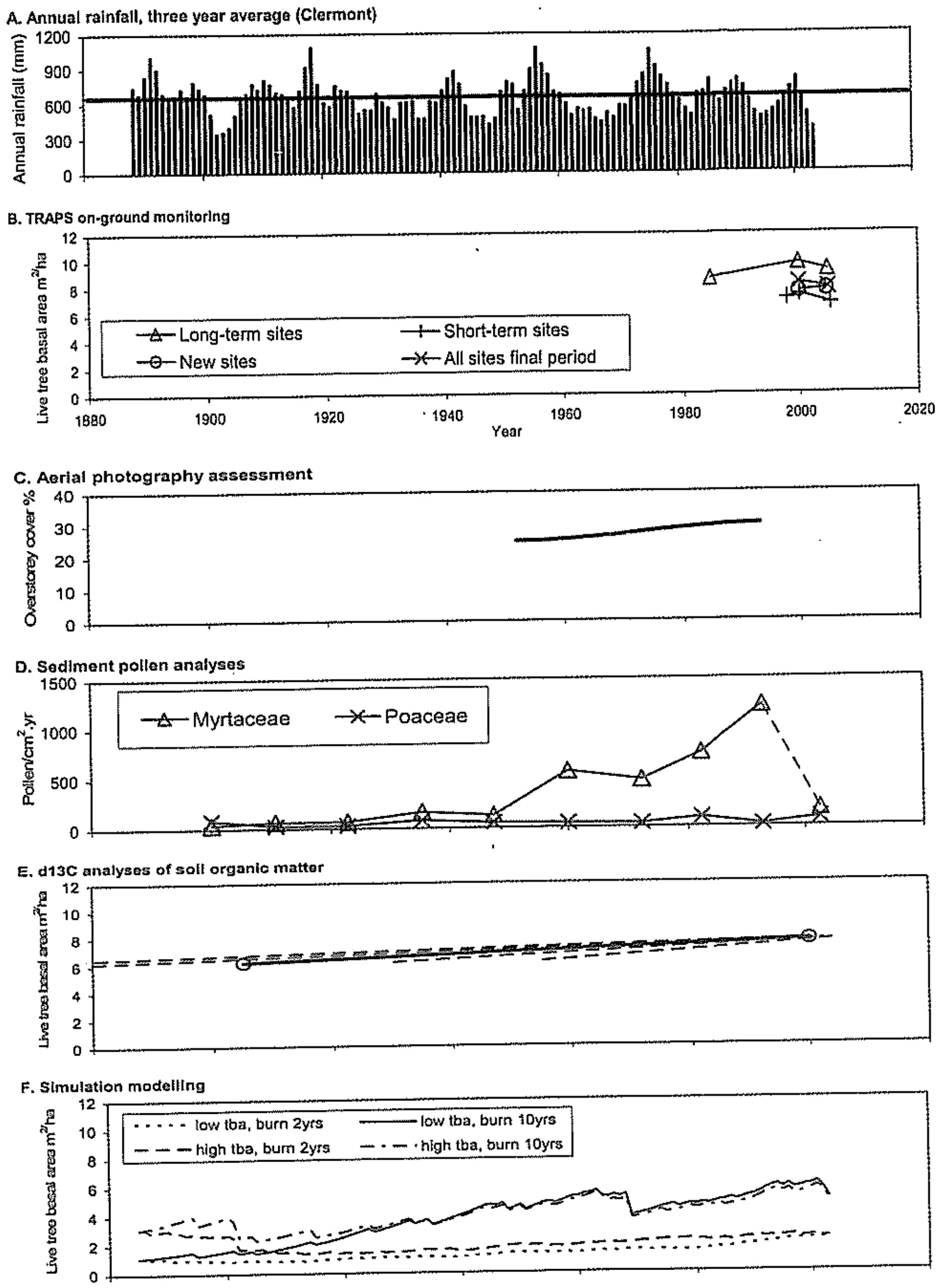

Fig. 2. Compilation of woody vegetation change datasets from central Queensland. A. Three year progressive mean rainfall record at Clermont (Clewett *et al.* 2003)(solid line is long term mean); B. Live tree basal area estimated for the TRAPS on-ground woodland monitoring network (Back *et al.* 1997; Burrows *et al.* 2002). The monitoring sites have been divided into 'Long-term' sites, 'Short-term' sites and 'New' sites. Mean basal area for the average period September 1999 until October 2004 for 'All' sites is presented; C. Overstorey cover for uncleared 'Eucalypts on texture contrast soils' vegetation type assessed from aerial photography (Fensham *et al.* 2003); D. Myrtaceae and Poaceae pollen numbers in a dated sediment core from Lake Dunn (Sim 2004); E. Live tree basal area change estimated from $\delta^{13}C$ analyses of soil organic matter at 44 sites in the Burdekin catchment (Bray *et al.* in prep; Krull *et al.* in review). The historical basal area value has a date range of 50 to 150 years ago. The solid line represents the median historical date (100 years ago) while the outside dashed lines represent 50 or 150 years ago; F. FLAMES simulation modelling of live tree basal area for 4 scenarios, two fire regimes and two initial tree populations (tba = initial tree basal area) (Cook *et al.* in-prep).

Sediment pollen record

Poaceae (grass) and Myrtaceae (commonly *Eucalyptus* and *Melaleuca* spp.) pollen numbers were stable from the early 1900s to the late 1940s (Fig. 2D) (Sim 2004), whereafter the Myrtaceae pollen numbers increased substantially until the early 1990s while the grass pollen numbers remained relatively stable. The increase in Myrtaceae pollen numbers indicates an increase in tree 'dominance' during this period.

Myrtaceae pollen numbers were greatly reduced in the recently deposited sediment surface layer. Low sample mass and therefore limited sample availability may have impacted on the pollen assessment. Lower confidence is held in this datapoint. However other possible explanations include the significant drought period in the early 1990s and early 2000s and significant tree clearing that occurred in the region during the 1990s.

$\delta^{13}C$ analyses of soil organic matter

Across the 44 remnant sites in the Burdekin Catchment the current tree basal area estimated from the $\delta^{13}C$ value of the soil particulate organic carbon fraction was 7.7 m^2/ha (Fig. 2E)(Bray *et al.* in prep). The predicted historical average tree basal area dated between 50-150 years ago was 6.2 m^2/ha. (Krull *et al.* in review) report that 64% of sites were assessed as thickened, 30% of sites as remaining relatively stable and 6% of sites had probably thinned over the 50-150 year time period.

Simulation modelling of woodland dynamics

This simulation modelling exercise used 118 years of historical climate data (Fig. 2F). If we assume the tree population in the late 1800s was similar to the present day (high) and fire frequency is low (1 fire every 10 years) the model predicts the live tree basal area would follow a cycle of increasing basal area until high basal area coincided with a major drought event (e.g. early 1900s, 1960s and early 2000s) resulting in substantial thinning of tree basal area. The low initial tree population and low fire frequency treatment increased in tree basal area, becoming similar to the high tree population simulation by the 1930s. These two scenarios predict an increase in tree basal area since the 1960s drought followed by a recent decline in the early 2000s drought. The impact of a widespread drought on woodland tree basal area in the Burdekin has previously been documented by (Fensham and Holman 1999).

If we assume the initial woodland population in the late 1800s was one third the current population with high fire frequency and conservative grazing, the basal area remained relatively stable until the 1980s followed by a slight increase for the rest of the century. Despite the differences in initial tree basal area both high fire frequency treatments had a similar a tree basal area from the 1920s to the end of the period with the basal area remaining relatively stable year-to-year with apparently little impact from droughts.

Discussion

The most common period of comparison across the datasets is from the 1950s until the 1990s (Fig. 2). The aerial photography, sediment pollen and $\delta^{13}C$ analyses of soil organic matter datasets indicate an increase in woody vegetation over this period which is supported by the on-ground woodland monitoring data from the early 1980s until the late 1990s. The two low fire frequency model simulations also predict an increase in tree basal area from the late 1960s until the late 1990s, while the high fire frequency simulations also show a slight increase.

Prior to 1950, comparison between datasets becomes more difficult. The $\delta^{13}C$ analyses of soil organic matter dataset has low temporal resolution. The dataset does indicate a lower average tree basal area in the 1850s to 1950s period relative to the current tree basal area. This is supported by the sediment pollen record, which indicates low and stable woody vegetation between the early 1900s and 1950s. The low initial basal area and low fire frequency model simulation is generally consistent with the above observations. The high fire frequency simulations however are able to maintain low stable basal area over time.

From the late 1990s until 2004, only the simulation modelling and on-ground monitoring can be compared, as the temporal resolution and end date of the other datasets does not allow comparison.

The on-ground monitoring is generally consistent with the low fire frequency simulations where basal area increases and then declines with the recent drought.

The model simulation which is most consistent across the other datasets is the low initial basal area and low fire frequency simulation which predicted that the tree basal area increased substantially by the 1960s. Our simulations assume that the fire frequency has remained constant over the 118 year period. It is likely the fire frequency may have changed over this period due to changes in infrastructure, fire fighting technology and technology that enables greater utilisation of herbaceous forage (for example *Bos indicus* cattle and livestock supplements).

The on-ground woodland monitoring dataset currently covers a relatively short period, and highlights the need for caution when predicting the rate of vegetation change using short-duration datasets from highly variable climate zones. The monitoring data also supports the prediction by the low fire frequency simulations, that generally, the tree basal area across the woodlands is currently at a level which is periodically severely impacted by major droughts. Consideration should be given to whether dense woodlands in a condition susceptible to droughts is advantageous from a landscape function and condition standpoint.

All vegetation change datasets presented here have made a valuable contribution to understanding vegetation change and cross-checking trends. The fact that the techniques are generally consistent provides a strong indication of the true change that has occurred across the woodlands of central Queensland. Satellite imagery interpretation has potential to revolutionise assessment of woody cover change across landscapes into the future, however linking these trends to the past and ensuring the satellite imagery trend is consistent with other datasets will remain an important research issue.

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Fire in northern Australia: a research update

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Abstract. Fire is an important ecological factor in northern Australia as it is in most of the continent's ecosystems. The link between fire and people in northern Australia is important because, as they have for thousands of years, people have helped determine fire regimes, they have exploited it as a tool, and they have had to respond to the immediate and longer-term consequences of fire. Recent research on fire in northern Australia can be classified in terms of the physics of fire, the chemistry of fire, the geography of fire and the ecology of fire.

The physics of fire describes how the characteristics of individual fires relate to the characteristics of the fuel on which it depends and the nature of the weather during the fire. These relationships are not specific to the region though the region's climate and weather patterns differ from those of other parts of Australia and help govern when fire is more or less likely and the characteristics of fires at different times of year.

The chemistry of fire is important in relation to (i) the impacts of fire on soil chemistry and nutrient cycling; and (ii) how fire influences the chemistry of the atmosphere. The latter has been of increasing interest because of the greenhouse gas and climate change issues. The extensive fires that occur in northern Australia each year potentially contribute significantly to greenhouse gas emissions and recent research has explored these contributions.

The geography of fire describes our knowledge of where and when fires occur. Considerable effort has been made to develop the means of mapping fires in northern Australia and making information on fire occurrence generally available. This information can be used (i) to plan responses to current fires; (ii) to understand broad scale patterns of fire occurrence; and (iii) to inform development of strategic fire management plans.

The ecology of fire in northern Australia has received research attention in recent years so that we have added to our understanding of fire in different ecological systems. Work has been directed at (i) understanding some of the conservation consequences of fire; (ii) exploring fire as a tool for the management of specific weeds; (iii) examining how fire affects native trees and shrubs in certain ecosystems. There are general principles that describe how species, communities and ecosystems respond to fire but inter-regional variation is important. Some regions have received considerably more attention than others.

Animal welfare - why is it so important?

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Abstract. Animal welfare of food producing animals is coming under increasing focus both in Australia and around the world. Pressure from special interest groups combined with retailers releasing new labels for "welfare friendly" products and slowly changing consumer sentiment has seen changes to the standards of animal welfare required by government, business and retailers. These changes provide ongoing momentum to the issue of animal welfare. With Australia's considerable beef exports it is important to understand the factors that are influencing national and global welfare requirements and where this may be heading in the future. This paper provides a summary of recent changes in the area of animal welfare and explores the possible implications this has for the Australian beef industry.

Introduction

Animal welfare of food producing livestock is coming under increasing focus both in Australia and around the world. In recent years the Australian community has become more aware of animal welfare issues and the Australian government has increased the focus on animal welfare through development of the Australian Animal Welfare Strategy (AAWS). The strategy was finalised in 2004 and highlights the Australian Government's commitment to animal welfare (DAFF 2005). The strategy will provide direction for future animal welfare policies and facilitate the establishment of priorities and development of acceptable welfare standards. The AAWS will receive $6 million in federal funding over 4 years and addresses the care, uses and effects of human activity on all sentient animals in Australia. The increasing focus on animal welfare has been encouraged by special interest groups and consumers and has led business and government to implement changes that could impact on the Australian meat industry's ability to access overseas export markets. This is particularly true for the premium markets which are often the target for Australian products.

Discussion

Market Access – retailer requirements and international finance organisations

As consumers become more aware of, and respond to, animal welfare issues, business and government follow suit. For example one third of the leading global food retailers with turnovers ranging from US$25-250 billion have public animal welfare policies (International Finance Corporation 2006). McDonald's has made a global commitment to animal welfare through the establishment of McDonald's Global Animal Welfare Guiding Principles, which were put in place in 1999 (McDonalds Corporation 2006). The McDonalds Guiding Principles on animal welfare are aimed at treating animals with care and respect and keeping them free from cruelty, abuse and neglect. They cover 7 key elements which include food safety, animal treatment and supplier auditing. McDonald's also established the industry's first independent expert Animal Welfare Council to guide the efforts of their animal welfare program in an ongoing process of study, consultation, and innovative improvement. The core of the animal welfare program is a global audit system for beef, poultry and pork processing plants. This system is based on scientific animal behaviour research and consists of technical standards for animal treatment and protocols for measuring compliance. In 2005, approximately 520 audits were completed, reaching facilities in all the major areas of the world where McDonalds source their products.

International finance and lending organisations are also beginning to consider animal welfare. In 2005 Rabobank released an industry note (138-2005) titled "Animal welfare requirements: changing production and trade" (Rabobank 2005). The paper included an outline of animal welfare activities and changes in expectations of retailers and end-users in relation to animal welfare assurance for products. The report also discussed changes in relation to animal welfare regulation and the impact welfare changes within a supply chain can have on market access, such as the EU changes in relation to regulations for housing calves for veal production. Producers in the Netherlands were early adopters of new EU group housing requirements and as a result they experienced increase in demand for their product over other countries in the EU who had not implemented these changes (Rabobank 2005). In 2006 the International Finance Corporation (IFC) also released a good practice note on animal welfare in livestock operations (International Finance Corporation 2006). The IFC is the private sector arm of the World Bank Group and currently invests $300 million in livestock operations in developing countries. The Good Practice Note states the IFC will "consider animal welfare issues when selecting projects and will seek ways to promote systems that positively impact animal welfare" (International Finance Corporation 2006).

Rabobank also raised the possibility of animal welfare becoming a pseudo trade barrier with barriers not necessarily part of government or World Trade Organisation rules and regulations, they could be industry, consumer or even activist led (Rabobank 2005). One clear example of this is the PETA campaign against mulesing and the potential impact this has had on market access for Australian wool.

In 2005-2006 Australia exported 65% of the total beef produced which had a total value of approximately $4.5 billion (ABS 2006). If welfare issues were to disrupt Australia's exports or prevent exportation to current markets it could have a significant impact on the market prices for livestock. This would have flow on impacts not only for producers but all sectors of the red meat supply chain.

Consumer surveys

A survey conducted in 2001 (Harper and Henson 2001) investigated consumer concerns about farm animal welfare and the impact on food choice in the United Kingdom, Ireland, Italy, France and Germany. The work identified and analysed the nature and level of consumer concern within the study countries. The results showed that although consumers were concerned about farm animal welfare, this concern was not always a major priority in their food choices. Consumers defined animal welfare in terms of natural lives and humane deaths, suggesting that animals should be reared, fed, housed, mated and allowed to behave as close to natural conditions as possible. This sentiment may provide an advantage for Australian production systems which are traditionally more natural than many production systems in Europe.

The Harper and Henson (2001) study showed consumers claimed they were uninformed about livestock production systems and would like more information to inform their purchase choices. Although consumers claimed they were willing to pay more for improved animal welfare, this did not always translate into practice at point of purchase (Harper and Henson 2001). Reported barriers limiting purchase of 'animal-friendly' products include lack of information about production methods, lack of availability of products, lack of belief in the ability of individual consumers to make a difference to animal welfare standards, disassociating the product from the animal of origin and the increased cost of 'animal-friendly' products (Harper and Henson 2001). When consumers do choose welfare products, invariably they buy free-range eggs. These products are relatively inexpensive and, therefore, the premiums are not so prohibitive. Consumers indicated they would like to see changes including establishing acceptable minimum standards and changing EU agricultural policy to provide farmer incentives for higher welfare systems (Harper and Henson 2001). Therefore they supported the ongoing subsidisation of the agricultural industries within the EU and suggested this should be linked to animal welfare standards.

Another survey of EU consumers (known as the Eurobarometer survey) was conducted in 2005 focusing on the attitude of consumers to the welfare and protection of farmed animals across the 25 member countries within the EU. The outcomes of the survey indicated that European consumers were willing to pay more for animal welfare friendly food products but wanted the products to be more easily identified (Eurobarometer 229 Report 2005). The survey showed 43% of respondents considered animal welfare when buying meat and that 74% of consumers believed they could improve animal welfare through purchasing choices. Furthermore 57% indicated they were willing to pay more for animal welfare friendly products however they would only pay a price premium of 5% or less for eggs sourced from a welfare friendly' production system. Labeling is providing challenges for the development of a welfare friendly category, with 32% of consumers indicating they could never identify welfare friendly food products when shopping.

It could be concluded that between 2001 and 2005, the attitudes of consumers have changed with more consumers indicating a willingness to pay more for welfare friendly products and indicating better product labeling is important to assist with this purchase choice.

A survey of community attitudes in Australia in 2006 showed participants were very interested and showed an emotional engagement with the topic of animal welfare (TNS Social Research 2006). The survey also found that participants lacked some knowledge and/or were misinformed in relation to animal welfare issues such as live export, battery hens and mulesing (TNS Social Research 2006). This suggests that campaigns and media around these issues can raise community awareness, therefore it is important to ensure factual information is available to assist the communities understanding of welfare issues.

Farm Assurance Systems and product labeling

The increase in consumer focus on animal welfare is supported by the development of the RSPCA monitored freedom foods program. The program is a UK based farm assurance scheme established in 1994 (RSPCA UK Freedom Foods 2006) and it underpins the "freedom foods" label which assists consumers to identify welfare friendly products. The system allows certification for farmers, transporters, abattoirs, processors and packers and it covers free-range, organic and indoor systems. Products include eggs, meat, poultry, fish and dairy. Species-specific standards cover each stage of an animal's life, including handling and transportation. Members are inspected before entering the system and re-inspected each year. The UK RSPCA claim freedom foods labelled products are stocked by major supermarkets, independent stores and farm shops throughout the UK and can be purchased online. However there are only 2,200 members presently in the program (RSPCA UK Freedom Foods 2006). While there is obviously a niche market for these products, the mainstream consumption is still limited by demand and supply.

Building on the 2005 Eurobarometer survey which indicated 32% of consumers had concerns with food labeling of welfare friendly products, in 2006 the European Commission released a 5 year EU plan to promote animal welfare which includes creation of a special "animal welfare" label for meat and fish products. The action plan sets out 5 main areas of action until 2010 (European Commission 2006) and includes upgrading the minimum standards for animal welfare, promoting research, introducing standardised animal welfare indicators and informing the general public on animal welfare issues. The welfare label is expected to help consumers make informed choices and allow for differentiation between products. The animal welfare plan, requested by the Executive Council, proposes development of this animal welfare label.

The movement towards labelling of products to differentiate between production standards is also occurring in the Whole Foods Market chain which has 189 stores across North America and the United Kingdom (Whole Foods Market 2006). Whole Foods have launched a new line of meat labelled 'animal compassionate' which covers animals from production, transport and slaughter. The chain indicates there is a lot of interest in other items it sells such as 'free-range' chickens (Ahmed ElAmin 2006). While it is unknown exactly how large the niche market is for humane labelled products, Whole Foods believes there is a general consensus that it will "expand substantially" when they begin offering their animal-compassionate line in stores. This builds on the observation that cage-free eggs, which usually cost a great deal more, are already a popular item in Whole Foods' refrigerated case (Ahmed ElAmin 2006).

The Whole Foods plan to adopt the 'animal compassionate' logo has taken 3 years to develop. The Animal Compassionate Standards require production systems to support the animal's physical, emotional, and behavioural needs. Animal welfare requirements for products sold under the 'animal compassionate' label include an annual affidavit from each producer outlining their raising and handling practices, feed, facility design, environmental conditions, employee training, veterinary practices, and animal welfare at the farm (Whole Foods Market 2006). The standards allow husbandry practices only when the overall physical and psychological welfare of the animal is benefited, to prevent possible injury and only when conducted by a trained operator. In addition, spaying female cattle is prohibited and animals must be castrated before the calf reaches 8 weeks of age. Branding, de-horning and de-budding is prohibited along with electro-immobilization and the use of electric prods. Furthermore if transportation is to exceed 8 hours, the animals must be rested for 24 hours (off the truck) before continuing, unless the destination can be reached in a total of 12 hours (Whole Foods

Market 2006). While these requirements outline the standards to supply this niche market they do highlight possible areas of concern for consumers and indicate what future changes may be required for other production systems.

The Australian RSPCA also has a national food accreditation system (RSPCA Australia 2006). The RSPCA believes that farm animals must be treated in a way which meets their physical, physiological and psychological needs. Farm animals must not only be provided with appropriate food, shelter and veterinary care, they must have the freedom to express normal behaviours and be kept in an environment which avoids suffering (RSPCA Australia 2006). The RSPCA therefore opposes some common practices in farming and animal husbandry because it believes the practices do not meet the animals' needs. An example of one of the practices they consider unnecessary is hot iron branding of livestock (RSPCA Australia 2006). In the 1990's the RSPCA developed a set of standards for egg producers that supports a high standard of welfare for hens. This requires that hens are not kept in battery cages, they have litter in which to dust bathe, space to flap wings, stretch and socialise, nests in which to lay their eggs, and adequate perch space. Accreditation is granted if producers meet the standards and allow regular inspections to ensure standards are maintained. Eggs are sold with the RSPCA logo so consumers can identify them. More recently the RSPCA developed standards for welfare friendly pork production (RSPCA Australia 2006). Under these standards accreditation requires all pigs are kept either in well-managed extensive outdoor systems or within enhanced indoor environments that cater for the behavioural and physical needs of sows, boars, and piglets and where considerate handling, transportation and humane slaughter are observed (RSPCA Australia 2006).

International developments

The World Organisation for Animal Health (OIE - Office International des Epizooties) has taken a lead role in international animal welfare activities. Animal welfare was identified as a priority in the OIE's 2001-2005 Strategic Plan (OIE 2006). In May 2002 the 167 OIE member countries agreed to start development of policies and guidelines for animal welfare. A permanent working group on animal welfare was established and met in October 2002 with priority given to welfare of animals used in agriculture and aquaculture, particularly transportation (land and sea), humane slaughter and killing for disease control purposes. The primary task for the working group was the development of policies and guiding principles that could be used as a foundation for recommendations and standards.

In May 2005, the International Committee of OIE Member Countries adopted 4 animal welfare standards to be included in the OIE Terrestrial Animal Health Code (OIE 2006). These standards covered the transport of animals by land, the transport of animals by sea, the slaughter of animals and the killing of animals for disease control purposes. Animal welfare is not covered by the World Trade Organisation Agreement on the Application of Sanitary and Phytosanitary Measures. Therefore the developed standards cannot be used as a basis for trade barriers under the WTO agreement, however OIE Member Countries wished to have guidelines and recommendations to assist them in their international negotiations (OIE 2006).

In November 2006 the Council of Europe, the European Union and the World Organisation for Animal Health (OIE) adopted a joint declaration on animal welfare (European Union 2006). In the declaration, the organisations committed to further development of animal welfare guidelines set by the OIE, development of basic legislative or practical tools to assist application of welfare standards and raising public awareness of the societal value of animal welfare (European Union 2006).

In recent months animal rights have also been launched into the political arena. In the Netherlands, the Party for Animals (founded in 2002) became the first animal rights party to win seats in a European parliament with 2 candidates elected out of 150 seats (Party for the Animals 2006). The party see advancing animal rights as a follow-up to liberating slaves and giving rights to women. Their priorities are to phase out factory farming throughout the Netherlands, grant animals constitutional rights, establish an animal police force and ban animal testing. A new political party campaigning for animal rights was also launched in the UK, called Animals Count. It is linked with the Dutch Party and intends to contest the Welsh National Assembly elections in 2007 with plans to then extend the work into England and Scotland (Animals Count 2007). Party policies include an end to transportation of live animals for over 200 miles to or from destinations within the UK, European continental destinations and further afield (Animals Count 2007). There have been suggestions that these groups are vying for the ethically and socially conscious vote.

The greater focus on animal welfare both through international organisations and political activities further supports the ongoing momentum behind animal welfare.

The concept of animal welfare v. animal rights

In any discussion of animal welfare it is important to distinguish between the animal welfare and animal rights approaches. The animal welfare position argues there is nothing inherently wrong with using animals for food, as entertainment and in research, however, human beings do have an obligation to ensure animals do not suffer unnecessarily (Frey 1980, Scruton. 2000). This position is held by some of the oldest of the animal protection agencies such as the Royal Society for the Prevention of Cruelty to Animals (RSPCA). In comparison Animal Rights proponents argue for the moral rights of non-human animals such that they are not used or regarded as property by humans. This is supported by Tom Regan's book (1981) which proposes that non-human animals are the bearers of moral rights which means they have the right to be treated with respect, including the right not to be harmed. This philosophy is to protect non-human animals from being used or regarded as property by humans, which can extend not just to preventing animal use for food or fiber production but also for use as companions or even use of guide dogs to assist the blind. Some special interest groups are concerned with animal welfare (eg: RSPCA) while others are interested in animal rights (eg: PETA).

Special interest groups: animal welfare and animal rights

The number and activity of special interest groups in the area of animal welfare are increasing. The RSPCA philosophy is "wherever animals are used by humans, they must be treated humanely, compassionately and with consideration" (RSPCA Australia 2006). The RSPCA believe that as long as farm animals are in our care, we have a responsibility to provide for (at least) their basic needs in accordance with the RSPCA's Five Freedoms which can be described in general terms as, providing adequate space, food, and water; veterinary treatment when required; shelter from the elements; and freedom to express some essential natural behaviours (RSPCA Australia 2006).

The Australian RSPCA has held annual scientific seminars since 1999 and in 2005 the seminar focused on the Five Freedoms and improving welfare of production animals (RSPCA Australia 2006a). The seminar considered the biological and behavioural needs of production animals and how farm animal welfare science can help to align husbandry and management practices to meet those needs. The focus on production animals highlights the attention given to livestock and current productions systems. The RSPCA science based approach supports ongoing industry investments through research and development to identify suitable management practices and improve understanding of the animal welfare outcomes of such practices.

The RSPCA has campaigns against some livestock production practices including battery hen farming, live exports and the use of sow stalls in pork production (RSPCA Australia 2006b). Concerns raised by the RSPCA include the fact that these practices are within the bounds of the law and the RSPCA encourage people to contact their federal and state governments requesting that these practices be outlawed. The RSPCA have considerable profile within the community with a survey in 2006 showing they are the preferred channel for information on animal welfare issues (TNS Social Research 2006). RSPCA information relating to farming practices must be respected as it could have a significant impact on community views.

In comparison, People for the Ethical Treatment of Animals (PETA) slogan is "animals are not ours to eat, wear, experiment on or use for entertainment." PETA rejects the idea of animals as property and the organisation's website states: "PETA believes animals have rights and deserve to have their best interests taken into consideration" (PETA 2006). PETA is the self proclaimed largest animal rights organisation in the world, founded in 1980 they are funded almost exclusively by contributions of members with a self reported income of US$27.8 Million in 2005-2006 (PETA 2006).

Since 2004, PETA has led an aggressive campaign against the practice of mulesing merino sheep in Australia. They carried out a very public attack against Benetton fashions to encourage them to boycott Australian wool and are campaigning for an immediate ban on mulesing without consideration for the impact on sheep through greater risks of fly strike. Recently PETA and the Australian Wool Growers Association (AWGA) reached agreement with some farmers choosing to replace mulesing with alternative practices. PETA claim that following this agreement more than a dozen retailers, which have annual combined sales of more than $30 billion, have pledged to purchase the new wool brand (Save the Sheep.com 2006). PETA have also targeted the Australian live export trade, particularly the sheep trade to the Middle East. While it is possible for livestock production industries to find common ground with groups such as the RSPCA on some issues, the basic philosophy of animal rights groups such as PETA which claims "animals are not ours to use" prevents this.

Conclusion

Growing focus on animal welfare both nationally and internationally supports ongoing momentum for this issue. Animal welfare awareness will continue to grow and it is essential for industry to maintain its commitment to improved understanding and implementation of welfare best practice throughout the red meat supply chain.

The activities of special interest groups bring animal welfare to the attention of consumers both nationally and globally, encouraging them to put greater emphasis on the way in which food and fibre producing animals are treated throughout their lives and this focus can influence their buying habits. Animal welfare is beginning to have an impact on consumer choices and has the potential to impact on future market access. One clear example is the establishment of the free range egg market in many retail stores. This differentiation in product and the on-going demand for free range eggs supports the growing social awareness of animal welfare and the link between consumers food choices and the animals and production systems that it comes from.

Recent developments include the establishment of specific welfare friendly labels which are currently seen as niche markets, and standards for retailers including significant players such as McDonalds. Results from consumer surveys indicate growing consumer awareness of animal welfare however this does not always translate into a willingness to pay more for welfare friendly products. Increasing activity and media coverage of animal welfare and animal rights groups also increases the profile of animal welfare and broadens the community's awareness of animal welfare issues. Recent political developments in the Netherlands and the UK also suggest welfare will enter the political field which will add further attention to the growing interest. Closer to home impacts have been felt with changes to mulesing and live export regulations occurring following issues that have been raised by activist groups and in some cases supported by the public. In short, animal welfare is an issue which needs to continue to be addressed proactively by industry to minimise the potential for any negative impacts on future growth and development.

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Horns inheritance and the role for polled genes in tropical beef cattle

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Abstract. Breeding polled cattle is a cost effective alternative to the practice of dehorning. The inheritance of polled / horned condition is presumably under the influence of three genes i.e. polled, African horn and Scurs. Because of the relative complexity of inheritance and the sex – influenced nature of these genes, DNA markers would greatly help the introgression of polled genes into the cattle breeding population in northern Australia. Results from a simulation study demonstrating the importance of genetic marker tests for implementing marker assisted introgression strategies for polledness are presented. The current research plans of a Beef CRC project on developing genetic markers for polled, African horn and Scurs genes are also outlined and the preliminary results from the segregation analysis are presented.

Introduction

Dehorning is routinely practised in beef cattle, as horns are an important cause of bruising, hide damage and other injuries, particularly in yards, feedlots and during transport. Besides economic losses through carcase damage estimated to be $22.5 million per year, horns cause injury to cattle handlers, dominant behaviour in yards and handling difficulties in crushes and during transport. Mustering practices in Northern Australia and the labour intensive nature of the dehorning, especially in older calves, make breeding polled cattle an ideal alternative. However, estimates derived from breed society records, show that the major breeds of cattle in Northern Australia such as Brahman and Santa Gertrudis are predominantly (around 90%) horned (Prayaga, 2005). The high number of horned cattle in tropical breeds is mostly due to a lack of selection for polledness and a relatively complex mode for the inheritance of horns. In this paper, the complexity of inheritance of horns in tropical breeds and the use of DNA markers to increase the number of polled cattle is discussed. The current status of the MLA funded Beef CRC project aiming to develop genetic markers for polled, African horn and Scurs genes in tropical beef cattle is also outlined.

Inheritance of horns

The inheritance of horns was one of the earliest reported examples of Mendelian inheritance in cattle. However, as it turned out, it was a more complex inheritance pattern in cattle than initially assumed. Absence of horns, referred to as the polled condition, supposedly originated with a single gene mutation (from *p* to *P*) in many breeds of cattle. In 1902, Bateson and Sanders (reported in Shrode and Lush, 1947) were the first to report that the polled condition was dominant over the horned condition in cattle. White and Ibsen (1936) proposed a most comprehensive hypothesis explaining the mode of inheritance of horned, polled and scurred conditions in cattle. Over the years, several other breeding experiments were conducted to help understand the mode of inheritance of horns in cattle (see Prayaga 2007 for a review).

Several researchers working on the discovery of genetic markers, closely linked to the polled gene, have followed the hypotheses of polled/horned/scurred inheritance (Georges *et al.* 1993; Table 1). The African horn gene (*Ha*), as the name suggests, is rare in British breeds but supposedly at a higher frequency in Zebu cattle. The African horn gene is believed to be segregating independently but with an epistatic effect on the 'polled' locus and is sex-influenced in its inheritance i.e. heterozygotes in males are horned and in females are polled. The expression of the scurs gene is also sex-influenced. The heterozygote (*Sc sc*) is scurred in males, but only homozygote (*Sc Sc*) is scurred in females. However, Georges *et al.* (1993) cautioned that scurs and African horn gene could also be different alleles at the same locus. Table 2 illustrates the expected phenotypic frequencies for the different sexes under the Georges *et al.* (1993) mode of inheritance shown in Table 1.

For both Table 1 and Table 2, if 'polled' means 'favourable' then: Polled gene – 'P' is favourable and 'p' is unfavourable allele; Scurs gene – 'Sc' is unfavourable and 'sc' is favourable allele; African horn gene – 'Ha' is unfavourable and 'ha' is favourable allele.

Table 1. Inheritance of scurred and African horn genes in beef cattle (Georges *et al.* 1993)

Genotype	Males	Females
Inheritance of the scurred phenotype		
P/- Sc/Sc	Scurred	Scurred
P/- Sc/sc	Scurred[a]	Polled
P/- sc/sc	Polled	Polled
p/p -/-	Horned	Horned
Epistatic effect of the African horn gene on the polled locus		
P/- Ha/Ha	Horned	Horned
P/- Ha/ha	Horned	Polled
P/- ha/ha	Polled	Polled
p/p -/-	Horned	Horned

[a]*Sc/sc* males express the scurred phenotype only when heterozygous *P/p* according to Long and Gregory (1978).

Table 2. Percentages of horns status phenotypes at various allele frequencies of Polled, African horn and Scurs genes

	Males (%)	**Females (%)**
Very High favourable allele frequencies (P=0.9; ha=0.9; sc=0.9)		
Horned	19.8	2.0
Scurred	15.2	1.0
Polled	65.0	97.0
High favourable allele frequencies (P=0.7; ha=0.7; sc=0.7)		
Horned	55.4	17.2
Scurred	22.7	7.4
Polled	21.9	75.4
Moderate favourable allele frequencies (P=0.5; ha=0.5; sc=0.5)		
Horned	81.2	43.7
Scurred	14.1	14.1
Polled	4.7	42.2
Low favourable allele frequencies (P=0.3; ha=0.3; sc=0.3)		
Horned	95.4	74.0
Scurred	4.2	12.7
Polled	0.4	13.3
Very Low favourable allele frequencies (P=0.1; ha=0.1; sc=0.1)		
Horned	99.8	96.4
Scurred	0.2	2.9
Polled	0.0	0.7

The phenotype frequencies were based on the assumptions of genes in Hardy–Weinberg equilibrium (Falconer and Mackay 1996) and the hypothesized inheritance model (Table 1). For these calculations, the Long and Gregory (1978) exception of *Sc/sc* males expressing scurs only in *P/p* was ignored. It is clear that even at very high frequencies (90%) of the favourable alleles (*P*, *ha*, *sc*), 35% of males are either horned or scurred. More than 95% of males and around 60% of females are either horned or scurred at intermediate allele frequencies (0.5) of polled, scur, and African horn genes. At low (0.3) and very low (0.1) frequencies of favourable alleles, males and females are predominantly horned or scurred. This highlights the potential problems associated with breeding polled animals in populations with relatively low to moderate gene frequencies of the favourable alleles. Another complicating factor is that at least 50% of the polled males would be heterozygous at the poll gene and at least 50% polled females would be heterozygous at the poll, scur, and African horn genes. This poses problems relating to selection of breeders. The availability of DNA tests would enable the identification of homozygous polled animals for future breeding and thus, effective introgression of polled genes into the population.

Marker Assisted Introgression

In beef cattle introgression is only viable for genes of large effect and genes affecting traits such as presence or absence of horns, because of long generation intervals and low reproductive rates. Introgression of the polled gene into beef cattle breeds can be attempted by continuously breeding polled bulls with horned cows and selecting for polled cows and bulls for breeding in later generations. This is simple and is readily achievable in principle, but the complexity of the mode of inheritance and the lack of sufficient numbers of genetically superior polled bulls in some breeds poses problems for its successful implementation.

Introgression strategies benefit from using marker information (marker assisted introgression) because of increased accuracy in identifying the genetic status of individuals (i.e. homozygous *vs.* heterozygous). These markers can be direct markers or linked markers. Direct markers are the actual genes that code for the phenotype and linked markers are those that are closely linked with the genes that code for the phenotype. The effectiveness of introgression strategies are also affected by the frequency of the desired gene in the population. To help understand the importance of genetic markers for introgression of polled genes into a tropical beef cattle population, a simulation study was conducted.

Simulation

Given the complexity of inheritance and the phenotypic expression of horns status at various allele frequencies explained above, a simple simulation was conducted to compare various scenarios arising out of four combinations of low (0.3) and high (0.7) favourable allele frequencies at polled and African horn loci. These scenarios were compared to estimate the number of years taken to achieve 100% polled animals with or without the availability of DNA tests. This simulation was conducted under the following set of assumptions and conditions:

- Each year 1000 cows were joined to 25 bulls. Initially, 10 years of breeding is conducted to stabilise gene frequencies without any selection for polledness. Selection for polled breeders was implemented from year 12 in the simulation.
- Selection of breeders (from year 12) was based on polled condition only, ignoring the rest of the traits. This assumption is unrealistic under practical conditions. Each year, both bulls and cows were selected for polledness and if there are fewer than 1000 polled cows, horned cows were used for breeding.
- Bulls were used for 2 years and cows had their first calf at 2 years and were kept in the herd up to 7 years.
- Replacement cows and bulls were from the same herd.
- Horned / polled condition was under the influence of polled gene (*P/p*) and African horn gene (*Ha/ha*). Scurs were ignored.
- Best case scenario of gene test was assumed (direct marker test i.e. not a linked marker test). Four scenarios based on allele frequencies were: Low *P* (0.3) and low *ha* (0.3); Low *P* (0.3) and high *ha* (0.7); High *P* (0.7) and low *ha* (0.3); High *P* (0.7) and high *ha* (0.7). Scenario 1 with lower allele frequency of polled gene and lower frequency of favourable allele of African horn gene was comparable to the *tropical* breeds and Scenario 4 with higher frequencies of favourable alleles at polled and African horn loci was comparable to the *temperate* breeds in Australia.
- In each of the above mentioned allele frequency combination, selection of breeders was based on: no DNA test (based on polled phenotype); polled gene test only; African horn gene test only; and both tests.

Table 3. Estimated number of years to achieve 100% polled animals at various frequencies of favourable alleles (years after initial 12 years of stabilisation)

Scenarios	No DNA test	Polled gene test	African horn gene test	Both tests
1. Low '*P*' and low '*ha*'	39 years	25 years	38years	8 years
2. Low '*P*' and high '*ha*'	33 years	18 years	33 years	6 years
3. High '*P*' and low '*ha*'	30 years	23 years	30 years	6 years
4. High '*P*' and High '*ha*'	30 years	18 years	28 years	4 years

Number of years to achieve 100% polled animals in the simulated population (average from 50 replications) varied substantially in various above mentioned scenarios (Table 3). While the availability of the African horn gene test alone did not hasten the introgression process, it was evident that knowledge of both tests gives substantial advantage in achieving the objective of 100% polled animals in all the scenarios. However, it should be noted that it was an optimistic view of selection decisions being based exclusively on poll phenotype.

Especially in Northern Australian beef herds and in breeds where favourable alleles (P and ha) are at low frequency, it is crucial to have information on both gene tests to effectively introgress the polled gene. The problem in these breeds is that relatively few polled bulls are available and specific polled bull breeding programmes cannot be implemented easily, unless DNA tests are available. Information on any one of the genes is ineffective because of the complex nature of inheritance. However, it is possible that in some of the *Bos taurus* breeds, the unfavourable allele of the African horn gene may be at very low frequencies or even fixed for its favourable allele. In such cases, a test for the polled gene only may be effective for achieving desirable results. The importance of DNA tests increases under more realistic scenarios such as lower selection pressure on the polled gene, because of the emphasis on other economic traits. Under practical conditions, these tests will be useful in deciding selective use of genetically proven bulls i.e. two polled bulls of relatively similar EBVs for important production traits can be compared for their genotype at the polled, scurred and African horn loci before making breeding decisions.

Beef CRC Project – Genetic Markers for Poll, African horn and Scurs genes

A research project, funded by Meat and Livestock Australia, under the auspices of Cooperative Research Centre for Beef Genetic Technologies (Beef CRC) is currently underway to develop genetic marker tests for poll, African horn and scurs genes in *Bos-indicus* and Sanga derived cattle of tropical Australia. This project is aiming to exploit the novel genetic technologies such as gene expression and systematic search of the entire genome using single nucleotide polymorphisms to identify chromosomal segments containing genetic elements associated with polled, horned and scurred condition in cattle.

Segregation analysis

As an initial step, a segregation analysis of the horns inheritance based on the historical Belmont Research Station databases is being conducted. Preliminary results from this study are presented here. Data consisted of horn status phenotypes of 8 breeds / composite lines recorded from 1973 to 2000. Out of a total of 19,842 animals, only 10,702 animals had records on horn status phenotype; and only 6,587 animals had phenotype records on themselves and their sire and dams. Hence, this subset of the data was used for segregation analysis. The hypotheses on horns inheritance (Table 1) presented by Georges *et al.* (1993) and a slight variation of it as per Long and Gregory (1978) were tested by postulating three bi-allelic loci: Poll (P / p), African horn (*Ha* / *ha*), and Scurs (*Sc* / *sc*). The observed number of individuals in each of the possible phenotypes were compared with expected number of individuals under two hypotheses for all possible gene frequencies. The least unlikely (most likely) ranges of allele frequencies are reported (Table 4) after a complete grid search of the parameter space for all gene frequencies between 0 and 1 in increments of 0.01 using a maximum likelihood method.

Table 4. Range of least unlikely gene frequencies for three loci (Polled - *P*, African Horn - *Ha*, Scur - *Sc*) under two hypotheses

Population	Males	Females	Hypothesis	f(*P*)	f(*Ha*)	f(*Sc*)
All	3234	3353	Georges *et al.*	0.34-0.46	0.34-0.40	0.20-0.27
			Long and Gregory	0.25-0.31	0.38-0.49	0.21-0.62
Belmont Red[a]	649	700	Georges *et al.*	0.25-0.37	0.0-0.05	0.25-0.36
			Long and Gregory	0.25-0.34	0.0-0.06	0.34-0.46
Belmont Cross[b]	440	466	Georges *et al.*	0.18-0.27	0.20-0.37	0.34-0.41
			Long and Gregory	0.18-0.25	0.51-0.64	0.50-0.61
Brahman	269	270	Georges *et al.*	0.0-0.05	0.80-0.87	0.00-0.15
			Long and Gregory	0.0-0.05	0.79-0.86	0.00-0.15

[a]Belmont Red – ½ Africander, ½ Hereford-Shorthorn. [b]Belmont Cross – ½ Brahman, ½ Hereford – Shorthorn.

Neither the complete nor any of the subsets of data fitted either hypothesis and showed departures from expectations ($P<0.001$). The lack of support for either hypothesis by the data probably arises from parents and progeny not being in equilibrium, or errors among the phenotypes and/or other factors involved in these hypotheses.

The frequencies occurring in the least unlikely 1000 samples are presented in Table 4. The range of least unlikely frequencies for *P*, *Ha* and *Sc* suggest that both alleles for each locus are present in the population. There is some evidence for the presence of African horn gene at moderate frequency in the population. For example, Belmont cross horn phenotypes are most likely to arise from the African horn gene rather than the recessive poll gene. The incidence of '*P*' in Brahmans appears to be low whereas that of '*Ha*' is high. The molecular genetic studies searching for *Ha* gene will have greater success if the genetic status (haplotype) at the poll locus is known. Further exploration of data with alternate hypotheses of considering a model with two bi-allelic loci (*P* and *Ha*) will be carried out.

Conclusion

Because of the seemingly complex nature of horns inheritance in tropical beef cattle, further research is needed to determine the genetic basis of presence or absence of horns. The current research program aims to capitalise on the results from segregation analyses and identify genetic markers closely linked to the genes of interest through whole genome scan and gene expression approaches.

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MLA's animal welfare research in the northern beef industry

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Abstract. There is increasing consumer interest in the welfare of animals used in food production systems. As a consequence there is increasing scrutiny of the practices and production systems being used by food producing industries. In 2005 MLA developed an Animal Welfare R&D Program Strategy which has directed the establishment of the animal welfare research program. Key research activities in this program of interest to the northern Australian beef industry include: research to demonstrate the welfare outcomes for long haul transport (up to 48 hours), development of alternatives to castration and dehorning and the identification of objective measures which can be used to assess animal welfare.

Introduction

Interest in animal welfare is growing both nationally and internationally. Changes include increasing political focus on welfare, major retailers implementing their own welfare assurance schemes and a move to product labelling to identify products from welfare friendly systems. Given the increasing momentum of animal welfare it is important to consider the position of the Australian northern beef industry in relation to animal welfare.

Meat and Livestock Australia's involvement in animal welfare research in the past has focussed on livestock management issues within a production context. Specific examples include the feedlot and live export industry's focus on heat stress, ventilation and animal disease. Production focussed industry initiatives have resulted in positive impacts on animal welfare including the Willis Spay technique for northern beef cattle, buffalo fly control, vaccine development and the livestock management aspects of the Meat Standards Australia. These practical improvements have been important in demonstrating that animal welfare and production efficiency are often complimentary. Ensuring that these linkages continue to be identified and communicated in future research will be an important element in the Animal Welfare R&D Program.

In December 2003, Meat and Livestock Australia (MLA) undertook a process to determine research priorities in animal welfare and develop a strategy to guide future investments. A range of stakeholders including representatives from industry, government, research organisations, non-government organisations (NGO's), the private sector and animal welfare groups were involved in development of the program strategy through a series of workshops conducted in each state. The Livestock Production Animal Welfare R&D Program Strategy has been developed as a result of these consultations. The strategy was finalised in February 2005 and forms the basis for the establishment of the current R&D investment program.

This paper will provide a summary of the 6 priority areas outlined in the MLA Livestock Production Animal Welfare R&D Program Strategy and provide details on projects in key areas of interest. It will also provide information on current developments in some of these key areas and explore the potential implications for Australia's northern beef industry. It is important to note this strategy does not aim to address feedlot and live export research issues which are dealt with in the feedlot and joint MLA-LiveCorp R&D programs respectively. Furthermore, the animal welfare benefits that accrue from MLA's environment, health and productivity programs will also not be covered in the paper.

MLA Welfare Research Strategy

The overarching objective of MLA's Livestock Production investments in animal welfare R&D is to support productivity, product quality and market access by providing tools and knowledge to improve the well-being of Australian livestock and address issues of community concern. The priorities outlined in the strategy include:

- building Australian research capability;
- improving the well-being of livestock raised under Australian production systems;

- to prevent trade / market access from being interrupted by animal welfare concerns;
- to provide innovative, cost effective alternatives to practices that may be considered by the community to adversely affect animal welfare and impact on the efficiency of production, product quality and market access;
- to address consumer and regulatory concerns with evidence based science that will be available to facilitate informed decisions including policy decisions;
- to provide a balance of targeted short-term and applied research and longer-term fundamental research to enable industries to act quickly in response to arising needs while building the expertise base and knowledge required to support the industry.

More detailed information on some of these key areas is outlined in this paper with a focus on areas and projects that have direct relevance to the northern beef industry and where recent research developments can be reported.

Land transport

Issues associated with confinement of animals are always a focal point for those with concerns for the welfare of animals. This is clearly shown by the focus of many welfare issues around the more intensive production systems such as pork and poultry production which utilise year round housing systems. The issue of land transport has been the subject of increasing international focus with the World Organisation for Animal Health (OIE) developing international standards and guidelines for both road and sea transport of livestock (OIE 2006).

The European Union also released a new Council Regulation (EC No 1/2005) relating to animal transport within the EU (EU 2004). This regulation came into force in January 2007 and requires among other things that a journey log must be submitted and from January 2009 all trucks must be fitted with an appropriate navigation system to record and provide information which can be compared to the journey log. Furthermore journey times shall not exceed 8 hours after which a rest period of at least 1 hour is required. For extended journey times it is necessary for:

- the truck to have a roof and appropriate bedding to allow urine and faeces absorption
- ventilation in stationary or moving vehicles must maintain a temperature range of 5°C to 30°C and a temperature monitoring and recording system must be in place as well as a warning system to indicate when temperature exceeds these limits.

If these requirements above are met journey times can be extended to:

- 9 hours for unweaned calves which are still on a milk diet after which they must be rested and fed for 1 hour and then they may be transported for a further 9 hours.
- 14 hours for adult cattle after which they must be rested for 1 hour to allow watering and if necessary feeding then they can be transported for a further 14 hours.
- After this all animals must be unloaded, fed and watered and be rested for at least 24 hours.

In comparison, the Australia Model Code of Practice for the Welfare of Animals: Land Transport of Cattle (Standing Committee on Agricultural Resource Management 2000) requires that transport durations range from 8 hours for pregnant females but can be extended to up to 48 hours for mature cattle if the cattle are travelling well and the journey can be completed within 48 hours. This transport duration time is set by the maximum time that animals can be kept off water therefore any water curfew imposed before transport would reduce the total allowable transport time. The Australian standards obviously contrast to the EU regulation requirements but until recently there has been only limited scientific evidence relating to the welfare of cattle trucked under Australian conditions.

MLA has funded research to provide scientifically defensible quantification of the animal welfare outcomes of Australian livestock transport practices. The research was conducted by CSIRO and investigated the animal welfare outcomes for yearling cattle transported under controlled conditions for 6, 12, 30 or 48 hours from farm to feedlot. Liveweight changes were measured on all animals in the study and detailed measurements including body temperature and blood and urine chemistry were collected from focal animals before transport as well as immediately on arrival, and 24 and 72 hours after arrival. This research showed whilst animals on longer journeys (especially 48 hours), were more tired, the physiological data indicated they were not clinically compromised. These results show that based on animal welfare grounds the journey times within the Australian Model Code of Practice for the Land Transportation of Cattle are appropriate for the class of cattle used in this study. Furthermore it is important to note the study involved healthy cattle that were not subjected to restricted food or water access prior to transport and they were transported using best practice during moderate weather conditions. Therefore these results must be kept in context and it will continue to be the responsibility of those in charge of livestock to manage the animals in a way that results in acceptable animal welfare taking into account differences in animal class, previous experience, weather conditions, truck design etc. This study required considerable involvement of pastoral and transport companies to ensure the research was commercially relevant.

This work will be progressed to investigate the effect of pre transport curfews on animal welfare outcomes following transport. Three pre-transport curfew treatments will be considered (0, 12 and 24 hours) along with 2 transport durations (12 and 24 hours).

Objective measures of animal welfare

Industry, government and the public require sound and objective information on animal welfare to support decisions in the area of policy development, production practices or consumer purchase choices. The objective for this research is to identify objective measures of welfare which will support the development of sustainable welfare practices and policies. Australia has different production systems to many other countries, particularly in northern Australia which operates extensive grazing production systems with relatively low inputs (Pethrick 2005). There is a need to demonstrate equivalence of outcomes for welfare which allows for flexibility in practices rather than equivalent systems which may be unsuitable within Australian production systems. It is imperative that any objective measures developed in Australia are accepted by trading partners, consumers and regulators, are truly reflective of an animal's welfare status and can be practically applied under industry conditions. Research collaboration has been encouraged both nationally and internationally to ensure developed measures are internationally recognised. Research is this area has been progressed as part of the European Welfare Quality project (Welfare Quality 2007) and outcomes from this research will continue to be considered as part of the research program. The benefits of developing objective measures which can be used to assess an animal's welfare include the ability to optimise on-farm practices and provide assurances to consumer and trading partners of the welfare standards within the production system.

A framework outlining possible measurements and challenge models for future research has been developed with joint investment from MLA and Australian Wool Innovation (Fisher *et al* 2005). MLA aims to achieve ongoing joint investment in this research area to reduce the potential for duplication, allow greater leverage of industry research investments, ensure sharing of information and facilitate integration of research projects within this field. At present no research has been contracted in this area however project applications are being considered for funding. Recent international research in this field has considered current measures which are particularly relevant to more intensive industries and include observation of abnormal behaviours, lameness and foot claw lesions, health issues such as mastitis and skin lesions and abrasions which can occur from contact with hard floors, pressure against feed racks and cubicles (Winckler 2006). This list highlights the challenges that will be faced by more extensive production systems to identify robust, practical and relevant welfare measures.

Husbandry procedures

Invasive husbandry procedures such as hot iron branding, ear marking, dehorning and castration are of concern for welfare groups such as the RSPCA (RSPCA Australia 2006), particularly if carried out on older animals without pain relief. Castration and dehorning are important practices for producers that can improve the long term wellbeing of individual animals, the herd and the safety of people handling animals. Removing the need for these practices through alternative, non-invasive procedures would improve welfare outcomes and may increase profitability by removing the additional costs associated with many of these procedures and the potential impacts they can have on animal growth and weight gain.

The move by some countries to require provision of pain relief for animals undergoing surgical procedures after a certain age has important implications for the northern beef industry given the fact that some animals are missed during mustering, which can result in animals being considerably older than the ideal age for surgical castration and dehorning when they are finally mustered. The "Australian model code of practice for the welfare of animals – Cattle" (Standing Committee on

Agricultural Resource Management, 2004) requires that castration of cattle without the use of local or general anaesthesia is confined to calves at their first muster (preferably under 6 months of age) and only in exceptional circumstances should castration be left to older than 6 months. If this occurs it is preferred that a veterinarian carry out the procedure. It is recommended castration using rubber rings occurs before 2 weeks of age, and use of the burdizzo should be performed as young as possible. In contrast in Ireland, anaesthesia is required for surgical or burdizzo castration of cattle over 6 months of age (Oireachtas, 1965) and in the UK castration of calves without anaesthesia must occur before 2 months of age (DEFRA, 2003). Both Ireland and the UK, require rubber ring castration (without use of anaesthesia) can only be performed before 7 days of age (Oireachtas, 1965; DEFRA, 2003). In New Zealand, cattle should be castrated as young as possible and if over 6 months of age pain relief must be used and if tightened latex bands are used pain relief must be provided irrespective of age (New Zealand National Animal Welfare Advisory Committee, 2005). For all of the countries discussed above, when anaesthesia is required the procedure must be either carried out by a veterinarian or under veterinary supervision. The development of alternative castration methods in Australia that remove the need for surgical castration seems a logical, proactive response to developments in international animal welfare standards.

Unfortunately identifying practical, cost effective alternatives to husbandry practices is not always a simple process. This is a clear example where breeding poll cattle to remove the need for dehorning provides a good example. Due to the limited availability of poll genes within the *Bos indicus* population in Australia (Prayaga 2005) and the complexity added by scur and African horn genes which affect poll inheritance, it can be very difficult to select for poll animals in breeding programs. MLA's project to identify markers for poll genes in cattle may assist the industry fast track poll breeding programs. More detail on this project is outlined in the paper titled "Horns inheritance and the role for polled genes in tropical beef cattle" being presented at this conference by K. Prayaga.

MLA is working to develop a manual which outlines the best practice for castration, dehorning and branding of cattle. This approach is seen as a positive step in improving awareness of animal welfare and on-farm practice when carrying out these procedures. The document will include information on a number of different techniques that can be used for each procedure and their limitations, the equipment required and its maintenance and key steps both in preparation for, carrying out and follow-up after the procedure is complete. This document is in the final stages of drafting and it will be made available to education providers such as TAFE and Agricultural Colleges as well as producers. Summary documents will also be produced for use in the field.

A longer term project is being carried out with the University of Queensland which is attempting to develop a product that will allow permanent, non-surgical castration in rams and bulls with a single treatment. The project is in the very early stages and it is anticipated it will take considerable time before it can be determined whether the research is successful. Stages required in this research include identifying the best method of producing the compound, the optimal dose need for castration and the duration of activity of the compound in both prepubertal and sexually mature bulls and rams. While development and commercial release of a product is still uncertain, if successful it will provide a simple alternative to surgical castration of bulls.

Communication and education

Communication and education are essential if livestock production practices are to be complemented or improved by R&D outcomes. One recent production which has resulted in considerable positive feedback was the production and distribution of a national guide outlining the requirements for transport of livestock. This national "Is it fit to load" guide provides a pictorial representation of some of the key requirements in the national model code of practice for the transport of livestock (Standing Committee on Agricultural Resource Management 2000). It specifically covers the preparation and selection of animal for transport and includes requirements for mustering and holding prior to transport and issues such as open wounds, lameness, late pregnancy and weakness that can mean animals are not suitable for transport. This guide has been made available through State Agricultural Departments, RSPCA Inspectors and MLA and is designed for use by producers, stock agents, transporters, saleyards and abattoirs to determine an animal's fitness for transport and communicate these standards to others within the industry. Other planned communication activities include the development of guidelines for best practice of castration, branding and dehorning of cattle as outlined above.

Conclusions

Animal welfare is a growing issue which is of particular importance to the Australian northern beef industry given the extensive, low input nature of the production systems. Some of the animal welfare requirements of other countries foreshadow potential changes to Australian standards particularly the transport durations allowed within Australia and the requirements relating to surgical husbandry procedures. MLA is progressing research across these areas to ensure future policy has a firm basis in science. Recent research has found that healthy cattle that were not subjected to restricted food or water access prior to transport, and transported using best practice, can be transported for up to 48 hours without any major compromise to their welfare. Research is also being progressed with the aim of developing a single treatment, permanent, non-surgical castration alternative for bulls and a gene marker to assist selection of poll cattle in breeding programs. Additional research to develop objective measures for welfare is also being considered. Developing objective welfare measures would allow industry to provide assurances to consumer and trading partners of the welfare standards within the production system and support an "outcomes based" approach to ensuring animal welfare.

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Nutrition R&D: Past, present and future

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Abstract. The growth of animals is directly related to metabolisable energy intake (MEI). Most of the feed base in northern Australia provides maintenance level of feeding for most of the year interspersed by periods of medium to rapid growth, the duration of which is set largely by rainfall. The only way in which growth rates can be markedly increased on this feed base is to replace it or supplement it with special purpose crops/pastures or supplements. The economics of such strategies vary. Low input supplements (e.g. urea) are valuable but do not markedly increase growth rates at least to the high levels needed to meet the higher price markets. It is suggested that work on increasing the efficiency of microbial protein production within the rumen would enhance the responses to such supplements. Improving annual growth rates will depend on using strategies to develop novel feedplans to replace or supplement the existing feed base. The existing feed base adequately meets maintenance of the reproductive cow especially with low input non-protein N (NPN) supplements. It is the growing animal for which novel feedplans need to be devised and there is an urgent need to resurrect novel agronomic strategies to achieve this. Molecular methods, to date, have not outlined any strategies by which to increase growth rate but they have identified markers for traditional genetic selection programs. They have also clarified the metabolic pathways involved in the response to level and type of nutrients. This outcome opens up the possibility that populations of animals may be identified which respond differently to level of specific nutrients and so growth paths or supplements may be targeted better. It took at least 30 years for many of the current management strategies to become established. It is unlikely that the new areas of research will result in a replacement of basic established energy metabolism principles and the only way animals will ever grow faster from an existing situation is to increase MEI by strategies which are well known at present, but used more strategically.

Introduction

In assessing the present state of nutritional knowledge, we need to know where we want to go in the future and what lessons may be learnt from the past. In the various reviews and workshops conducted by the MLA and its client base, the producers, a clear objective emerges. They want animals to grow rapidly on pasture and produce desirable carcase characteristics. Growth rate and hence age at slaughter affect turnover profit and carcase quality, especially tenderness. More recently much of the genetic work (molecular and traditional animal breeding) has focussed on identifying animals with desirable carcase characteristics with particular emphasis on marbling and tenderness. Yet many consumers and health advocates want lean meat with desirable levels of specific fats, eg conjugated linoleic acid (CLA) and omega 3, and processing may have as large an effect on tenderness of the final product as selecting for specific genes eg mince is very tender and occupies a large market share (>29%, MLA 2006). Growth rate is thus a very clear objective but meat quality is not and there are many varied markets for the meat product.

Growth rate

Growth rate is a fairly simple phenomenon which is directly related to metabolisable energy intake (MEI). Fig. 1 shows the very close relationship for any one diet with or without a supplement. This relationship underpins nutrition and biology. There are many false claims made about growth responses of animals to various manipulations. There is but one simple solution and that is to increase MEI. No substantial increase in liveweight gain can occur without a substantial increase in MEI. The difficulty is how to do this at pasture.

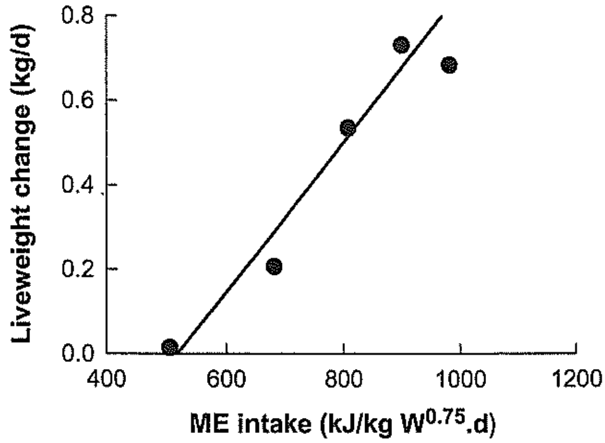

Fig.1. The liveweight change (kg/d) of steers consuming low quality hay with increasing levels of barley grain supplement

Liveweight gain varies markedly between pasture types and pasture maturity with the extreme being the high growth rates achieved on temperate pasture and the low growth rates achieved on tropical pastures. Winter *et al.* (1991) and Bortolussi *et al.* (2005) summarised the growth rates achieved from various pasture communities and seasons. Tropical pastures can achieve as high a growth rate as temperate pastures but only for a short period of weeks compared to several months on temperate pastures. Hence annual liveweight gains are around 70-240kg/year (mean 136) for native pasture, 60-260kg/year (mean 161) for improved tropical pastures (Bortolussi *et al.* 2005) and 250->300kg/year for temperate pastures (Nicol and Nicoll 1987) with the main difference being the extent to which a high growth rate is maintained over the year. This is a direct function of the MEI of the animal.

Strategies to increase MEI

There is a forlorn hope that increasing MEI may be simply achieved by injection of a compound or insertion of a gene. The reality is that it is much harder to achieve but simple in concept. Intake of forages is controlled largely by a physical mechanism whereby the rate at which material is digested and passed out of the rumen regulates intake. Thus digestibility is a common parameter which is related to these factors, such that material with a higher digestibility has a higher intake. This principle explains most of the differences in intake observed between forage types. By contrast, a nutrient deficiency affects intake and hence MEI by its effect on the rumen microbes (eg N deficiency in the rumen) or by its effect on metabolism (e.g. P deficiency or amino acid deficiency at the tissue level).

There are three very simple ways to increase MEI

- Change the forage feed base eg an improved pasture or crop
- Remedy a specific nutrient deficiency by a low input supplement eg urea supplement
- Add a high input supplement of ME eg grain supplement

Changing the forage feed base

This has been the traditional manner in which to increase liveweight gain from a pasture. It has fallen from favour as an approach and has largely been neglected in funding to the extent that the profession of pasture agronomy is now in danger of extinction. This might be contrasted to crop agronomy where new advances and strategies are constantly being devised. The approach has traditionally followed a process of either introducing new plant species or breeding improved cultivars. It has been very successful in certain areas. Irrespective of the current malaise in research funding in this field, it is apparent that the only way in which liveweight gain is to be increased from pasture is to devise better feed plans utilising different plant species throughout the life of the animal. The feed base has to be changed either in part or over the whole life of the animal. We know that the current native pasture system provides a low level of production but if we are to increase on that it will not be possible on that pasture base alone.

The strategy in the past was to look at replacing the whole forage base and this mimicked the NZ scene where a successful ryegrass/white clover system was devised. It is now apparent that this is not possible, nor desirable in northern Australia. Given that the native pasture base will continue to provide the bulk of the pasture base, on an ecological and economic basis, then what is required is a more innovative approach to incorporate special purpose pastures or crops within annual feed plan systems. The basic agronomy of what species and how to grow them in specific environments is known (Cook *et al.* 2005). However, there are very few novel systems being proposed but this needs urgent encouragement. There are some specific examples eg stylo and leucaena. Both of these have been around for a long time. The area planted to leucaena has recently increased dramatically some 60 years after it was first introduced. The rationale for this has been the desire to increase growth rates of animals at pasture and to meet new market targets of weight for age. The ingredients for its success have been the very substantial increase in growth rate of cattle that has been achieved on leucaena, the development by producers of simple methods of establishment and the development of systems to use it effectively within an annual feedplan (Petty *et al.* 1998, Shelton *et al.* 2005). Novel feedplans have been established to fill feed gaps in quality and quantity and there is recognition that only a proportion of the area needs to be developed. These are not new features and they were recognised many years ago in the systems developed by Addison *et al* (1984) at Brian Pastures but it has taken a long time for them to be embraced. Stylo on the other hand followed a path whereby large areas were developed and the approach was to include it across the landscape. The responses to stylo were more modest and reflect the lower soil fertility of the areas in which it grows. The concept of growing it across the landscape has ecological risks. However, similar systems of high input and minimal use of stylo were investigated by Winks (1984). In a similar manner Addison *et al.* (1984) investigated systems of special purpose crops or pastures within an annual feedplan eg Leucaena, Dolichos lab lab. Warren *et al.* (1998) successfully showed how small amounts of ryegrass could be used within an annual feedplan to exploit compensatory growth. The dairy industry (Kaiser *et al.* 1993, Callow *et al.* 2005) has a much greater degree of success in organising novel annual feedplans than the beef industry but the fact remains that if we are to increase growth rate either daily or on annual basis then more agronomic and pasture management research is needed into developing novel feedplans (Scattini 1981). This should not take the approach of altering the whole landscape but rather small intensive areas.

Low input supplements

The most successful low input supplement system has been urea supplements but even this simple system took a long time to be widely adopted. McDonald (1952) showed that the rumen microbes used ammonia as the main N substrate to synthesize microbial protein. Virtanen (1966) showed that NPN could provide the sole N source for dairy cows and hence the rumen microbes could synthesize all the amino acids needed by an animal. He further proposed that we were on the cusp of a revolution whereby ruminants could use NPN to synthesize protein to feed the world. Winks *et al.* (1970) showed in northern Australia that urea based supplements could arrest the liveweight loss of animals in the dry season when CP was low and a response in the order of 200-300 g/d could be obtained. The response came about through an increase in intake and hence MEI. It follows that most low input supplements (eg NPN, P) result in modest increases in MEI and hence liveweight gain. NPN supplements by virtue of the fact that they are used with pasture of low quality will only ever alter liveweight gain around the maintenance level of production. Claims of production feeding and high liveweight gain have no basis in fact without being associated with sources of high ME eg high levels of molasses. It took some 30 years for urea based supplements to be widely used and accepted in the beef industry.

Urea is used by the microbes to produce microbial protein (MCP) which is used by the animal as a source of amino acids. The animal cannot use NPN per se in its tissues. The synthesis of MCP was characterised for a range of temperate pastures by Hogan and Weston (1970) who found that with adequate N, at least 130g MCP was synthesized per kg digestible organic matter (DOM) which is a measure of the protein produced per unit of ME. The feeding standards from around the world recognise that 130 gMCP/kgDOM is the minimum level. Temperate pastures can reach 170gMCP/kgDOM. The difference in this efficiency of microbial protein production (EMCP) has been calculated to result in a difference in liveweight gain of approximately 200-300g/d. Urea based supplements will only ever result in an EMCP of 130 gMCP/kgDOM and it appears that true protein degradation products are needed to reach the higher values seen with temperate pastures. This may be a feature of the energetics of growth of microbes (absorption and use of preformed amino acids) or of the supply of essential growth factors released on degradation (branch chain fatty acids required by cellulolytic microbes). This identifies an opportunity for rumen manipulation to increase liveweight gain. It implies that there are changes in the rumen microbial population in response to these nutrient additions. We now have the methodology to track and identify the rumen microbes as they respond to diet and it has been suggested that we only know about 10% of the microbe species within the rumen (Mackie *et al.* 2002). Recently, Tolosa (2006) has found novel forms of *Quinella ovalis* in high molasses diets which were the dominant bacterial species in the rumen and presumably contributed the majority of the MCP absorbed by cattle. The interest in this is that understanding how diet influences the rumen ecology, in terms of bacterial species and proportions, may lead to novel means to increase MCP supply to the animal and its subsequent liveweight gain, over and above that achieved with a NPN supplement. We know very little about the ecology of the rumen and how to influence it with nutrition.

The response of animals to NPN show another very interesting feature. There are two key experiments with sheep which illustrate this. Egan (1977) showed that animals on low CP diets, a feature of the dry season in the tropics, have a low intake which is regulated not by digestibility and physical regulation within the rumen but by a metabolic mechanism. The rumen was not full and animals increased intake in response to post-ruminal infusion of protein ie the animal was responding to protein supply and the basis of the urea response was a result of increased MCP production. This concept has influenced our view of intake of low CP diets ever since. However some results show variation in this concept. Elliott *et al.* (1984) fed five low CP diets to sheep and showed that, with some diets, intake was increased markedly with urea but with others it was not changed. They related this to the CP of the diet although all were deficient in CP by conventional levels (<7%CP). An alternative explanation is that the level of rumen fill varied with each diet. Sheep on diets which resulted in a low level of fill had the physical capacity to respond to extra protein. A similar phenomena is seen with lactating cows which increase intake on roughage diets by increasing rumen fill. This is the only physical way in which an increase in intake can be accommodated. In the data of Egan (1977) a similar phenomena appears to be happening. Thus a new idea is emerging. Intake can increase markedly if rumen fill is low in animals eating a low CP diet and rumen fill appears to vary with diet and with individual animals. The variation in rumen fill of individual animals is interesting because it suggests that some individuals may be more sensitive to absorbed amino acids in their metabolic regulation of intake than others or that some individuals have very efficient rumens producing high levels of MCP. Thus there is variation between individuals, as a result of their rumen ecology, in the supply of amino acids to the animal and this may result in large variation in intake between animals. We now have the technology to examine this phenomenon. Certainly, in pen studies, with small numbers of animals, there can be considerable variation in intake on low CP diets. Recently, N. MacDonald *et al.(pers. comm.)* have shown, in a survey across the NT, that weaners have very large variation in liveweight gain across the dry season (from 0-*ca.*200kg) and one contributing factor in that may be the issue of rumen function and variation in the sensitivity of the animal to metabolic regulation of intake by CP supply.

It is important to realise that the response to low supplement input will always be low because the level of MEI is low. It is unrealistic to expect high levels of liveweight gain from pastures of low quality with low inputs of supplement.

High input supplements

There is only one way in which a high MEI and high liveweight gain can be achieved from a pasture base which promotes a modest liveweight gain and that is to use a high ME supplement. This ME supplement may come from grains, protein meals, other by products (eg molasses) or allocation to specialist high quality forages. The only alternative is to replace the pasture base entirely with another of higher quality as outlined earlier. The issues with using such supplements have been outlined by McLennan and Poppi (2007) in this conference and relate to questions of what type, how much and when best to use a supplement over the growth path to slaughter.

The application of molecular genetic technology to nutrition

There has been considerable effort expended in cattle genomics but there is little evidence that this molecular approach will devise strategies to increase MEI and liveweight gain. The genomic molecular approach is gathering information hitherto unknown in the hope that it will lead to new developments. At present, the approach has focussed on identifying genes of interest with respect to meat quality (marbling and tenderness) but there are no avenues by which animals will grow significantly faster on a pasture based diet. This is because the laws of thermodynamics apply and Fig 1 holds whatever the genotype of the animal.

This is not to criticise the approach but rather to put it into perspective. The approach has most use in understanding what is happening under the various nutritional regimes and with that knowledge the hope is that ways to increase growth may emerge. This area of nutritional influence on gene expression is in its infancy.

There are some examples where the technology has exciting application. Residual feed intake is a procedure whereby individuals are identified which deviate from the general relationship seen in Fig 1 (Arthur *et al.* 2001). This deviation means that the selected animal eats less food for a particular liveweight gain and that this can be linked to a genetic marker. The mechanism by which this comes about is less certain (Kolath *et al.* 2006) but important to determine as it must be a result of a reduction in maintenance requirement of an animal or some aspect of the synthesis or degradation pathways of protein and fat. Breed types also differ in these aspects with the best example being *Bos indicus vs Bos taurus* animals where *B.indicus* animals have lower maintenance requirements. So we already have practical examples between breed types where changes in metabolism affect animal performance and the response to nutrition. The potential is there to exploit these effects practically. The principle, in this approach to nutritional effects on gene expression, is that the population is not seen as a homogenous group and also that the variability always seen in the population response to nutritional manipulation may be exploited by identifying those individuals with the characteristics to respond more or less to the nutritional regime imposed. In other words, a level of nutrition or a balance of nutrients results in the expression or inhibition of a metabolic pathway leading to a phenotypic response ie what we see in the animal.

There are some examples whereby knowledge of the nutrition x gene expression pathway leads to population differences in response to nutrition. We are interested in population differences rather than a specific individual although it is recognised that identifying a specific individual can lead to breeding programs. This is a much slower process than identifying how to differentially treat current populations by varying nutrition.

The definitive work in this area is from humans and their interaction with caffeine (Cornelis *et al.* 2006). This demonstrates a population response to a specific compound, caffeine, and provides an example of how nutrient gene expression principles may be exploited. In this example, sub-groups of the population metabolise caffeine either rapidly or slowly and the slow metabolism group with high caffeine intake are linked to higher risk of nonfatal myocardial infarction. We do not have comparable examples yet of population responses to nutrients in animal production.

Cake *et al.* (2006), Greenwood *et al.* (2006) and Natrass *et al.* (2006), with sheep selected for growth or eye muscle depth, varied level of nutrition (high or low). They showed altered skeletal elongation, muscle fibre types and metabolism and a genetic line x level of nutrition interaction. They also concluded that the effects of level of nutrition were large on all parameters but that the effects of genetic selection were much smaller, a salient observation with respect to the factors having most effect on growth.

The French have characterised the response of Charolais cattle to either concentrate (maize silage) or pasture based diets and have shown differential gene expression with respect to the diet but much greater changes in gene expression with respect to muscle type (Cassar-Malek *et al.* 2005)

Recently Lehnert *et al.* (2006) have shown differential abundance of various mRNAs in Belmont Red cattle undergoing weight loss or weight gain and in the compensatory growth phase. Some unexpected pathways were identified, eg the increased abundance of stearoyl-CoA desaturase mRNA under feed restriction suggested increased lipogenesis under feed restriction, and the authors suggested the need to be careful and identify tissue types as the result may simply be a consequence of changes in cell types within the muscle.

Quigley (2005) showed in sheep that low levels of nutrition *in utero* alter subsequent growth of the foetus and muscle hypertrophy but muscle fibre numbers and type were unaffected. mRNA levels in muscle were altered by stage of development, while myf-5 and myogenin transcripts were nutritionally regulated. These two genes regulate proliferation and differentiation of muscle cells respectively. This has particular relevance to cattle in northern Australia as level of nutrition can vary markedly throughout pregnancy.

We outlined earlier how molecular tools have been used to track changes in the microbe species within the rumen. This has identified new bacterial species that are the dominant microbes. Understanding if the shift in microbial populations results in changes in the energetics of fermentation such that more microbial protein or faster rates of fibre digestion result is an important area to research with the low quality diets of the north.

Most of this work implies that a shift in the nutrient balance and level of nutrition has some effect on the deposition of fat or muscle or on some parameter of the meat eg tenderness. Whilst these are important characteristics they do little to affect growth other than the traditional response to level of MEI as outlined in Fig 1. There do not appear to be any studies on the fundamental drivers of growth (eg skeletal growth) whereby specific nutrient manipulation increases growth other than that set by MEI and the energetics of nutrient use. Most of the current work has concentrated on trying to manipulate tissue or specific cell types to alter characteristics such as marbling or tenderness rather than growth per se. There is an urgent need to look at diet manipulations of relevance to the north and how these relate to low CP diets and low MEI set by physical regulation of intake or by the differential metabolic control of intake by populations. The large variation in growth rate observed in weaner steers on low CP diets indicates that there is a population effect which could be exploited to manipulate growth rate of the herd by increasing the growth rate of the lower growth individuals (N.MacDonald *pers. comm.*.).

Where to for the future

There are two main areas in which nutritional principles will enhance growth of cattle in the north

- Use existing knowledge more effectively
- Application of molecular methodology in nutrition gene expression studies

Use existing knowledge more effectively

Fig 1 clearly shows that MEI drives growth rate. We have a lot of knowledge on what plants can grow where and how to alter plant growth. Similarly we have information on stocking rate or utilisation rate on animal growth. We have a lot of nutritional information on the response of animals to level and type of nutrients. We need to use this existing information more effectively. A series of decision support models are needed, rather than one large complicated model, with the ability to answer specific questions. A framework for how this might occur is as follows. Agencies, rather than individuals, can predict pasture growth through the Aussie GRASP model and information updates broadcast in much the same way as the weather. This is being examined in WA with ryegrass pastures (Gherardi 2005). The Pigeon Hole Project and the Wambiana project (see this conference) show how this information can be used to devise stocking rate and grazing management strategies (wet season spelling, water and fence infrastructure) so as to maximise utilisation within sustainable levels as stocking rate is the single most important factor affecting profit and land degradation. Prediction of intake is needed as part of this process and the QUIKINTAKE model based on the energetics of Fig 1 can do this. Faecal NIRS, using either historical or actual data, can be used to measure the ME and CP content of the pasture from which decisions on supplementation can be made using the QUISUPP model. Finally satellite imagery and the VEG Machine model can be used as a watching tool to ensure all is going to plan. The application of these items ensures good benchmarking is done across a region and identifies for individual producers which items need to change so that they can move to the top group of producers in their region. Good information and correct application is the key.

This approach enables the best use of an existing resource. There is no alternative to altering the feed base (through new pasture systems or supplements) to increase the growth of animals if the current system does not meet target requirements within a growth path. It is unlikely that we will ever see the large landscape alteration of a pasture community that was proposed in the 1950's but we need more imaginative agronomic developments of pasture based systems and growth paths.

Application of molecular methodology in nutrition gene expression studies

This has exciting possibilities to gather new information. Currently it offers no solutions to improving growth rate but it seeks to understand why the differences come about. It has largely focussed on aspects of meat quality and food conversion ratios in feedlot type diets but there is a need to apply it to pasture diets representative of the north. The recent CRC studies in this area (Lehnert *et al* 2006, Tomkins *et al* 2006) illustrate how very useful and novel information may be obtained. The challenge is still in how to devise new feeding systems to exploit this information. The energetics of nutrient use by cattle (Fig 1) indicate that new feeding systems/growth paths, through novel use of pastures and judicious use of supplements, will still be the practical way in which this can be achieved but the nutrition gene expression studies may show us smarter ways to use these long recognised means of altering growth of cattle.

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Supplementation – getting bang for buck

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Abstract. Supplements provide one option for cattle producers to increase growth rate of their cattle and target desired market opportunities but both the costs of feeding and risks are high. Although urea-based supplements are the most widely used throughout northern Australia, they are not formulated to achieve high growth rates required to increase weight for age of cattle. In this paper the emphasis is on production feeding of male cattle. The successful implementation of a cost-effective feeding programme can be achieved with attention to several strategies, viz., choosing the most appropriate supplement type, feeding supplements under appropriate pasture conditions, optimising use of the pasture base and timing the use of supplements and the marketing of cattle to optimise growth responses and minimises erosion of responses through compensatory growth. These aspects are discussed in the context of contributions from our own research findings. Where the feeding standards and their derived decision support models have been assessed, they have not been successful in predicting growth performance of cattle grazing tropical pastures due to their poor predictions of intake but not through inadequacies in the equations describing energy utilisation, which were sound.

Introduction

Over the last 2-3 decades the markets for northern Australian cattle and beef have changed and expanded greatly. Although the more traditional markets of USA manufacturing and Japanese high quality beef still dominate the market scene northern cattle are also now directed to prime beef markets in South Korea, live export markets in south-east Asia and northern Africa, and are backgrounded for the rapidly growing feedlot industry supplying both export and domestic markets. Having the flexibility to access the most profitable of these markets at any time often requires that producers have strategies to change their production system, notably to increase cattle growth rates, at short notice and the feeding of supplements provides an important option for this.

In order to increase growth rates it is necessary to increase intake of digestible energy (see later) and there are various options outside supplementary feeding by which to achieve this. These include changing the pasture base to incorporate a higher quality forage, e.g., a legume such as stylo or leucaena. This option is one being used in some parts of Queensland in particular, for instance leucaena in southern and central Queensland, and can result in large increases in per head and per hectare production (Shelton *et al.* 2005). However, limitations of rainfall, temperature and soil type will restrict the expansion of most of these improved species into all but a relatively small proportion of northern Australia and will not provide a practical option for many producers. In this paper the emphasis is given to the supplementary feeding alternative.

Historically, urea-based supplements have predominated the northern beef cattle scene since the mid-1960s and continue to be the major supplement types used today. Originally based on the urea-molasses roller drum system, variations have included dry loose salt-based licks and urea dispensed directly into the drinking water, as well as the myriad of commercial urea-based licks available in loose or block form. These supplements increase growth rate by increasing intake of the available pasture. However, only relatively modest increases in intake are usually achieved (up to about 30%; Winks *et al.* 1970) and the pasture is of such low digestibility that the corresponding increase in energy intake, and thus growth response, is relatively low. The early 1980s saw the introduction of fortified molasses survival feeding system, the most notable example being the M8U system (molasses/urea; 100:8, w/w). These innovations were supported, if not initiated, by key research from Swans Lagoon Research Station, Ayr, Qld (e.g., Winks *et al.* 1970; , McLennan *et al.* 1991). However, both the urea and M8U supplements were mainly intended for ensuring survival of the animal, primarily weaners and cows, and were not formulated to achieve the high growth rates required for production feeding. It is important to recognise that they are not production supplements and for higher growth rates the only real feeding option available to producers is to provide the additional energy required, balanced for other nutrients, in the supplement rather than rely on increased pasture intake alone. This form of feeding is expensive and requires a careful examination of the costs and benefits for an economically favourable result to occur.

Increasing the efficacy and profitability of supplementary feeding, or the "bang for the buck", will be a function of three main principles: (i) choosing the supplement which will provide the highest growth response per unit cost; (ii) optimising use of the available pasture; and (iii) integrating the chosen supplementation strategies into a longer term growth path through to when the animal is sold or slaughtered. Some of the issues relating to these aspects are discussed below in the context of recent research findings from our own research group. The major emphasis in this paper is given to feeding male cattle for production.

Growth responses to supplement

The choice of supplement is based on several factors, the main nutritional considerations being the growth response per unit intake and per unit cost, but the overall aim does not deviate from that of increasing total nutrient, and specifically energy, intake. The importance of this key principle is further examined later. Energy intake is most commonly increased by feeding a supplement high in energy content, for instance grains or molasses, or by feeding a high protein supplement which stimulates intake of the pasture as well as providing energy *per se*. Reference to the former supplements as "energy sources" and the latter as "protein sources", as is common practice, can provide a misleading conception of their relative contributions to the nutrient supply to the animal. For instance, McLennan *et al.* (1995) calculated that whilst cottonseed meal (11.1 MJ metabolisable energy (ME)/kg DM; 37.5% crude protein (CP)) had a three-fold higher CP content than barley (12.8 MJ ME/kg DM; 11.4% CP) the amount of metabolisable CP it supplied to the animal was only 1.6 times and 1.8 times greater per kg DM or per MJ ME, respectively, by virtue of the high capacity of the rumen microbes to use the energy from barley for microbial protein production. Thus both supplement types provide both energy and protein to the animal but it is the proportion in which these are supplied that seems most important as is shown by results considered below.

The growth responses to various supplement types have been compared in a series of pen feeding and grazing trials with young growing cattle (McLennan 1997; 2004). These experiments, without exception, used a dose response approach so that the various supplements could be compared over a wide range of supplement intakes. The advantage of this approach compared to that of using only one or two levels of feeding is that the resultant dose responses can be used to tailor a response under practical grazing conditions. The results are discussed below.

Comparison of supplement types

For our research, supplements were grouped into major types, for instance grains with low (sorghum, corn) or high (barley, wheat) starch degradability in the rumen, high sugars (molasses), and protein meals with low (cottonseed meal) or high (copra and palm kernel expeller (PKE) meals, whole cottonseed) lipid content, and were fed over about 70 days to young growing cattle given low quality tropical hays in pens. An example of the resultant response curves is shown in Fig. 1A. From a number of similar experiments, generic response curves were developed (Fig. 1B) comparing protein meals and "energy sources" (grains and molasses). These results suggested a linear response to the energy sources across the full range of supplement intakes whereas the response to the protein meals tended to be curvilinear, with a much greater response (kg gain/kg supplement) at low intakes than at higher intakes of supplement. Notably, growth responses were similar for the two supplement types when intakes of supplement were high. These responses in our own studies were consistent with cumulative published data, as reviewed by Poppi and McLennan (1995) and Poppi *et al.* (1999).

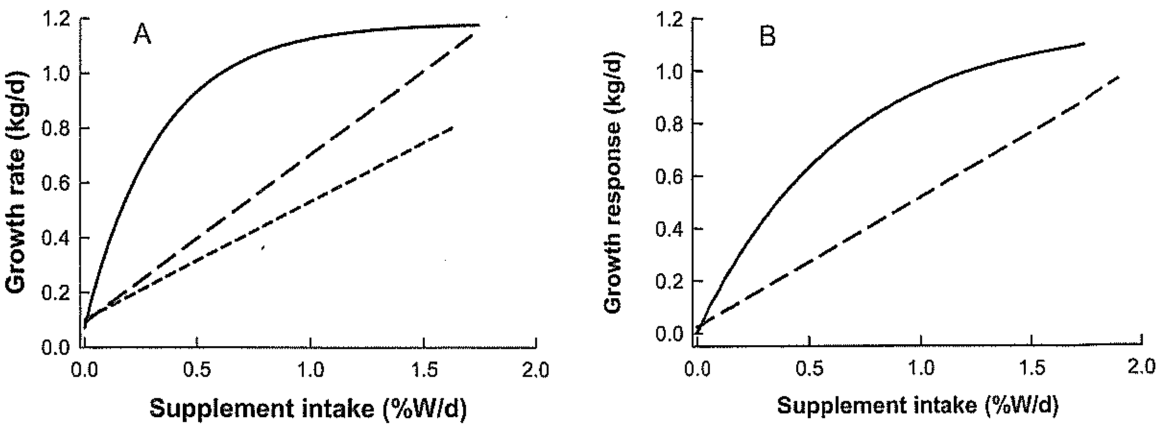

Fig. 1. (A) Effect of supplements of cottonseed meal (solid line), barley (long dash) and sorghum (short dash) on the growth rate of steers fed a low quality hay in pens; and (B) generic relationships between the growth response (gain in excess of unsupplemented control) and supplement intake for protein meals (solid) and "energy sources" (dashed) based on the results of several experiments.

The higher responses with protein meals relative to energy sources suggests a requirement for protein in young, rapidly growing cattle which is not being met completely from microbial protein production alone. Orskov (1970) showed that ruminants undergoing rapid growth required more protein than could usually be provided as microbial protein produced in the rumen. Furthermore, cattle deposit proportionally more protein than fat at a younger age (ARC 1980) and their requirements for protein *per se* are thus greater then than during the finishing phase of growth. The derived response curve (Fig. 1B) can be translated into one for use in comparing supplement requirements for a particular growth response by rotating this figure through 90° and these comparisons can be made on a cost basis if the cost per unit weight of supplement is included. Obviously, supplement costs will vary widely with seasonal availability, distance from source etc., so the response trends have been incorporated into a spreadsheet ("WhichSupp") which allows individuals to directly input the supplement costs. The limitations of these comparisons is that they currently apply only to young cattle and only to low quality forages and they do not include all of the variable costs associated with feeding. Nevertheless, they provide a starting point in the decision process on the appropriate supplement to feed.

Within supplement types, there were differences between supplements in response. For instance, the response to barley was greater than to sorghum across the full range of supplement intakes (Fig. 1A), presumably reflecting the greater digestion of starch in the rumen and total tract with barley (Huntington 1997). Responses to molasses supplements were even lower and highlight the low net energy value of molasses relative to grains (Lofgreen 1965). The practical significance of these findings is that producers can afford to spend more for barley compared to sorghum or molasses although the results with sorghum in particular will be variety specific (S. Bird, pers. comm.). This highlights the need for a simple assay by which grains can be screened for both ruminal and post-ruminal digestion prior to use in ruminant diets.

Protein meals vary widely in composition, especially CP content, yet research carried out by our group (McLennan 2004) showed similar performance by steers receiving supplements of cottonseed meal (42.8% CP) and copra meal (24.2% CP) across the full range of supplement intakes (0-1%W/day); PKE meal (16.9% CP) had slightly lower performance. Other workers have similarly shown similar performance of copra and cottonseed meals albeit at only 1-2 levels of feeding (Hennessy *et al.* 1989; Gulbransen *et al.* 1990). Rumen ammonia concentrations were linearly increased 3 h post-feeding by cottonseed meal but not copra meal but both supplements were associated with elevated plasma urea concentrations albeit at higher levels with cottonseed meal. These results suggest different modes of action of the protein meals with copra protein perhaps bypassing initial digestion in the rumen to be absorbed as amino acids post-ruminally and slowly recycled back to the rumen as urea. Support for this recycling of urea was provided by the linear increases in microbial protein production (221-651 g/d) in the rumen with increasing intake of copra meal. Based on these results the choice of protein meal may be more aligned with cost per kg DM than per kg CP, although this requires confirmation with other protein meals.

Effect of pasture quality

Research carried out with young Brahman crossbred steers grazing a buffel grass pasture on brigalow soils in central Queensland showed that responses to supplements were highly dependent on the quality of the basal forage diet. When the steers grazed dry season pasture the unsupplemented controls gained 0.2 kg/d and the responses to a barley-based supplement (including urea and minerals) and cottonseed meal were substantially greater than when the steers grazed wet season pasture and the unsupplemented steers gained 0.9 kg/d overall (Fig. 2). Differences in supplement type were generally small in this study perhaps indicating that, with these pastures, even during the dry season microbial protein provided most of the protein requirements of the cattle when a source of readily fermentable energy and rumen degradable protein (barley supplement) was available. Based on these results and those from the pen studies described above, a theoretical relationship is offered between base pasture quality (and growth of unsupplemented steers), supplement intake and liveweight gain response (Fig. 3). This figure suggests that, under commercial conditions, the likelihood of a cost-effective response to feeding protein/energy supplements diminishes directly with increasing pasture quality. An economic response is highly unlikely during the wet season, and doubtful even during the wet/dry transition period in some regions and years.

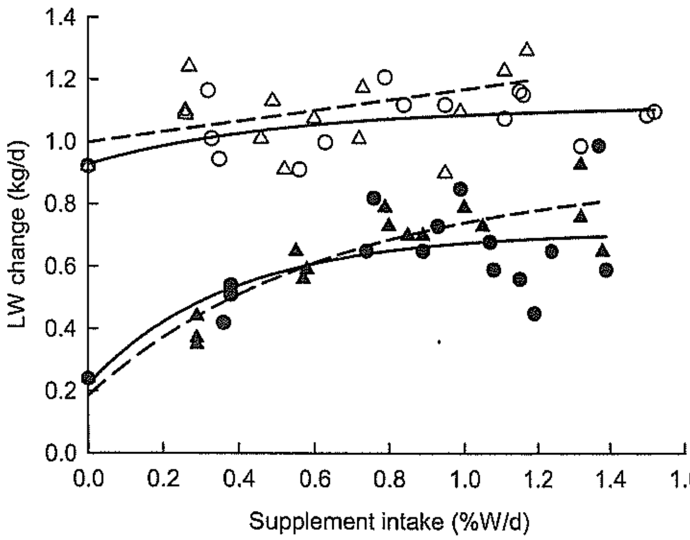

Fig. 2. Growth responses by steers grazing buffel grass pastures during the dry season (closed symbols) and wet season (open symbol) and receiving supplements of barley fortified with urea and minerals (circle; solid lines) or cottonseed meal (triangle; dashed lines).

Prediction of the growth response to supplementary feeding

It is obviously not feasible to evaluate every supplement combination under every set of conditions so an alternative is required to predict the performance of cattle given a particular supplement, or to formulate a supplement to achieve a desired production response. The various feeding standards relate the performance of animals to nutrient intake and thus provide a basis for assessing the nutritional requirements of animals in various physiological states. It should, therefore, be possible to use these feeding standards or the decision support systems (DSS) derived from them, to achieve the outcomes outlined above. However, there has been some scepticism about the usefulness of the feeding standards for predicting performance of *Bos indicus* cattle grazing tropical pastures as most feeding standards have largely been developed from feeding experiments carried out with British/European cattle consuming temperate diets.

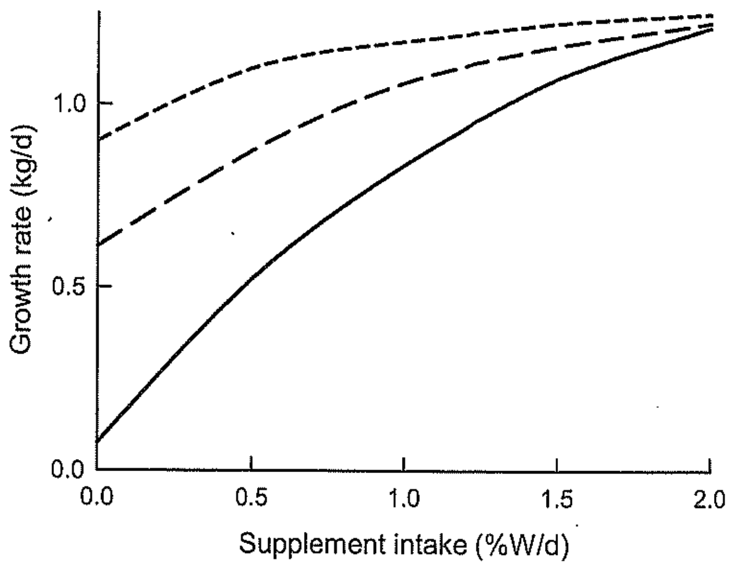

Fig. 3. Theoretical responses to a protein meal supplement for steers grazing low (e.g., dry season; solid line), medium (e.g., wet/dry transition; long dash) and high (e.g., wet season; short dash) quality pastures.

The basic premise underpinning the feeding standards is that liveweight gain is a function of intake of metabolisable energy (MEI). This concept was examined recently by pooling data of our own research group (see McLennan and Poppi 2006) derived from a number of pen feeding experiments with young growing cattle given tropical grass hays and a wide range of supplements. The results confirmed the close relationship between liveweight gain and MEI and indicated that, despite the large range in responses to different supplements, the major difference was in their effect on MEI and not on the relationship of MEI with LWG *per se*. The relationship was as follows:

Growth rate (kg/d) $= - 1.061 + 0.0020$ MEI (kJ/kg $W^{0.75}$.d), ($R^2 = 0.80$; rsd = 0.144).

This work was expanded to assess how well the DSS predicted liveweight gain of cattle given tropical diets, using the same data sets. Two DSS were used; the Australian feeding standards, SCA (1990), based on the ME system and from which the GrazFeed model (Freer and Moore 1990) was derived and the Cornell Net Protein and Carbohydrate System (CNCPS; Fox *et al.* 2004) based largely on the NE system and used also by NRC (1996). The results indicated that, providing intake and diet composition of the cattle was known, both SCA (1990) and the CNCPS gave reasonably good predictions of liveweight gain thereby suggesting that the principles of energy utilisation were sound and applied equally well to cattle and diets of tropical and temperate origin. However, both systems provided poor estimates of voluntary intake based on diet composition suggesting that, under field conditions where intake was unknown but diet composition could be estimated using, for instance, the faecal near infrared reflectance spectroscopy (NIRS) method (Coates 2004), these models would not accurately predict animal performance. The lack of a reliable and accurate method to estimate intake will, it appears, continue to jeopardise the use of the feeding standards and derived DSS for predicting cattle performance in northern Australia.

Effects of supplement on pasture intake

For most cost-effective production, livestock producers should aim to maximise use of the pasture base, being the low cost component of the animal's diet, and use supplements as an addition to the nutrients provided by the pasture. However, the reality is that as supplement intake increases pasture intake by the animal declines; that is, the animal substitutes supplement for pasture. This substitution effect is well documented (e.g., Horn and McCollum 1987; Schiere and de Wit 1995; Dixon and Stockdale 1999) although the reasons for it are less well understood. Whilst pasture intake is reduced in this way it is common for total intake of DM to increase and for energy intake to increase even more steeply by virtue of the usually higher energy density of the supplement relative to the pasture it replaces. Nevertheless, the efficiency of use of supplements would increase if a more additive rather than substitutional effect of supplement on pasture intake prevailed.

Research undertaken by our research team (Marsetyo 2003; McLennan 2004) has, in support of other evidence (Schiere and de Wit 1995; SCA 1990), demonstrated that different supplements vary in the degree to which they substitute for pasture, and that as pasture quality increases so too does the extent of substitution for any supplement type. Marsetyo (2003) described a two-phase effect of feeding supplements on intake of the base forage. When rumen degradable protein (RDP) supply from the forage base was limiting for the animal provision of a small amount of a supplement (up to about 0.5% W/d) which reduced this deficit in the rumen resulted in a small or nil decrease in intake of forage. However, as supplement intake increased and the deficit of RDP was eliminated forage intake declined linearly. Where supplements did not correct a deficiency in RDP content, for instance because they also had low RDP content or were fed with forages not limiting in RDP supply, there was a linear decrease in forage intake across the full range of supplement intakes. In the linear phase of this relationship, differences between supplements in their substitution effects were broadly related to their ME content such that supplements with the highest ME content resulted in the greatest depression in forage intake. This finding was consistent with the conceptual model of intake regulation proposed by Weston (1996) who suggested that ME intake is regulated by the balance between the capacity of the animal to use net energy (NE) and the useful NE intake. An example of these effects is shown in Fig. 4 where supplements low (barley) and high (barley/cottonseed meal/copra meal, 2:1:1, w/w) in RDP content were fed with a low quality tropical hay. The barley supplement was associated with a linear depression in hay intake whereas the barley/protein meal mix had minimal effect on hay intake at low intakes but a linear depression thereafter.

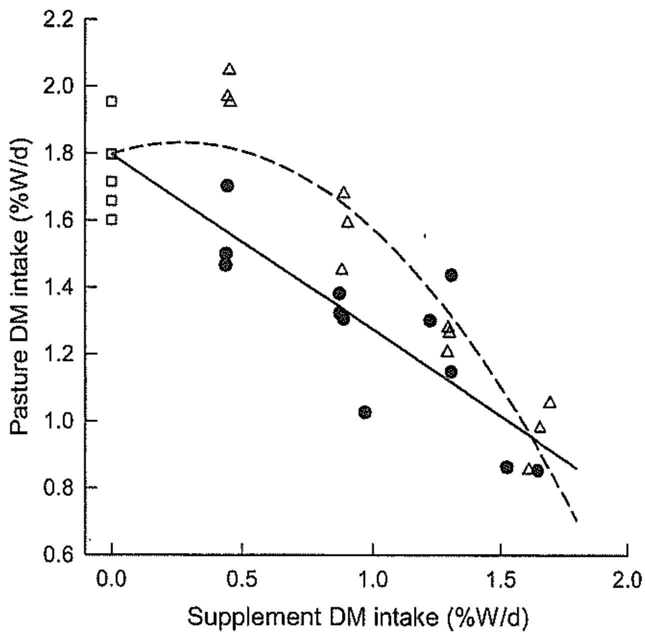

Fig. 4. Effect of supplements of nil (square symbol), barley (circles; solid line) or barley/cottonseed meal/copra meal (2:1:1; triangles; dashed line) on the intake of pasture by steers in pens.

In our studies, other approaches to reducing substitution effects such as changing the site of digestion of the supplement were not successful. Consequently, at this stage the most effective strategy available to limit substitution and maximise pasture utilisation is to ensure that RDP supply in the rumen is not limited when supplements are fed. This would include ensuring adequate inclusion of an RDP source such as urea in energy-rich concentrates such as grain and molasses.

Integration of supplementation events into growth paths

The fore-going discussion has detailed some of the component research aimed at optimising the efficiency of supplement use within discrete phases of the total growth path of the cattle. In practice, most supplementary feeding occurs during the dry seasons when growth of the cattle is otherwise low and these feeding events are interspersed by wet seasons when growth is comparatively higher but supplementation uncommon (except perhaps for phosphorus feeding). When cattle growth is restricted, for instance during the dry season, the animal often grows at a faster rate in the period following restriction, i.e., the wet season, than it would if there was no previous restriction. This phenomenon is known as compensatory growth. A common example is that cattle that are not supplemented during the dry season often grow faster during the following wet season than those which received dry season supplements and had high growth rates accordingly. Winks (1984) suggested that wet season compensatory growth could erode 0-100% of the weight advantage from dry season supplementation with urea-based mixes. This was supported by other research at Swans Lagoon Research Station, Ayr (J.A. Lindsay, pers. comm.) using supplements providing higher levels of energy and protein. Obviously, any diminution of the growth response to supplements reduces the cost effectiveness of feeding.

An example of the compensatory growth effect is shown in Fig. 5 where grain-based supplements were fed during the dry winter-spring months to cattle grazing buffel pastures on brigalow soils (T. James, pers. comm.). In the first year of feeding the liveweight response of 69 kg at the end of the dry season was reduced to 29 kg by the end of the following wet season. The corresponding dry season response in year 2 of 168 kg was reduced to 37 kg by the end of the next wet season. The net effect of these feeding and compensatory growth events was a feed conversion ratio of 2.5 t of grain for an additional 37 kg liveweight gain, demonstrating the importance of considering the potential effects of compensatory growth in determining the ultimate cost-efficacy of feeding. In this case feeding only in the second year and marketing the cattle at the end of the second dry season would have markedly improved the economics of feeding.

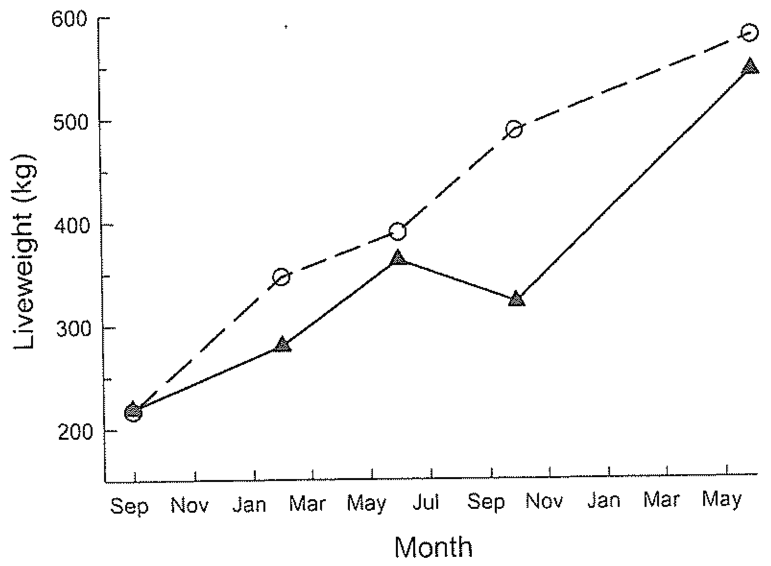

Fig. 5. Comparison of the growth of steers given a barley-based supplement (circle; dashed line) during two successive dry season compared with that of unsupplemented steers (triangle; solid line) grazing buffel pastures on brigalow soils.

Conclusions

This paper has described some of the research that has been aimed at improving the efficiency and profitability of supplementary feeding. Various strategies can be taken to improve these aspects, including making the right choice of supplement, formulating supplements to optimise use of the pasture base, feeding for the right pasture conditions, and reducing the inefficiencies of feeding associated with compensatory growth by marketing cattle at appropriate times. However, these decisions should only be taken after a full appraisal of the production system establishment of a clear target for production, and a realistic evaluation of whether the target is achievable or economically realistic.

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How to make the most from kangaroos – a ruminant perspective

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Abstract. The high fibre content of Australian native grasses and the slow rate of digestion in the rumen reduces the ability of cattle and sheep to achieve their growth potential. The microbes present in the kangaroo foregut evolved to utilise native pasture and therefore may more efficiently utilise these plants. The rate of digestion of low-quality spear grass was increased from 5.9% to 9.4% by the addition of kangaroo fibrolytic isolates during the intermediary period of *in vitro* fermentation. *Ruminococcus flavefaciens* isolate YE125 established a stable population within the fermentor; three other isolates were below detectable levels within three to five days. Further studies will be undertaken to determine the ability of these bacteria to establish in the rumen of beef cattle and to improve the digestion of native pasture.

In addition, unlike sheep and cattle, kangaroos emit very little methane as they possess an alternative mechanism to methanogenesis to remove hydrogen from the rumen. The mechanism appears to be reductive acetogenesis and a variety of reductive acetogens (bacteria) have been isolated. These bacteria were evaluated in a fermentor and although they did not remain above detection limits for the entire period of fermentation, while present they did appear to limit methane emissions, methanogen numbers were reduced and there was an increase in acetate production. This work is to continue with further fermentor based studies to improve the ability of these bacteria to colonise a rumen-like environment and to gauge their ability to limit methane emissions.

Introduction

A large proportion of Australia's beef industry is reliant upon the use of native pastures as the primary feed source. Ruminants feeding on C_4 pastures, including native pastures, do not achieve their genetic potential for growth performance largely due to their inability to intake sufficient feed to supply the nutrition that they require (Weston 2002). The primary constraint on intake is the high fibre content (cellulose, hemicellulose and lignin) of the grasses and the slow rate of degradation via the fermentative processes of the rumen (Mackie *et al.* 2002), which physically limits the size of particles that can flow out of the rumen and consequently reduces intake. Very few rumen bacteria are capable of breaking down plant fibre, particularly cellulose, and the rate that plant fibre can be degraded is therefore dependant on the intrinsic metabolic activity and population density that these bacteria can achieve (Stewart and Bryant 1988).

In addition, methane is a by-product in the digestion of plant material by all cattle and sheep. Methanogenesis is a microbiological mechanism that removes hydrogen (produced by the fermentation of feed) from the rumen. Methane is generated in the rumen by methanogenic archaea that utilise hydrogen to reduce CO_2, and is a significant electron sink in the rumen ecosystem. However, reductive acetogenesis has been suggested as an alternative electron sink (Joblin 1999; Mackie and Bryant 1994; Nollet *et al.* 1997). Despite methanogenesis predominating in the rumen, reductive acetogenesis predominates in other anaerobic gut ecosystems (Breznak and Switzer 1986). Not only does this reduce or nullify methane emissions, it can also supply a considerable proportion of the energy needs of the animals. In the termite, reductive acetogenesis has been calculated to produce enough acetate to account for 33% of the animals total energy requirement (Breznak and Switzer 1986). If methane was wholly replaced by acetate in ruminants this would represent an energetic gain of 4 - 15% to the animal (Joblin 1999; Nollet *et al.* 1997).

The geographic isolation of Australia has meant that large domestic herbivores were not present on the continent when Europeans arrived about 200 years ago. Marsupials had evolved to fill the niche occupied predominantly by sheep and cattle (ruminants) elsewhere, and like the ruminants, the macropodid marsupials (kangaroos) developed an enlarged complex forestomach for fermentation of cellulosic and other complex plant materials prior to further digestion (Hume 1982). Like ruminants a complex microbial ecosystem exists in the forestomach of macropodid marsupials. Bacteria, fungi, protozoa and viruses are known to be present but until recently (Ouwerkerk *et al.* 2005) have not been characterised or studied in very much detail. These microbes have evolved to utilise Australian native pasture plants and it is likely that the macropodid marsupials possess gut microorganisms more highly evolved to utilise these plants, particularly the more refractile fibrous components of these plants. Furthermore, unlike sheep and cattle, kangaroos emit very little methane (Kempton *et al.* 1976) and appear to possess an alternative mechanism to methanogenesis, although their digestive process is analogous to sheep and cattle.

The aim of the current work with kangaroo forestomach bacteria is twofold:-

1) To isolate and characterise superior plant fibrolytic bacteria from the kangaroo forestomach and determine whether they can be transferred to cattle to improve the digestion of native pastures and increase productivity from these pastures.
2) To determine the alternative pathway to methanogenesis in kangaroos and to isolate the bacteria responsible for future transfer to cattle and sheep to both reduce emission of the greenhouse gas methane and also increase productivity.

This paper reports on the isolation of fibrolytic bacteria and reductive acetogens and preliminary assessment of their ability to persist in a rumen-like environment.

Methods

Sample collection and bacterial isolation

Samples of foregut contents (approx. 15 – 25 gm) were collected from kangaroos that had been grazing native grass pastures in Western Queensland. Samples were taken from the tubiform region of the forestomach (Hume 1982), into bottles containing 100 ml of an anaerobic solution of rumen fluid (RF)-based medium and glycerol (1:1) (Klieve *et al.* 1998). These samples were frozen and stored at –20°C.

Isolation of plant fibrolytic bacteria followed the methods described by Ouwerkerk *et al.* (2005), except that a range of growth substrates were used (ball milled cellulose, birchwood xylan, oatspelt xylan and the neutral detergent fibre fraction (NDF) of curly Mitchell grass (*Astrebla lappacea*) in order to allow for the isolation of a broad range of bacteria that could digest plant structural carbohydrates.

Isolation and culture of reductive acetogens followed standard anaerobic procedures (Hungate 1969). Culture medium RF30 (Joblin *et al.* 1990) was modified by the addition of yeast extract (0.2 %, w/v) and trace element solution (0.01 %, v/v), with bromoethanesulphonic acid added to tubes after autoclaving (final concentration 25 mM) to suppress methanogens. Samples of foregut contents were serially diluted and roll-tubed as previously described (Klieve *et al.* 1998). The head-space of each tube was pressurized to 30 psi with H_2 and cultures were incubated with shaking at 39°C for up to five days. Headspace gas pressure was subsequently measured (Joblin *et al.* 1990) and reductive acetogenesis confirmed by acetate production.

Fermentor studies

Plant fibrolytic bacteria. A two-litre fermentation apparatus was used to select the kangaroo bacteria or combination of bacteria that were most efficient at degrading native pasture grass and maintaining viable populations in a rumen–like environment. The methodology used was similar to that devised to produce a live inoculum for cattle grazing leucaena (Klieve *et al.* 2002).

Fermentation commenced with a 100 mL starter culture being added to 2 L of a rumen-fluid-based (RF) medium. At commencement of the fermentation 30 g of finely ground spear grass was added as substrate for the fermentor. On the second day of fermentation the amount of ground hay added was reduced to 10 g and maintained at this level thereafter. Every 24 hours, half of the fermentor liquid was removed and replaced with an anaerobic balanced salts solution. The fermentor vessel was maintained at 39°C and continuously bubbled with a mixture of CO_2:H_2 (95:5 v/v) to maintain anaerobic conditions. On the second day of each experimental run either a pure culture of one of the fibrolytic kangaroo isolates or pure cultures of two isolates were inoculated into the fermentor, following replacement of fermentor liquor with balanced salts solution, to give a final density of 1 × 10^7 cells/mL of each bacterium.

To determine effects of plant fibre digestion in the ruminal environment, 12 nylon bags on a metal support were inserted into the fermentor. Each bag contained a pre-weighed amount of ground spear grass (approx 1 g). At zero time and at two day intervals, two bags were removed to determine dry matter disappearance. Total fermentation time per experiment was 11 days.

Each day, at the time of replacement of fermentor liquor with fresh salts solution, samples of fermentor liquor were collected for determination of volatile fatty acid (VFA) production (Ouwerkerk and Klieve 2001) and to enumerate the fibrolytic kangaroo isolates by real-time PCR (see below).

Two pure bacterial isolates and one combination of two bacteria were evaluated. Fermentations were run in duplicate.

Reductive acetogens. The ability of the reductive acetogens to colonise a rumen-like environment and to reduce methane emissions was also gauged using a fermentor. This was similar to the methodology used with the fibrolytic bacteria except that the volume of the fermentation was 3 L and all ingredients added were 1.5 times the amount used with the 2 L fermentations. Furthermore, each day, at the time of replacement of fermentor liquor with fresh salts solution, samples of fermentor liquor were collected for VFA determination (as above), to enumerate inoculant bacteria and total methanogens (by real-time PCR) and to profile methanogen populations (by denaturing gradient gel electrophoresis (DGGE)). Methane concentrations in the outflow gas from the fermentor were measured continuously throughout the experiments using an Environmax NDIR Methane analyser (Liston Scientific).

DGGE and real-time PCR

Total genomic DNA was extracted from thawed samples of fermentor liquor, using a bead-beating protocol (Whitford *et al.* 1998). Partial 16S rRNA genes of archaea were amplified from the extracted genomic DNA by PCR. A nested PCR procedure was used with primers Arch46F (Ovreås *et al.* 1997) and Arch1017R (Barns *et al.* 1994) in the first round of amplification. The resulting PCR product was used as template in the second PCR which amplified across the variable regions 2 and 3 (V2V3) of the 16S rRNA gene using the primers Arch344F-GC (Raskin *et al.* 1994) and Univ522R (Amann *et al.* 1995). Denaturing Gradient Gel Electrophoresis (DGGE) through a 30 – 60% gradient was used to separate the resulting PCR products to show which DNA bands (corresponding to methanogen species) were present in the fermentor.

Real-time PCR assays have been developed to enumerate total archaea (as per Takai and Horikoshi 2000), four kangaroo fibrolytic bacterial species and three kangaroo reductive acetogens. The species specific real-time PCR assays were designed and validated following the principles and protocols used previously for ruminal bacteria (Klieve *et al.* 2003; Ouwerkerk *et al.* 2002). Specific details of individual real-time PCR assays are too extensive to include with this publication.

Results and Discussion

Bacterial isolates

Five highly fibrolytic bacteria were selected for further work. Three of these were cellulose degraders (isolate numbers YE125, YE137 and YE166) and based on the DNA sequence of the 16S rRNA gene all were in the genus *Ruminococcus* and were related (97, 96 and 93% sequence similarity respectively) to *R. flavefaciens*. The remaining bacteria (YE129 and YE161) did not degrade cellulose but had a high affinity for xylan. Both were distantly related to butyrate producing bacteria (YE129, 96% similarity to butyrate-producing bacterium ART55/1; and YE161, 94% similarity to *Butyrivibrio fibrisolvens* strain 49).

Four species of reductive acetogens were isolated that showed a high affinity for hydrogen. One was a strain of the species *Clostridium glycolicum* (designated YE255), while the other three species, YE257, YE266 and YE273, were not closely related to any previously isolated acetogens but appear to be related to the Clostridiaceae and Lachnospiraceae (92% DNA sequence similarity in the 16S rRNA gene). Strains YE266 and YE273 were closely related to each other. In addition, a mixed population of three bacteria (*Desulfovibrio desulfuricans, Escherichia coli,* and *Enterococcus sp.*) was maintained that rapidly reduced hydrogen without methane production but also without reductive acetogenesis. This mixture was used to provide a further alternative to methanogenesis.

Fermentations with fibre degrading bacteria

Dry matter disappearance. The spear grass used in fermentations comprised 72.3% neutral detergent fibre and 0.25 % nitrogen, as a proportion of dry matter

The addition of the kangaroo fibrolytic strains had a noticeable effect on the rate of dry matter disappearance within the fermenter (Fig.1). This effect was most evident between days 3 and 5, where rate of digestion was increased from 5.9 % loss in the control experiments to between 8.9 to 9.4 % loss in the same time period when the kangaroo isolates were present. All the dry matter digestion experiments reached a maximum of approximately 50% dry matter loss after 11 days, with the YE125/YE161 combination digesting 43.1% (compared to 34.9% in the controls) by day 7.

The increase in rate of dry matter digestion observed while kangaroo fibrolytic isolates were detectable (see below) suggests that these marsupial bacteria may be an important addition to the rumen, where feed material is constantly removed and replaced with fresh material at a rate of approximately 2% per hour on low quality forage (Bowen, 2003). An increased rate of digestion would allow increased intake and therefore more of the cellulosic material in the feed to be converted to microbial protein and VFA's in the rumen, improving feed utilisation efficiency. The possible extent of any improved feed efficiency will be determined *in vivo* in future studies.

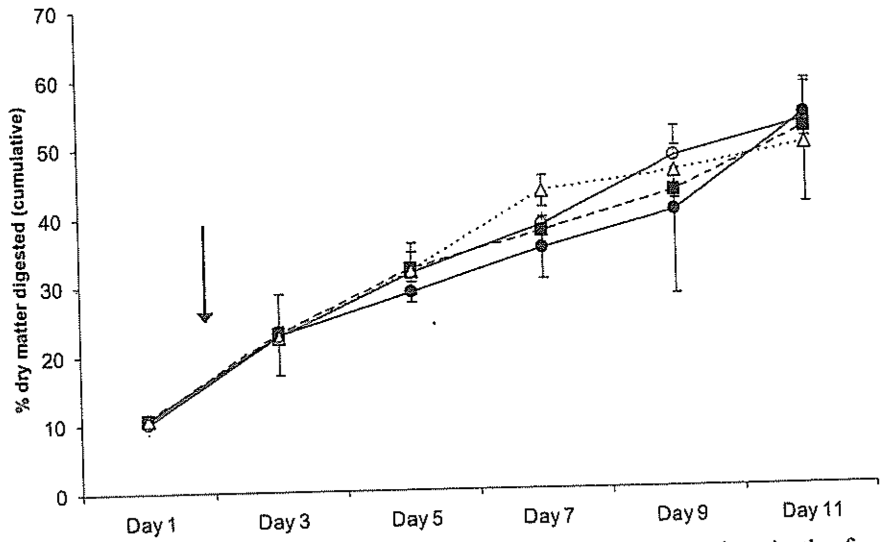

Fig. 1. Percent removal of ground spear grass from nylon bags over time in the fermenter (average of two fermentations). Control (●), YE137 (■), YE125 and YE161 (△) and YE166 (○). Bars show standard deviation from the mean. Kangaroo fibrolytic strains were added following sample collection on day 2 (indicated by arrow).

VFA production. VFA production was variable between experiments, but there was a noticeable trend towards increased acetate and decreased propionate production, particularly early in the fermentations following the addition of the kangaroo bacteria. As *Ruminococci* typically produce acetate from cellulose digestion (Mackie *et al*, 2002) this is consistent with the increased rate of dry matter digestion during this period.

Establishment of kangaroo bacterial populations. The total numbers of the kangaroo fibrolytic isolates persisting in fermentations, as determined by real-time PCR, are presented in Fig. 2. The control experiments were assayed for the four kangaroo isolates, and none were detected at any stage of the control fermentations.

Most isolates did not establish well in the fermentor and followed a pattern of reduction in numbers to below detectable levels over the course of 3 to 5 days. *R. flavefaciens* isolate YE125 was an exception and stabilised at between 10^5 to 10^6 cells/mL following an initial increase in cell density. The isolates that apparently did not establish may have been maintained below the detection threshold ($<10^4$ cells/mL). As the three cellulolytic isolates (YE125, YE137 and YE166) were related, it is possible that conditions in the fermentor were too nutritionally limiting and may require modification to allow the strains to establish stable populations.

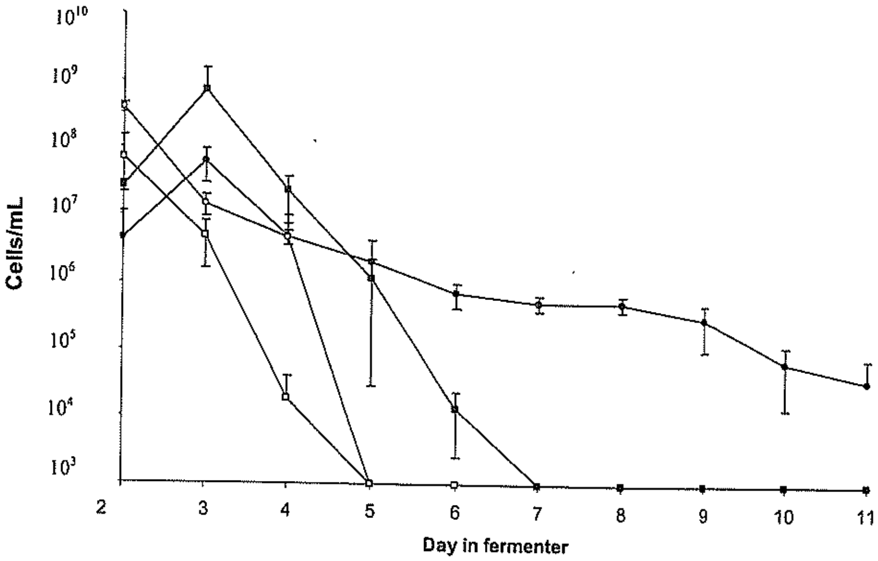

Fig. 2. Survival of kangaroo fibrolytic bacteria in the fermentor; YE125 (●), YE137 (□), YE161 (O) and YE166 (■). Each series was averaged from two fermentations. Bars show standard deviation from the mean.

Fermentations with reductive acetogens and sulphur reducing bacteria

Methane production. Daily methane produced by the fermentations is presented in Figure 3. To date, reliable methane data has been obtained from one control fermentation and further data is required. Promising trends do appear in the data. YE266 reduced methane emission marginally to day eight but then there was no difference to the controls, YE255 reduced emissions throughout but more so up to day 7 (up to 50% reduction), and the *Desulfovibrio* mix reduced emissions throughout by at

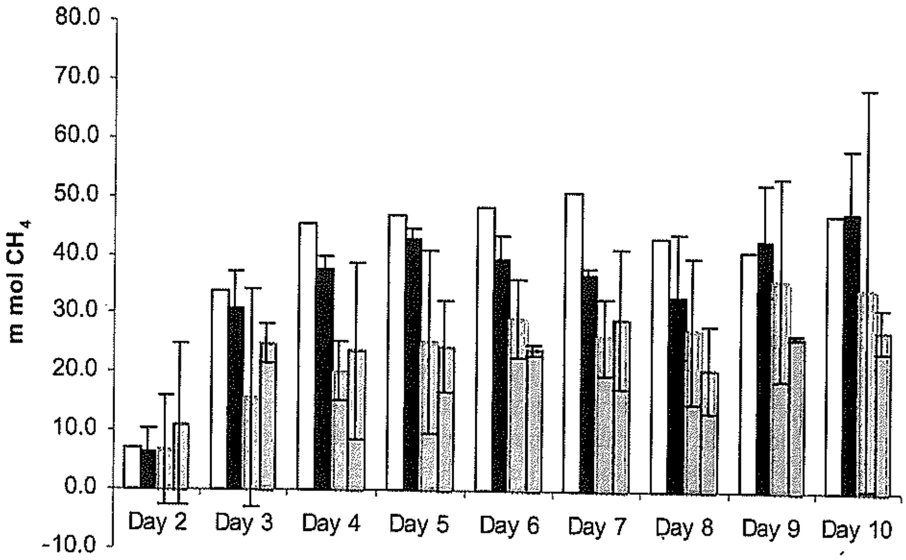

Fig. 3. Daily methane production from fermentations with kangaroo bacteria added; Control □, YE266 ■, YE255 ▒ and the *D. desulfuricans* mix ▤. The bacteria were added on day two and data is from duplicate fermentations, except for the control where reliable data was available from one fermentation only. Bars show standard deviation from the mean.

least 50%. However, with a single control run and very large variations in emissions from duplicate fermentations, further work will be required to confirm these preliminary observations.

Methanogen population densities and diversity. The total number of methanogens, as determined by real-time PCR, present in the fermentations is presented in Fig. 4. The number of methanogens in fermentations with kangaroo bacteria was fewer, particularly with the *Desulfovibrio sp.* containing mix, than in this control fermentation. However, further fermentations are required to confirm these results as there was considerable variability between duplicate fermentations.

From DGGE profiles (data not presented) the diversity amongst the methanogen community changed very little throughout each fermentor run with and without the addition of kangaroo bacteria. A clone library of the DNA from a typical sample run on DGGE showed that the three most dominant bands represented 96% of the methanogen community and were represented by three species of methanogens that were closely related to two different *Methanobrevibacter sp.* (currently unnamed), one isolated in Western Australia and the other in New Zealand. The closest related named species was *Mbb. thauri.*

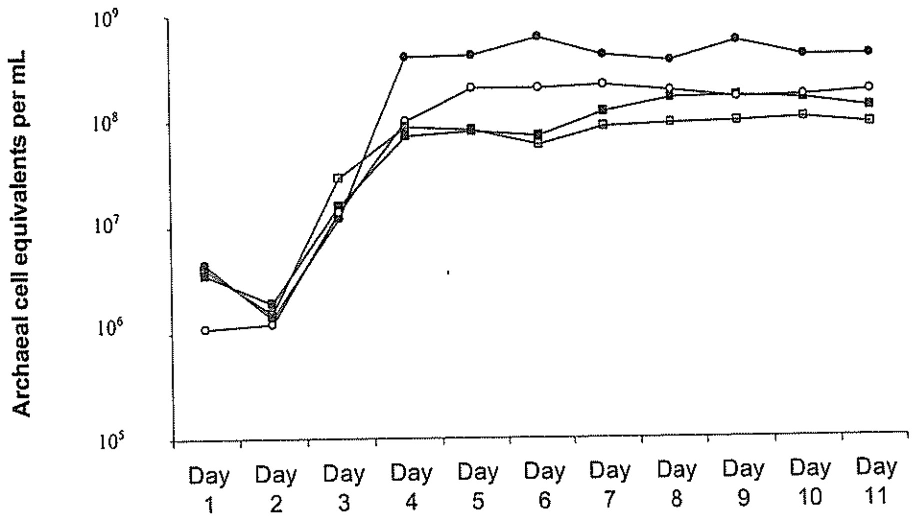

Fig. 4. Cell equivalents of total archaeal numbers in fermentation liquor. Curves are averages of two fermentations except for the control (single run), following addition of kangaroo bacteria on day 2; Control (●), YE255 (■), YE266 (O) or the *D. desulfuricans* mix (□).

Maintenance of acetogen populations. Neither YE255 nor YE266 remained at high densities for the entire period of fermentation (11 days) but they persisted at detectable densities for five and six days on one occasion each (of two) and may well have persisted for longer below detectable levels. As with the fibrolytic bacteria the selection pressure exerted may have been too intense and conditions in the fermentor system may require modification to allow the bacterial strains to become established. We deliberately asserted a high degree of selectivity by using very poor quality native pasture to maximise methane generation. With hindsight this may have been too harsh and not reflected the extra nutrients that would be available to the bacteria in the rumen. The initial increases in some isolate numbers over the first day following inoculation, while nutrient levels were still comparatively high from the initial starter media, suggests that the isolates may be competitive in a slightly nutrient richer environment. An assay to enumerate *Desulfovibrio sp.* is being developed and the persistence of this species will be determined in due course. Acetogens represented by YE257 are yet to be screened for their ability to colonise the fermentor.

VFA production and dry matter disappearance. VFA production was highly variable. However, the addition of the kangaroo bacteria appeared to increase total VFA production slightly and this appeared to be mainly from increased acetate (as expected) and propionate. The impact was more pronounced early to mid (up to day 8) fermentation when, in most cases, reductive acetogens were above detectable limits.

The inclusion of reductive acetogens and a mixture of bacteria including *Desulfovibrio sp.* appears to have had neither a positive or negative impact on the ability of fibrolytic bacteria to digest fibrous plant material. These results were not unexpected. As long as hydrogen is being removed from the fermentation fibre digestion shouldn't be inhibited and reductive acetogens or methanogens *per se* appear to play no other role in fibre digestion than removing hydrogen.

Conclusions

A range of fibrolytic bacteria and hydrogen utilising bacteria, mainly reductive acetogens, were isolated from foregut contents of red and eastern grey kangaroos. These bacteria were then assessed for their ability to persist in a rumen-like environment. Results to date are promising but not as conclusive as hoped. The stringent conditions initially selected for the fermentor experiments possibly do not accurately reflect the levels of nutrients available in the rumen, and further *in vitro* experimentation with less stringent conditions will be undertaken. Modifications to the fermentor pH and media protein concentration (in particular) is likely to improve the ability of the kangaroo isolates to survive and maintain populations. In addition, a trial with rumen cannulated cattle will be undertaken to gauge the ability of the fibrolytic bacteria to persist in the rumen.

The reductive acetogens and the *Desulfovibrio* mix appeared to reduce methane emissions and methanogen numbers while at the same time increasing total VFA production through increased acetate and propionate production. However, the kangaroo acetogens were also not able to maintain high density populations in the fermentor and the degree of variability in the parameters measured means that while we can comment on apparent trends in the data, we cannot unequivocally state that these bacteria will be beneficial. Further *in vitro* experimentation with less stringent conditions will be undertaken to evaluate the ability of additional kangaroo isolates (including reductive acetogen YE257 which has not been evaluated) to colonise the fermentor and reduce methane emissions prior to selecting those to be evaluated in cattle.

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SoFT – A new database and selection tool summarising current knowledge on adaptation and use of warm season forages throughout the tropics and subtropics

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Abstract. Over 50 years of research and development has identified about 200 tropical and subtropical species that have forage potential in farming systems in the tropics and subtropics. Information on these species such as their adaptation, feeding values, required management and constraints has not always been easily available. While some of the information is in the published literature, the majority is in publications which have had limited distribution, such as annual reports and project reports, or has not been published at all, but is only available from experienced regional forage specialists.

A database of information gathered from a wide range of sources, especially from experienced forage agronomists, was assembled so that this information is more easily accessible. In addition to the database of information, delivered in the form of fact sheets, a selection tool which enables users to identify forage species of possible potential for their intended use was also developed.

SoFT (Selection of Forages for the Tropics) has been released for 18 months and feedback from users has been very encouraging, and plans are now underway to develop a similar system which will include sown forages for southern and northern Australia.

Introduction

The role of warm season forages in improving livestock production has been demonstrated repeatedly over more than 50 years of research on their selection, management, and their positive contribution to economic and biophysical sustainability of smallholder mixed livestock-cropping farming systems and open grazing systems throughout the tropical world (e.g. Shelton *et al.* 2005).

Shelton *et al.* (2005) reported some of the most significant examples of widespread adoption of forages in the developing world. That review also demonstrated the degree of diversity of forage species being used and how they had been incorporated into the complexity of smallholder farming systems in climates ranging from the semi-arid to humid tropics. However forage species of importance in the developing world is not restricted to those reported by Shelton *et al.* (2005), and many others, both grasses and legumes, are being used in a range of farming systems around the world.

In Australia, the long research history has also provided a wealth of information on forage species adaptation and management and resulted in the release of over 50 forage cultivars for use in the beef and dairy industries and in the mixed crop-livestock farming systems of southern and central Queensland and northern NSW. Only a relatively small number of these cultivars remain commercially available for various reasons such as susceptibility to disease (e.g. *Stylosanthes humilis*, *S. scabra*), difficulties in seed production (e.g. *Aeschynomene falcata*), changes in industry structure (e.g. decline in the dairy industry in northern Australia following deregulation), duplication of cultivars (e.g. *Cenchrus ciliaris*, *Chloris gayana*), and weed potential (e.g. *Hymenachne amplexicaulis*).

Research across the tropics in cultivar development and forage management has been undertaken by a large number of national and international research agencies including CSIRO, DPI&F (Queensland), USDA, EMBRAPA (Brazil), various universities from around the world (e.g. Queensland (Australia), Florida (USA) and Hohenheim (Germany)), and the international CGIAR (Consultative Group on International Agricultural Research) centres, CIAT (Centro Internacional Agricultura Tropical) and ILRI (International Livestock Research Institute). During all that work in excess of 200 forage species have been identified as being of potential use in various farming systems around the world.

Despite this large amount of research and development, information on the adaptation and use of this large number of forages has not been readily accessible. Much of it has been published in scientific literature, and in "grey" literature such as annual reports. It also exists in the minds of a large number of experienced forage scientists.

Even where information is accessible, it is often regionally focused so that its use ignores its potential role in other parts of the world. Nevertheless, information on many of the most important forages has been assembled for regional use, such as those produced by the DPI&F (Qld) and NSW DPI. These information sources are also available on the web, as is cultivar information provided by seed merchants. Probably the most comprehensive information on warm season forages is that published by FAO in books (Skerman *et al.* 1988, Skerman and Riveros 1990) and on the web (http://www.fao.org/ag/AGP/AGPC/doc/GBASE/, http://ecocrop.fao.org/). In short, the information available was fragmented, often regionally focused and required some assembling of information from many sources to gain an overview of a species.

The aim of SoFT was to assemble as much information as possible on the adaptation and use of what were identified as 180 of the most important forage species, and to present that information in such a way that it would be accessible to a wide range of potential users, from researchers and extension specialists, to agribusiness, development agencies, and more informed farmers.

Methodology

The SoFT tool as developed has three key components:

1. A selection tool which enables users of the database to identify which forages might be best suited to particular environments and farming systems.
2. A series of fact sheets which summarise the adaptation and other characteristics of each of the 180 forage species.
3. A bibliography of some of the most important scientific papers associated with each species.

These components arose from the nine overall design and implementation concepts which the database development team identified in partnership with collaborators. These concepts were:

1. SoFT was intended for use in developing and developed countries across the tropics and subtropics and by a wide cross section of the agricultural community.
2. The development of a selection tool would enable users to select appropriate species options for defined farming systems and environments.
3. The selection tool would be developed using the Lucid knowledge management software.
4. The database would include fact sheets for all tropical forage species in or near commercial use.
5. The selection tool and the fact sheets would be available on the web and CD.
6. Information would be gathered from forage specialists during workshops held across the tropics and from "grey" and formal literature.
7. Fact sheets would be written by forage agronomists who had specialist knowledge of particular species.
8. Where possible, fact sheets would be checked by one or more appropriately experienced reviewers.
9. Given the extensive range of users, the tool would use easily recognised descriptions of environmental and farming systems on which the selection would be made.

Meeting these concepts could only be achieved in collaboration with a wide range of forage agronomists. By the time SoFT had been completely developed, 69 collaborators from around the world had made substantial contributions, and many more had contributed at workshops held in Australia, Asia, Africa, Latin America and Europe, in which regional agronomists were given the opportunity to highlight their particular priorities in terms of species, environments and farming systems.

The information on which the selection process is based in SoFT was derived from literature and from the broad experience of the collaborating team, and that information was continually reviewed as new information became available from other regions and farming systems. The team's input was especially important in defining the description of environmental and farming systems, in the identification of the key attributes to be used in defining environment and farming systems, and finally in the evaluation of the outcomes of selection process, i.e. in commenting on whether the particular species selected were in fact realistic options.

The selection tool

The selection tool was developed using the Lucid knowledge management software specifically designed for identification and diagnostic purposes developed by the University of Queensland (Centre for Biological Information·Technology, 2004). In the case of SoFT, Lucid allows the user to select from a range of environmental and farming systems characteristics that reflect their target system and based on those characteristics, the selection tool presents one or more best-bet forage options which might be considered. The list of best-bet options is dependent on the degree of definition of the environment and farming system and importantly, the user can see the immediate impact of inclusion or exclusion of particular characteristics as the selection process is undertaken.

SoFT incorporates many environmental selection criteria which includes a broad classification of latitude x altitude interaction (e.g. high altitude tropical), rainfall, soil texture, soil fertility and some attributes of soil chemistry (pH, aluminium levels and salinity) (Fig. 1). For ease of use, all of these attributes are defined in readily understood and available states. For instance, soil texture is defined simply as light, medium or heavy and pH as strongly acidic, acidic, neutral and alkaline. In our attempts to simplify, we have caused some concern to those who need more precisely defined categories.

The selection tool also incorporates 15 parameters which define the farming system or intended use for the selected species (Fig. 2).

The data on which selections are based within SoFT are in the form of a yes/no answer for each state within each of the parameters describing the environment and farming system. i.e. is a particular species adapted to a particular altitude/latitude combination; is it able to be used in a particular farming system such as cut and carry systems; is it adapted to clay soils etc.? Coding for each of the over 100 different parameter and states was developed by six of the key collaborators who had forage research and development experience from around the world. The coding was continually reviewed during the testing stage to finetune the selection tool.

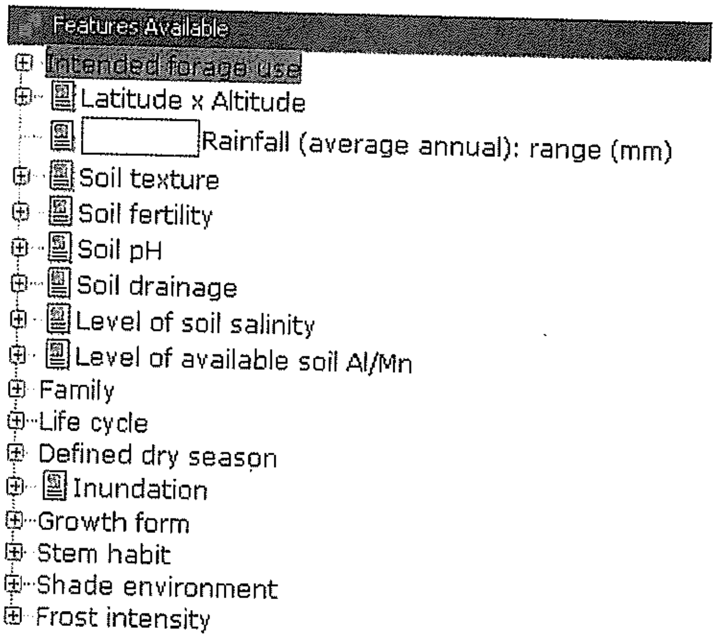


Fig. 1. Environmental attributes used in the SoFT selection tool to define environments, plant family (usually grass or legume) and lifecycle (whether or not an annual of perennial species is being sought.

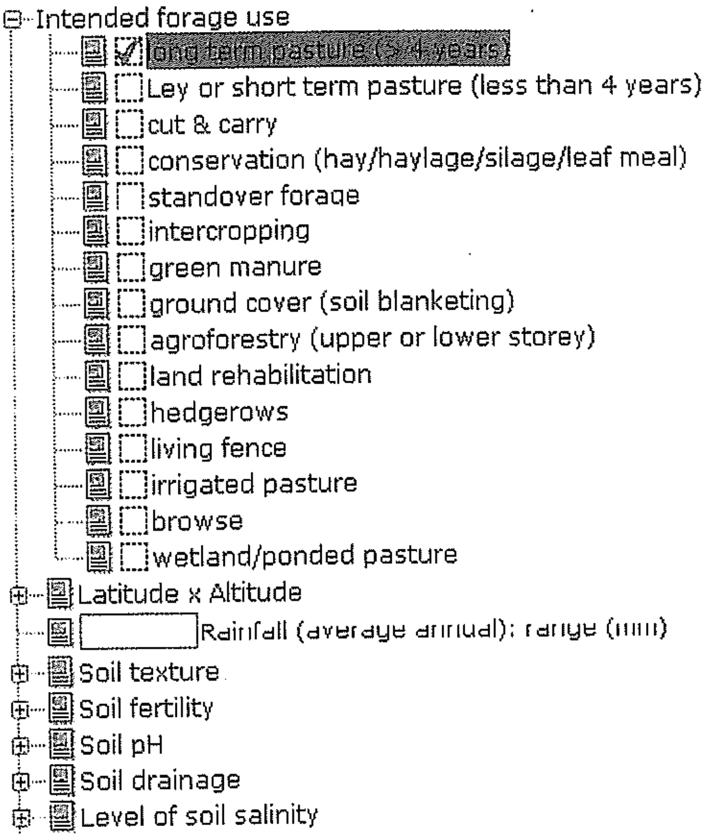


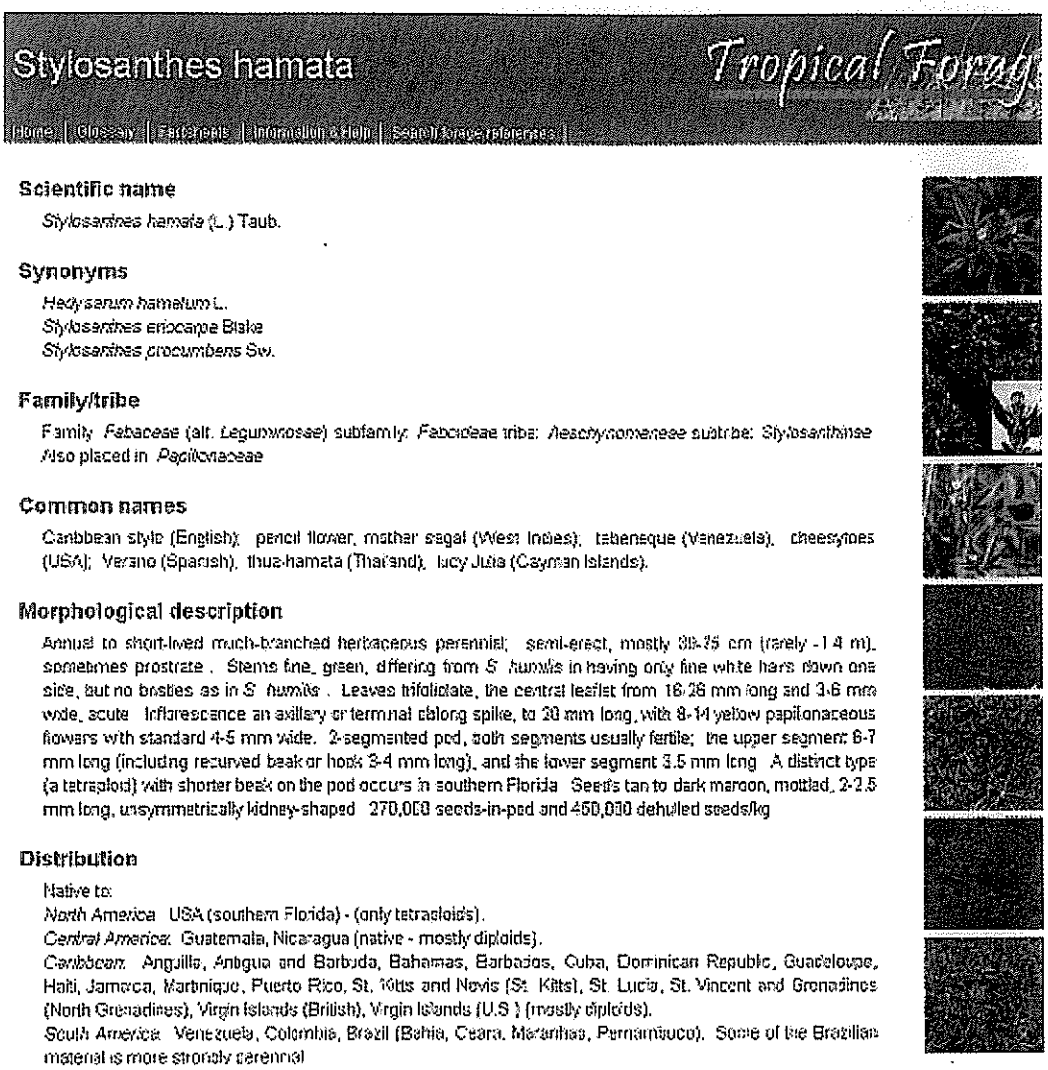
Fig. 2. The range of potential forage uses included in the SoFT selection tool to cover the wide range of farming systems in which improved forages can be used in developed and developing countries of the tropics and sub tropics.

Fact sheet design and development

A standard design and format for the fact sheets was adopted, based largely on the FAO Grassland Index page, but also drawing on PROSEA 4 "Forages" (1992), and the personal experience of the collaborators. This design facilitated uniform collation of information, and enabled flexibility between species, something that was required given the large differences among species in the information available. The standard format was also adopted to enable easier updating of the fact sheets as new information becomes available.

A fact sheet was developed for each of the 180 species included in SoFT and since there was such a wide range of intended users the fact sheets needed to be designed to cover the breadth of information that these users might seek. Consequently the fact sheets provide information as diverse as the taxonomy of the species (e.g. family, botanical name and authority and synonyms), adaptation to climate and soils, management information, pests and diseases, and weed potential (Fig. 3). The fact sheets also include information on cultivars and their particular attributes (especially where more than one cultivar has been released from one species). It was considered particularly important to include identity and background of elite germplasm, i.e. accessions of a species which have been identified in research programs as having commercial potential, but which have never advanced to being released for use by producers. This information has not previously been assembled from research reports and made available in one source. The development team believed that it was this information which was most in danger of being lost to future researchers and research programs.

Finally, each fact sheet is accompanied by a number of high quality colour images and line drawings generously provided by collaborating individuals and institutions around the world. These photographs were selected to assist users in recognising particular species and to provide images of them being used in farming systems.


Stylosanthes hamata

Tropical Forages

Scientific name

Stylosanthes hamata (L.) Taub.

Synonyms

Hedysarum hamatum L.
Stylosanthes eriocarpa Blake
Stylosanthes procumbens Sw.

Family/tribe

Family: *Fabaceae* (alt. *Leguminosae*) subfamily: *Faboideae* tribe: *Aeschynomeneae* subtribe: Stylosanthinae
Also placed in: *Papilionaceae*

Common names

Caribbean stylo (English); pencil flower, mother segal (West Indies); tebeneque (Venezuela); cheesytoes (USA); Verano (Spanish); thua-hamata (Thailand); lucy Julia (Cayman Islands).

Morphological description

Annual to short-lived much-branched herbaceous perennial; semi-erect, mostly 30-75 cm (rarely -1.4 m), sometimes prostrate. Stems fine, green, differing from *S. humilis* in having only fine white hairs down one side, but no bristles as in *S. humilis*. Leaves trifoliolate, the central leaflet from 16-26 mm long and 3-6 mm wide, acute. Inflorescence an axillary or terminal oblong spike, to 20 mm long, with 8-14 yellow papilionaceous flowers with standard 4-5 mm wide. 2-segmented pod, both segments usually fertile; the upper segment 6-7 mm long (including recurved beak or hook 3-4 mm long), and the lower segment 3.5 mm long. A distinct type (a tetraploid) with shorter beak on the pod occurs in southern Florida. Seeds tan to dark maroon, mottled, 2-2.5 mm long, unsymmetrically kidney-shaped. 270,000 seeds-in-pod and 450,000 dehulled seeds/kg

Distribution

Native to:
North America: USA (southern Florida) - (only tetraploids).
Central America: Guatemala, Nicaragua (native - mostly diploids).
Caribbean: Anguilla, Antigua and Barbuda, Bahamas, Barbados, Cuba, Dominican Republic, Guadeloupe, Haiti, Jamaica, Martinique, Puerto Rico, St. Kitts and Nevis (St. Kitts), St. Lucia, St. Vincent and Grenadines (North Grenadines), Virgin Islands (British), Virgin Islands (U.S.) (mostly diploids).
South America: Venezuela, Colombia, Brazil (Bahia, Ceara, Maranhao, Pernambuco). Some of the Brazilian material is more strongly perennial

Fig. 3. Example of the first section of a fact sheet in which taxonomy, morphology and distribution is defined. The fact sheets also include detailed information on environmental adaptation, management and potential use.

References and links

The development of SoFT also provided an opportunity to bring together the published information on the 180 species included in the database, and SoFT includes over 7000 individual journal papers or book chapters. The published information is provided in the main as abstracts, rather than just references since many of the intended users, particularly those in developing countries, would not have access to libraries from which they could source publications.

In addition to the material published in the traditional literature, a number of web sites have been developed by various agencies which provide information on particular species (e.g. the FAO web sites already listed or provide information on particular species and their use and management in particular regions). The fact sheets developed in SoFT include links to additional electronic sources of information so that users are able to more easily access that information.

Delivery

The SoFT database was released in June 2005, on the internet at www.tropicalforages.info and in compact disc (CD) format. The release in CD format was aimed at providing access to those users with limited internet access (Cook *et al.* (2005)). Over 10,000 users world wide are accessing the database on the web each month with most users coming from the CGIAR international research centres and national centres in Australia, Mexico and the USA, and feedback from users worldwide has been particularly encouraging. Although development for use by students at universities was not initially one of the main aims, universities in South Africa, Australia, USA, Costa Rica, and Mexico, are now using the tool in forage agronomy teaching, particularly in encouraging student users to relate choice of plants to environment and application. In addition to the web delivery, around 1200 CDs have been distributed to Latin America and the Caribbean, Sub-Saharan Africa, South-East Asia and the Australian and Pacific region.

Some Australian seed companies are using SoFT to support staff in their sales teams and are using the fact sheets for information on particular species. It has been suggested that SoFT could be adapted for training "counter staff". There are also an increasing number of people from around the world seeking permission to use parts of SoFT in new products such as books and software tools; CIAT for example is working on using the SoFT format in making available a farmer and NGO directed species profiles tool in Spanish language available through the Net.

Discussion

SoFT provides a technically sound tropical forage information product which has been successfully tested by a large number of experienced forage scientists and which provides information which is relevant to the farming systems in four continents. One of the most important aspects of the development process was the cooperation of >100 forage agronomists from those continents in providing information and in reviewing the selection tool and fact sheets. This cooperation is indicative of the value that these agronomists saw in developing such a tool.

The development of the selection tool itself was based around previous identification and diagnostic tools (keys) built with Lucid. Identification of the best attributes on which to make forage selections proved challenging, and the final attribute list and the options within them evolved throughout the project. The main challenge was to have a tool which was easy to use and avoided complexities and confusion as much as possible. For instance the "intended forage use" selection criteria is as comprehensive as we could make it, and the climate and soils "classifications" avoid the need to refer to detailed published classifications. In the final analysis the value of the selection tool depends on its being able to provide believable results. The result of each selection depends on the coding for each species and relies on a good understanding of adaptation of the species as we know it, not just a single cultivar. In short it had to address both the complexity of the adaptation and the taxonomy of the species. For these reasons the scoring process was particularly demanding.

SoFT ought to be seen as the first stage in an ongoing process. It is clear from the number of users and the comments from users that the database is meeting a need in teaching, extension and even in commercial application in seed companies. However there will always be need to update the fact sheets with new information of new species, cultivars and elite germplasm.

SoFT is available in English only, and this limits the use of the tool by forage scientists in non-English-speaking countries particularly China, Vietnam, and Indonesia, but also other Asian countries with rapidly growing livestock industries, and the whole of South and Central America. Translation to French would benefit many West and Central African scientists, and translation to Spanish and Portuguese would benefit South and Central America and Mexico. Plans are already underway to have translations made to Vietnamese, Khmer (Cambodia) and Bahasa (Indonesia).

SoFT is already making a significant contribution to information available to livestock industries in Australia, especially via agribusiness, particularly the seed industry, through forage agronomy teaching and to some extent, by direct use by producers. Based on the success of SoFT, the development of an Australia-wide database and selection tool to cover all of the Australian sown forages (temperate and tropical) has now commenced. This should be available within two to three years.

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New science and technologies – what next?

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Abstract. As noted previously, animal genomics is an expensive research and development activity that should significantly accelerate the rate of genetic improvement in cattle in Australia, and that benefits greatly from spillovers from global mammalian genomics research. But genomics is only one of several new technologies that are likely to influence the practice of animal production in northern Australia. In this paper, we will describe some of the technologies that are likely to flow from global research and development in electronics, information sciences and biotechnologies other than cattle genomics. The potential impact of these technologies will be discussed in context with their likelihood of occurrence:: e.g. "Reasonably certain"; "Maybe some chance"; and "If we were dreaming". Likewise these impacts will be discussed in context with scenarios for industry in the future. Global technological markets are competitive and Australian industries are to some extent competing for access and public largess. So whilst it is true that technologists need to strive to build utility and ease of application into the products they supply, cattle businesses need to articulate their technological needs clearly and be prepared to contribute more for access to innovators and innovations.

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Buffel grass (*Cenchrus ciliaris*) invasion at Epping Forest National Park

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Introduction

'Epping Forest' National Park north-west of Clermont in Central Queensland (22° 22' S, 146° 41' E) is home to the only remaining colony of Northern Hairy Nosed wombats (*Lasiorhinus krefftii*), an endangered large mammal with a population of 115. The wombats live in burrows excavated in deep sandy soil along an ancient watercourse and this disturbance has allowed buffel grass (*Cenchrus ciliaris*) to become established. Cull and Ebersohn (1969) showed that buffel grass was markedly better at colonising a sandy levee than black speargrass(*Heteropogon contortus*). In 1987 monitoring the invasion of buffel grass and its impact on other grasses, particularly black speargrass which was thought to be the preferred diet of wombats, was commenced.

Materials and methods

Two permanent transects each 100 m long were established near each of four active and one abandoned burrow system to monitor the spread of buffel grass. Transects ran north-south with each pair positioned 25 m apart and with the burrows near the northern end. One hundred quadrats, each 0.5 m x 0.5 m, were recorded at each site and the presence of herbaceous flora was recorded in each quadrat. By this we determined the frequency for each species across time.

Results and Discussion

The mean frequency of buffel grass increased from 7.8% in 1987 to peak at 54.2% in 2000 (Fig. 1). Black speargrass frequency declined from 21.8% in 1987 to 1.8% in 1994 and to <1% ever since. The frequency of wiregrass (*Aristida* spp., 81% in1989, 28% in 2006) and bottle-washer grass (*Enneapogon* spp.), (38% in1989, 14% in 2004), has declined over the period with mean wiregrass frequency appearing to be very responsive to rainfall. The frequency of buffel grass increased steadily from 1987 till 2000, through the 1991-1993severe drought, effectively replacing the black speargrass which has not returned even through the quite wet years from 1997 till 2003. Buffel grass appears to have peaked and its spread out from the disturbed areas has ceased. The other two grasses are present mainly some distance from the disturbed burrows and their frequency has declined, but not to the extent of black speargrass, and wiregrass appears to be more influenced by rainfall.

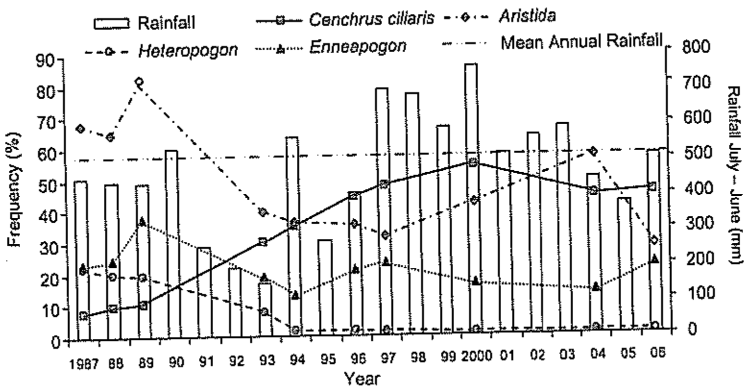

Fig. 1. The frequency (%) of four grasses and rainfall (mm) at Epping Forest National Park.

We conclude that Buffel grass displaces native grasses around wombat burrows at this location.

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How stems affect forage intake rate and selectivity by cattle grazing tropical grasses

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Introduction

Cattle select leaves and avoid stems or plant species which are difficult to prehend. Recent studies suggest that this is associated with the high tensile resistance (TR) of stems (Benvenutti *et al.* 2006). The aim of the present work was to confirm the results from previous studies using natural swards.

Methods

Trained steers (211 kg se 12 kg) were allowed to take 8 bites from 0.25 m^2 swards. The experiment had a randomized complete block design with 3 steers as replicates and consisted of a factorial combination of 5 tropical grasses [*Bothriochloa pertusa* (Bp), *Chloris barbata* (Cb), *Chloris gayana* (Cg), *Cynodon dactylon* (Cd) and *Heteropogon contortus* (Hc)] and 3 stem densities (0, 400 and 800 stems/m^2). Grazing behaviour variables and the TR of stems were measured. Significance of treatment effect was determined by standard analyses of variance.

Results, discussion and conclusion

Cb, Cg and Hc (group A) had stems of significantly higher TR (110.3, 211.3 and 167.2 Newtons respectively) than those of Bp and Cd (19.1 and 15.1 Newtons respectively) (group B). The steers avoided stems of group A and thus, reduced bite mass and intake rate (IR) as stem density increased ($p<0.05$) (Fig. 1). However, the animals did not avoid stems of group B and there was no effect of stem density on any of the grazing behavior variables ($p>0.05$). These results suggest that IR and plant part selection is closely associated with the TR of the stem. Stem was eaten when TR was low.

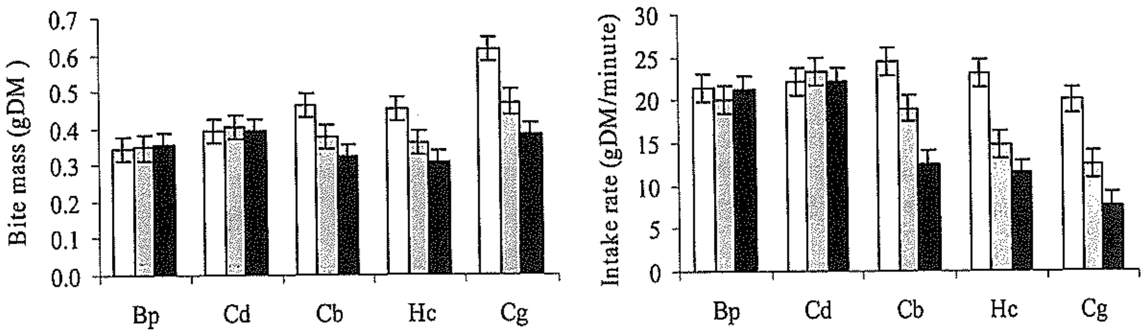

Fig. 1. The effect of stem density and grass species on bite mass and intake rate. White solid, striped and black solid columns represent 0, 400 and 800 stems/m^2 respectively. See text above for grass specie keys. Vertical lines are standard errors of the mean.

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Development of a wireless sensor network for understanding and controlling animal behaviour

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Recent advances in technology have enabled the automated collection of animal behaviour data. For example, bite meters can record the grazing and ruminating behaviour of cattle (Rutter *et al.* 1997). This paper describes a wireless sensor network (WSN) and explores the feasibility of using the network to collect data on, and control the behaviour of, animals in extensive grazing systems. A heterogeneous WSN has been deployed at Belmont Research Station (150° 13′E, 23°8′S), located 20 km NW of Rockhampton in Queensland (Sikka et al. 2004). This network is solar powered and has been running for over 18 months. The current deployment consists of 30 sensors that provide soil moisture profiles in the plant rooting zone, sensors that measure the quantity of supplement and water consumed by animals, electronic tag readers, up to 40 sensors that can be used to track animal movement (GPS, 3-axis magnetometer, accelerometer and gyro), 20 sensor/actuators that can be used to apply audio, visual and tactile stimuli to animals and 6 camera nodes for forage assessment. The network is designed for continuous day and night operation and is connected to the Internet via a dedicated high-gain radio link, also solar powered. Each node has the ability to process the information it collects allowing the network to summarise and/or perform calculations, thereby reducing the amount of data that has to be transferred over the network and/or stored.

The WSN provides infrastructure for experiments focussed on network design and functionality and allows the continuous real-time collection of data in extensive grazing systems. Using this technology, cattle behaviour is not influenced by the presence of people observing the cattle. The WSN enables monitoring and automated management for improved environmental and production outcomes for the beef industry of northern Australia. More specifically, the network has been used in the past twelve months to: a) monitor soil moisture and schedule irrigation (Figure 1), b) identify behavioural traits in animals, c) test the cues and controls related to automated management and d) identify states of animal behaviour.

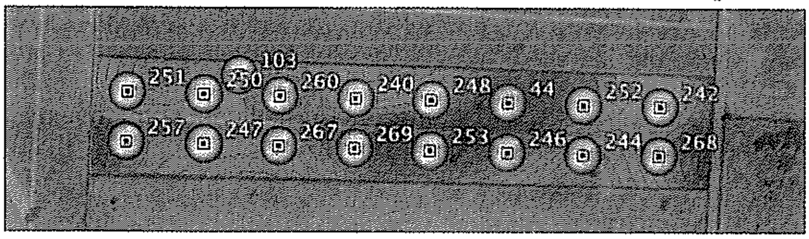

Figure 1. Paddock volumetric water content based on nodes (circles with numbers) dark shading =>0% light shading => 100%

The research being conducted within CSIRO at Belmont Research Station using the WSN is providing a detailed automated monitoring and actuator platform for cattle control in large-scale extensive grazing systems. The information gained will give scientists a better understanding of animal behaviour and contribute to the development of guidelines to producers on how to manage livestock for increased production and environmental and economic sustainability. In addition the interaction between livestock scientists and information communication researchers will identify and develop new WSN telemetry applications for the livestock industries.

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Modelling the energetics of northern Australian beef systems

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Introduction

The extensive grazing systems of the northern beef industry are characterized by low outputs, both on a per hectare and per animal basis. However, production systems have been developed that underpin a large and diverse industry worth $1.5 billion to the Australian economy. A key characteristic of the northern industry is the high feed [metabolizable energy (ME) and protein] overheads required to operate a low input-output beef system. With branding rates around 70% and growth rates of 100 to 200 kg/year, up to 90% of feed inputs may be devoted to maintenance requirements. Funding through the CSIRO flagship "Water for a Healthy Country" has been used to develop a systems based model to explore management changes that may increase energetic efficiency without compromising pasture sustainability or ground cover.

Modelling approach

The model consists of a livestock component (Fig. 1) which links into a property and regional component. Pasture inputs include peak yield and quality, seasonal change in quality, and utilization rate. Animal inputs include the type (breed, sex, reproductive status) and age of the animal, birth and slaughter weights, physical activity and milk production. The model runs scenarios without or with energy supplementation. The model calculates the lifetime (or part thereof) ME requirements for maintenance; growth, reproduction and milk production for typical northern Australian production scenarios. In addition methane output can also be calculated. Currently the model is primarily intended to explore "what if" outcomes to assess the impact of management changes on energetic efficiency of the animal.

Model outputs

Model outputs for a Brahman cross steer grazing spear grass or buffel grass are summarized in Table 1. In this scenario the higher quality and yield of buffel grass reduced age to slaughter by 6 months and reduced maintenance costs from 81% to 78% of ME. The model also highlighted the potential saving in molasses supplementation associated with the higher pasture quality.

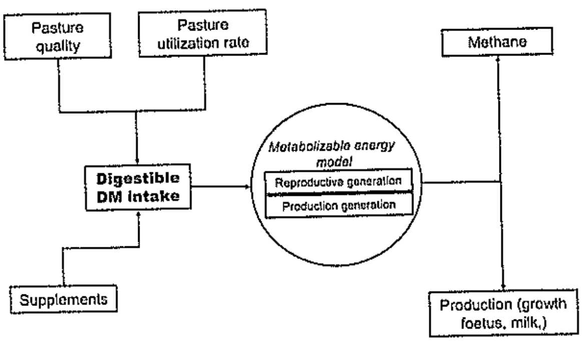

Fig. 1. Conceptual diagram of the livestock model

Table 1. Example of model outputs for spear grass or buffel grass

	Spear grass		Buffel grass	
	No molasses	With molasses	No molasses	With molasses
Supplement per year (kg)	0	104	0	53
LWG (kg/yr)	142	218	162	225
Age at 550kg (months)	44	29	38	28
% of ME for maintenance	81	68	78	57

Industry implications

The major value of this research is its ability to quickly and simply compare different production scenarios. Users can readily assess the relative impact of various options, as shown in the data above. Ongoing development will refine predictions. The greater challenge will be defining inputs that accurately reflect scenarios typically encountered in the northern beef industry.

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Value adding to the EDGEnetwork® Grazing Land Management package: Is there a role for GLM within an Environmental Management System?

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Introduction

A case study is underway which seeks to develop an environmental management system (EMS) incorporating the Grazing Land Management (GLM) framework for Legune Station, NT. The aim of the project is to determine the applicability and success of such a union, and document the process. It is believed that the process will:

1. Add to the GLM package by strengthening its planning and assessment elements
2. Increase knowledge and understanding about EMS and GLM
3. Increase the uptake of both of these beneficial tools
4. Develop the ability of pastoralists to sustainably manage their land

Background

There is mounting scrutiny and regulation of natural resource management and the beginnings of market pressure for the production of environmentally friendly agricultural goods as seen in the organic movement and products such as Eco Bananas. Pressure from regulatory bodies, non-government organisations, markets and the wider community is encouraging producers to address the environmental impacts of their pastoral enterprises.

A system currently available for documenting environmental accountability is the EMS. The concept of an EMS is often misunderstood. Essentially an EMS is a management system (akin to Quality Assurance Management Systems) which allows businesses to document and improve their impacts on the environment. It is not a standard by which businesses should adhere, but a system of continual improvement which allows the individual to identify the relevant issues and then set their own environmental targets. An EMS has the potential to be certified to the international standard ISO14001 allowing recognition of the environmental commitment of a business.

There are many other potential benefits to implementing an EMS:

- maintain or improve natural resource condition
- enhance image of primary producers as responsible land managers
- regulatory relief
- improved business planning and production efficiencies
- market advantages

Despite these benefits, EMSs have not been widely implemented across the pastoral industry. There remains confusion as to what it actually is, scepticism as to its benefits and trepidation about the involved and complex process that it is seen to be. While the Centralian Land Management Association (CLMA) have developed a customised EMS template for central Australian producers, it is not completely relevant to the northern environment, nor ISO14001 compliant and has not included the GLM framework.

An opportunity exists to develop an appealing EMS template which is tailored to the issues existing within extensive northern beef operations. Grazing land management is the single biggest environmental issue in a pastoral situation. An excellent framework for addressing this currently exists in the MLA EDGE*network* Grazing Land Management (GLM) education package. Currently GLM is very well received amongst the pastoral industry and would provide producers with a strong base for an EMS. The credence of the GLM package has the potential to increase the uptake of environmental management systems by making them a more attractive process. Incorporating GLM into an EMS would give land holders the added advantages of an EMS, such as increased market access and certified recognition of sustainable land management. Further, the rigorous continuous improvement system in an EMS may strengthen the GLM package.

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The Australian tropical forages collection – under threat?

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A valuable resource for Australian primary industries

The DPI&F is the custodian of an extensive genetic (seed) resource of 2,677 ecotypes (255 species) of warm-season grasses and 10,016 (614 species) legumes collected throughout the sub-tropical and tropical world over 40 years (Lawrence 2002). The represented ecotypes are adapted to a wide range of north Australian climates and soils and the collection has been refined for particular application to meet the needs of major primary industries (Cook pers. comm.. 2006).

The forage collection has significantly benefited the grazing industries through improving pasture productivity. The grasses and legumes are today the basis of sub-tropical dairy production and the benefit to the beef industry was estimated in 1997 at $712 million (Walker *et al.*, 1997). The collection is now being applied to the development of sustainable beef systems in salt-prone areas (Moore *et al.* 2003), warm-season forages for southern Australia (Cook pers. comm. 2006) and ley legumes to condition degraded cropping soils in dry-land environments (Clem and Cook 2004). The collection is also an international development resource, accessible through the DPI&F web-site (AusPGRIS) and linked to other tropical forage collections and web-based selection tools.

Threats to the collection

The collection requires maintenance and upgrading to enable efficient application of the genetic material. A DPI&F review of the collection identified the need to regenerate 2,736 accessions of low volumes and 597 accessions of low viability (mostly grasses) (Lawrence 2002).

A DPI&F seed regeneration program was begun at Walkamin during 2004, with priority on genera of best future application: 379 grass accessions across 36 species of 13 genera (notably *Bothriochloa, Dichanthium, Digitaria, Megathyrsus* and *Urochloa*); 250 legume accessions across 29 species of 7 genera (notably *Centrosema, Desmanthus, Macroptilium* and *Stylosanthes*). Each accession was raised in controlled conditions before transfer to field plots. Mature seed was progressively harvested by hand, dried and cleaned and later tested for viability. Simple characterisation data (habit, flowering characteristics, major pathogens, seed production) and digital images were collected for future inclusion in AusPGRIS. Seed was successfully collected for 94% of both grass and legume accessions over two years, although small amounts only (< 2 g) have been collected for 39 (mostly *Digitaria* and *Centrosema* spp.).

Funding the maintenance and development of the Collection is a long-term challenge. Failure to do so will result in the slow decline of the collection and present a significant cost to primary industries in Australia as the material must be introduced once again through quarantine.

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Using NIRS to measure the composition of extrusa from oesophageally fistulated cattle

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The diet selected by grazing cattle has usually been measured from the constituents of extrusa collected from oesophageally fistulated animals. Botanical and morphological composition of the extrusa is normally determined by extremely laborious manual sorting or microscopic examination of the extrusa. The proportions of grass, forbs and the principal grass species in extrusa have been measured using NIRS (Volesky and Coleman 1996). The present study examined NIRS as a technology to measure the composition of extrusa from cattle grazing tropical grass pastures.

Extrusa samples (n 87) were collected in March 1993-1996 and 1998 from oesophageally fistulated steers grazing 18 paddocks (2 replicates each of 9 grazing treatments) of speargrass-based pasture at Galloway Plains, Calliope, CQ (Orr 2005). Each paddock was sampled by 6-8 steers. Proportions of green leaf, dead leaf, green stem and dead stem of each plant species present in extrusa, and N content, were measured. Samples from each paddock in each year were dried, ground and bulked. NIRS spectra (400-2500 nm) were measured using a Foss 6500 scanning monochrometer fitted with a spinning cup. Chemometric analysis used ISI software and involved transformations of the absorbance data (SNV+D, 1,4,4,1 and 2,4,4,1) and MPLS to develop and test calibration equations.

Table 1. The population (n 87), calibration (n 63) and validation (n 24) statistics (g/kg dry matter) for the first derivative (1,4,4,1) calibration equations

Measurement	Mean	s.d.	Min.	Max.	Calibration		Validation	
					R^2_{cal}	SECV	Bias	SEP(C)
N content	11.6	3.1	6.7	19.7	0.92	0.97	-0.11	0.83
Heteropogon contortus	284	202	6	794	0.85	98	-41	93
Bothriochloa bladia	200	147	13	590	0.70	109	45	105
Grass leaf blade	671	237	118	968	0.93	77	-15	77
Total grass	760	231	205	987	0.94	68	16	51
Stylo	158	248	0	763	0.96	68	4	44
Forbs (other dicots)	59	69	0	294	0.74	58	-20	38

s.d., standard deviation; Min, minimum; Max, maximum; SECV, standard error of calibration; SEP(C), standard error of prediction following correction for bias.

The calibration equations indicated that N content and the proportions of total grass leaf blade, total grass and total stylo could be measured with an accuracy suitable for many experimental purposes. Measurements of the proportions of green and dead components of grass, of the forbs and sedge plant groups, or of the specific grass species, was generally less satisfactory. It may be possible to use NIRS to measure satisfactorily some of these latter constituents when they comprise higher proportions of the extrusa (Volesky and Coleman 1996).

In conclusion, NIRS can be used satisfactorily in a closed population to measure the proportions of leaf blade, total grass and stylo in extrusa obtained from oesophageally fistulated cattle grazing speargrass pastures at a specific site over a number of years. Additional reference values are likely to be required to expand the NIRS calibration equations to measure constituents in extrusa obtained from cattle grazing other pasture systems.

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Enhancements for Australian Brahman BREEDPLAN

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Introduction

Results from recent research have been implemented by Brahman BREEDPLAN to improve the genetic evaluation for the breed. Using updated genetic parameters ensures the genetic evaluation reflects the current population, in particular for traits which have accumulated most of their records in the recent years: ultrasound scan and carcase traits.

Materials and Methods

Data were extracted from the Australian Brahman database, and included pedigree information for 192,073 animals. The model of analysis for all traits was the corresponding model used by BREEDPLAN, as described in detail by Graser et al. (2005). Univariate analyses were undertaken for traits to obtain heritability estimates, and multivariate analyses for genetic correlations.

Results

Table 1 contains summary statistics for growth, fertility and carcase traits for which BREEDPLAN EBVs are reported. Genetic parameters reported include heritability and genetic correlation with 200d weight. Heritability estimates were relatively similar to previous parameters for traits with many records, while some differences were observed for traits which have accumulated the majority of their data since previous parameters were estimated (mainly carcase traits). While other weight traits were highly correlated with 200d weight, low genetic correlations were estimated with fertility and carcase traits. Standard errors for genetic correlations ranged from 0.02-0.09 (other weight traits); 0.06-0.10 (fertility traits) and 0.16-0.25 (carcase traits).

Table 1. Summary statistics for growth, fertility and carcase traits.

Trait	Number of records	Heritability *(SE)*	Genetic correlation with 200d wt
Birth weight	5,111	0.30 *(0.06)*	0.71
200d weight	89,274	0.19 *(0.01)*	1.0
400d weight	31,153	0.35 *(0.03)*	0.83
600d weight	24,162	0.48 *(0.02)*	0.78
Mature cow weight	3,626	0.45 *(0.07)*	0.66
Milk	89,274	0.06 *(0.01)*	-
Scrotal size	7,315	0.44 *(0.04)*	0.19
Days to calving	11,947	0.08 *(0.01)*	0.12
Carcase wt	1,972	0.33 *(0.09)*	0.59
Eye muscle area	1,156	0.32 *(0.11)*	0.23
Rump fat	1,755	0.27 *(0.09)*	-0.20
Retail beef yield	577	0.39 *(0.17)*	0.24

Implications

Updated genetic parameters were used in the 2006 Brahman BREEDPLAN analysis to ensure that EBVs were based on underlying parameters that best reflect the Australian Brahman population.

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* AGBU is a joint venture of NSW Department of Primary Industries and the University of New England

Effect of maternal liveweight gain in early pregnancy on birth weight and conformation of calves born to 2-year-old beef heifers

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Introduction

Retarded early foetal growth rate may alter the growth trajectory of the fetus for the duration of gestation and result in smaller calves. As calf birth weight is associated with the incidence of dystocia in 2-year-old heifers, this study aimed to determine whether differences in heifer liveweight gain in early pregnancy would affect the birth weight and conformation of their calves.

Materials and methods

Forty-four 15-month-old Angus heifers were inseminated with semen from one of five Angus bulls at a synchronised oestrus and were allocated to either a 'high' liveweight gain treatment (583 g/day) or a 'low' liveweight gain treatment (193 g/day) for the first 93 days of pregnancy. Heifers were then managed so that both groups were the same liveweight at calving. Calves were weighed within 24 hours of birth, and sex of calf, and a range of body measurements were recorded (Nugent *et al.* 1991).

Results and discussion

Table 1. Effect of 'High' or 'Low' maternal liveweight gain during the first trimester of pregnancy and sex of calf on birth weight and conformation of calves. Values are least square means ± SE.

	High	Low	P values		
			Treatment	Birth weight	Sex
Number	17	24			
Birth weight[A] (kg)	33.0 ± 0.7	33.8 ± 0.5	NS		0.05
Body length (cm)	77.8 ± 1.4	78.7 ± 1.3	NS	NS	NS
Height at withers (cm)	65.6 ± 0.6	65.5 ± 0.5	NS	0.001	NS
Head circumference[A] (cm)	46.1 ± 0.2[a]	47.5 ± 0.2[b]	0.001	0.05	NS
Thoracic girth (cm)	73.6 ± 0.5	73.8 ± 0.4	NS	0.001	NS
Width of hips[B] (cm)	19.7 ± 0.2	19.6 ± 0.2	NS	0.05	NS
Cannon bone circumference (cm)	11.3 ± 0.1	11.5 ± 0.1	NS	0.01	0.001
Cannon bone length[A] (cm)	16.6 ± 0.3	16.1 ± 0.2	NS	0.001	NS

[A]3 dead calves were included so 27 records in Low group; [B]16 records in High group.

Maternal liveweight gain during the first trimester of pregnancy did not affect the birth weight of calves born to 2-year-old beef heifers when the heifers had the same total liveweight gain over pregnancy. Conformation parameters were related to calf birth weight for all parameters except body length, indicating that calf size was proportional to birth weight. The findings are in general agreement with Nugent *et al.* (1991) and Prior and Laster (1979). These maternal liveweight treatments are unlikely to reduce dystocia in 2-year-old beef heifers.

Acknowledgements

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GIS and the Pastoral Industry

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Geographic Information Systems (GIS) are computer based systems that allow geographic features to be recorded, displayed and analysed. Features that can be mapped include, but are not limited to, roads, fence lines, water points, soil and vegetation types, fire scars, land systems and rainfall patterns. Given the large areas managed by NT cattle producers it is important to have objective information to assist with land management decisions over such a variable and vast spatial scale.

GIS information can be used to produce maps to assist land managers with property planning and environmental management strategies. For example, GIS can be useful when planning new developments by relating proposed fence lines to soil type in order to minimise erosion and limit the number of creek crossings.

GIS is an important tool for assisting with the development of grazing management plans. Examples of the type of information that can be generated include:

- Calculation of areas of land types within a given grazing radius to help determine potential carrying capacities
- Assist in the optimal placement of new infrastructure and development, allowing more accurate costing of required materials such as pipe, fencing materials or pasture seed
- Mapping of existing weed infestations and identifying areas of concern for potential incursions
- Changes in cover and condition through satellite imagery monitoring
- Planning of fire management strategies based on historical fire information
- Identifying areas of potential concern for land condition decline or conservation value
- Planning and recording of ground sites to monitor land condition which can be revisited

In addition, GIS can be used in conjunction with other computer models such as AussieGRASS to monitor rainfall and pasture growth trends across a region. This can assist with drought management strategies such as de-stocking and agistment. GIS also allows data from current seasons to be compared to historical records allowing for a more informed assessment of the long-term productivity of an area.

Data currently available in the Northern Territory include:

- Property Infrastructure
- Soils, Land Systems and Land Unit
- Vegetation Information
- Water Resources
- Remote Sensing and Satellite Imagery datasets
- Topographic data at various scales
- Pasture growth and rainfall models

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Landscape instability can occur when desirable plants are recruiting

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Summary
Recruitment of desirable grasses can occur even when landscape stability is being compromised and grazing pressure may be too high for long term sustainable management. Recruitment of Desert bluegrass (*Bothriochloa ewartiana*) increased with increasing grazing pressure during several years of a grazing trial in central Queensland (Silcock *et. al.* 2005). While land condition and growing conditions were fair, this increased recruitment in the short term may not be a sensible indicator of sustainable management.

Methods
A major grazing trial was conducted from 1994 to 2001 on Ironbark (*Eucalyptus melanophloia*) pastures at Rubyvale, Central Queensland. Pasture dynamics, runoff and soil loss (ROSL), rainfall and animal production were recorded under low, medium and high grazing pressure. The recruitment of desert bluegrass, a desirable perennial, is discussed.

Results
There was a trend for increasing recruitment of desert bluegrass with increasing grazing pressure for 5 of the 6 years of data (**Table 1**). The trial site did not experience extended dry conditions. Landscape instability was evident at high grazing pressure. Average annual soil loss was 4 t/ha under high grazing pressure, and 2 t/ha under medium grazing pressure. The trend for increasing recruitment with increasing grazing pressure occurred in the summers before, during and after the summer when major erosion events were happening. The seedbank of desert bluegrass was not reduced by increasing grazing pressure. The survival of recruiting plants was reduced by increasing grazing pressure, however the resultant nett density was not affected.

Table 1. Recruitment (plants/m2) of desert bluegrass under varying grazing pressure

Grazing pressure	Year					
	1995	1996	1997	1998	1999	2000
Low	0.9	0.2	0.8	0.4	0.9	0.8
Medium	1.7	0.2	2.4	0.5	1.2	0.9
High	2.4	0.6	3.5	1.0	1.0	1.9

Discussion
The increasing recruitment of desert bluegrass with increasing grazing pressure was recorded under periods of fair rainfall, good land condition and an adequate seed bank. It should not be expected that this trend would continue, as seed banks would eventually exhaust, especially during dry conditions. Also, the recruitments would only occur during good growing conditions. Similar trends have been recorded in other grazing trials in their first year. However, it does indicate in the short term that increasing recruitment may not be a sensible indicator of sustainable management. Desert bluegrass is a major component of the pasture yield and the resilience of the pasture was demonstrated by the density being maintained by increasing recruitment levels as grazing pressure increased.

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Automated monitoring of cattle for behavioural phenotyping

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Ten thousand years ago domestication of cattle resulted in the implicit selection for docile behaviour – presumably animals too wild to tame were either eaten or escaped. Recent genetic improvement technologies have focused on traits of production and product quality such as milk, liveweight and marbling, largely ignoring animal behaviour (Emmans and Kyriazakis 2001). Behavioural traits associated with feeding/foraging (Urton *et al.* 2005), maternal care (Komdeur 2006) and bull libido (Petherick 2005) have until recently been difficult to quantify and/or involved field observations and subjectivity. The advent of telemetry technologies e.g. UHF transmitter-receivers (contact loggers), Global Positioning Systems (GPS) and Wireless Sensor Networks (WSN) have enabled researchers to collect a continuous real time record of behavioural traits. Linking data from these devices into a WSN allows the generation of a behavioural dataset with minimal disruption to the cattle. This paper highlights work at the CSIRO Rendel laboratory and Belmont Field Station that demonstrates the potential use of contact logger data for the quantification of behavioural traits.

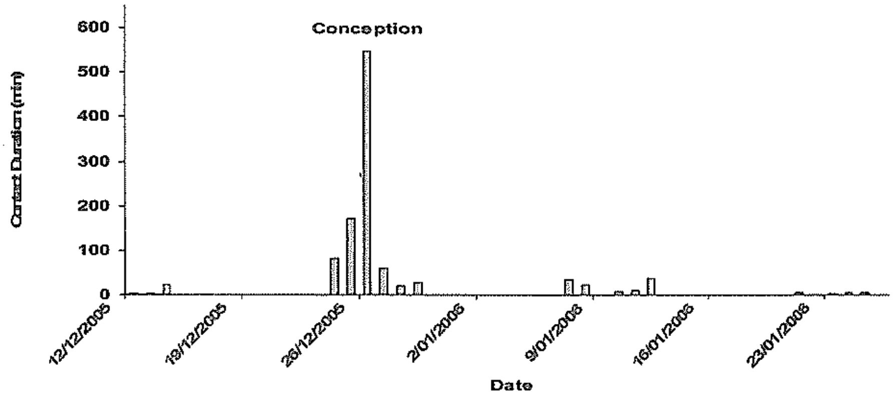

Fig. 1. Daily contacts at fortnightly intervals between cow 99-840 and bull 00-094 over the 2005-06 breeding season. Oestrus and time of conception (26 December 2005) was determined by ultrasound.

Figure 1 provides an example of behavioural data using contact loggers which were set to a maximum read-range of 5 m. The data show contact activity between a cow and bull and reveals how telemetry data, in terms of number and duration of contacts, can be used to automatically monitor bull libido, a cow's onset of oestrus and calf parentage.

The successful domestication of cattle demonstrates that it is possible to breed for behavioural traits. There is the potential to use telemetry technology to generate data of behavioural phenotypes and provide an interface with genetic improvement programs.

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Grazing management studies warrant long term focus

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Introduction

Four major grazing studies conducted in Queensland between 1988 and 2006 have examined the impacts of grazing management on vegetation dynamics and animal production. Three of these studies failed to demonstrate consistent differences in density of the key perennial grasses. This paper examines these studies and the implications for further grazing management research.

Methods

Grazing studies were conducted at: Glenwood, Mundubbera; 1990-1996, characterised by severe drought; studied *Heteropogon contortus* (black speargrass) (Orr *et al.* 2004). Galloway Plains, Calliope: 1988-2001; seasonal rainfall generally below the mean; studied *H. contortus* (Orr 2005). Keilambete, Rubyvale: 1994-2000; seasonal rainfall generally favourable; studied *Bothriochloa ewartiana* (desert bluegrass), *Chrysopogon fallax* (golden beard grass) and *H. contortus* (Silcock *et al.* 2005). Wambiana, Charters Towers: 1988-current; initial rainfall above the mean but below the mean since 2002; studied *B. ewartiana,* and *C. fallax* (O'Reagain and Bushell 1999). The dynamics of key perennial grasses was measured by charting annually the survival of existing plants together with any seedling recruitment in permanent quadrats. Density integrates survival and seedling recruitment.

Results and Discussion

These studies recorded few consistent differences in density except for *H. contortus* at Galloway Plains and the final year at Keilambete. Nevertheless, these studies provide valuable data on the dynamics of 4 important perennial grasses. *H. contortus* is characterised by large variation in density resulting from a short life span and large variation in seedling recruitment. At Galloway Plains, the 13 year study revealed that heavy grazing reduced *H. contortus* density because heavy grazing reduced seed production which, in turn, reduced seedling recruitment (Orr 2005). In contrast, both *B. ewartiana* and *C. fallax* displayed little variation in density because of their inherent longevity and associated low levels of recruitment. Clearly, longer time periods will be necessary for these 2 species.

The failure to record consistent differences in density was associated with the short time of these studies relative to the life spans of these perennial grasses. Jones and Mott (1980) indicated that population studies should continue for sufficient time to make final measurements on plants recruited during the study and not only on the original plants. The impact of drought is also important and population studies should continue well into a period of above average rainfall seasons to adequately record the impacts of grazing treatments on the recovery of those plants present during the drought.

It is concluded that these studies have failed to continue for sufficient time in relation to the longevity of these grasses. Further studies of perennial grass dynamics need to consider this long term nature of perennial grass persistence and allow sufficient time to detect meaningful differences.

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NT Pastoral Industry Survey

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The NT Pastoral Industry Survey 2004 provides a snapshot in time of the management practices, challenges and attitudes of cattle producers in the NT.

The survey was initiated to provide the basis for future industry strategic planning and research and development needs.

The Pastoral Production team felt that the relatively small number of producers in the NT provided an opportunity to engage *all* cattle producers in a face to face survey rather than taking a random sample. We wanted to give everyone the opportunity to contribute their voice and opinions, not just a representative few.

Four regional surveys were carried out in the Top End, Katherine, Barkly and Alice Springs regions, with an NT wide report summarising all four also produced.The hundreds of phone calls and thousands of kilometres travelled by the survey team were rewarded with a 71% response rate of all cattle producers in the NT identified as managing a herd of 300 or more breeders. The time taken to conduct each survey varied between 45 minutes and five hours, with the average being around two hours.

The survey questionnaire was 26 pages of detailed questions in the topic areas of ownership and management structure, infrastructure and area, herd husbandry and management, grazing management, natural resource management, major issues and constraints, suggestions for research, how producers access information and why they choose to be a member of the pastoral industry. The data from the survey is completely anonymous and remains the property of the producers of each region.

The most significant challenge named by producers was attracting and maintaining staff and the most significant environmental concern was the encroachment of exotic weeds. Producers named lifestyle as being the predominant reason they choose to be a member of the pastoral industry.

In the Alice Springs, Barkly and Katherine regions results were able to be compared to previous surveys-all of which were undertaken over 20 years previously.

Table 1 outlines an example snapshot from the Katherine region detailing a dynamic industry that has made huge leaps in production performance whilst undergoing rapid change.

Table 1. A comparison in management practice and benchmarks in the Katherine region between 1982 and 2004.

Management Practice	1982	2004
% producers undertaking two or more full rounds	9	87
Branding %	45	71
% who wean males	68	100
% who wean females	35	100
% who attempt to segregate maiden heifers	21	79
% who supplement	35	98
% turnoff live export	6	89
% turnoff meatworks	66	< 1
Averag number main turnoff months	6	3
Average bull %	4.3	4.4
% of properties with less than 50% of the herd showing *Bos indicus* blood	68	0
% who dehorn calves	38	100

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Short Courses for Stock Camps

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Station hands are the often the "frontline" of our industry if we consider that their day to day activities determine how our cattle are presented on arrival at their destination. In addition to this they spend much of their time moving around a property with the potential to identify environment and production problems or create them! Often these staff are inexperienced and new to the region, with little understanding of the important role their activities can play on the industry scale.

To address this, with the intention of improving staff skills and retention the Katherine Pastoral Production team have created two short courses aimed at all interested station staff-including everyone from the stock camp to the grader drivers or bore men. These courses were formulated in consultation with the Katherine Pastoral Industry Advisory Committee and through asking station hands about the topics they were interested in learning about.

The Rangeland Management course covers:

- Basic pasture identification and the principles of pasture management
- Weed identification and eradication
- Principles of fire management
- Station planning and grazing management

The Stock course covers:

- Animal Health and Emergency Disease Protocol
- Cattle Breeding
- Cattle Production and Nutrition
- Horse Nutrition
- The Live Export Market

Both include lots of practical exercises, which involve demonstrating how overall management objectives relate to their day to day activities, mixed in with some blood and guts to keep things interesting! At any point in a day they may be conducting a post mortem, castrating, planning station infrastructure or a management calendar, or role playing being anything from a station manager to a cow's reticulum!

Attending these courses gives staff the chance to gain an understanding and appreciation for the environment and production system they will be working in. It helps to prepare them to be more motivated and useful employees on a day to day basis, examples of this include:

- Being able to recognise weed species and understanding the crucial importance of early detection and eradication of isolated plants
- Being better equipped to identify potential animal disease outbreaks
- Understanding the importance and relevance of their hard work in activities such as putting out supplement, and ensuring other husbandry and welfare activities are carried out with a high standard of care and expertise

The aim of both courses is to help station staff understand how important their role and taking pride in their everyday work is to the industry as a whole. We achieve this by providing best practice advice and focusing on how the manner in which they carry out their day to day duties can relate all the way back to the Territory's profile in our export markets, and the wider implications of weed outbreaks, land condition and fire management for our environment.

These courses are delivered in a fun, energetic and interactive style, aimed at people more used to riding horses and working in yards than sitting in a "classroom".

The courses have been running throughout the Katherine region since 2001, with hundreds of participants on average rating their satisfaction with relevance and usefulness at 86% and motivation to learn more at 84%.

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Cooper Creek & Diamantina catchment flood 'rules of thumb'

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The beef industry identified the need for formal research, development and extension to ensure the sustainable management of the floodplains of the channel country in the mid 1990s. The Department of Primary Industries and Fisheries (DPI&F) has conducted the project 'Sustainable Grazing in the Channel Country Floodplains' in partnership with MLA, private producers and pastoral companies since 1998. The project has published books which bench-mark current industry practice (Edmonston 2001), review available literature (White 2001) and report on the initial phase of research (Phelps *et al.* 2003). A number of conference proceedings and popular articles have also been produced.

Research to date has highlighted the critical role of flooding in providing the moisture necessary to initiate and maintain pasture growth on the heavy cracking clay soils of the floodplains. Floods of any size will initiate growth, whilst falls of rain of up to 150mm have failed to (Phelps *et al.* 2003).

One of the recent management tools developed in the project 'Sustainable Grazing in the Channel Country Floodplains' is a guide to improving managers' ability to predict the size of the flood and the likely pasture growth to ensue. Managers currently predict the flood extent, subsequent pasture production and cattle numbers required from their previous experience (or that of neighbours and previous managers) and anecdotal evidence. Information which can provide an early estimate of the numbers of cattle needed subsequent to a flood event has operational and tactical management advantages, especially to pastoral companies seeking to truck cattle in from other stations, or to purchase additional numbers to take advantage of the flood induced pasture growth.

Maps combining historical flood and rainfall records, Digital Terrain Model and the best local and scientific knowledge have been produced as a guide to assist graziers to predict flood events in the Channel Country. These maps will help mangers determine the likelihood of receiving a good, handy, gutter or channel flood once the rains start further north, and put planning cattle movements 6 - 8 weeks in front of the flood arriving.

Consultation with key industry members has demonstrated that moving cattle off the flood plains and estimating additional cattle numbers are crucial management decisions. Additional cattle numbers are being estimated as soon as a flood starts, especially by the experienced mangers, whilst actual cattle numbers to be run are generally determined during the peak of the flood. Information to help decide cattle numbers and re-stocking dates would greatly enhance operational planning, especially within the larger companies.

In general, managers follow the upstream progress of a flood as soon as rains are received. They use a combination of Bureau of Meteorology information sources (web, fax and radio) on rainfall and flood height, as well as upstream properties, to trace the speed at which the flood is moving and the rise or fall in water level as it approaches. In some cases, the conditions for a good flood on one property differ from those for another (e.g. the eastern and western side of the Cooper). The maps will allow information such as this, to be quickly interpreted at the property scale to estimate a flood's progress, speed, potential coverage, cattle numbers and restocking schedules.

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Edmonston V (2001) 'Managing the Channel Country sustainably: producers' experiences.' (Queensland Department of Primary Industries: Brisbane)

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Phelps DG, Day KA, Jeffery MR, Connelly PT, Fraser GW, McCallum BS, Sullivan MT, White IA, Robertson SA, Cobon DH (2003) 'Sustainable grazing in the Channel Country floodplains. A technical report on findings between June 1999 and August 2002.' Meat and Livestock Australia Ltd, North Sydney.

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Vaccinating maiden heifers once against vibriosis in northern Australia.

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Bovine vibriosis (caused by Campylobacter fetus subspecies venerealis) has been found to be widespread throughout the Northern Territory (N.T) (Jayawardhana 1998) although the prevalence and impact of the disease is not known. Due to the extensive nature of NT cattle properties, not all bulls get mustered and vaccinated and so there is always a chance that females may contact infected bulls.

A field test was conducted to determine whether there was any economic benefit from giving maiden heifers 1 injection of a vibriosis vaccine (Vibrovax™, Pfizer Animal Health, Australia) just prior to joining. The vaccine instructions state that heifers that are older than 18 months of age only require 1 injection of the vaccine to gain immunity from vibriosis for 2 years. Since most heifers are joined for the first time at two years of age in the N.T, giving one injection of a vaccine is a practical treatment, whereas a vaccine that requires 2 injections several weeks apart is not practical due to the high mustering costs associated with large paddocks.

The experiment was repeated with two year groups of maiden heifers in 2004/5 and 2005/6 at Newry station (16° 00' S, 129° 25' E). Prior to joining, maiden Brahman heifers were weighed and pregnancy tested (manual palpation per rectum) and every second non-pregnant heifer was given a vibriosis vaccination. The vaccinated group (VIB) and the control group (CON) all grazed together in the same paddock and bulls (mixed ages) were introduced to the heifers in late December and remained with them continuously from that point onwards. Several fences were washed down over the wet season and as a result other bulls gained access to the paddocks and not all heifers were re-mustered. The heifers were weighed and their stage of pregnancy determined at the first round muster (WR1) in April/May and then again at the second round muster (WR2) in September/October.

Table 1. Average weight and fertility of maiden heifers in each treatment group.

Year	Treatment	Pre-joining avg. weight	WR1 % pregnant	WR1 avg. weight	WR2 % pregnant
2004/5	VIB	238 kg	53^a	323 kg (N=252)	78^a (n=276)
2004/5	CON	234 kg	42^b	322 kg (N=343)	72^a (n=385)
2005/6	VIB	256 kg	70^a	333 kg (N=202)	84^a (n=198)
2005/6	CON	254 kg	59^b	332 kg (N=222)	75^b (n=232)

[a,b] Pregnancy rates with different superscript letters in each year are significantly different (P<0.01, using Maximum Likelihood Chi-squared tests with Yates Correction for Continuity).

Conception rates were significantly higher (+11%) in the VIB group at the WR1 muster in both years (Table 1). By the WR2 muster the advantage in conception rate of the VIB over the CON groups was reduced (6% in the first year and 9% in the second year), however the higher proportion of late conceptions in the CON groups is not desirable, as these heifers will calve and lactate in the dry season. This will reduce their chances of re-conception and increase the likelihood that they and/or their calf will die. Their progeny are also likely to take an extra year to reach turn-off weight.

If an extra calf is valued at $300 then (using the most conservative figure) a 6% increase in conception rates from vaccination results in a return on investment in the order of 600%. However the actual benefit is much greater, as there are significant benefits from having an increased proportion of calves conceived early in the joining period.

Reference

Jayawardhana G (1998) NT Dept of Primary Industries Fisheries and Mines, Agnote No. 745.

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A use for second round weaner heifers in the Northern Territory

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It is common practise for most cattle stations in the Northern Territory (NT) to perform 2 weaning rounds each year and to join their heifers for the first time at approximately 2 years of age. Depending on the length of the wet season, the first round of mustering (WR1) usually begins around April and the second (WR2) around September. Heifer calves weaned at WR2 usually don't reach sufficient joining weights by the end of the next year for good fertility to occur. As a result managers are faced with a decision of either culling WR2 heifers (usually sold to live export) or keeping them for an extra year until they reach weights that are conducive for good fertility.

In a review of data collected at Victoria River Research Station (VRRS) NT between 1985 and 1991, Sullivan *et al.* (1997) reported that 74% of heifers weaned at WR1 were selected to become replacement breeders while only 28% of WR2 heifers were selected. Subsequently 77% of WR1 heifers conceived at their first joining compared to only 31% of WR2 heifers.

Another solution of what to do with WR2 heifers may be to transport or sell them to areas within the NT where higher growth rates are achieved (such as the Douglas Daly region) so that joining weights sufficient for good fertility are reached by the start of their second wet season. These observations were conducted to determine whether this practise would be successful.

Brahman WR2 heifers were transported from VRRS to the Douglas Daly Research Farm (DDRF) shortly after weaning in September in 2003 and 2004. At DDRF they grazed fertilised Buffel pastures and had access to mineral supplement blocks year round. The heifers were kept separate from bulls from the time they arrived at DDRF until the start of their second wet season there. Then they were joined to bulls from mid December until the end of March and pregnancies were diagnosed (by manual palpation per rectum) in late May.

Table 1. Performance of WR2 heifers.

Year weaned	n	Mean weaning weight (kg)	Mean joining weight (kg)	% Pregnant
2003	15	120 *(Sep 2003)*	321 *(Dec 2004)*	93
2004	51	152 *(Sep 2004)*	297 *(Dec 2005)*	76

Table 1 shows that in both years the heifers grew to sufficient weights by the time they were joined for good fertility to result. In effect the higher growth rates that occurred in the Douglas Daly district meant that the WR2 heifers reached similar joining weights by 18 months of age as heifers that were weaned at WR1 but stayed at VRRS. (In comparison, heifers that were weaned at VRRS in WR1 2004 and that remained there had an average joining weight in December 2005 of 305 kg and a subsequent conception rate of 87%).

The cost of transporting 100 weaners from VRRS to DDRF (approximately 550 km) is about $2,200 (at $1.45 per deck per km) and the value of the extra weaners that are produced from joining WR2 heifers a year earlier is $13,500 (assumes 76% weaning from WR2 heifers at DDRF and 31% weaning for WR2 heifers at VRRS [Sullivan *et al.* 1997], and that weaners are valued at $300 each). These figures show that transporting WR2 heifers from the Victoria River District to the Douglas Daly region may be a viable option for companies with properties in both regions. Alternatively WR2 heifers that may be considered problem animals to manage in drier areas of the NT could be sold to properties in areas like the Douglas Daly region as they should perform quite well there.

References

Sullivan RM, O'Rourke PK, Neale JA (1997) Aust. J. Exp. Ag. 37. 287-93.

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Adoption of sustainable grazing land management practices in the Burdekin Rangelands

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Introduction

Extension projects and activities in the Burdekin Rangelands in the past 10 - 15 years have focused on sustainable land management - a change from the primarily production extension approach pre-1990. This paper provides a summary of this recent extension effort and the resultant adoption of practices which have contributed to the current sustainable management of grazing land.

Extension effort

The extension effort was broad-based in terms of participation by industry, the Dalrymple Landcare Committee with support by government departments and external funding from MRC/MLA, NHT-1 & 2 and the Queensland Government. This funding was more than matched by participating graziers. The type of projects included awareness raising via field-days, forums and seminars; training including PMP, Local Best Practice, Smart Manager and EDGE packages; testing of on-ground activities via PDS/PIRD, and infrastructure to facilitate changes in land management eg fencing, stock-waters, land rehabilitation and weed management. The awareness raising and training were supported by well targeted research performed by DPI&F, CSIRO, Tropical Weeds Research Centre (NR&W) and Australian Centre for Tropical Freshwater Research (JCU).

Adoption of land management practices

A representative sample of Upper Burdekin graziers were surveyed in 2005 to ascertain changes in their natural resource management from 1994 to 2004 and establish the benchmarks of current NRM practices among graziers. The most important changes in NRM practices include:

Grazing Management

- *Pasture monitoring* – graziers using objective monitoring methods has increased from 12% to 29%
- *Pasture composition* – 75% of graziers stated 3P pasture species have increased on their properties
- *Wet season spelling* – wet season spelling of paddocks has increased from 51% to 85%. The greatest increase has occurred with those graziers who spell 0-25% and 26-50% of their property.
- *Infrastructure* – 69% of properties have increased the number of paddocks, with those who received external funding installing twice as many paddocks.
  - 83% of properties have increased the number of watering points. In 1994 only 21% of the surveyed properties had more than 20 watering points, this had increased to 52% by 2004.
- *Use of fire* – 54% of graziers either do not currently use fire, or have reduced their use of fire; a further 8% have a lack of fuel or believe fire to be unnecessary.

Riparian management. The percentage of graziers fencing >25% of their riparian areas increased from 17% to 59% between 1994 and 2004. Included in these figures are graziers with >50% of their riparian areas fenced, which increased from 5% to 26% of graziers . External funding had a strong influence on the extent of riparian fencing.

Weed management. There has been a net increase in the use of chemical and biological weed control methods in the period from 1994 to 2004 by 40% and 38% respectively.

Focusing extension effort on sustainable land management practices has successfully improved practices of many graziers in the Burdekin Rangelands. These improvements will mean better health of riparian areas and improved land condition and water quality.

Acknowledgements. Alistair Gordon conducted the survey of graziers with the assistance of NLP funds provided by the Dalrymple Landcare Committee's SPIRAL project.

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Another way to describe sustainable grazing

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Introduction

Heavy grazing pressure disturbs the soil surface but at what stage is the extra destabilisation counter-productive? In Australian savannas, there are sacrifice areas around yards and water points just as there are around towns and cities. The form of sacrifice varies but may include soil erosion, excessive runoff, loss of wildlife, vegetation or aesthetic value, or chemical pollution. How such sacrifices are valued is debatable but we present grazing trial data that calibrates surface soil movement and soil loss in runoff against animal production at a range of grazing pressures.

Methods

Crossbred weaner steers were run at three grazing pressures on native pastures in cleared woodlands near Injune and Rubyvale between 1994 and 2001. Stock numbers were adjusted annually after the growing season to potentially consume 25% (low), 50% (moderate) and 75% (high) of the standing pasture at that time, without any allowance for the growth that might occur in the following growing season. Mid-slope soil movement from those small (3-6ha) paddocks was also recorded via Gerlach troughs at moderate and high grazing pressure. Ungrazed exclosures that were sometimes burnt were also monitored for soil movement and loss. All treatments had two replicates.

Results and Discussion

Baseline soil movement in the absence of grazing was 2.3t/ha for Injune poplar box and 2.7t/ha for Rubyvale silver-leaved ironbark. Soil type had a big effect on the peak movement of 22 t/ha for Rubyvale gritty granitic soil while only 3.8 t/ha for the grey, hard-setting Injune soil. Movement was episodic at both sites and greatest in wet years. Weight gain per head tended to be better at the light grazing pressure, gain per hectare was sometimes highest at the high grazing pressure but the latter animals always had a poorer condition score. Instead of financial economics we present (Fig. 1) the beef grown (kg/ha) per kg of soil moved per ha by runoff. At both sites the optimum was not at the high grazing pressure.

Where soil movement was unmeasured at low grazing pressure, animal production/ha was 65-70% that at moderate grazing pressure at both sites. Therefore in our final report (Silcock *et al.* 2005) we suggest that the moderate grazing pressure used on the poplar box pasture was probably optimal economically as well as environmentally but that the optimum on silver-leaved ironbark country may lie between our low and moderate levels because of the higher erodability of that soil.

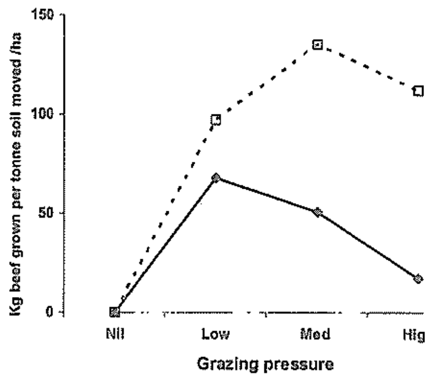

Fig 1. Relationship between grazing pressure and soil movement per kg of beef grown over 7 years at Injune (□) and Rubyvale (◆). Note: The 2 data points for low grazing pressure involve an interpolated soil movement estimate.

Silcock RG, Jones P, Hall TJ, Waters DK (2006) Enhancing pasture stability and profitability for producers in poplar box and silver-leaved ironbark woodlands. MLA Final Report for NAP3.208.

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Northern Territory Carrying Capacity Project

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Introduction

The Northern Territory is a vast area of geographically unique regions, from desert sand dunes to open floodplains and almost every habitat is in some way involved with the pastoral industry. With this industry comes the issue of sustainability both environmental and economic, which vary considerably between regions.

To address these issues, the Northern Territory Carrying Capacity Project is investigating pasture growth on different landsystems within three regions of the NT. These include the eucalypt woodlands of the Sturt Plateau, the Mitchell and associated grasslands of the Barkly and the desert shrublands of the Alice Springs region.

The project combines the methodology of SWIFTSYND, an abbreviated version of the methods used in the GUNSYNpD project and the calibration of the GRASP pasture growth model. In the future, pastoralists from these regions will be able to apply information from these pasture growth models with the confidence that they have been calibrated using data from their specific regions and land systems. Modelled long-term pasture growth will then allow properties to better estimate their potential carrying capacities for better economic and environmental outcomes.

Methodology

Using the SWIFTSYND methodology, exclosures (30m x 30m) are established throughout the regions on landsystems considered significant to the pastoral industry. For the northern NT, data is collected within these exclosures four times per year (known as 'harvests') for two entire growing seasons. Data that is collected includes grass yields, soil moisture, daily rainfall, detached plant material and plant nutrient contents. Each harvest aims to capture a unique growth stage including initial growth flush from stored reserves, peak nitrogen during flowering, maximum standing biomass where nitrogen becomes limiting and natural pasture detachment (Cobiac 2001). The Alice region does not have predictable growing seasons, and harvests are timed to follow significant rainfall events to capture growth pulses throughout the year.

Conclusion

There are three stages of the Carrying Capacity Project, data collection, calibration/pasture growth modelling and implementation of the modelled pasture growth information to develop long-term carrying capacities. Where relevant, the regions will also investigate additional factors influencing carrying capacity such as browse, preferential grazing and land condition. The project is still in the "data collection" phase with calibrations and pasture growth modelling to begin in late February 2007. The modelled pasture growth for the different land types will be used in the Grazing Land Management workshops and will be a valuable tool for estimating carrying capacities across the NT.

Reference

Cobiac MD (2001) Primary Productivity of important native pasture grazing lands in the Victoria River District of the Northern Territory. B.App.Sc (Ag) Masters Thesis, Adelaide University.

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Modelling the bio-economics of grazing systems in northern Australia

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Introduction. Highly seasonal rainfall and infertile soils present significant challenges for pasture and beef production in northern Australia. Consequently, the energetic efficiency of native pastures for animal production (ability to convert digestible energy to a given output) is generally low. The sustainability of these systems in terms of environmental outcomes (e.g. soils and vegetation cover) and economic viability is determined by a range of factors including stocking rate, the ecological state of the land, climatic and market conditions. Bio-economic modelling techniques, which draw on available biological and economic information, can offer significant insights into resource use trade-offs between livestock production and environmental outcomes. They can also be used to explore opportunities for complementary outcomes for production and environmental benefits.

Modelling approach. Funding through the CSIRO Flagship "Water for a Healthy Country" has been used to develop a systems based model to explore whether management changes can increase energetic efficiency of beef production without compromising land condition or ground cover for water quality outcomes. The model includes a livestock component which requires pasture quality and utilisation rate inputs to calculate animal performance for typical northern Australian production scenarios (companion poster). By linking the livestock component and energetic efficiency with an economic model for representative herd and property types (in this case the Breedcow-Dynama economic herd model developed by the Queensland Department of Primary Industries and Fisheries, Version 5.04), the framework can evaluate enterprise profitability for different scenarios (Figure 1). The livestock component can also calculate methane output. Management options likely to influence the industry in the future include improvements in genetics, nutrition, pasture and stock management and marketing practices. Data required for the bio-economic model of these systems include pasture growth and quality indices, animal production energy requirements and market costs and prices. A key challenge is to collate and improve the quality of such data for the various pasture communities of northern Australia, and to incorporate ground cover and soil impacts from available ecological studies.

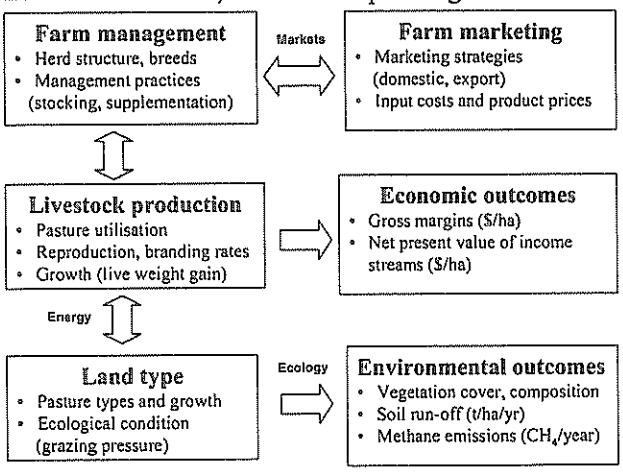

Figure 1 Conceptual diagram of the bio-economic framework

Table 1. Example of economic outputs for a Brahman cross herd in the Brigalow region

Breeding and finishing operation	Buffel grass	
	Without molasses	With molasses
Prime market	Japanese Ox	Japanese Ox *
Supplement costs ($/kg)		0.22
Supplement used (kg/head/yr)		20
Annual steer turn-off (head)	214	252
Turn-off weight (kg/steer)	612	600
Turn-off age (years)	3-4	2-3
Net sale price ($/head)	1047	1024
Gross margin ($000/herd)	240	294
($/ha)	37	45

* This option could also market to the European Union given weight for age at 2.5 years.

Model outputs. The relative profitability of a steer supplementation strategy for a 1350 adult equivalent Brahman cross herd grazing buffel grass is summarised in Table 1. In this scenario, supplementation improved gross margins by around 20 per cent, with turn-off age reduced by 12 months to around 2.5 years. The feasibility of various management and marketing strategies for different pasture types and qualities can be similarly evaluated based on the energetic efficiency of each system.

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The Missing Link. Taking GLM from Classroom to Paddock

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The MLA EDGE*network* Grazing Land Management (GLM) education program for sustainable grazing practices in the Northern Territory has been developed by local researchers, producers and the MLA. In making grazing management decisions, pastoralists need to consider land condition, evenness of grazing and diet quality to ensure sustainable short and long term carrying capacities are implemented. Planning is a critical starting point in achieving this, and the GLM course focuses on seven key areas:

- Understanding the grazing system
- Managing Grazing
- Managing Fire
- Managing Sown Pastures/ Pasture improvement and restoration
- Managing Weeds
- Understanding Tree-Grass Balance
- Planning for Grazing Management

Two 3 day courses were run in Katherine throughout 2006 with attendance from 12 different cattle stations (total of 16 pastoralists and 9 agency representatives). Central Australia's first GLM workshop was also held with attendance from 4 different pastoral stations. The course is delivered through a practical 'hands on' approach, where individual participants are encouraged to use the planning sessions to focus on management decisions for their own properties. As a direct result of the success of the GLM course, there has been an increased demand from pastoralists to be provided with further assistance to help develop property management plans for a more sustainable long term enterprise.

Two GLM extension officers have been employed (based in Katherine and Alice Springs) to continue the promotion of the GLM course in the Northern Territory, as it continues to evolve in conjunction with improved land management practices and new grazing management research. In value adding to the GLM package, these extension officers are offering follow up support to the GLM graduates, providing key assistance in fields such as GIS, dry season forage budgeting, calculating sustainable short and long term carrying capacities and land condition assessment.

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Using global positioning systems to quantify landscape association by cattle across northern Australia

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Introduction

The grazing impact of cattle on extensive pastures is primarily driven by the quality and availability of forage. Given the spatial heterogeneity in forage quality and productivity across large paddocks (>1000 ha) in northern Australia, this presents a major challenge for efficient utilisation. Fences control livestock distribution, but fencing different land types is expensive and often impractical. Strategies used by the animal to select areas offering the greatest intake rate of digestible energy determine the intensity, timing and spatial location of grazing.

Scope

How can we quantify landscape association and pasture utilisation by cattle? Estimating pasture utilisation is labour intensive and relatively crude. Direct observation methods are tedious, time consuming and possibly biased by the effects of human observers. Global positioning systems (GPS) for livestock provide a relatively reliable and easy method to quantify animal-landscape associations. Combining GPS data and geographic information systems (GIS) with spatially explicit models will be instrumental in developing sustainable land management strategies for northern Australia, but sufficiently large data sets on grazing animal distribution are needed.

Research output

CSIRO research scientists are; 1) using GIS software and GPS units to quantify animal-landscape associations, 2) identifying key environmental drivers of patch grazing (Fig 1), 3) developing relationships based on animal activity (Fig 2) that relate to land type association and, 4) measuring the role of riparian zones in grazing systems. These research efforts will contribute to a better understanding of the spatial grazing patterns observed in heterogenous paddocks.

Fig. 1 Grazing distribution in a large (1530 ha) heterogeneous paddock near Charters Towers, Qld

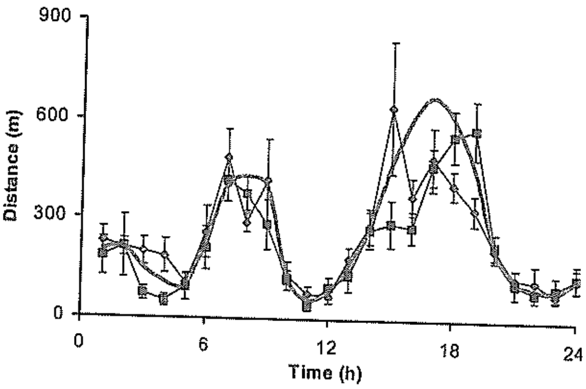

Fig. 2 Diurnal patterns of travel are not affected by stocking rate (◆4 ha/beast, ■ 8 ha/beast)

Research opportunities

Further studies with GPS collared animals and satellite imagery will be important in evaluating the impact of management strategies or the alternative location of water points and fences, to manipulate grazing distribution in large heterogeneous paddocks. Areas susceptible to over-grazing can be identified and will assist in the development of sustainable land management practices. Identifying herd dynamics and seasonal variability will be future challenges for researchers. Work on commercial properties is crucial to developing technologies immediately relevant to the northern beef industry.

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The effect of tender stretching on the genetics of tenderness in tropically adapted breeds

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Extensive consumer evaluation has demonstrated that tenderness is the most important characteristic in determining the level of satisfaction reported for cooked beef products (Egan, *et. al.* 2001). This experiment examined the process of tender stretching (hanging sides by the aitch bone as opposed to the Achilles tendon) as a means of improving tenderness and reducing variation for the trait, and aimed to quantify the genetic parameters for tenderness in sides hung using the two methods.

The experiment measured tenderness via peak force measurements (Perry, *et. al.* 2001) in meat samples taken from the *Longissimus dorsi* muscle for feedlot finished animals of two tropically adapted genotypes: 986 Brahmans (BRAH) and 1192 Tropical composites (TCOMP: bred to comprise 50% *Bos indicus* or African Sanga, and 50% non-adapted *Bos Taurus*). The left sides of each carcass were tender stretched while the right sides were hung conventionally. Fixed effect models for each trait by genotype combination tested the significance of: birth month and location, post-weaning management group and date of kill. Terms to account for possible heterosis were tested in models for TCOMP steers. Genetic parameters were estimated in ASReml®, with the relationship matrix built using a three generation pedigree. Genetic correlations were estimated using bivariate analyses, and predicted means were calculated based on the results for animals sourced from one location, where BRAH and TCOMP were managed within the same contemporary groups.

Table 1 presents the mean peak force (PF) in the tender stretched (TS) and Achilles hung (AT) sides for BRAH and TCOMP, with the phenotypic variance and heritability for each trait. It can be observed that mean PF for TS sides were significantly lower ($p < 0.05$) than those which were Achilles hung, and that the phenotypic variation for PF was dramatically reduced in both BRAH and TCOMP when sides were tender stretched. This did not significantly reduce the heritability of peak force traits in either of the genotypes ($h^2 = 0.33$ and 0.31 for BRAH AT and TS sides respectively, and 0.32 and 0.30 for TCOMP), though it shows that, compared to AT hung sides, selection based on tenderness measured in animals hung by TS would produce approximately half the genetic progress.

Table 1. Number of measurements, phenotypic variances (V_p), and heritabilities (h^2), with standard errors (SE), for peak force (PF) of Achilles hung (AT) and tender stretched (TS) carcasses from Brahman and Tropical composite steers.

Trait	Brahmans				Tropical composites			
	n	Mean*	V_p	h^2 (SE)	n	Mean*	V_p	h^2 (SE)
ATPF (kg)	955	5.48^a	1.12	0.33 (0.10)	1174	4.70^a	1.09	0.32 (0.10)
TSPF (kg)	880	4.58^b	0.26	0.31 (0.08)	1046	3.77^b	0.24	0.30 (0.11)

* Predicted breed means for Brahmans and Tropical composite steers managed together since birth
[a b] Within breeds, predicted PF means with different superscripts were significantly different ($p < 0.05$).

The genetic correlation for Peak force between AT and TS hung sides was 0.65 (0.18) and 0.87 (0.13) for BRAH and TCOMP steer carcasses respectively. This, combined with the comparable heritabilities observed above, suggests that selection for tenderness based on objective measurements in BRAH and TCOMP steers from AT or TS hung carcasses will result in improvement for the trait.

Egan AF, Ferguson DM, Thompson JM (2001) 'Consumer sensory requirements for beef and their implications for the Australian beef industry.' *Australian Journal of Experimental Agriculture* **41**, 855-859.

Perry D, Shorthose WR, Ferguson DM, Thompson JM (2001). 'Methods used in the CRC program for the determination of carcass yield and beef quality.' *Australian Journal of Experimental Agriculture* **41**, 953-957.

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Quality rather than quantity: a view inside a family-operated beef enterprise

Alex O'Neill
"Doondoon", Mundubbera

Key principles that underpin our operation

- Quality of cattle – premium returns for maximum kg of meat
- Quality of operation – safe, enjoyable work environment, easy handling, good-doing (i.e. good reproductive rate, good growth) cattle,
- Quality of environment – next year's profit does not need to be compromised by this year's turnoff. If the paddock is suffering – sell cattle as stores or to feedlot.
- Remain aware of stocking levels. Maintain good grass cover; consider feed needs for coming season.

Our operation does not focus on quantity – of cattle or of land. Focus on these would provide us with pressures we don't need nor see as desirable.

Like many things in this industry this is a subjective approach. This is OUR view of Quality and OUR view of Quantity. It is OUR owner/operator story.

I believe there are "stages" of ownership of cattle operations. To qualify our position – I would call us in the "mature" stage of property ownership. We can afford to be selective about what we do. There is no "one rule fits all" but our operation would be different if we were in a build-up phase. We have faced the fact that we have a finite time on this earth, and without children to set up can be selfish about how we run our property. We are aware there are many other ways to make money. We live this life from choice and a love of this environment.

Our enterprise

"Doondoon" ("Many ironbark")

When James O'Neill first selected the block in the Hawkwood ballot in 1968 there was one fence through the place, a set of yards and an old miner's hut used by stockmen from Hawkwood Station. In accordance with the conditions of his lease, James proceeded to erect fences, purchase cattle, and clear country. He went straight into the '69 drought.

The lack of natural water taught him a lesson still pertinent today. He has always strived to have at least two water points per paddock, sinking bores and building dams to ensure sufficient water supply. Poly pipe and solar power have allowed us to maximise use of our stock water resource, encouraging cattle to use the whole of each paddock.

The property is now largely developed; in the last 38 years many paddocks have been created, lanes installed, improved grasses sown (buffel – Nunbank, Biloela and Gayndah, and in the last 10 years hatch and bissett creeping blue along with the legumes Siratro and Seca).

Located in the Auburn River district to the west of Mundubbera, Doondoon and Gammon Park (a neighbouring property acquired in 1988) have a total area of 24,500 acres (10,211 ha) split almost equally between cleared to open forest and sown forest and scrub soils. We presently carry a breeding herd of 850 Droughtmaster cows (the figures later are based on last years numbers - 900 cows), 70% of which is mated to Droughtmaster bulls and the remaining 30% mated to Euro breed bulls (Charolais). The breeders and young heifers are generally carried on cleared or thinned forest country comprising native "speargrass" pastures with some areas sown to buffel-legumes. Steers are carried on buffel-legume pastures from weaning (9 months) until about 2.5 to 3 years of age for sale into North Asian markets. Some opportunistic feedlotting also occurs.

We had a permanent man for two years but he has gone to the mines. We use contract musterers to get our cattle work done and development work is generally carried out by contractors.

James and I have no children. You know the slogan "Every Family Needs a Farmer" – well - we are the farmers who need a family.

estimates were made of their impact on gross margins when these values were changed by 10% (positive where these were judged to increase gross margin, and negative where a cost reduction was implied). Impact on gross margin was the main criterion for identifying a potential driver, because this measure is common to the other profit measures - the exception being overhead costs which have no effect by definition on gross margins, but do impact on profit and return on capital.

The results (modelled) of changing the various model parameters as described before are presented in Table 3.

Table 3. Impact of changing parameters on Total Gross Margin (TGM).

Parameter	change in parameter	Total gross margin ($) $608,540 (present)	% change TGM
Branding %	10%	662,279	9
Mortality %	-10%	610,193	<1
Culling %	10%	611,067	<1
Price - steer	10%	648,430	7
Price - cull breeder	10%	615,000	1
Price - heifer	10%	619,449	2
Price - CFA	10%	615,484	1
Price - all stock	10%	674,716	11
Sale weight - steer	10%	644,451	6
Sale weight - cull breeder	10%	612,913	1
Sale weight - CFA	10%	613,253	1
Bull ratio %	10%	608,520	<1
Supplements ($)	10%	607,693	-1
Age of joining to 15 months	-12m	612,892	<1
Overhead costs	10%	476,840*	-3

* Change to net profit

The set of parameters that was examined included the following:

Branding % (+10%) - calves weaned per 100 cows mated
Mortality % (-10%) - deaths per 100 animals
Culling % (+10%) - dry breeders culled (i.e. % of breeders not producing calves that are culled)
Price (+10%) - $/kg liveweight for different classes of stock separately and collectively
Sale weight (+10%) - steer
Sale weight (+10%) - cull breeder (non CFA)
Sale weight (+10%) - CFA
Supplementary feeding (+10%) - $ total of all supplements fed to all stock
Age at first joining (reduced by 1 year) - join at 15 months .

Apart from price, the parameters that have the greatest impact on profitability of our enterprise are branding rate (a 9% increase in total gross margin for a 10% increase in branding rate) and sale weight of steers (a 6% increase in total gross margin for a 10% decrease in age at sale). The latter depends directly on steer growth rate.

[Note - The analysis gave a guide to where improvements could be made no costs were allocated to making the increase or decrease in the various parameters. The next move from this analysis would be to include the costs of making the improvement and then look at effect on overall income. For example I suspect that with a branding rate of somewhere near 80% that the cost of lifting this by10% would be quite high and may be more than the extra value. I'm not saying we should not try to improve branding rates but we need to keep a watch on the dollars. The point that struck me about these figures was that there was not one or two real standouts for improvement it was basically keeping a good watch on every aspect of the business. Russ Tyler]

Improving profitability and sustainability for next 5 years

(a) our challenges

- our age and health may affect our ability to manage
- climate – more dry years will mean less cattle carried (= less return on investment)
- tick line – we are in an area where the line will be moved so we will be working on cleaning up ticks(extra work and expense)
- implement knowledge from information provided by research & extension within the industry e.g. Breeding Edge workshop (annual bull evaluation)
- whether the cattle market will remain firm
- what global food chain ownership may deliver to us as producers
- Legislative requirements – whether Government and industry will impose more rules with which we must be compliant (e.g. Vegetation Management, Workplace Health and Safety, LPA).

(b) our opportunities

- our low debt level – allows us to invest in more land or off-farm;
- tick line – cleaning up should provide more marketing opportunities and options;
- better use of NLIS tags to provide data to assist in management of cattle – weighing and placing in paddocks for finishing;
- smarter use of supplements to advance the herd;

I hope this has provided an insight into our cattle operation as an owner/operator. James is the driving force in this operation. His hobby, his work, his spare time interest – it is all tied to our cattle operation. I can't put a value on the constant supervision he provides. Bulls in wrong paddocks, troughs out of water, bores playing up, fences broken – being constantly around to monitor and fix this and to absorb herd information observed at these times. It is all part of this owner/operator's management process.

Review of Remote Management Technologies for Australian Livestock Production

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Labour shortages and increasing labour costs are major impediments for sustainable and profitable livestock industries in Australia. Advances in telecommunications, computer and sensor technologies provide the capability to monitor and control business remotely. The adoption of similar technologies in agricultural management will improve farm efficiencies and reduce production costs and will ensure agricultural enterprises remain profitable in the future despite isolation and harsh environmental conditions.

Currently monitoring and controlling resources, for example water supplies can be an expensive exercise as fuel and labour costs continue to rise. Not only is time wasted by farm staff performing unnecessary travel to the remote site if maintenance is not required but other tasks may not be performed and therefore the efficiency and productivity suffer.

Remote management technologies include sensors, actuators, interface and signal conditioning electronics, microprocessor based data storage/manipulation equipment, telemetry or communication systems and the office computer or some display/indicator device. As an example a door chime at the local shop is a simple remote management technology that allows the shop keeper to perform other tasks and attend to the shop only when necessary.

Typical examples of remote management technologies applicable to agriculture are:

- remote sensing through the utilization of satellite images for yield predictions of crops or forage
- water lever monitoring in tanks, dams or troughs
- status and condition of bore equipment e.g. on/off, fuel levels/consumption, oil pressure.
- identification, condition monitoring or drafting of animals entering watering points
- fence integrity
- locating stock for mustering

Currently there are two commercially available systems being adopted by Australian beef producers. These are Observant and GME Electrophone, each utilizing UHF radio to transmit and receive data. There are other systems used in other industries that utilize 900MHz and 2.4GHz that also have potential for some agricultural applications. Research and development is being conducted by universities and government agencies around Australia on sensor networks incorporating low cost imagery sensors and telemetry systems utilizing wireless networks.

This technology has already proven itself to save time and money at Pigeon Hole Station in the Northern Territory (Observant system) and Quinyambie Station in South Australia (GME Electrophone System).

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Faecal NIRS measurements of diet quality and growth of cattle grazing Mitchell grass - forest country pastures near Richmond, N Qld.

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Faecal near infrared spectroscopy (F.NIRS) can measure many of the components of the diet selected, intake, and liveweight (LW) change of grazing cattle (Coates 2004, Dixon and Coates 2005). F.NIRS measurements were made in a herd to determine diet characteristics and to predict LW.

From Sept 2001 until Feb 2003 cattle grazed a 280 ha paddock, half black soil Mitchell grass downs and half red soil open woodland on Morungle Station. The herd comprised 2 age groups of Brahman and Brahman cross steers (350 kg, n 17; 178 kg, n 24). In April 2002 the heavier subgroup was replaced with young steers (156 kg, n 21). Steers were weighed and sampled regularly and F.NIRS predictions made using Coates (2004) calibration equations.

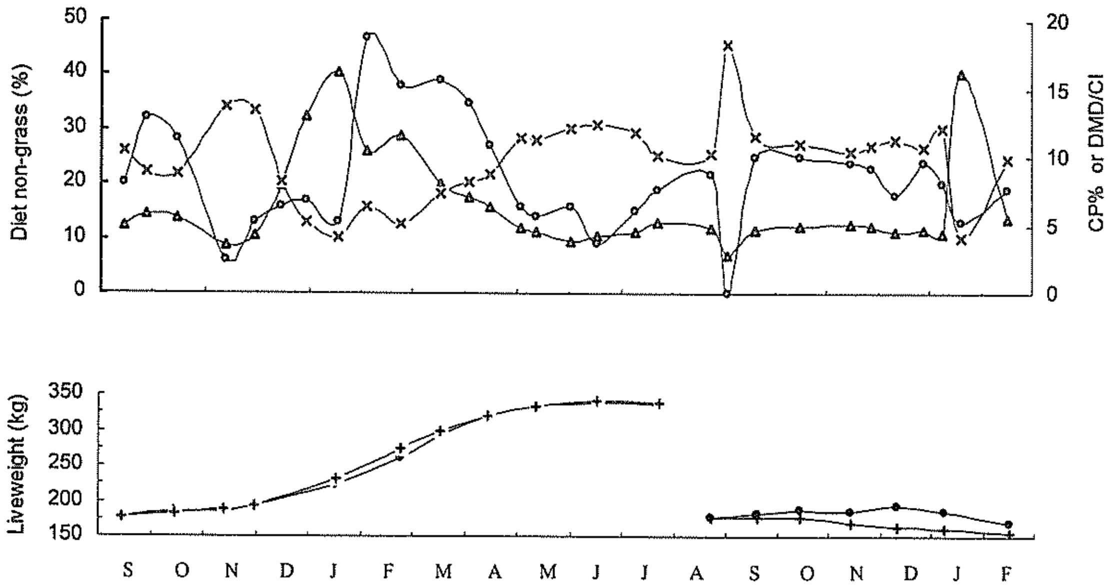

Fig. 1. The non-grass (○), crude protein (Δ) and DMD/CP ratio (x) of the diet selected by grazing steers, and the actual (●) and F.NIRS predicted (+) liveweight of steers in successive drafts.

There was 975 mm rain from Nov 2001 to Feb 2002, but thereafter only 25 mm until Feb 2003. Pasture availability was about 4000 kg pasture/ha in Sept 2001, about 3000 kg/ha in May 2002, and then declined progressively. Non-grass (i.e. forbs) often comprised a substantial part of the diet and the animals apparently selected for this pasture component. Forbs apparently made an important contribution to diet protein. Diet CP did not decrease to the very low concentrations, or the DMD/CP (ratio dry matter digestibility to crude protein) increase to the high values often observed in cattle grazing tropical native pastures. F.NIRS satisfactorily predicted steer LW change. Diet quality was generally in accord with expectations from the rainfall, and steer LW changes in accord with the quality and quantity of pasture available at various times.

Coates DB (2004) 'Faecal NIRS - Technology for improving nutritional management of grazing cattle.' MLA Project NAP3.121 Final Report.

Dixon RM, Coates DB (2005) The use of faecal NIRS to improve nutritional management of cattle in northern Australia. *Recent Advance in Animal Nutrition in Australia,* 15, 65-75.

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F.NIRS measurements of diet quality and growth of cattle grazing arid grassland-browse associations near Charleville, SW Qld.

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Faecal near infrared spectroscopy (F.NIRS) can measure many of the components of the diet selected, intake, and liveweight (LW) change of grazing cattle (Coates 2004; Dixon and Coates 2005). F.NIRS measurements were made in a herd to determine diet characteristics and to predict LW.

From Nov 2001 until Apr 2003 cattle grazed one of 2 paddocks (300 or 430 ha) on Croxdale Research Station comprising Coolibah flats of black/grey clays and loams, and red sands with Mulga/turkey bush vegetation. The herd initially comprised Brahman cross steers (251 kg, n 19). In June 2002 the heavier steers were replaced with heifers (177 kg, n 21). Steers were weighed and sampled regularly, and F.NIRS predictions made using Coates (2004) calibration equations.

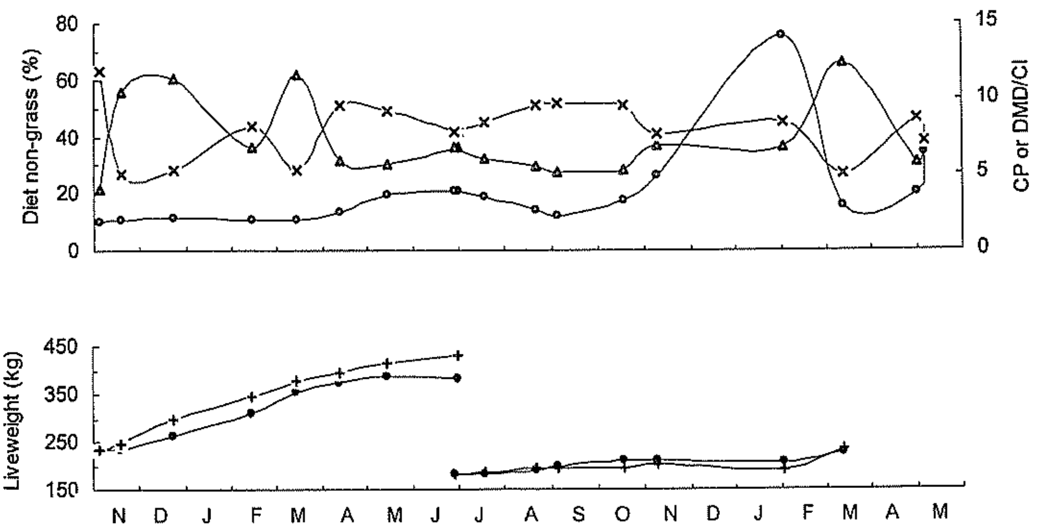

Fig. 1. The non-grass (o), crude protein (Δ) and DMD/CP ratio (x) of the diet selected by grazing steers, and the actual (•) and F.NIRS predicted (+) liveweight of steers in successive drafts.

There was 365 mm rain from Nov 2001 to Feb 2002, then 90 mm through until Jan 2003, 82 mm in Feb 2003 and 18 mm in Mar and Apr 2003. Pasture availability was about 1000 kg pasture/ha from Nov 2001 through to July 2002, and then declined progressively to about 400 kg DM/ha by Apr 2003. Non-grass comprised 10-21% of the diet from Nov 2001 until Oct 2002, but then increased in Nov 2002 and Jan 2003 indicating increased ingestion of browse following extended dry season conditions. Non-grass declined following the rain in Feb 2003 before increasing again in Apr-May 2003. Diet CP was initially low (4%) but increased with the rain and new pasture growth in Nov 2001 to Mar 2002. Diet CP then declined and was 5-7% until the rain in Feb 2003. F.NIRS tended to over-estimate steer LW change during Nov and Dec 2001. Diet quality and steer LW changes were generally in accord with expectations from rainfall and observations of pasture. Browse made a major contribution to the diet when little pasture was available.

Coates DB (2004) 'Faecal NIRS - Technology for improving nutritional management of grazing cattle.' MLA Project NAP3.121 Final Report.

Dixon RM, Coates DB (2005) The use of faecal NIRS to improve nutritional management of cattle in northern Australia. *Recent Advance in Animal Nutrition in Australia,* 15, 65-75.

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