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Climate savvy grazing

(Developing improved grazing and related practices to assist beef production enterprises across northern Australia to adapt to a changing and more variable climate)

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Abstract

There is uncertainty over the potential changes to rainfall across northern Australia under climate change. Since rainfall is a key driver of pasture growth, cattle numbers and the resulting animal productivity and beef business profitability, the ability to anticipate possible management strategies within such uncertainty is crucial. The Climate Savvy Grazing project used existing research, expert knowledge and computer modelling to explore the best-bet management strategies within best, median and worse-case future climate scenarios. All three scenarios indicated changes to the environment and resources upon which the grazing industry of northern Australia depends.

Well-adapted management strategies under a changing climate are very similar to best practice within current climatic conditions. Maintaining good land condition builds resource resilience, maximises opportunities under higher rainfall years and reduces the risk of degradation during drought and failed wet seasons. Matching stocking rate to the safe long-term carrying capacity of the land is essential; reducing stock numbers in response to poor seasons and conservatively increasing stock numbers in response to better seasons generally improves profitability and maintains land in good condition. Spelling over the summer growing season will improve land condition under a changing climate as it does under current conditions.

Six regions were included within the project. Of these, the Victoria River District in the Northern Territory, Gulf country of Queensland and the Kimberley region of Western Australia had projections of similar or higher than current rainfall and the potential for carrying capacity to increase. The Alice Springs, Maranoa-Balonne and Fitzroy regions had projections of generally drying conditions and the greatest risk of reduced pasture growth and carrying capacity.

Encouraging producers to consider and act on the risks, opportunities and management options inherent in climate change was a key goal of the project. More than 60,000 beef producers, advisors and stakeholders are now more aware of the management strategies which build resource resilience, and that resilience helps buffer against the effects of variable and changing climatic conditions. Over 700 producers have stated they have improved confidence, skills and knowledge to attempt new practices to build resilience. During the course of the project, more than 165 beef producers reported they have implemented changes to build resource and business resilience.

Executive summary

Climate change has the potential to cause substantial changes to the operating conditions in the grazing industry of northern Australia. Increasing CO_2 levels will improve pasture growth but increased temperature will lead to higher evaporation. It is predicted that by about the year 2070 it is likely that pasture growth gains from increased CO_2 will be cancelled out by higher evaporation and increased soil moisture loss. There is great uncertainty over the likely changes to rainfall, which is the main driver of pasture growth and hence of cattle numbers, productivity and beef business profitability. This project sought to provide greater clarity of the potential risks from climate change, and the best-bet management strategies to adapt to variable and changing climate. A key assumption was that maintaining land in good condition would provide the resilience need to buffer against a changing climate. This assumption was tested through industry engagement and computer simulation to compare how current best management strategies will perform under best, median and worse-case future rainfall scenarios.

Through this project, more than 60,000 beef producers, advisors and stakeholders were exposed to management strategies to build resource and business resilience, and the message that resilience helps buffer against the effects of variable and changing climatic conditions. Over 780 producers stated that they now have the confidence through improved skills and knowledge to try new practices to build resilience. More than 170 have already implemented changes which will build resilience.

Six key regions across northern-Australia were chosen for analyses based on industry interest, existing knowledge and geographic spread: the Kimberley of Western Australia; the Victoria River District and Alice Springs region of the Northern Territory; and the Gulf Savanna, Fitzroy catchment and Maranoa-Balonne of Queensland. Of these, the Alice Springs region, the Maranoa-Balonne and Fitzroy are at the greatest risk of reduced rainfall, reduced pasture growth and hence reduced carrying capacity. There is greater potential for land degradation and declining incomes in these regions if on-property practices fail to adapt. In regions where rainfall could stay at similar to current averages, such as the Gulf country of Queensland and the Kimberley region of Western Australia, carrying capacity may increase slightly. Slight increases in carrying capacity may be possible through improved pasture growing conditions with increased CO_2. These regions could benefit from improved whole property income.

Well-adapted strategies under a changing climate are very similar to best management under current variable climatic conditions. Maintaining good land condition builds resource resilience, maximises opportunities under higher rainfall years and reduces the risk of degradation during drought and failed wet seasons. Matching stocking rate to the safe long-term carrying capacity of the land is essential; reducing stock numbers in response to poor seasons and conservatively increasing stock numbers in response to better seasons generally improves profitability whilst maintaining land in good condition; and spelling over the summer growing season is predicted to improve land condition under a changing climate as it does under current conditions.

The project adopted a consistent approach across northern Australia by:

- consolidating a wide range of existing scientific and industry knowledge into a useful framework e.g. the regional technical guides for industry advisors

- focussing on key issues in case studies, demonstration sites and publications e.g. stocking rates and wet season spelling to ensure good land condition
- defining the current resource management strategies and their value e.g. how wet season spelling is currently practiced and the resulting land condition, cattle production and economic implications
- seeking industry feedback on current and possible future grazing land management, such as linking land condition and grazing strategies with herd dynamics, live-weight gains, reproductive efficiency and profitability
- engaging beef producers in activities and computer simulation, to identify knowledge gaps such as inconsistent carrying capacity evidence in the Maranoa-Balonne
- extrapolating the results of decades of existing long and short-term research across northern Australia
- exploring longer term trends without expensive on-ground studies through computer simulation e.g. the implications of different stocking rates over a 25-30 year time-frame
- providing a mechanism to validate computer simulations in the real world e.g. by presenting simulation results to industry groups
- challenging some of the existing scientific and industry perceptions e.g. the time land takes to improve from poor to good condition through wet season spelling, the level of stocking rate adjustments that are economically viable
- identifying gaps in practical knowledge e.g. the frequency and duration of wet season spelling to maximise good land condition
- identifying gaps in scientific knowledge and skill e.g. existing constraints in simulating cattle live-weight gains needed to be addressed for economic simulation to be realistic
- developing a regional engagement and evaluation framework e.g. assessing achieved awareness and practice change against measureable targets
- creating the ability to test implications of climate change on management strategies, land condition, cattle productivity and economic performance.

The project encouraged collaboration of research, development and extension professionals across northern Australia. This improved our understanding of different regions and more effectively directed limited resources. The collaboration provided insights into on-ground management, extension approaches and key messages through the sharing of knowledge, experience and ideas. The project team clearly desire to maintain this collaborative approach.

The legacy of publications, demonstration sites and producers' intention to adopt new practices leaves the project in good stead. A challenge now is to consolidate and build on this new knowledge, information and networks in a structured way and to make the information widely available. It will be important to maintain the established demonstration sites and associated industry engagement.

The northern-Australian beef industry can take advantage of the new knowledge, information products, demonstration sites and networks to better prepare for the risks of a changing climate. It will be important to benchmark these risks against other key profit drivers for northern-Australian beef businesses to place the message in a whole-of-business context. For instance, tree and shrub regrowth, thickening and encroachment may present a greater risk to profitability in some regions than climate change *per se*. Poor land condition, whilst likely to be exacerbated by climate change, already has a dramatic impact on business resilience. We do not fully understand how climate change ranks as a risk against declining terms of trade, or in the context of improving breeder efficiency. We also do not know if current infrastructure in more intensively developed regions, such as the Maranoa-Balonne, where rainfall is predicted to decline will need to be modified. Of particular concern is the Northern Beef Situation Analysis (2010) which presents a grim financial status for industry in the middle of a run of good seasons. The risks inherent in climate change and the other key profit drivers need to be considered in the context of an industry that is already under financial stress, and may lack the economic resilience needed to adjust.

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1 Background

Northern Australia's beef industry relies on native pastures and natural rainfall patterns for breeding and backgrounding. Approximately 30% of the native pasture lands has been reduced in productivity and health (Tothill and Gillies 1998). A key reason for this decline is high rainfall variability and the consequential delay in detecting on-ground changes which result from grazing management. Often change remains undetected until an extreme drought or flood leads to wide-scale death of preferred pasture species or soil loss from erosion.

Climate change presents a challenge to the sustainable management of grazed lands, particularly since the relationship between rainfall and rising CO_2 levels and temperature and subsequent pasture growth are unclear. This project sought to redress declining productivity by integrating scientific tools and knowledge with industry knowledge and experience and explore the potential impacts of—and solutions to—the risk of climate change. A key focus was to elucidate whether the current best-management strategies would be effective under the broad range of climate change scenarios. We made the assumption that management practices which enhance the resilience of both the resource base (i.e. ensure good land condition) and the business (i.e. maximise long-term profitability) will reduce the risks of future shocks—such as climate change—to grazing enterprises.

Science can help build resilience through improved grazing management, but risks being conducted in isolation from the grazing industry, can lack the applied focus necessary for industry to use the findings, or may not be sufficiently relevant at a management scale. Climate savvy grazing—as a project within the Northern Grazing Systems portfolio—integrated applied science at the regional level to maximise the usefulness of findings to industry. It did this by reviewing existing grazing science from northern Australia (McIvor *et a*l. 2010) and by scaling computer simulation modelling (McKeon *et al*. 2000; 2008, Rickert *et al*. 2000) down to more relevant regional, property and paddock levels. This integrative approach had not been attempted before, and it was anticipated that relevant lessons in practicing this approach would be learnt by both industry and the project team.

The project was implemented in six key regions to provide a geographic spread of land types and rainfall patterns. The Alice Springs, Kimberley, Gulf Savanna, Victoria River District, Fitzroy catchment and Maranoa-Balonne regions (Figure 1) were chosen based on adequate existing scientific knowledge, resources for implementation and the perceived willingness for industry to engage with the project (***Table 1***). The cattle industry in all six regions rely on the natural resource base (rainfall, soils and native pastures) for production in extensive grazing enterprises but have different resource and production issues. All six regions share the issues of:

- high rainfall variability
- uncertain predictions of rainfall and pasture growth changes under climate change
- marginal economic returns
- areas of declining land condition.

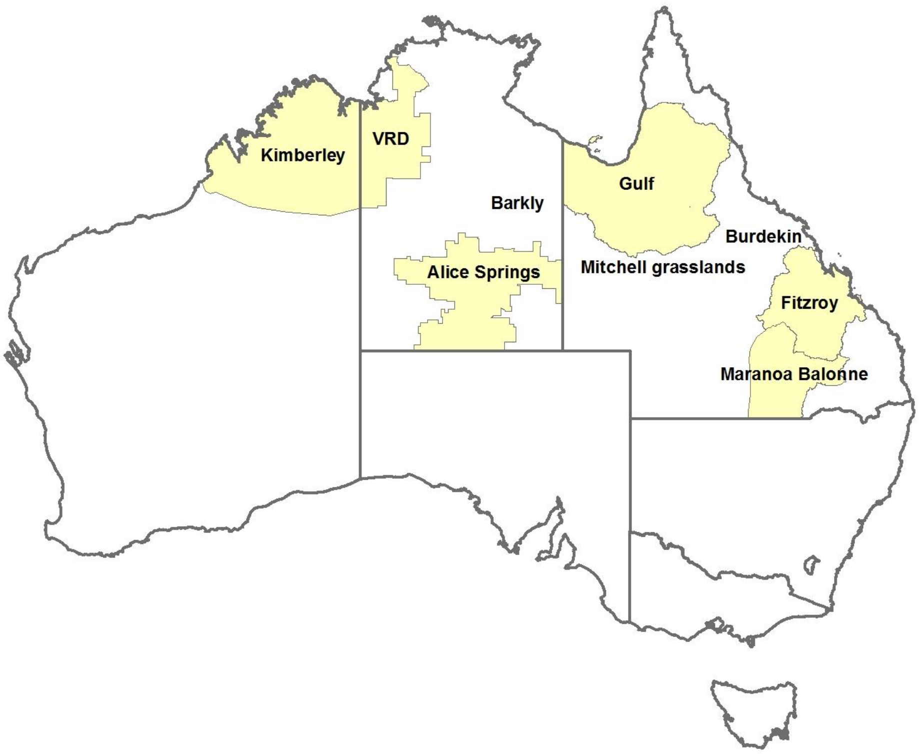

Figure 1 The six target regions within the current project (shaded) and three additional target regions in the companion Climate Clever Beef project. Together, these comprise the nine target regions within MLA's Northern Grazing Systems Initiative.

Table 1 Audience (number of producers) and impact (land area and herd size) sizes for each of the project regions.

Region	*Number of producers*[1]	*Total area*	*Cattle number*
Gulf	280	20,889,082	1,435,607
Fitzroy	2579	10,122,719	1,890,019
Maranoa-Balonne	1184	7,206,835	724,653
Mitchell grasslands	738	31,417,833	1,016,479
Barkly Tableland	28	15,961,270	608,520
VRD-Douglas Daly	28	8,172,877	484,075
Alice Springs	61	22,202,626	280,918
Kimberley	91	17,959,636	730,522
Burdekin	450	13,000,000	1,500,000
Total	5439	146,932,878	8,670,793

[1] Based on ABS 2006 data

All share the common management themes of:

- long-term stocking rate as the main driver of land condition
- the need to adjust short-term stock numbers in response to a variable climate and variable pasture growth
- the potential for wet season spelling to maintain or improve land condition
- the potential for fire to redress woodland thickening
- the potential to spread grazing pressure more evenly through water and fence placement (infrastructure development).

The six regions have contrasting climate change predictions (OzClim 2013, http://www.csiro.au/ozclim/presets.do). Predictions suggest mean annual rainfall in the:

- Alice Springs district is likely to become much drier and possibly more variable
- North-Eastern Kimberley wetter and Western Kimberley similar to slightly drier, although there appears to be some uncertainty due to the influence of Asian aerosols
- Gulf should remain about the same as it currently is (slightly wetter to slightly drier in some places), albeit with greater rainfall intensity during events. There is the potential to increase the flooding risk within the region
- Victoria River District should remain about the same as it currently is (slightly wetter to slightly drier in some places)
- Fitzroy catchment is likely to be similar to slightly drier compared with current conditions
- Maranoa-Balonne is likely to be similar to slightly drier compared with current conditions.

In each case, ensuring stable and resilient soils and pastures through good land condition is paramount to coping with—and rebounding from—future climate shocks. Good land condition coupled with good management and business strategies will help minimise the risks associated with a variable and changing climate.

2 Project objectives

Over the project period from November 2009 to May 2012, we aimed to:

1. Describe the existing industry management practices and situation, and identify potential grazing and related management strategies for building resilience and coping with a changing climate for six target regions (Kimberley; Victoria River District; Alice Springs District; Gulf region of north-west Queensland; Fitzroy catchment; and Maranoa-Balonne).

2. Identify best-bet grazing and related management strategies and guidelines for building resilience for each of the target regions.

3. Develop and implement a plan in each region for evaluation, improvement and extension of a selection of best-bet grazing and related management strategies.

4. Identify the likely biophysical, production and economic impacts of climate change for each region, using the best available climate projections and bio-economic modelling.

5. Identify best-practice future grazing and related management strategies and responses for each region, using the best available climate projections and bio-economic modelling.

3 Methodology

The project integrated industry consultation and engagement with a review of the existing information and computer simulation modelling in six key regions across northern Australia, namely the:

- Maranoa-Balonne region of Queensland
- Fitzroy catchment of Queensland
- Victoria River District of the Northern Territory
- Alice Springs District of the Northern Territory
- Gulf region of north-west Queensland
- Kimberley of Western Australia

3.1 Synthesis of existing information

The existing literature and major reports on grazing management across northern Australia was consolidated and synthesised by CSIRO, NT Department of Primary Industry and Fisheries and Department of Agriculture, Fisheries and Forestry Queensland (DAFF) (McIvor *et al*. 2010) within the project 'Enhancing adoption of improved grazing and fire management practices in northern Australia: Bio-economic analysis and regional assessment of management options' (B.NBP.0578; Scanlan and McIvor 2010). The underlying principles of stocking rate management, wet season spelling, fire as a management tool and infrastructure to support these activities identified within the synthesis were used as the framework for extension and computer simulation within the current project.

3.2 Industry consultation and engagement

Industry consultation and engagement proceeded through workshop and adoption phases within each region, based on the approach successfully used in a preceding project (Scanlan and McIvor 2010).

The workshop phase described the current situation and identified candidate grazing management strategies based on the best available evidence, including: local producer and advisor knowledge; the synthesis framework (Scanlan and McIvor 2010); and computer simulation modelling. Each region conducted two workshops which were held 12-18 months apart. The refined management strategies arising from the workshops then formed the basis for the evaluation, improvement and extension process (adoption phase). Workshops were typically run with expert groups, with the Gulf region conducting industry extension forums to draw on as large a cross section of beef producers as possible.

The first workshop in each region described the attributes of a hypothetical (representative) property for computer simulation scenarios. Workshop participants agreed to property size, land types and condition, number of paddocks, herd/grazing management, costs, production efficiencies, turnoff and marketing which were representative of the region. This information was validated against published data and current costs and market prices. Workshop participants nominated grazing management strategies which they considered would ensure good land condition and business resilience within a variable and changing climate. The representative property for each region was then used to simulate results of these strategies at the business, land-type and paddock scales. The representative property was intended to reflect an average enterprise, with average rainfall and a realistic mix of country types for the region.

The follow-up workshop presented the results of the modelling of the different strategies proposed by industry representatives, validated how closely the simulated results matched regional reality and provided opportunities to discuss the relative merits of the management strategies.

For instance, first workshops were held at Kununurra and Broome in the Kimberley with 14 producers and 12 professional experts. The second workshop was held at Fitzroy Crossing with nine producers and eight professional experts. Facilitated questioning, within-workshop focus groups and presentation of existing results revealed that stocking rates and fire were the key resource issues. Fire was a more prominent issue in the relatively reliable rainfall of the Kimberley, with tree thickening and encroachment a strong impediment to resilience in the red-soil Pindan land types. These priorities were followed by wet season spelling and the infrastructure required to implement spelling. Market and access issues were more important than other regions, with Kimberley cattle marketed almost exclusively through the live export trade. This was to become a major financial issue for industry and an engagement issue for the project throughout 2011.

The process was opened up to a wider audience within the Gulf region, where public meetings were held in conjunction with production-focussed events—such as improving cattle fertility—to draw on a greater cross section of industry in defining the representative property. A total of 45 graziers participated in the workshops held in town and on properties near Croydon and Normanton in May and October 2010. This broad cross-section identified the need to improve the computer simulation live-weight gain estimates.

The adoption phase focussed on promoting resilience through good land condition and best-bet management practices in each region. The key elements promoted within each region were based on the synthesis of existing information, the validated results of the computer simulations and feedback from the workshops. For instance, stocking rate was chosen within the Maranoa-Balonne region based on a reported mismatch between recommended and industry practiced stocking rates. Their campaign was to promote the need for stocking rates to match carrying capacity (extension effort) and to refine the safe carrying capacity figures (scientific effort) for the region.

Each region determined its own schedule of activity and targets to achieve increased awareness, KASA (Knowledge, Attitudes, Skills and Aspirations) and on-ground practice change based on the project objectives (Appendix 1 – Monitoring, Evaluation and Reporting table and guide). All regions were expected to:

- customise the synthesis document using regional examples
- increase awareness of their key practice(s) via the media
- begin the adoption of new practices via training workshops, events and publications
- achieve on-ground practice change within and beyond the project through demonstrating their key practice(s) e.g. with on-ground case studies and demonstrations
- challenge their own approach to extension by adopting new tools and means of engaging clients

- evaluate progress and adapt delivery methods as appropriate
- challenge their own understanding of best grazing land management practices and building resilience to climate change.

The synthesis document was customised into six new regional technical guides, incorporating regional and local information. Resources such as existing case studies were used to make the messages regionally specific and enable the audience to better relate the messages to their own situations. In a departure from a customary focus on land managers as the key audience, these regional technical guides were aimed at industry advisors, such as agency and natural resource management group staff, agri-business consultants and financial advisory staff.

On-ground case studies and demonstrations have been successful in achieving practice change within the grazing industry as these provide observable, real-world and tangible examples that managers can both relate to and modify to suit their own circumstances (Pannell *et al*. 2010). In the Maranoa-Balonne demonstration was conducted through their focus group participants, using one to two paddocks on each landholder's property. In the Kimberley, successful long-term land condition improvement through reduced stocking rates was documented. This began as a demonstration site in 1988 and the case study was able to draw on reports and data from that project, from earlier monitoring, from the land-holder's experience and using time-series remote sensing. In the Northern Territory VRD region, a recently established demonstration site was included in the project. This site, on Delamere Station 140 km south-west of Katherine, was set-up to test the interaction between wet-season spelling and management burning to increase productive, palatable and perennial (3P) grass density, hence improving land condition and forage quality. The site includes replication of the treatments to provide scientific rigour and credibility to the results.

A common guide to Monitoring, Evaluation and Reporting (MER) was developed for the project, and for the sister project 'On-farm demonstration of adaptation and mitigation options for climate change across northern Australia' (Climate Clever Beef—B.NBP.056; Bray *et al*. 2013). The MER guide was used as the primary tool to assess progress against regional targets and adapt delivery methods as appropriate.

3.3 Computer simulation modelling

Two long-standing and scientifically accepted computer simulation models developed specifically for northern Australia were refined into a single platform to simulate both the biological (GRASP) and economic (ENTERPRISE) production systems at a property and paddock scale (McKeon *et al*. 2000; 2008, MacLeod and Ash 2001). These models were then used to simulate the results of changing grazing management under current climate, market and resource conditions for industry and then under potential future climate scenarios.

3.3.1 Refining the models

GRASP was first developed in the early 1980s and includes a wide range of pasture growth and grazing impact parameters. GRASP simulates and uses the processes which grow grass, such as atmospheric conditions, soil moisture, soil fertility and nutrient cycling on a daily basis. It then estimates daily grass production for any soil type that is parameterised under any growing conditions from rainfall and climate files. It produces daily growth estimates for a single location rather than across the landscape. To simulate a range of management strategies within hypothetical regional properties, GRASP was improved to run across a maximum of 20 paddocks.

To simulate possible future climate scenarios, the underlying processes for growth within GRASP had to correctly mimic the effects of increasing CO_2 level in the atmosphere. Data from the 'Australian Savanna Free Air CO_2 Enrichment' (OzFACE; Stokes et al 2005) experiment were used to test, validate and improve how GRASP simulates the effects of CO_2 on pasture growth. Using OzFACE the following data sets were compiled to compare directly with GRASP output:

- stored soil water (in 3 soil layers at 4-weekly intervals)
- standing dry matter in pastures (annually at end of growing season)
- annual pasture production
- pools of nitrogen in the grass sward (annually)
- levels of leaf nitrogen (weekly).

For each data set, statistical analyses were conducted to obtain measures of the 'main effects' of CO_2 and other experimental treatments. This was to ensure that we were comparing and fitting the model to experimental treatment effects (to reduce the danger of trying to 'over-fit' the model to random noise and artefacts in the data).

ENTERPRISE is an economic and cattle herd simulation model which was designed to accept pasture growth, live-weight and stocking data as inputs to herd dynamics and profitability. It was modified to run with a maximum of 20 paddocks, to more readily accept GRASP data and to better simulate stock movements between paddocks within a property.

3.3.2 Simulating the current situation

The ability of different management options over the 25-30 years prior to 2011 to ensure good land condition, productive cattle herds and positive business profits were compared with the current management typical of each region. Representative properties and management practices were defined by industry and expert representatives for each region (section 3.2) and detailed climate information obtained from the Bureau of Meteorology for representative locations (towns or properties) as recommended through the consultation process.

The representative properties used within the computer simulation defined:

- land types and condition (including rainfall, soils, pasture communities and tree and shrub cover) to indicate the inherent productive capacity of the resource base
- infrastructure lay-out (e.g. paddock sizes, water point locations, fencing in relation to land types and natural features)
- herd and enterprise structure (e.g. the mix of breeding and growing cattle, calving rates, growth rates, weaning age, bull joining ratio, number and type of animals within paddocks)
- input costs (e.g. labour, mustering costs, weed control, depreciation of infrastructure and vehicles, running costs, bull purchase price, animal husbandry costs, cattle sale transaction costs)
- income generated (e.g. cattle sales, cattle prices).

The detailed level of financial information required, and predicted, from these simulation models forced the decision to use hypothetical properties instead of basing the simulations on actual properties. We did not want to expose real properties to detailed public scrutiny with potential repercussions for the people involved.

The management strategies tested for each region included adjusting stocking rates, incorporating wet season spelling and using fire to reduce tree and shrub cover.

Historic climate records included daily rainfall, temperature (maximum and minimum), evaporation, CO_2, day-light (solar radiation) and vapour pressure at pasture height.

Various scenarios were also tested at a land type scale without the constraints of property infrastructure.

3.3.3 Simulating future scenarios

Stocking rate, wet season spelling and fire management options to build resilience to potential climate changes were evaluated for:

- land condition
- cattle productivity and
- economic performance.

The same representative properties used to describe the current situation were used under three possible future climate scenarios. These climate scenarios applied increases projected in 2070 for temperature (approximately 3^{o}C warmer) and CO_2 (525 ppm compared with current levels of 350 ppm) and a range of high, median and low rainfall changes to the original 25-30 years climate information. Each region thus had three new simulations for each management strategy based on these future climate projections. The ability of each management strategy to maximise the opportunities or minimise the risks associated with each future climate scenario was assessed for land condition, cattle productivity and economic performance compared with current management. These scenarios provided a fair comparison between historical and possible rainfall patterns, and between current and best-bet management strategies.

4 Results and discussion

The project framework provided a consistent approach across northern Australia in:

- consolidating a wide range of existing scientific and industry knowledge into a useful framework e.g. the regional technical guides for industry advisors
- focussing on key issues in case studies, demonstration sites and publications e.g. stocking rates and wet season spelling to ensure good land condition
- defining the current resource management strategies and their value e.g. how wet season spelling is currently practiced and the resulting land condition, cattle production and economic implications
- seeking industry feedback on current and possible future grazing land management, such as linking land condition and grazing strategies with herd dynamics, live-weight gains, reproductive efficiency and profitability
- engaging beef producers in activities and computer simulation, to identify knowledge gaps such as inconsistent carrying capacity evidence in the Maranoa-Balonne
- the ability to extrapolate the results of decades of existing long and short-term research across northern Australia
- exploring longer term trends without expensive on-ground studies through computer simulation e.g. the implications of different stocking rates over a 25-30 year time-frame
- providing a mechanism to validate the computer simulations in the real world e.g. by presenting simulation results to industry groups

- challenging some of the existing scientific and industry perceptions e.g. the time land takes to improve from poor to good condition through wet season spelling, the level of stocking rate adjustments that are economically viable
- identifying gaps in practical knowledge e.g. the frequency and duration of wet season spelling to maximise good land condition
- identifying gaps in scientific knowledge and skill e.g. existing constraints in simulating cattle live-weight gains needed to be addressed for economic simulation to be realistic
- the regional engagement and evaluation framework e.g. assessing achieved awareness and practice change adoption against measureable targets
- the ability to test the implications of climate change to management strategies, land condition, cattle productivity and economic performance in six key regions.

The project encouraged collaboration of research, development and extension professionals across northern Australia. This improved our understanding of different regions and more effectively directed limited resources. The collaboration provided insights into on-ground management, extension approaches and key messages through the sharing of knowledge, experience and ideas. The project team clearly desire to maintain this collaborative approach.

4.1 Synthesis of existing information

The synthesis of existing grazing management science helped focus the computer simulation and extension approach within the themes of stocking rate, wet season spelling, fire as a management tool and infrastructure development. The report provided a sound basis for regional guide and fact sheet development and has left a legacy of six regional technical guides and numerous new and updated fact sheets.

The combination of synthesis, regional engagement and computer simulation identified the key regional issues and knowledge gaps.

4.2 Industry consultation and engagement

4.2.1 Workshop phase

The representative properties defined in workshop one varied considerably in property (17,000-460,000 ha) and herd (2,300-15,000 head) size (***Table 2***). All regions included breeding in their production system, although the age and weight at sale and markets varied. For example, the Kimberley focused on selling 320 kg animals for live export whilst the Maranoa-Balonne sold weaners within a well established regional market system (e.g. through the Roma saleyards). Despite the different property and herd sizes and different sale focus, all six regions identified sustainable stocking rates and wet season spelling as the strategies to be tested by computer simulation.

Table 2 Summary of the key features of the six hypothetical properties representative of each region and the key strategies for computer simulation testing.

Region	Property size (ha)	Herd size	Production system	Management strategies
Kimberley	210 000	10,000	Breeding with sale of 320 kg animals for live export	Reduced stocking rates, wet season spelling
VRD	460 000	15,000	Breeding with sale of 320 kg animals for live export	Reduced stocking rates, wet season spelling
Alice Springs	340 000	3,000	Breeding/fattening with sale of steers	Reduced stocking rates, land rehabilitation, wet season spelling
Gulf	145,000	11,000	Breeding with sale of steers	Reduced stocking rates, wet season spelling
Fitzroy	24,000	2,300	Breeding with weaner steers agisted prior to live export	Reduced stocking rates, wet season spelling
Maranoa-Balonne	17,000	1500 plus 920 weaners	Breeding/fattening with sale of weaners	Reduced stocking rates, wet season spelling

The workshops highlighted similarities between regions, but also identified unique regional traits.

The Alice Springs and Maranoa-Balonne regions have less summer rainfall dominance due to a weaker monsoonal influence and a chance of reasonable winter rains to promote pasture growth. With cool to cold winters, including frosts, the pasture growth in winter is generally cool season herbages that contribute to high cattle weight gains. However, Alice Springs has highly variable rainfall and is located in an arid environment, with long distances to cattle markets. The highly variable rainfall leads to cycles of ‘boom-or-bust’ for both the environment and for cattle production. The Maranoa-Balonne has a relatively high and reliable rainfall and is close to key markets, such as the Roma saleyards and direct sale to feedlots.

The Kimberley, VRD, Gulf and Fitzroy regions share monsoonal influence, strong summer rainfall dominance, relatively reliable rainfall, warm temperatures and high humidity. In the Kimberley and Gulf, this includes flooding and limited road access during the summer wet season. This limited road access plus being relatively close to Indonesia has provided access to markets and strong demand for live cattle. This has, in turn, lead to development and strong reliance on live-export trade.

Within the Kimberley and the VRD a lack of infrastructure was identified as a key constraint to effective wet season spelling, both in terms of paddock size and restricted access to move cattle between paddocks during the wet season. Roads are often cut by swollen or flooding streams. Roads are often cut in the Gulf, especially in the floodplains of the Flinders River. Forest land type soils become too wet to be able to muster cattle, which also limit the ability to rotate cattle through paddocks during the wet season. Full wet season spelling can be achieved by moving cattle in the second round muster, prior to the start of the wet season. The Gulf, Kimberley and VRD also shared problems of tree and shrub thickening and encroachment. In the Gulf, gutta-percha is encroaching into other-wise naturally open grasslands. In the Kimberley, Pindan land-types have thickened and land condition declined to the point that industry question the capacity for land condition to improve. Kimberley and VRD managers consider fire to be an effective management tool, and are willing to make use of fire. In the Gulf, however, fire is generally not considered to be a viable management option.

Fire was a more prominent issue in the relatively reliable rainfall of the Kimberley, with tree thickening and encroachment perceived as a strong impediment to resilience in the red-soil Pindan land types. These were followed by wet season spelling and the infrastructure required to implement spelling. Market and access issues were more important than other regions, with Kimberley cattle marketed almost exclusively through the live export trade. This was to become a major financial issue for industry in both the Kimberley and the VRD and an engagement issue for the project throughout 2011.

The industry extension meeting held in the Gulf highlighted the need for key data, such as live-weight gains, to be as close to industry expectations as possible. The relative changes in live-weight gains over time and between scenarios were consistent, but outside of the range that producers would expect for their region. This highlighted the emphasis that industry place on live-weight gains, and also reminded the team that producers relate to cattle weights instantly and make instant decisions on the relevance of information based on these factors.

4.2.2 Adoption phase

Each region set targets to increase awareness, KASA (knowledge, attitude, skills and aspirations—a measure of the intent to adopt new practices) and practice change of their identified key issues. The targets were set to be ambitious, yet appropriate to the number of producers within each region (***Table 3***). Common methods were used to achieve these outcomes within each of the regions, including on-property demonstrations and case studies, delivering training, holding events (such as field days), speaking at industry or other group events and publishing new fact sheets, case studies and guides. Whilst these methods were used within each region, they were not necessarily used to address each key issue (***Table 4***).

This project was complementary to, and run concurrently with, Climate Clever Beef with the same staff involved, the same target audience and three regions in common. The targets for both projects were hence combined—as were events in many instances to enhance the efficiency of delivery and avoid overwhelming the grazing community with two sets of events on similar themes facilitated by the same agency staff.

Table 3 Regional engagement and adoption levels achieved and project targets. KASA (knowledge, attitude, skills and aspirations) is a measure of the intention to adopt new practices.

Region	Number of producers[2]	Awareness*	KASA**	Practice change**	Training events**	On-property demonstrations	Engagement events	Publications
Gulf	280	233	197	20	2	2	11	5
Fitzroy	2579	1187	139	25	1	4	10	5
Maranoa-Balonne	1184	47,531	288	42	6	7	14	9
Mitchell grasslands	738	250,000	86	49	0	5	14	3
Barkly Tableland	28	9,000	22	10	2	2	8	3
VRD-Douglas Daly	28	900	40	17	3	7	10	4
Alice Springs	61	500	11	7	0	3	8	5
Kimberley	91	20	0	4	0	1	2	2
Burdekin	450	20	0	0	0	0	0	0
TOTAL	**5,439**	**309,391**	**783**	**174**	**14**	**31**	**77**	**36**
Target		*3,325*	*613*	*210*	*22*	*42*	*45*	*32*

* entire audience ** target audience only

[2] Based on ABS 2006 data

Table 4 Summary of the key issues addressed within each of the project regions, and the methods (case studies, demonstration sites, field days and publications) used to enhance KASA (knowledge, attitude, skills and aspirations) and practice change.

Region	Key issues	Case studies	Demonstration sites	Farm walks and field days	Fact sheets
Maranoa-Balonne	Stocking rate management, including addressing the research gap around long-term carrying capacity recommendations		4 collaborators. 4 demonstration sites within a grazier focus group: The Peaks (Mitchell), Canberra (Roma), Yendon and Woolerina (Bollon) and Glenlinden (Injune)	4 field days: 3 on managing flooded pastures at Condamine, Surat, St George in March 2011 and stocking rate management at Muckadilla in March 2012 1 GLM workshop updated and held at Mitchell in June 2011 3 Stocktake workshops: Wallumbilla August 2011, Surat July 2011, Taroom July 2011 2 Testing Management Options workshops at Mitchell November 2011, Roma March 2012	7 fact sheets: 'The Northern Grazing Systems Initiative. Introduction to the Maranoa Balonne project and fact sheet series, 'Benchmarking your property: Establishing long term carrying capacities', 'Forage budget – a useful tool to help balance supply and demand', 'Estimating dry matter yield', 'Pasture recovery from floods' (in conjunction with other regions), 'Weeds following flooding' (in conjunction with other regions), 'Benchmarking your property. Establishing long-term carrying capacities'
Maranoa-Balonne	Wet season spelling to improve land condition	2 case study collaborators. Yendon & Woolerina are family owned breeding and backgrounding properties in the Bollon district			2 case studies: 'Andrew and Lauren Winks, 'Yendon', Bollon with Ian and Wendy Winks, 'Woolerina', Bollon' and

		Arakoola, Bollon is a family owned cattle breeding and growing out property			'Peter, Diana (Tiki) and George North, 'Arakoola', Bollon'
Maranoa-Balonne	Balancing grass production and tree regrowth	1 case study collaborator. Mourilyan, Bollon, is a 16,300 ha family owned cattle and sheep property		1 webinar on fire management 2 thinning sustainably field days at Mitchell and Dirranbandi	1 case study 'Alan and Liz Browning, 'Mourilyan', Bollon'
Gulf	Stocking rate management and wet season spelling to improve land condition	2 case study collaborators. Gum Creek station; Croydon, a 64,000 ha family owned breeder property Herbertvale Station; Camooweal a 137,000 ha family owned breeder, backgrounding and fattening property		1 field day at Gum Creek Station: May 2011 2 GLM workshops updated and presented: July and Nov 2011 6 producer forums incorporating forage budgeting at: Almaden, Croydon, Alehvale, Donors Hill, Cobbold Gorge and Gilberton 1 Camtasia Slidecast incorporating stocking rate management, 'Managing Breeder Condition' 2 producer demonstration site field days at Hughenden and Richmond incorporating grazing management in November 2011	2 fact sheets: 'Infrastructure to manage grazing'; 'Wet season spelling in the Gulf. Good for your pastures and your pocket'
Gulf	Fire as a management tool				1 fact sheet: 'Fire. Management of native and invasive woody weeds in the Northern and Southern Gulf

Fitzroy	Stocking rate management	1 case study collaborator. Bon Accord, Anakie is a family owned breeder, backgrounding and fattening property.		1 field day at Berrigurra, Emerald 3 presentations at grazier events: Laurel Hills Clermont June 2010Mornish Landcare October 2010, Billaboo CQ BEEF group October 2010. 2 field days flooded out in March 2012 rescheduled for June 2012: Monteagle Clermont and Alpha town hall	1 case study: 'Stocking rate management in the Fitzroy Woodlands, Richard Hawkins Bon Accord Anakie' 3 fact sheets: 'Land condition in the Fitzroy Woodlands Forest country' 'Land condition in the Fitzroy Woodlands Scrub country' 'Stocking rate management in the Fitzroy Woodlands Matching pasture supply to animal demand'
Fitzroy	Fire as a management tool	1 case study collaborator. Mount Mica and Florence Vale, Rubyvale are family-owned backgrounding and fattening properties			1 fact sheet 'Burning management in the Fitzroy Woodlands The use of fire for healthy ecosystems 1 case study 'Fire management in the Fitzroy Woodlands Glynn Williams Mount Mica and Florence Vale, Rubyvale'

Fitzroy	Wet season spelling to improve land condition	1 case study collaborator. Avocet, Emerald is a family owned breeder, backgrounding and fattening property			4 fact sheets: ‘Phases of pasture growth - buffel grass. A visual aid to restocking after wet season spelling’, ‘Wet season spelling in the Fitzroy Woodlands The use of spelling for healthy ecosystems’, ‘Spelling strategies for recovery of pasture condition’ (associated project)
VRD	Wet season spelling and fire to improve land condition		1 collaborator. Delamere station, 150 km south west of Katherine, a 3,003 km2 breeder property owned by AACo	2 GLM workshops updated and held in April 2010 and February 2011.	1 case study booklet
VRD	Wet season spelling to improve land condition	1 case study collaborator. Waterloo station in the western VRD			1 draft fact sheet
Alice Springs	Stocking rate and spelling management to improve land condition		1 collaborator. Old Man Plains research station, Alice Springs	1 paddock walk at OMP	1 draft case study on Old Man Plains
Alice Springs	Integrated fire and grazing management to improve land condition	1 case study collaborator. Narwietooma, Alice Springs			2 draft case studies on Narwietooma
Kimberley	Reduced stocking rates to improve land condition	1 case study collaborator. Jubilee Downs and Quanbun Downs, Fitzroy River floodplain, a 222,000 ha family owned breeder operation			1 draft fact sheet

Overall, the awareness target was exceeded by nearly 100-fold, albeit primarily through the screening of an ABC TV Landline episode for the Mitchell grass region within Climate Clever Beef. Even without this high figure, awareness was nearly twenty times the target at 60,891 readers and listeners exposed through magazines, newsletters, newspapers and radio. For example, Maranoa-Balonne articles were included in the Rural Weekly supplement published by Rural Press and inserted in a number of rural newspapers, such as the Western Star. Examples of media articles and press releases are provided in Appendix 2.

Over 780 beef producers and their advisors are planning on adopting a relevant new practice and about 170 have made a change already. This is a good result within the limited project time-frame. The KASA target was exceeded by 25%, with a total of 783 beef producers and their advisors planning a change in practice. The actual practice change fell short of the target by about 20% partially due to the diversion of resources, and industry interest, away from natural resource management and into live export. The highest practice change was recorded in the Queensland Maranoa-Balonne and Mitchell grasslands regions.

The Kimberley region engagement efforts were diverted by the negotiations over banning live-exports that occurred during 2011. Given the Kimberley's reliance on live-exports to sell cattle, it was appropriate for the Western Australian Government to re-direct their resources into this topical and crucial issue. Industry's attention was also focussed on this issue, rather than land management or climate change. Without markets for their cattle, Kimberley beef producers would have no ability to implement stocking rate or wet season spelling strategies to improve land condition and build resilience. The issue did highlight a lack of market resilience which is relevant to, and may have implications for, this region's capacity to deal with future shocks such as climate change. The re-direction of agency and industry resources towards the live industry issue prevented the completion of the extension programme. Despite this re-direction of resources, the technical guide and one key case study were produced for the Kimberley region.

Beef producers within Northern Territory regions were also affected by, and directed their attention towards, live export. This made it difficult to engage with producers to establish demonstration sites, especially when many feared their businesses would become unviable and forced sales may result. Project staff did not have to be diverted, but their efforts had to be doubled to engage their audience.

Targets within the Burdekin were delivered through separate Reef extension efforts, and not counted within the Climate Clever Beef project (Bray *et al*. 2013). Reef extension materials, the regional technical guide and messages around stocking rates, wet season spelling and fire were influenced and guided by the synthesis and computer simulation thus contributing to the consistency of the approach and the message. Staff resources originally intended for this project were re-directed into Reef efforts to meet the Queensland Government's highest priority need.

Demonstration sites were established or case studies produced within each of the six Climate Savvy Grazing regions. In the Fitzroy region of Queensland, three new case studies were produced in collaboration with land-holders and through on-ground evidence. These highlighted managing for flood recovery, stocking rate management and the positive role that fire can have in the long-term. The Climate Savvy Grazing prioritisation process identified that greater knowledge of applying wet season spelling to improve country in poor land condition, especially the timing, duration and frequency of spelling needed for recovery. The project 'Spelling strategies for recovery of pasture condition' (B.NBP.0555) was initiated as a result, concentrating effort within the Fitzroy and Burdekin regions.

The Delamere demonstration site in the VRD has so far shown there was more of the preferred curly bluegrass at 2 km from water than at 1 km from water. This reflects the historical pattern of preferential grazing of this palatable plant. The plots that had been burnt in November 2010 and then spelled for the whole wet season had slightly more curly bluegrass than the plots that had been spelled but not burnt. It also appears that the seeding levels of curly bluegrass were highest on the plots that had been burnt and spelled. Full results will take at least six years to become evident, as the wet season spelling cycle is repeated every three and four years in different plots.

The four grazing families involved in the Maranoa-Balonne focus group decided to each host demonstration sites to review stocking rates for land condition and productivity within their businesses. This included integrating on-ground monitoring, weighing livestock, NIRS faecal analysis for diet quality for two paddocks per property and undertaking business analysis through the Testing Management Options (TMO) process.

Demonstration paddocks were generally in good (A) condition across a diverse range of land types including:

- Poplar Box on alluvial plains
- Cypress pine on deep sands
- Brigalow-Softwood Scrub
- Poplar Box and brigalow
- Softwood scrub
- Mitchell grasslands.

Safe long-term carrying capacity ranged from 3 to 11.4 ha/AE (***Table 5***), depending on land type, land condition and tree basal area. Current stocking rates range from 2.9 to 22.1 ha/AE, with most paddocks stocked below the safe long-term carrying capacity despite the high amount of feed on offer resulting from above average rainfall. Six of the eight paddocks were spelled for at least 20% of the monitoring period.

Table 5 Stocking rate and long-term carrying capacity comparisons across the eight demonstration paddocks in the Maranoa-Balonne region.

Paddock	Land type	Dates	Period monitored (days)	Rest (% in period)	Stocking rate (ha/AE)	Long-term CC (ha/AE)	ADG guide (kg/hd/day)
Carbeen	Poplar Box on alluvial plains	14/06/11 - 21/03/12	281	60	10.6	5.2	0.91 (heifers) 1.1 (steers)
Pine	Cypress pine on deep sands	14/06/11 - 21/03/12	281	27	7.5	11.4	0.1 (heifers) 0.04 (steers)
Swampy	Brigalow-Softwood Scrub	30/11/10 - 21/03/12	477	52	22.1	8	0.77 (dry cows) 0.91 (steers)
Dougalberry	Brigalow-Softwood Scrub	30/11/10 - 21/03/12	477	22	7.7	6.9	0.98 (summer) 0.11 (winter)
Farm	Mitchell grasslands	20/07/11 - 21/03/12	245	0	4.6	4.5	
Well/Basalt	Poplar Box and brigalow	20/07/11 - 21/03/12	245	0	3.9	3	1.0 (steers)
Back	Softwood scrub	12/08/11 - 21/03/12	222	23	2.9	3.1	0.4 (steers)
Tinkers	Mitchell grasslands	12/08/11 - 21/03/12	222	90	7.8	5.8	

Two demonstration sites were established in the Gulf, near Croydon and Camooweal. These 64,000 and 137,000 ha properties have focussed on practical wet season spelling and stocking rate management strategies, using feed budgeting and fire as a management tool. Both locations have hosted field days and are presented in case study publications.

All six regions produced a regionally customised technical guide for advisors, consultants and other professionals working with beef producers, based on the original synthesis document. This as been well received, for example the Fitzroy Basin Association (a Queensland NRM group) has requested an additional 100 copies of the Fitzroy guide for their staff and key clients to improve their understanding of industry issues and advice provided. A further seven publications were produced for the Fitzroy region.

Extension practices and networks were expanded, and messages clarified through the project. The synthesis document, and the discipline required in customising the document to each region, helped focus attention on the key natural resource management issues. This was further enhanced by the computer simulation results and industry engagement.

Existing training packages were updated and the new content delivered. For example, Grazing Land Management Certificate IV training workshops were delivered at Cloncurry and Gregory Downs to 27 producers and advisors. Following these workshops, producers indicated they would take feed on offer, landtype, distance to water and land condition into account when adjusting carrying capacity.

Each region built on existing networks but also challenged themselves to find new collaborators and reach out to a wide audience using traditional and new technology.

Whilst engaging with individual producers has the greatest practice change impact, the use of web-based technology has provided the ability to reach a wider audience. For example, the Gulf team released an e-learning slide-cast featuring stocking rate management as a central theme to improving reproductive efficiency. The Maranoa-Balonne team delivered and recorded a webinar on the role of fire. These are now hosted on the Future Beef website (http://www.futurebeef.com.au). The Gulf team is trialling incorporation of smart phone QR codes on fact sheets to link to the FutureBeef website for more information. These codes are scannable on-screen, providing the end-user with greater flexibility in how they access information products.

Regional teams adapted to situations as they arose. For instance, the flooding through-out Queensland in early 2011 was challenging for industry but also provided opportunities to adapt our key messages of building resilience through good land condition, appropriate stocking rates and wet season spelling. Both the Fitzroy and Maranoa-Balonne teams quickly produced fact sheets in response to the flooding, providing timely advice to industry. The clarity of these messages was made possible through the synthesis and industry engagement within this project.

The most successful extension programs were in regions that had adequate resources to be flexible when faced with external issues such as live-export or flooding, and/or were able to build on existing networks and programs. Industry members within the VRD region were impacted as severely as producers within the Kimberley. Within the VRD there were adequate Agency staff to increase efforts in engaging industry in building resilience. Resources within the Kimberley, however, were diverted towards addressing the live-export issue and were not available to continue work within the project's delivery time-frame. Similarly, the extra efforts required in the VRD diverted resources away from the Alice Springs region which led to some project delays. In the Gulf, success came from being able to build on the already well-established $avannPlan networks and the reputations of experienced staff who were already well respected within industry. The existing networks and respect allowed for case-study and demonstration properties to be quickly established, for the workshop phase to be quickly completed and the adoption phase to be commenced.

4.3 Computer simulation modelling

The computer simulations extrapolated research results and expert-knowledge spatially and temporally, exploring long-term trends within the six regions. This has provided guidance without repeating expensive on-ground research, or expensive industry mistakes to learn from. Simulations require validation, which was achieved through engaging regional experts from industry, science and extension; and conducted through reference to published information such as scientific journals, current price indexes and statistics. It has been invaluable in reinforcing the need for good land condition and best-management of resources, cattle and the business of production and focussing our extension efforts within the current project. The project modelling demonstrated the capacity to capture industry interest in linking management, land condition and grazing management with herd dynamics, live-weight gain and economics effectively in one platform. The current models still have constraints which limit this integration to strategic, rather than day-to-day tactical, decision making. The simulations, which ran into the hundreds of thousands of model runs, produced such a large volume of data that our objective of guiding further R&D has not yet been realised. There is value in making use of this information to focus the R&D effort before the currency of the information is lost.

The real power of the computer simulations came from being able to explore the risks and opportunities inherent in climate change. Whilst there is discrepancy between the details of temperature and CO_2 increases, the trend is clearly upwards. In the medium-term, it appears that increased plant growth from increasing CO_2 will offset reduced growth from higher evaporation rates under higher temperatures. At some stage beyond the year 2070, however, reductions from higher temperatures are likely to exceed the fertilisation effect of CO_2 (Stokes *et al.* 2012).

In the short to medium term, leading up to 2070, the rainfall trend is likely to remain uncertain. The beef industry will need to implement best-management, and be highly adaptable in the face of this uncertainty. The computer simulations provide a degree of certainty that current best-management strategies of matching stocking rate to carrying capacity in the longer-term, maintaining flexible stocking rates through feed budgeting and implementing wet-season spelling will maintain good land condition. A key uncertainty is what that safe long-term carrying capacity may be, as it is driven by pasture growth based on rainfall.

4.3.1 Refining the models

A number of enhancements were made to the pasture and livestock production simulation model GRASP and herd and economic simulation model ENTERPRISE. These enhancements were made in the current project, the concurrent Climate Clever Beef project and in the preceding project 'Enhancing adoption of improved grazing and fire management practices in northern Australia: Bio-economic analysis and regional assessment of management options' (B.NBP.0578, Scanlan and McIvor 2010). These enhancements enabled the simulation of multiple management strategies across multiple land types or paddocks and predicting changes in pasture growth, land condition, cattle productivity and profitability under a range of climate change scenarios. The enhancements with the greatest benefit to this project include:

- a refined dynamic relationship between the proportion of perennial grass in the pasture sward and land condition, enabling more realistic changes between land condition classes
- stocking rates changes which mimic real-world constraints to adjusting numbers
- a more realistic representation of the higher impact of over-grazing in the early growing season, as opposed to over-grazing during later growth phases or during the dormant phase. This includes feedback as grass basal area, a major factor in grass growth, increases or decreases in response to seasonal conditions as well as to grazing
- pasture growth rates corrected for the latest research findings for the effects of increased temperature and CO_2 levels
- increased capacity in ENTERPRISE from a dynamic 'one-paddock' to a dynamic, 20-paddock model in which constraints imposed on the herd by the paddock structure influenced herd dynamics and sales. This has enabled the economic analyses of various management options to be applied on representative properties for various management strategies, given the particular constraints of the modelled property.

The exposure of the simulated results to a real-world audience in the extension workshop phase reinforced the need to make changes which had previously been identified as constraints, as well as identifying new constraints. This occurred both during the preceding project (Scanlan and McIvor 2010) and this project, which used the same engagement and validation approach. Whilst there were known constraints in both GRASP and ENTERPRISE, it was only through pushing these models to simulate real-world management scenarios and presenting the results to a modelling-naïve, yet real-world savvy, audience that key constraints were fully exposed and prioritised for improvement.

The importance of improving the simple live-weight gain approach used within GRASP was highlighted in the Alice Springs and Gulf regional workshops. Live-weight gain is a key output from GRASP in estimating economic performance within ENTERPRISE. It is also integral to real-world beef producers, who are gaining a better understanding of the performance of their livestock and land types through Near Infra-red Spectroscopy (NIRS) predictions and regular cattle weighing. To be credible to industry, live-weight gain predictions need to be close to the values graziers are finding in their own businesses. This shortcoming is now being addressed within a separate MLA funded project (Mayer 2012, Mayer *et al*. 2011).

Alice Springs and Gulf regional workshops also identified limitations in the perennial grass modelling, despite it having already been enhanced over and above previous versions of GRASP. Improvements to GRASP in the VRD and Barkly regions of the NT are being used to refine property level carrying capacity estimates. For Alice Springs, many land types are based on annual and ephemeral pastures even under good land condition. This is also true for a number of other arid regions, such as the channel country of far-western Queensland. It is likely that additional biological research is needed to better define the condition classes of these land types before enhancements can be made within GRASP. Enhancements are needed to accurately simulate the outcomes of management strategies in non-perennial grass dominated land types. In the Gulf, graziers questioned if the modelled representation of perennial grass composition reaching a steady plateau within good condition, even under fluctuating rainfall, was realistic. The perennial grass composition is likely to vary by 5-10% from year to year in response to below and above average rainfall, rather than reach a steady state. This fluctuation is unlikely to make any difference between the results of management strategies, but may provide greater credibility to a real-world audience.

4.3.2 Simulating the current situation

Representative regional properties were used to simulate a range of strategic management options in comparison with current practice. In many cases, current practice stocking rates and the lack of planned wet season spelling will continue to drive land condition downwards and erode resilience to future climate variability or the risks of climate change. This assumes, however, that managers would not respond to the evidence of declining land condition and declining productivity.

The approach to stocking rate, as a general guide, needs to be more flexible in the regions with the highest rainfall variability. These regions also tended to need longer spelled periods to improve land condition; for example the Alice Springs region required a full year spell in alternate years to achieve the same results as a 6-month spell every year in other regions. Some regions, such as the Fitzroy, demonstrated similar increases in land condition from reduced stocking rates as from wet season spelling. More productive land types were generally more resilient to the effects of variable rainfall and over-grazing than less productive land types.

Land types where tree and shrub thickening was a risk always benefitted from the early use of fire, although there was no comparison with mechanical or chemical control options. In each case a point was reached where fire was no longer possible due to fuel loads being reduced below the yield needed to carry an effective fire. Low fuel loads were exacerbated by high stocking rates. In most cases reduced stocking rates were adequate to ensure adequate fuel loads, and pre-burn wet season spelling was not required. Post-burn wet season spelling coupled with appropriate stocking rates is likely to be required to promote land condition recovery.

Profitability of the representative property across the regions did not necessarily follow on from having a more productive resource base or having historically more reliable rainfall. Profitability, whilst linked to good land condition and carrying capacity, also depends on the scale of the operation, the cost of inputs and the prices received. The VRD property made the highest annual profit by far, but did not have the highest Gross Margin per AE (***Table 6***). Even though the Alice Springs region has the highest rainfall variability, it was the Gulf that had the greatest number of unprofitable years and Alice Springs was mid-range. Provided the assumptions made for each region were accurate, the relative differences between these economic simulations should be accurate but may not represent actual regional profits.

Table 6. Economic metrics for NGS regional 'representative' properties under current industry management practice based on the historical climate from 1981-2010.

Region	Maranoa-Balonne	Fitzroy	Gulf	VRD	Alice Springs	Kimberley
Annual profit (AP)	$346,438	$78,994	$101,019	$1,064,457	$194,669	$187,591
No. years AP<0	2	8	11	3	6	5
Average GM/ha or km^2	$31.00/ha	$21.90/ha	$2.88/ha	$251.66/km^2	$90.83/km^2	$161.16/km^2
Average GM/AE	$211.47	$239.62	$36.92	$113.96	$146.18	$65.09

4.3.3 Simulating future scenarios

Rainfall dominated the pasture response to the climate change scenarios leading up to 2070, even though evaporation and CO_2 are important factors. The two most intensively settled and most productive regions were estimated to be at the greatest risk of declining rainfall. Even under the best-case future rainfall scenario with a generally wetting trend across Australia, the Fitzroy and the Maranoa-Balonne failed to increase in rainfall, representing clear regional differences from the overall trend (***Figure 2***). The Alice Springs, Gulf, Kimberley and VRD all increased in rainfall under the best-case scenario. Even under the median-case scenario, the Gulf and Kimberley regions maintained parity with the historical rainfall averages. All regions received less rainfall under the worst-case scenario, with the Alice Springs region faring the worst and the Gulf and VRD faring the best (or perhaps the 'least-worst').

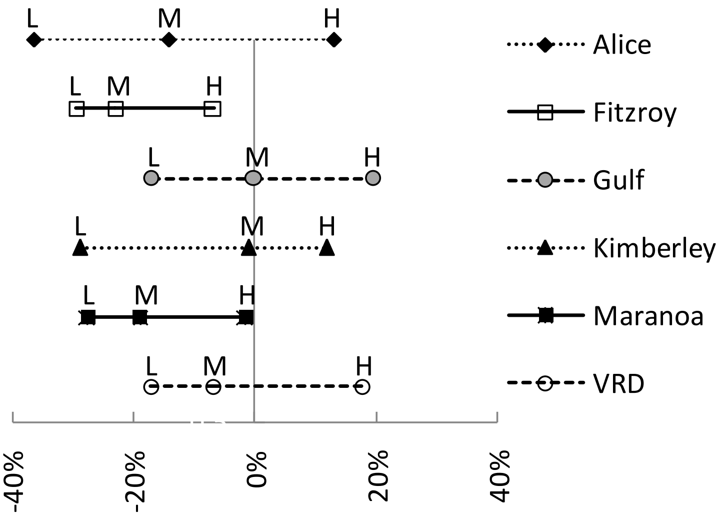

Figure 2 Relative change in rainfall compared to current climate for a generally drying trend (L), median trend (M) and generally wetting trend (H) future climate scenarios for the six NGS regions.

Stocking rate decline (***Table 7***) and economic performance (***Table 8***) was the worst in the Fitzroy and the Maranoa-Balonne regions, in line with rainfall for all scenarios. The largest increase in stocking rate under the best-case scenario was in the Alice Springs and Gulf regions, but the Gulf was the only region to maintain current stocking rates under the median-case scenario. All regions had worse stocking rates and reduced profits in the worse-case scenario.

Table 7. Average percent change (compared to current climate) in stocking rates to maintain land condition for the different regions and climate scenarios. Average of all land productivities and conditions.

Region	***Drying trend***	***Median trend***	***Wetting trend***
Alice Springs	-53%	-13%	+61%
Fitzroy	-42%	-25%	+3%
Gulf	-30%	+2%	+32%
Kimberley	-54%	-10%	+5%
Maranoa-Balonne	-47%	-31%	-10%
VRD	-23%	-13%	+13%

Table 8. The relative change in profit for the representative property in each of the six NGS regions, under three future climates compared to current climate.

Region	***Drying trend***	***Median trend***	***Wetting trend***
Alice Springs	-133%	-50%	+94%
Fitzroy	-254%	-189%	-38%
Gulf	-636%	-43%	+536%
Kimberley	-127%	-39%	+36%
Maranoa-Balonne	-147%	-115%	-5%
VRD	-60%	-29%	+26%

5 Success in achieving objectives

Climate Savvy Grazing delivered best-bet management practices to industry, in conjunction with the preceding (Scanlan and McIvor 2010) and concurrent (Bray *et al.* 2013) projects. We increased the knowledge of the risks and options under current climate variability and future climate scenarios and worked to a consistent framework and set of messages for industry.

The computer simulation models were greatly improved to allow useful management strategies to be compared under current and potential future climate scenarios. This, coupled with the earlier synthesis of north-Australian grazing management research, provided the framework for consistent extension messages and a strong platform for engaging beef producers in case studies and demonstration sites. Awareness targets set by each region were exceeded and KASA targets were met overall. The target of 210 producers adopting new practices fell short by 20%.

1. Described the existing industry management practices and situation, and identified potential grazing and related management strategies for building resilience and coping with a changing climate for 6 target regions (Kimberley; Victoria River District; Alice Springs District; Gulf region of north-west Queensland; Fitzroy catchment; and Maranoa-Balonne).

All six regions conducted the industry engagement workshop phase and defined regionally representative properties for use in simulation modelling, as per the project schedule.

Each region identified stocking rate and pasture spelling as high priority strategies to manage land condition, based on industry and professional experience, synthesis of research information and preliminary modelling results. The Fitzroy, Alice Springs and Kimberley regions also identified fire as a key strategy to improve resilience by reducing the impact of shrub and tree encroachment and improve land condition. Demonstration sites, case studies, new technical information, discussion forums, action learning groups, field days, paddock walks and training were used to engage beef producers and promote practice change. Because the extension programme and computer simulation modelling ran in parallel, the preliminary simulation findings for best-management strategies based on current climate guided the extension efforts in each region. This pragmatic approach has proved to be sensible, as the computer simulation of future climate management supports the fundamental management strategies being promoted.

The industry engagement workshops collated information about the current situation and practices. In every case, we found that some assumptions could be improved. The workshops improved the quality of the local intelligence that informed later modelling and on-ground demonstration priorities.

2. Identified best-bet grazing and related management strategies and guidelines for building resilience for each of the target regions.

Well-adapted strategies under a changing climate are similar to the best management under current climatic conditions. Having land in good condition is the underpinning objective for building resilience in each of the regions. Substantial improvement of resilience is dependent on managing land condition in the most profitable way while minimising risk.

Moderately flexible stocking rate strategies were the best option in most regions, especially when stock numbers were reduced rapidly in poor seasons and increased gradually in good seasons. Wet season spelling improved land condition in each region, although the practical application varied e.g. a full year spell for alternate years was required in the Alice Springs region whilst full wet season spelling was adequate in other regions. Such a substantial difference was only recognised through using the simulation modelling.

Modelling suggested that land condition can be improved through combining wet season spelling with moderate stocking rates and not solely through low stocking rates that are often recommended. This may be a more acceptable approach to industry in many regions.

More fertile land types had sufficient fuel to carry fires in enough years to be used to control woody regrowth, but low fertility land types often failed to grow adequate fuel. This was exacerbated by high stocking rates, high initial tree and shrub cover and in low rainfall regions.

Industry engagement was invaluable to improve the evidence-base and produce more realistic outputs from modelling. In two regions of the Northern Territory, the producer input lead directly to on-ground demonstration sites which have been well received by industry. The computer simulations were improved in the Northern Territory in particular, where the live-weight gains and subsequent economic simulations initially struggled to mimic reality.

The guidelines have been compiled in each region as technical guides and distributed to industry advisors. A range of new fact sheets were produced based on the technical guides, synthesis of literature, modelling and industry engagement (case studies and demonstration sites) and released to industry.

3. Developed and implemented a plan in each region for evaluation, improvement and extension of a selection of best-bet grazing and related management strategies.

Each region developed appropriate strategies to maximise the awareness, KASA and on-ground adoption of their key management approach(es) to build resilience. The best-bet management strategies were developed through the synthesis of information, computer simulation and industry engagement. In the Maranoa-Balonne, for instance, an action learning group was established with young and progressive graziers in exploring new management options on their own properties. The initial concept was for a single demonstration site managed by the group, but that has now strengthened to four locations. This group intends to be active over the long-term and is well positioned to explore refined strategies into the future. The Maranoa-Balonne technical guide was released to agribusiness, professional advisory staff and leading graziers. This publication was well received and lays the foundation for updated information.

In the Fitzroy, nine new information products were provided to industry at a field day in early December 2011. These included two case studies on stocking rate and fire management. The field day, held at Berrigurra Station, Emerald focussed on the ability of land managers to minimise risk and adapt to climate variability. The Fitzroy leads the on-ground refinement of wet-season spelling through a companion project (Jones 2013) funded by MLA and DAFF, which was identified through early industry engagement and computer simulation.

In the Northern Territory, demonstration sites were established near Alice Springs (Old Man Plains) to test the most promising flexible stocking rate and spelling strategies from the BEM over the long-term; and near Katherine (Delamere Station) to test spelling and burning strategies within the VRD. Existing training packages were enhanced and training conducted with industry; and field days and paddock walks consolidated existing networks. A major beef industry conference held in Darwin (NBRUC) allowed for adaptation strategies under a changing climate to be presented to a wide audience and to progress the discussion in the NT.

The Gulf region built on successful existing extension programmes to deliver the improved knowledge of management strategies by utilising existing networks and establishing on-ground demonstration sites. Existing extension within the Gulf integrates resource management with production through individually tailored business analysis, discussion groups, developing technical information and conducting paddock walks and field days. The demonstration sites at Croydon and Camooweal address reducing stock numbers to match carrying capacity and implementing wet season spelling to improve land condition and productivity. The team used their existing financial approach to analyse improved profitability, business resilience and integrate findings within a whole business context.

Overall, the project targets were exceeded for awareness, met for KASA but fell about 20% short for practice change. The demonstration sites, publications and industry networks established within the project will help to increase adoption over time.

4. Identified the likely biophysical, production and economic impacts of climate change for each region, using the best available climate projections and bio-economic modelling.

The magnitude and direction of the impacts of climate change in the six regions depend mainly on the amount of rainfall projected for each future climate, and partly on the productivity and condition of land types.

Under the best-case future rainfall scenarios, projected rainfall was higher than current climate in the Alice Springs, Gulf, Kimberley and VRD regions but not in the Fitzroy or Maranoa-Balonne. Projected rainfall was maintained at historic averages in the Gulf and Kimberley under the median future rainfall scenario but was reduced for the other four regions. Projected rainfall was lower than that of the equivalent current climate for all six regions under the worse-case future rainfall scenario.

High productivity land types generally had higher increases in growth and stocking rates under the best-case future rainfall scenario and smaller declines under the median and worse-case future rainfall scenarios, compared with low and moderate productivity land types. Similarly, good condition land types were impacted less than poor condition land types by reduced rainfall under future climate scenarios. The only exception was spinifex land types, which are predicted to increase growth with CO_2 fertilisation and enhanced nitrogen uptake disproportionately to rainfall changes. The most productive parts of the landscape will generally fare better under climate change, providing land condition is good. Improving land condition will enhance production now and under climate change.

The average annual profits of the representative properties in Alice Springs, Gulf, Kimberley and VRD regions under the best-case future climates were 26 to 536% higher than those for current climate, due mostly to differences in projected rainfall, In the Fitzroy and Maranoa-Balonne regions, where projected rainfall for the best-case future climate was lower than current climate, average annual profits were 5 to 38% lower than those under current climate.

In all regions, under the median and worse-case future climates, average annual profits of the representative properties were lower and the number of years when profit was negative was higher compared with current climate. With the median-case scenario, average annual profit declined by 29 to 189%, while under the worse-case profit declined by 60 to 636%.

5. Identified best-practice future grazing and related management strategies and responses for each region, using the best available climate projections and bio-economic modelling.

A number of industry best-management practices have potential to reduce adverse impacts or capture potential benefits arising from climate change. Ideally, the strategies with the most potential for adapting cattle properties to climate change will be those which perform well under both current and future climates. That is, they are able to achieve the best pasture condition, livestock productivity and property profit under current plus one or more future climate projections. This would facilitate a more seamless transition to future climatic conditions, as management is less dependent on knowing when and by how much to change current practices, and requires the least amount of change and disruption at the property and industry scale.

5.1 Adaptation through stocking rate management

The moderate flexibility stocking rate strategy allowed stocking rates to increase by up to 10-20% and decrease by up to 30-40% annually. It was the best performing strategy in the Gulf, Kimberley, Maranoa-Balonne and VRD regions under all climates when simulated with stocking rates that were more-or-less aligned with the carrying capacity of each climate projection. In these regions, moderate flexibility increased average annual profit by $7,000 (Gulf, worse-case future rainfall) to $409,000 (VRD, current climate), or by 4 to 260%, compared with current industry flexibility. As well as high average annual profit, moderate flexibility also often achieved the highest percent perennials and LWG/ha.

A key to success of the moderate flexibility strategy appeared to be low increases in annual stock numbers coupled with rapid decreases. Moderate flexibility also performed better when simulated with stocking rates lower than those required to maintain land condition for median-case and best-case future rainfall climates.

This cautious approach to setting stocking rates appears to effectively minimise the risks involved in the typical approach of setting stocking rates just once a year in northern Australia where annual rainfall is highly variable and unpredictable. Under these circumstances, moderate flexibility is able to maintain or improve pasture condition while still maintaining high livestock productivity and property profits.

Full flexibility was the best performing strategy in Alice Springs for worse-case future rainfall and median-case future rainfall scenarios. It increased average annual profit by $116,000 (182%) to $173,000 (179%) under the worse-case future rainfall and median-case future rainfall respectively, compared with current industry flexibility. Under best-case future rainfall moderate flexibility was the best strategy and increased average annual profit (above current flexibility) by $270,000 (72%). Moderate flexibility had much higher annual adjustment in Alice Springs than other regions (annual increases and decreases of 30 and 50% respectively). Full flexibility allowed stocking rates to increase too much under the best-case future rainfall scenario in Alice Springs, and restricted land condition recovery and profit. In Alice Springs, a very high flexibility is required to adjust stocking rates quickly and substantially enough to take advantage of the occasional peaks in pasture productivity. However, full flexibility is not a practical strategy for cattle producers in central Australia, and has considerable economic and land condition risk. For these reasons, current flexibility may be a more practical strategy for this region. With its limits of 10-20% for annual increases and 25-30% for annual decreases in stocking rates, it is similar to the moderate flexibility strategies of other regions. The practicality of these strategies need to be discussed with industry.

In the Fitzroy region, the good performance of full flexibility may have been specific to the 25-year climate period modelled, as additional modelling indicated that moderate flexibility is more suited to the longer-term climate of this region.

Stocking rate strategies that limit increases in stocking rates to 10-20% relative to higher decreases of 30-40% annually appear to perform well under both current and future climates in all regions (this was equivalent to current flexibility in Alice Springs), providing they are simulated with stocking rates that are appropriate to each climate. This moderate stocking rate flexibility has the potential to improve the sustainability and profitability of cattle properties under current climate and as climate changes. However, this good performance across all climates may be due to all future climates being based on the same climate variability and annual sequences in rainfall and temperature as current climate.

Management of stocking rate may also be improved through the use of appropriate long-term carrying capacities, seasonal forecasting tools and more frequent assessment of pastures and adjustments to stocking rates. These are tactics that may assist cattle producers to more closely match stock numbers to available forage, and reduce the need for large single annual adjustments in stocking rate.

5.2 Adaptation through pasture spelling

While the moderate flexibility stocking rate strategy is capable of improving the percent perennial grass composition of pastures, it is likely that pasture spelling will be required to prevent the continuation of patch grazing and increase the abundance of more palatable grasses.

The rotational spelling regime of a six-month summer-season spell, every four years, is capable of improving pasture condition, carrying capacity and animal productivity in the spelled paddocks and overall property profitability under both current climate and future climates, providing stocking rates are appropriate to each climate. This pasture spelling strategy improved percent perennials by 30 to 40%, more than doubled LWG/ha, and increased average annual profit by more than 50% under current climate and the best-case future rainfall scenario for all regions except Alice Springs. In the Alice Springs region, improvements in pasture condition, livestock productivity and property profit required longer and or more frequent spells such as a full 12-month spell every two years.

Even if industry adopted spelling strategies in conjunction with current stocking rates and flexibility, it is unlikely that properties would be viable under the more severe median and worst-case future climate scenarios. Under these low rainfall conditions, current stocking rates were predicted to be too high, leading to overgrazing and declining land condition which spelling was unable to halt. Future stocking rates under these harsher potential climatic conditions need to be reduced to account for the reduced pasture growth (forage supply) and may also require more frequent spelling with longer spelling periods to achieve improved pasture condition, animal productivity and financial outcomes.

Rotational spelling will only be effective if implemented in conjunction with stocking rates that are aligned with the long-term safe carrying capacity of each climate, and with annual adjustments in stocking rates which more closely align them with available forage (moderate flexibility strategy in most regions, high to full flexibility in Alice Springs and Fitzroy). This is likely to achieve improved pasture condition, animal productivity and financial outcomes under even the more severe future climates, and maximise the benefits from spelling under the best-case future rainfall scenario.

5.3 Adaptation through prescribed burning

The modelling undertaken here suggests that with appropriate stocking rate management, fire can be used to manage woody cover whilst maintaining or improving LWG/ha and profits in northern Australia. The ability to implement fire may decline under lower rainfall scenarios, but active stock management such as reducing stocking rates, matching stocking rates to available forage and spelling, can be used to facilitate fire use under lower rainfall. With higher rainfall there will be more opportunities to burn (including more risk of wildfire), but there may also be a greater need to burn as woody plant cover may increase in response to higher rainfall and CO_2.

These modelled results suggest that the implementation of fire is sound, both economically and ecologically, yet the incidence of planned fire management for woody vegetation management is still infrequent across the pastoral zones of northern Australia. The reasons for lack of fire implementation as a tool to manage woody cover in northern grazed lands are many. There may be costs that were not taken into account in this exercise; such as the impact of stock on recently burnt pastures, agistment of stock from burnt paddocks, and loss of infrastructure if fires ‘get away’, but there are also benefits, such as reduced mustering costs (Dyer and Stafford Smith 2003).

Implementing fire regimes requires skill to manage the considerable risk to infrastructure, livestock and people. Prescribed burns also require appropriate pre-fire management to ensure that fuel levels are sufficient to facilitate burns, and that paddocks are rested post-burn to prevent overgrazing of regrowing pastures. Where pasture utilisation rates are high, fuel levels may rarely be high enough to implement fire, except in rare very high growth years, when wild-fires often occur regardless of management. Wild fires are more likely in regions where development is less intensive, utilisation is lower and there are fewer roads and fence-lines to act as natural firebreaks such as the Kimberley, VRD and Alice Springs.

This modelling demonstrates the important role of fire management in these regions, but fire can only be implemented with appropriate stocking rates. Hence the management of grazing and fire are integrally related in the maintenance of productive and resilient grazing systems in northern Australia, both now and under future climate scenarios.

5.4 Integrating adaptations to climate change

In this report, management strategies that assist cattle producers adapt to climate change have largely been assessed on an individual basis. However, improving the sustainability and profitability of cattle properties in northern Australia now and as climate changes will require many management practices to be implemented at the same time, as an integrated grazing management system.

McIvor *et al.* (2010) concluded that of the factors which can be controlled by managers of grazing properties, stocking rate has the greatest influence on livestock productivity and the future condition and productivity of land. The modelling conducted in this study demonstrated that the best biophysical and economic outcomes occurred when stocking rates were aligned with the safe long-term carrying capacity of particular combinations of land types and climates, and that these need to be adjusted annually in response to annual variability in rainfall and pasture growth.

In the Gulf, Kimberley, Maranoa-Balonne and VRD regions, the best biophysical and economic results were achieved when safe long-term stocking rates were simulated with the moderate flexibility stocking rate strategy. Moderate flexibility increased stocking rates annually by up to 20% when pasture growth improved, or decreased them annually by up to 40% when pasture growth declined.

In the Fitzroy and Alice Springs regions, the best economic outcomes were achieved by the full flexibility stocking rate strategy. However, additional modelling indicated that when performance is averaged across a number of 25-year climate periods for the Fitzroy region, moderate flexibility achieved higher percent perennials and LWG/ha. Also, the equivalent of the moderate flexibility strategy is likely to be a more practical and less risk-adverse than full flexibility in Alice Springs.

Pasture spelling will be required in addition to varying annual stocking rate to increase the rate of recovery of degraded pastures, to reduce the incidence of patch grazing and decrease grazing pressure on the more palatable grass species which tend to decline under continuous grazing. In all regions except Alice Springs, a six-month spell every four years improved pastures that were in poor land condition, leading to increased livestock productivity and property profit. In Alice Springs, due to the lower incidence of suitable pasture growing periods, a longer 12-month spell every two years was needed to improve poor condition pastures. However, in all regions, less frequent and shorter duration pasture spells may be just as effective when combined with the best performing stocking rate strategies which are capable of improving pasture condition in their own right.

Less frequent and opportunistic pasture spelling may also be implemented to increase fuel loads for prescribed burning, as was the case for one of the burning strategies in Alice Springs.

Prescribed fire will be required in many parts of northern Australia for the management of woody plant cover, to maintain or improve pasture growth, LWG/ha and profits. The ability to implement fire may decline under lower rainfall scenarios, but active stock management such as reducing stocking rates, matching stocking rates to annual variability in forage supply, and pasture spelling, can increase the incidence and effectiveness of fire. With higher rainfall there will be more opportunities to burn, but there may also be a greater need to burn as woody plant cover may increase in response to higher rainfall and CO_2.

First and foremost, the foundation of productive, profitable and resilient grazing systems in northern Australia, now and as climate changes, is the adoption of long-term safe stocking rates which are adjusted annually in response to annual variability in pasture growth. With this foundation, pasture condition, quantity and quality can be improved further through pasture spelling. The combined effects of stocking rate management and pasture spelling create conditions that increase opportunities for prescribed fire. As such, an effective stocking rate management strategy is complemented by pasture spelling and prescribed burning to improve the sustainability and profitability of cattle properties, under current climate and as climate changes.

6 Impact on meat and livestock industry – Now and in five years time

Climate Savvy Grazing delivered best-bet management practices to industry, in conjunction with the preceding (Scanlan and McIvor 2010) and concurrent (Bray *et al.* 2013) projects. The project increased the knowledge of the risks and options under current climate variability and future climate scenarios and worked to a consistent framework and set of messages for industry. The value of consistent extension messages delivered within a consistent framework is often undervalued. The Grazing Land Management training package, and associated publications and training packages, was the first to provide a consistent approach and language to engage the north Australian beef industry in grazing management. Terms such as 'land condition', 'land types' and 'carrying capacity' are now commonly used by industry and advisors. The most popular download from the FutureBeef website (www.FutureBeef.com.au) has been land type sheets. This strongly suggests that the regional technical guides and derivative publications will have a similar impact in re-defining the understanding and language used within industry. Industry advisors, both those who worked direct within the project and those influenced by the project findings, share a framework for discussing stocking rates, wet season spelling, management burning and the role of infrastructure in enabling these practices to be applied. Experience globally e.g. in the USA and New Zealand has clearly demonstrated more rapid adoption of extension messages when these are consistent from a range of sources. Inconsistent messages lead to doubt, reduced credibility of the message and messenger, and poor adoption. Climate Savvy Grazing builds on the credibility and consistency begun under the GLM programmes and should lead to greater adoption.

Adoption of the best-bet practices identified and promoted within Climate Savvy Grazing is likely to continue. Most of the 5,500 beef producers across the target regions of northern Australia should be at least aware of project outcomes and improved management options, following a very successful awareness campaign which distributed information to 61,100 readers and listeners across the key regions. This campaign focussed on management options, rather than project targets, keeping our efforts directed towards outcomes. An estimated 783 beef producers and advisors were planning a practice change following project events and 174 indicated they had made changes since 2011. Presumably a proportion of those intending to change will do so unassisted, whilst others may require follow-up to ensure actual change. About 17% of the total audience will have made on-ground improvements in their management if all of those intending to change can be assisted through to implementation, when added to those already having made a change. It is worthwhile ensuring those intending to change are assisted to make actual changes through follow-up activities beyond the scope of this project. We learnt that we have the skills, capacity and networks to quickly raise awareness. This knowledge can be better utilised in future projects.

It was particularly encouraging to have new industry members attending events, training and as on-property collaborators. This has strengthened the networks between industry members, agency staff and MLA. This has created a stronger RD&E platform for the future.

Capacity within agencies, as well as within industry, was enhanced. The cross-border collaboration broadened thinking and skills within the team and provided a greater understanding of the industry issues across northern Australia. The team has strongly expressed a desire to keep collaborating across State boundaries. Building on this willingness will maximise the RD&E outcomes for northern Australia, by pooling resources and effort for efficiency gains and pooling intellect for enhanced effectiveness. It will also contribute to meeting the National RD&E Strategy.

The ability to measure awareness, KASA and practice change was improved and provides a platform for future projects. For example, the same approach has been adopted for northern Australian Carbon Farming Initiative projects. The assumptions used in measuring numbers need to be made more explicit, and standards developed for measuring and estimating KASA and practice change based on event participation and survey feedback. It is too resource intensive to attempt to determine if every participant has made an actual practice change. Tools such as longitudinal surveys of participants can be much more efficient but standards, e.g. to guide the minimum number of responses, are needed.

Computer simulation capacity was enhanced. The GRASP and ENTERPRISE models have been improved to better simulate management strategies and answer 'what if' scenarios at a property scale. The ability to use climate change scenarios has been instilled and is being extended into PaddockGRASP development for Reef programmes. Importantly, new staff have skills in modelling boosting the small numbers of skilled individuals and efforts in using the models have been re-enthused. The models are now at a stage that a wide range of industry, regional, property and land type scenarios can be tested. This capacity has only just started to be realised and more effort is needed to determine how to best tap this resource. For instance, it should be possible to conduct sensitivity analyses to test if declining terms of trade, increasing woodland thickening and encroachment, declining land condition or climate change pose the greatest risks to productivity and profitability in the coming decades. It may be possible to estimate the maximum north Australian and regional herd sizes under a range of climate scenarios or based on seasonal forecasts, as the USA does with crop yields. It may be possible to test industry and region-wide impacts of changing herd structures on resource condition, productivity and profitability. These could be very powerful tools to guide future RD&E investment and strengthen existing training packages e.g. GLM and Stocktake.

The computer simulations were able to extrapolate our existing knowledge and understanding from a relatively limited number of sites across northern Australia. The large number of simulations allowed best-bet management strategies to be identified and prioritised in a way not previously possible and could be used to identify best-bet physical research projects. The approach enabled testing of strategies across different climate windows and highlighted the importance of starting conditions in the success of wet season spelling and stocking rate adjustments. It enabled the exploration of complex interactions which would not be possible to conduct in a physical research environment, such as the interactions between stocking rates, starting conditions, spelling and fire. As a result, the project confirmed that:

- much of what is good practice today is likely to be good practice under changing climate
- stocking rate management is the key to success in many aspects of the business (animal performance, land condition, financial performance) under any climate scenario.

The simulations gave a more realistic picture of how long it can take for land condition to improve using spelling. This has been a major barrier, with producers spelling paddocks and expecting an instant result which is rarely realised, leading to discouragement and disinvestment in the practice. The simulations provide a more realistic idea of the "payback period" involved and is likely to lead to greater adoption through more realistic expectations.

There are a number of demonstration sites and case study properties across northern Australia which did not previously exist e.g. the Delamere fire site in the NT and the spelling strategies project sites in Queensland. These could be shaped into a learning network for both beef producers and professional RD&E staff, as well as providing an invaluable resource to guide future RD&E. To date, benchmarking and economic skills have been enhanced and the understanding that RD&E needs to fit within the whole property context to be relevant to producers was enhanced. For instance, we presume the decline in the use of fire across northern Australia will lead to increased tree and shrub thickening and encroachment. The Delamere demonstration site—whilst established to explore the roll of fire on 3P grass populations—can provide basic biological data to improve assumptions on both perennial grass and woodland changes within the models and also serve as a focal site for industry engagement and feedback. More thought needs to be given as to how we make strategic use of these new demonstration sites in continuing to improve modelling capacity and in engaging science and industry for improved applied RD&E outcomes.

The scientific and industry engagement process used within Climate Savvy Grazing and the preceding (Scanlan and McIvor 2010) project was a good model to build networks and trust. The process of engaging a group of graziers to define a representative property created interesting discussion about what is 'representative' for property size, herd structure and pricing and was a good learning platform for industry members and technical experts alike. Similarly, the management strategies that industry were interested in learning more about through computer simulation reinforced our understanding that they view their business as a whole. Even those producers with a focus on pasture, grazing or resource management perceive these as components of their overall business. Herd structure, reproductive efficiency, live-weight gains and meeting market specifications were equally prominent in discussions. This is a reminder for us, as professionals, that producers respond the best when aspects of their business are presented in the context of their overall business. It is also a reminder that future engagement needs to be whole-of-business literate.

Climate Savvy Grazing presents an opportunity to make the most of the computer simulation and industry engagement by updating business aspects within GLM and the associated training packages. GLM presents a minimum of business performance measures which are mostly based on outdated data. Updating the examples from BreedCow/Dynama and presenting new examples based on the simulation modelling would have benefits. It is worth considering replacing the older GLM hypothetical properties with the new regionally representative ones, which are based on industry collaboration. GLM materials have already been updated in regions which ran workshops during the current project.

A legacy of publications has been left, such the six regional technical guides which have become a repository of current northern Australian and regional grazing land management knowledge. A large range of fact sheets have been produced based on the technical guides and computer simulation modelling. The RD&E message has more clarity due to the rigour and structure in writing these publications.

7 Conclusions and recommendations

Towards the end of 2013 the northern beef industry had declared itself in crisis due to the combined shocks of drought and poor commodity prices; the latter generally blamed on the flow-through effect of the ban on live exports to Indonesia. Regardless of the causal factors, industry members are suffering. The Climate Savvy Grazing project explored the grazing management and natural resource aspects of resilience to shocks through industry consultation, on-ground events and research and computer simulation modelling. We conclude that good land condition is necessary to reduce the risk of exposure to high climatic variability—both under current and possible future climate change scenarios. For the six regions studied this was achieved through:

- matching stocking rates to carrying capacity e.g. through objective on-ground assessments, or future tools such as PaddockGRASP
- adopting moderate flexibility in annual stocking rate adjustments (increasing stocking rates by up to 10-20% and decreasing by up to 30-40% annually, with some regional variation) e.g. using forage budgeting tools such as the StockTake app
- implementing wet season spelling e.g. based on regional best-bet guidelines
- reducing woodland thickening impacts e.g. through fire management.

These strategies lead to profitable beef enterprises for current and best and median-case future climate scenarios in the Kimberley, Victoria River District, Alice Springs, Gulf Savanna, Fitzroy and Maranoa-Balonne regions.

We recommend working closely with the northern beef industry to further build on the adoption of these management strategies to build resilience to future shocks. This will be particularly challenging for an industry already in crisis.

Whilst we can assume that these management strategies will generally lead to greater (or at least preserve current) profitability across all of northern Australia, the project identified regional differences as to how well the strategies worked. It is recommended that further modelling be conducted in key regions where existing data is adequate e.g. the Mitchell grasslands, Mulga woodlands, Border Rivers, Burdekin, Barkly and Pilbara regions. This would help refine the extension messages for these regions and enhance adoption. Existing Grazing Land Management (GLM) hypothetical properties could be used as the basis for modelling to minimise the new information required.

The bio-economic modelling provided a unique opportunity to prioritise potential management strategies and both the GRASP and ENTERPRISE models and underlying data-sets were enhanced considerably. These models should be used to help identity where the largest gains in profitability can be made over the medium to long-term e.g. through sensitivity analysis of the relative impacts of declining terms of trade, woodland thickening, declining land condition or climate change. We recommend using this improved tool-set to help prioritise best-bet on-ground research in conjunction with industry identified needs.

A key strength of this project was the professional collaboration across northern Australia of scientific and extension staff from a range of agencies. We recommend that this be maintained in future projects and that it be enhanced through on-line tools to promote discussion, sharing of results and collaboration, and supporting face to face collaboration at conferences and research sites.

Climate Savvy Grazing exposed 61,000 readers and listeners to consistent themes of improved stocking rate, wet season spelling and fire management to better cope with a variable and changing climate. Over 780 beef producers and their advisors are planning on adopting a relevant new practice and about 170 have made a change already.

Industry engagement has reinforced the need to design future grazing land management work to include cattle production and economics explicitly in order to drive broad adoption. Despite decades of RD&E showing the benefits of reducing stock numbers, there still appears to be reluctance for producers to do so. One constraint is likely to be rainfall variability and the 'moving target' this creates for short-term stocking rates. Another constraint is financial pressure and the assumption that more cattle 'just has to' deliver greater income. Stocking rate management to improve land condition needs to be tied to herd performance to improve efficiency, reduce labour costs, reduce inputs and increase profitability. Producers work in a whole-of-business environment and resource messages need to be placed in this context.

New networks and collaborations were established which need time to mature and realise their potential. It is recommended that the focus group in the Maranoa-Balonne and the Gulf demonstration sites in Queensland and the Delamere and Old-Man Plains demonstration sites in the Northern Territory be maintained with associated industry engagement. It is also worth considering value adding to these sites by creating a formal learning network around these sites, their industry groups and similar sites across northern Australia. Follow-up extension is required in all regions if the high number of producers intending to implement change is to translate to actual on-ground change.

The worse-case future climate scenario presents a sobering picture for industry, with much reduced rainfall, productivity and income. The best-case scenario is less threatening and may even offer opportunities for increased production in the northern regions of the Kimberley, VRD and Gulf. The reality is likely to be somewhere in between, and even the median-case scenario tended to predict reduced profitability. This message may not yet be ready for presentation to the general industry, who are already sceptical about climate change, wary of 'scare campaigns' and facing depressed markets. The computer simulation modelling and feedback through industry engagement needs to be validated and considered further, and the best course of action determined. It would be useful to seek guidance from southern livestock and mixed cropping systems adaptation projects who are further along this path of engagement.

The management strategies which reduce the risks, or take the opportunities, under climate change are consistent with those that maximise land condition, productivity and profitability under current climate. These strategies of matching stocking rate to long-term carrying capacity, maintaining moderate stocking rate flexibility, implementing wet season spelling to improve land condition and using fire to control woody regrowth have been refined through modelling and engagement and should continue to be promoted to individual producers and their advisors. These messages are palatable and less controversial when presented in the context of a variable climate. A key difficulty is that we may no longer be able to rely on historic rainfall to derive safe long-term carrying capacity, and we lack the ability to predict future rainfall trends. More thought needs to be invested in defining the approach to estimating a long-term carrying capacity under these constraints, or a new approach to benchmarking the long-term estimates needs to be devised.

The potential impacts of climate change need to be benchmarked against other key profit drivers for northern-Australian beef businesses to place the message in a whole-of-business context. For instance, tree and shrub regrowth, thickening and encroachment may present a greater risk to profitability in some regions than climate change *per se*. Poor land condition, whilst likely to be exacerbated by climate change, already has a dramatic impact on business resilience. We do not understand how climate change ranks as a risk against declining terms of trade, or in the context of improving breeder efficiency. We also do not know if current infrastructure in more intensively developed regions, such as the Maranoa-Balonne, where rainfall is predicted to decline will need to be modified. Of particular concern is the 'McCosker report' (McCosker *et al*. 2010) which presents a grim financial status for industry even within a series of good seasons. The risks inherent in climate change and the other key profit drivers need to be considered in the context of an industry that is already under financial stress, and may lack the economic resilience needed to adjust.

Within the computer simulation modelling a number of research priorities were identified which would improve analysis of the impacts of and adaptations to climate change in the extensive beef industry of northern Australia. These include:

- sensitivity analysis of safe utilisation levels, recovery and degradation time-frames using existing data across a range of land types
- enabling two or more adjustments to stocking rates within any 12-month period
- identifying and using the most reliable, recent and suitable climate change projections in further analyses of the impacts of climate change
- determining if rainfall patterns may change greatly from historic patterns e.g. drought frequency
- re-running current analysis using corrected vapour-pressure deficit data
- running a selected set of strategies across a range of rainfall windows with different starting conditions and subsequent patterns e.g. what frequency of spelling is required to recover land condition when it is first implemented at the start of a run of good seasons compared with going into drought conditions? What stocking rate flexibility performs optimally under these different conditions?
- improved evidence of the impact of rising CO_2 on plant growth, and the potential for broad-leaved plants to be advantaged more than grasses
- incorporating diet quality into the live-weight gain modelling
- improving the way live-weight gain, trading and short-term price fluctuations are treated within economic modelling
- further validation of new model assumptions
- there is an increasing demand for predicting outcomes of grazing management practices at the fundamental land type level. In order to meet these demands, the land type models need to be reviewed, evaluated and calibrated with new data where available.

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9 Appendices – available on request

Appendix 1 – Monitoring, evaluation and reporting framework and guide

Appendix 2 – Project media releases and articles

Appendix 3 – Detailed regional customisation report

Appendix 4 - Detailed computer simulation report