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Developing improved industry strategies and policies to assist beef enterprises across northern Australia adapt to a changing and more variable climate

Component 2 of 'Beef Production Adaptation In Northern Australia' (DAFF/MLA project)

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Abstract

This project aimed to assist the northern beef industry to prepare for climate change by providing a cross-regional analysis of vulnerability to climate change and ways of enhancing adaptive capacity. It was to help representatives of the beef industry (both producers and government) to develop and implement climate adaptation strategies and policies. The project systematically evaluated and identified agro-ecological, economic and social factors contributing to vulnerability and the effectiveness of actions that could be taken to address them. Many of the findings support existing initiatives to improve resilience in the industry, adding further motivation for efforts to improve stocking rate management and improve land condition (although these will need to be supplemented with measures for coping with arising unique new climate challenges). Results also highlight the benefit of improving strategic planning skills and networking among producers.

Executive Summary

This project aimed to assist the northern beef industry to prepare for climate change by providing a cross-regional analysis of vulnerability to climate change and ways of enhancing adaptive capacity. It was targeted at peak representatives of the beef industry (both producers and government) who will have to develop and implement climate adaptation strategies and policies (complementing a partner project, 'Component 1' or B.NBP.0616 that targeted regional-specific, property-level adaptive management options). The project used a broad systematic framework to evaluate and identify agro-ecological, economic and social factors contributing to vulnerability and the effectiveness of actions that could be taken to address them.

Despite using the best available data and modelling tools, there are still many uncertainties and caveats in this report. Such uncertainties are likely to persist into the future (even with improved data and analyses) so it is important that adaptation approaches are flexible and robust enough to accommodate this uncertainty. In this sense, the analyses and the results presented should certainly NOT be used as 'predictions' of the future. Rather they should be used as indicative of the types of future challenges and opportunities climate change is likely to bring, and as a resource for scenario planning to ensure adequate measures and adaptation options are available to deal with such situations where and when they arise.

The agro-ecological assessment found that overall, the downside risk of declining productivity for the northern beef industry is only slightly higher than the upside risk of improving productivity. Those regions that are currently less productive tended to be more susceptible to the effects of climate change (particularly negative impacts) whereas some of the more productive regions tended to be less sensitive (to either drying or wetting trends). The results reinforce initiatives to improve grazing land management both because pastures in better condition tended to be less sensitive to negative climate impacts, and because associated improvements in productivity could offset declines under drier climate scenarios. Sandier soils (with less capacity to store plant-available water) tended to be less sensitive to climate change and more responsive to improving land condition (but modifying soil properties is not a viable management option). Other sources of local variation in pasture (such as fertility and tree density) had little consistent effect in modifying their sensitivity to climate change or adaptation options.

The economic impacts of projected climate change bear upon many aspects of enterprise management, including heat stress and the need to provide additional water and shade infrastructure, changing distributions of pests, weeds and diseases etc. Whilst these factors are important, the dominant effects on the vulnerability of northern beef enterprises are likely to be manifest through changing levels of carrying capacity and animal productivity – combining to effect beef turnover, the scope for productivity growth and capacity to yield ongoing economic profits. Using insights from a recent beef situation analysis and manipulation of regional benchmarks from MLA-DAFF funded project B.NBP.0616, the conclusion is necessarily drawn that the northern beef industry across the main production regions is highly vulnerable to relatively small adverse changes in its market and production context. This includes any adverse effects of projected climate change on either carrying capacity of range pastures or animal productivity, both of which are necessarily inter-related. Adverse terms of trade, limited recent gains in on-farm productivity and low profit margins under current management systems and current climatic conditions give limited margins to absorb climate change induced productivity losses. While there is necessarily a distribution of enterprise performance around sectoral averages, it is difficult to conclude otherwise than that many enterprises within the northern beef sector have relatively low resilience to adverse climate change trends and limited immediate capacity for adaptation.

The social component of the project set out to understand and assess the vulnerability of pastoralists across Northern Australia to climate variability and change as a basis for climate adaptation planning. We were able to identify the thresholds to change and the barriers that would most likely inhibit change processes. Most importantly, we were able to identify the factors and processes that could minimise vulnerability and enhance the resilience of the industry. Our approach was to interview 240 pastoralists across northern Australia by telephone after providing information to them about the project by mail and radio media. The key results were:

1. Vulnerability is a function of both climate sensitivity and adaptive capacity. We assessed the climate sensitivity of pastoralists as the levels of; (i) occupational identity, (ii) family circumstances, (iii) place attachment, (iv) employability, (v) formal and informal networks, (vi) business approach, (vii) business size, (viii) income diversity, (ix) environmental awareness, and (x) local environmental knowledge. We assessed the adaptive capacity of pastoralists as; (i) approaches to the management of risk and uncertainty, (ii) level of skills for planning, experimenting, reorganising and learning, (iii) level of psychological and financial buffers, and (iv) level of interest in adapting to change.
2. The vulnerability of the sample of pastoralists was high. We identified pastoralists belonging to one of four types of vulnerability. We found that two types representing 85% of pastoralists were highly vulnerable because they had low planning skills, low interest in adapting to the future, managed risk and uncertainty poorly and were not strategic in their business.
3. A threshold to change for one person is not necessarily a threshold for another. Thresholds were very much an individually-set construct. We think that individuals' proximity to their thresholds can be understood in terms of their sensitivity. For example, some pastoralists may be close to their thresholds of change if they have high occupational identity and the change event directly threatens their identity as a pastoralist.
4. Barriers to change were also able to be identified on the basis of the sensitivity of pastoralists to change. For example, pastoralists with a lifestyle approach would erect barriers around proposed adaptation strategies that threatened their sense of lifestyle.
5. Quantitative measures of adaptive capacity were highly correlated with many measures of climate sensitivity. Pastoralists that had higher adaptive capacity had stronger networks, a strategic approach to their business, had high environmental awareness and high local environmental knowledge.

The implications of our social research suggest that any investments into the development of adaptive capacity of pastoralists across northern Australia would heighten the success of any climate adaptation planning. We think that assisting pastoralists to develop their networks, strategic interest, environmental awareness and knowledge (through monitoring soil condition for example) is likely to be highly useful.

Many of these findings support existing initiatives to improve resilience in the beef industry, adding further motivation for efforts to improve stocking rate management, improve land condition, and manage climate variability (although these will need to be complemented by adaption options for coping with additional, unique new climate challenges). Results also highlight the benefit of improving strategic planning skills and networking among producers.

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1 Background

1.1 Introduction

Climate change is altering the quality and availability of natural resources. It is unlike any other disturbance experienced by contemporary societies; it has the potential to simultaneously and severely affect extensive areas of land and water spanning thousands of kilometres (Johnson and Marshall 2007; IPCC 2007). Those dependent on the goods and services provided by climate sensitive resources will be variably impacted. Primary enterprises and industries, including grazing, are especially vulnerable to climate change because they are dependent on highly climate-sensitive natural resources (Zamani *et al.* 2006; Howden *et al.* 2007a; Stokes and Howden 2010). In addition to the existing backdrop of conventional drivers including economic, biophysical, institutional, cultural and political pressures, they are expected to contend with more frequent extreme events (such as drought and flood), potential environmental degradation (such as eroding soils and diminishing harvests), cultural change (such as implementing new practices or using climate technology) and inevitable climate-related regulatory change. Humans can influence the outcomes of climate change in two ways (Fig 1.1). The first is mitigation: by reducing global emissions of greenhouse gasses we can deal with the root cause of the issue and limit the magnitude of human-induced global climate change. The second, and the focus of this report, is adaptation: by building the capacity to adjust climate-sensitive activities to plausible future climate scenarios, we can limit our vulnerability to the climate change that does occur. The two are linked in that the more effort that is put into mitigation efforts, the less effort will be required for adapting to climate changes (Howden *et al.* 2007a). While strong arguments exist to stabilise greenhouse gas concentrations before the climate system passes irreversible thresholds, we can also accelerate efforts to prepare for those changes that are inevitable.

This project aims to assist the northern beef industry to prepare for the future by evaluating vulnerability to climate change and ways of enhancing adaptive capacity. This component of the overall DAFF-MLA project (‘Component 2’) is targeted at peak representatives of the beef industry (in both industry and government bodies) who will have to develop and implement climate adaptation strategies. This work is coupled to a larger project (‘Component 1’, B.NBP.0616) that was focussed more on improving management practices at the property level. Our project complements the property-level work by providing a broader cross-regional analysis for northern Australia that includes agro-ecological, economic and social dimensions of vulnerability and adaptation.

In order to guide effective adaptation, it is first necessary to understand what characteristics make some people/locations/enterprises more susceptible to impacts (both positive and negative) of climate change (Fig 1.1). Past quantitative work on the effects of climate change on the northern beef industry has tended to focus on i) the exposure to climate change in terms of climate change projections (CSIRO and Australian Bureau of Meteorology 2007), and ii) sensitivity analyses of northern rangelands to step changes in the primary climate change influences of temperature, rainfall and carbon dioxide (CO_2) (the top left two boxes in Fig. 1.1) (Hall *et al.* 1998; McKeon *et al.* 2008; McKeon *et al.* 2009; Scanlan *et al.* 1994). Only since the start of this project have analyses sought to determine potential impacts of these combined influences, impacts that, by themselves, remain unrealistic in the sense that they ignore the inevitable responses from producers. Systematic analyses of climate vulnerability in agricultural systems are extremely rare, particularly those that include both agro-ecological and socio-economic dimensions of vulnerability and adaptation. In this report we seek to systematically characterise the potential climate sensitivities and impacts in northern beef production systems and, based on that understanding, identify potential avenues for adaptation to reduce sensitivities and offset negative impacts. While we apply this vulnerability approach specifically to future challenges associated with climate change, it is generic enough to be applied to other disruptive changes, and has strong overlaps with existing initiatives to improve resilience within the beef industry.

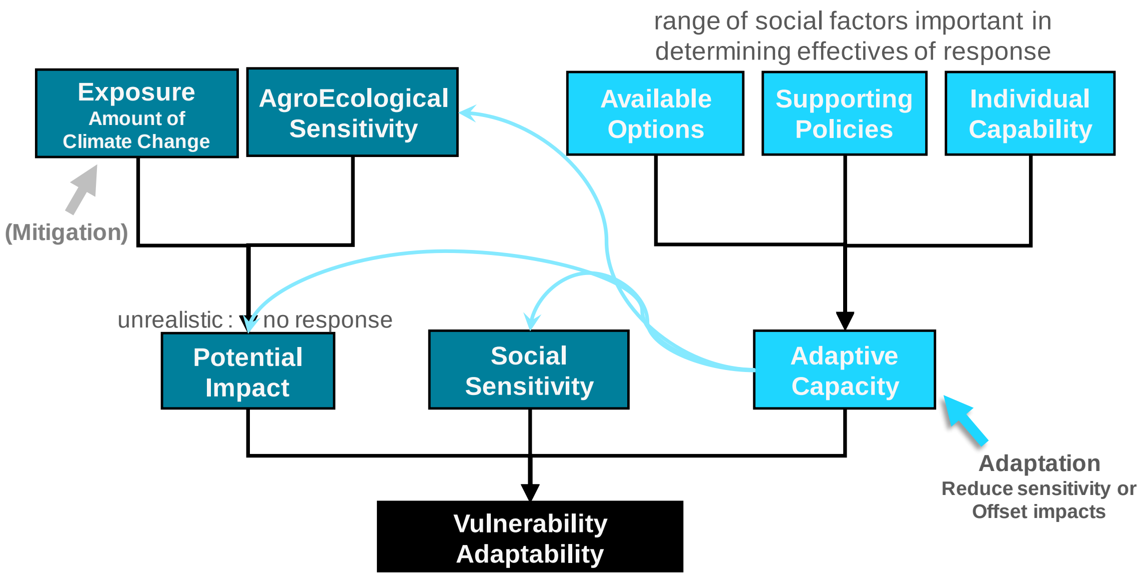

Fig. 1.1: Agricultural adaptation aims to reduce the ultimate vulnerability of production systems to change. This first requires building an understanding of the agro-ecological and socio-economic factors that contribute to vulnerability (dark cyan boxes on left). Adaptation approaches (light cyan boxes on right) can then be developed to target these sources of vulnerability to reduce sensitivity and offset negative impacts (after Allen Consulting Group 2005; Stokes and Howden 2010).

1.2 Objectives

The procedural contractual objectives of the project are listed below, and delivery against these commitments is summarised at the end of the report (Section 5.2):

1. Incorporated the effects of CO_2 on pasture production (including OzFACE results) into the modelling framework.
2. Identified effective responses for supporting producers to adapt successfully to a changing and more variable climate.
3. Extrapolated regional and property-level results to evaluate climate change impacts across the north, using the best available climate projections
4. Identified thresholds beyond which incremental adaptation is unlikely to be adequate.
5. Identified conditions / regions where incremental adaptation may be insufficient to offset climate impacts.
6. Identified coping mechanisms for the northern beef industry.
7. Provided draft input for use in forming a strategic industry response plan.
8. Presented project findings to peak industry bodies to help identify potential strategies and options for adapting to a changing and more variable climate.

The broader objectives of this report are set out in the two key questions outlined below.

1.3 Vulnerability envelopes and thresholds framework

The following three sections of the report systematically analyse the agro-ecological (Section 2), economic (Section 3) and social (Section 4) aspects of climate vulnerability and adaptation in the northern beef industry. In order to provide an overarching framework and integrating context for these components, we used a common "envelopes and thresholds" approach (Fig. 1.3).

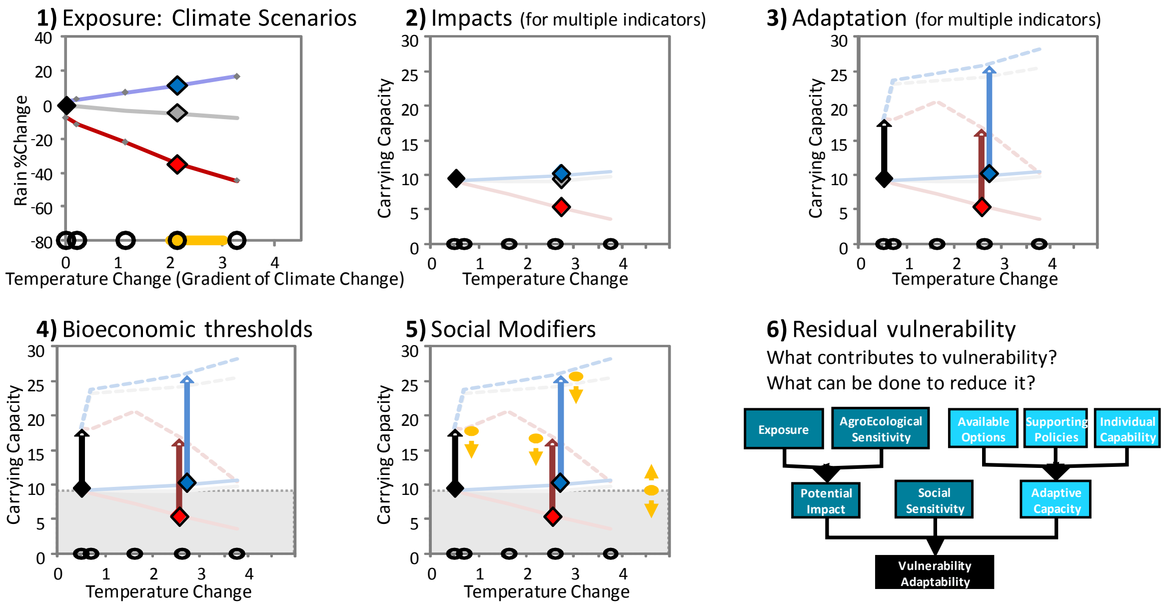

Fig. 1.2: An integrated agro-ecological, economic and social approach to exploring climate change impacts, sensitivities and adaptation.

For adaptation strategies it is particularly important not to choose an "expected" climate outcome, but to ensure approaches are robust enough and have sufficient flexibility to be able to cope with a broad range of alternative anticipated possibilities (Stokes and Howden 2010; Dessai *et al.* 2009). Importantly therefore, this approach seeks to emphasise the bounds of uncertainty (and how the envelope of potential challenges and outcomes expands over time, with a greater chance of broaching thresholds), rather than trying to pick a single "most-likely" trajectory of change.

The sequence of these analyses will be explained in detail in the following sections but, in brief, our approach entailed the following steps (Fig. 1.2): 1) the envelope of uncertainty in climate change projections for each region (Fig. 1.3) is summarised with reference to gradients of temperature change, emphasising three reference scenarios (Section 2.4); 2) modelling (using GRASP) is used to determine the associated impact envelopes along these gradients of climate change (on pasture growth, carrying capacity, liveweight gain etc.) and how various land/vegetation characteristics affect sensitivity to climate change (Section 2.5); 3) broad adaptation responses are considered in terms of those land/vegetation characteristics from (2) that can be influenced by management to improve enterprise sustainability/resilience in the face of climate change challenges/opportunities (Section 2.5); 4) economic analyses are conducted to indicate likely thresholds of change that would threaten enterprise viability, and determine economic sources of vulnerability and adaptation; 5) we then evaluate how social factors will modify thresholds and adaptation by considering social sensitivity (resource dependency) and the capacity of different types of pastoralists to adapt; 6) finally, the combined information is considered together with beef industry representatives to explore how the above factors combine to affect the overall vulnerability/resilience of different beef enterprises/regions, and strategic actions that can be taken to enhance the capacity of the pastoralists to respond appropriately to the range of foreseeable challenges and opportunities (Section 5).

The two key questions driving our synthesis are (Fig. 1.1):

1) What are the key agro-ecological, economic and social factors that contribute to places/enterprises/people being more or less vulnerable to climate change?
2) Based on this understanding, what adaptive actions can moderate these sensitivities and impacts to improve the resilience of the northern beef industry?

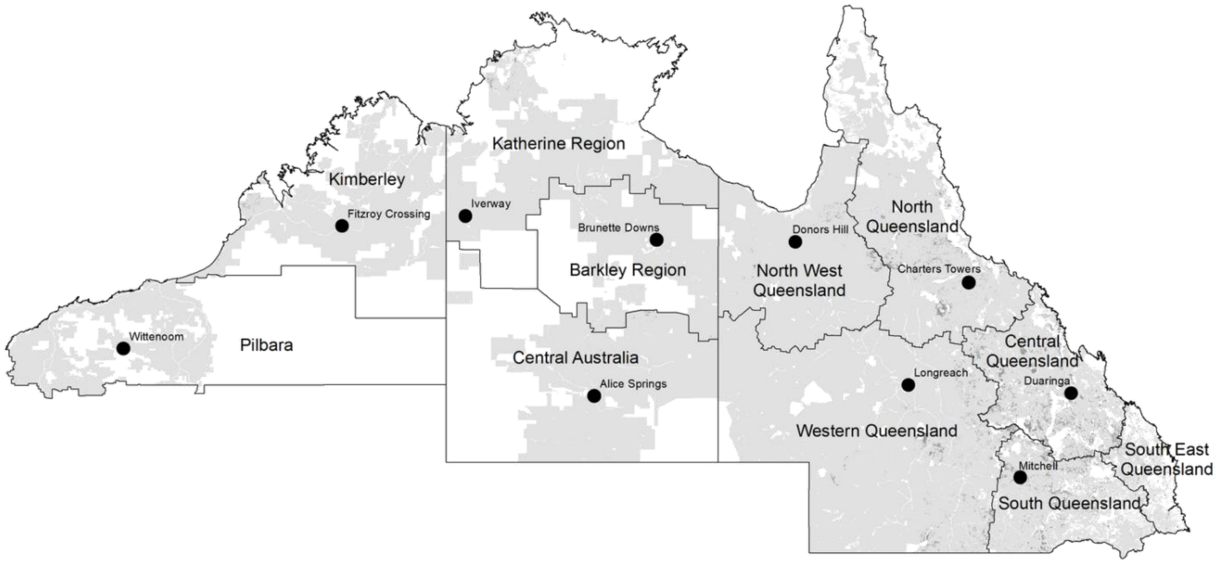

Figure 1.3: Agro-ecological zones used in the cross-regional analyses follow the North Australian Beef Research Council (NABRC) regions. Marked points indicate the locations used for weather station data and climate change projections.

1.4 References

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2 Agro-ecological vulnerability and adaptation

2.1 Introduction

In order to conduct the quantitative assessment of agro-ecological vulnerability (Section 2.5), the required tools had to be developed by first a) incorporating recent experimental results into improved modelling of pasture responses to rising CO_2 (Section 2.3) and b) developing the approaches to incorporate climate change projections into analyses (Section 2.4). We began this work with a qualitative assessment of climate change implications for the northern beef industry, and used this to engage with managers to discuss potential property-level adaption options, as a link to the property-level work in related Northern Grazing System (NGS) projects.

2.2 Climate challenges, opportunities and adaptation options

To assist discussions of appropriate climate adaptation responses with pastoralists, we described climate change in terms of the practical consequences it was likely to have on pasture growth and animal production. Quantitative assessments of climate change were not available until the end of the project. We therefore started the project with a qualitative assessment of practical challenges and opportunities that are likely to arise from each of the key drivers associated with climate change and possible adaption options for dealing with them. This was prepared by synthesising current knowledge and a review of existing literature (Appendix 6.1, Stokes *et al.* 2010).

This information was provided to land managers at workshops in each of the NGS focus regions, as a starting point for discussion seeking feedback from participants on how they could adapt their management. Discussions were framed in terms of the general Best Management Practice theme of the workshops, with a forward-looking view that explored how well suited existing practices might be under future conditions and what new options might be required. The process started by identifying the key drivers of climate-related changes (rising CO_2, hotter temperatures and changes in rainfall), the uncertainty associated with each, and how each factor would likely affect enterprises through impacts on plant growth, natural resources, pest and diseases, and animal production (Appendix 6.1, Stokes *et al.* 2010). These impacts and opportunities were translated into a set of specific practical on-property challenges that could arise:

- Changes in pasture productivity (wetter, drier and/or more variable)
- Shifts in seasonality of pasture production (and fire weather)
- Lower forage quality (protein and digestibility)
- Vegetation change (and woody thickening)
- Southern expansion of tropical pests, weeds and diseases
- Greater animal heat stress (water requirements and reduced travel from water)
- Other (rainfall variability, intensity, erosion risk)

Participants' responses to these challenges were discussed and cumulatively documented at each workshops in Roma, Emerald, Katherine, Alice Springs and the southern Gulf (Donors Hill and Alehvale stations) (Appendix 6.2). The aim in collating this list of potential adaptation options was not to achieve consensus of a few 'preferred' widely-applicable options, but rather to provide a diverse range of options that pastoralists would be able to consider and choose from, as appropriate for their particular situation. The practical challenges and opportunities were also used in developing the questionnaire for the survey in the social component (Appendix 6.10).

2.3 Improved modelling of CO_2 effects

Simulating the effects of climate change in agricultural models such as GRASP requires not only representing the effects of changing climate but also how rising CO_2 affects plant growth. The GRASP pasture production model has already been calibrated across a wide range of climates. However, representing effects of CO_2 is more complicated because there are no naturally-occurring regions with high levels of CO_2 that we can look to as indicators of the effects of rising CO_2 levels.

Table 2.1: Parameter adjustments made in GRASP to represent the effects of increased levels of atmospheric CO_2. Parameter adjustments are expressed as the percentage change made to parameters to represent a doubling in CO_2 levels (from a baseline level of 350 ppm to 700 ppm). The columns from left to right show the historic progressive improvements from 1998 to the newly-developed recommendations. This includes a set of parameters for degraded pastures (P181, 182, 184, 185) that match related parameters (P99, 45, 101 and 102 respectively) for undegraded pastures (or with the degradation model turned off). The scaling of these effects to CO_2 levels other than 700 ppm is described below.

GRASP Parameter	Description	DAQ139A (1998)	Howden99 (1998-2009)	OzFACE (2010)	Recommended (2010)
6	Potential regrowth	+ 10%	+ 10%	+ 10%	**+ 10%**
7	daily transipiration efficiency	+ 100%	+ 40%	+ 100%	**+ 40%**
8	radiation use efficiency	+ 5%	+ 5%	+ 5%	**+ 5%**
45	yeild at which tspn is 50% potl ET	+ 100%	+ 40%	+ 40%	**+ 40%**
182	(degraded equivalent)				**+ 40%**
98	N uptake (kg/ha) per 100mm traspn	+ 50%	+ 20%	+ 20%	**+ 20%**
99	Max N uptake	0%	0%	- 23%	**0%**
181	(degraded equivalent)				**0%**
101	%N at zero growth	-	-	- 43%	**- 15%**
184	(degraded equivalent)				**P101 + 0.2**
102	%N at maximum growth	-	-	- 36%	**- 10%**
185	(degraded equivalent)				**P102 + 0.2**

To scale these effects to CO_2 levels other than 700 ppm, make the simplifying assumption that changes in resource use efficiency (water, light and N) are approximately linear over CO_2 levels near 350 – 700 ppm, and scale the magnitude of response accordingly:

For parameters 6,7,8,45,182,98,99, and 181:

$P_{new} = P_{old} * (1 + f * d)$

where: P_{new} = new value of parameter adjusted for new CO2 level
P_{old} = original value of parameter (for 350ppm CO2)
f = delta percent adjustment factor for parameter (last column of above table)
d = percentage change in CO_2 level = (new CO_2 level ppm – 350)/350

Nitrogen parameters (101 & 102) are expressed in terms of concentrations (the reciprocal of nitrogen use efficiency), so the interpolations have to be adjusted to maintain linear scaling of nitrogen use efficiency improvements:

$P_{new} = P_{old} / (1 + d * (1/(1 + f) – 1))$

[where (1/(1+f)-1) converts the %change in N concentration to the %change in N use efficiency]

Parameters 184 and 185 are adjusted to maintain their conventional relationships to parameters 101 and 102 respectively (by adding 0.2 as in the table above).

Despite the limited experimental evidence available, there has been a longstanding interest in including the effects of CO_2 in simulating climate change in GRASP. The first well-documented efforts were made in the report 'DAQ139A' (Hall *et al.* 1998) with a comprehensive review of the available research at the time and how best to represent each functional plant response within GRASP by changing parameters to reflect the underlying processes that had changed (Table 2.1). A much more conservative representation of these CO_2 responses was subsequently developed (here labelled 'Howden99') and has since been used in simulation studies and reviews, including the recent Garnaut review and Rangelands Journal paper (Howden *et al.* 1999; Crimp *et al.* 2002; McKeon *et al.* 2008; McKeon *et al.* 2009). In the absence of suitable field data, the effects of CO_2 were conservatively represented and could not be validated and tested.

Elevated levels of CO_2 benefit plant growth by increasing the efficiency with which they use light, water and nitrogen resources. Previous representations of CO_2 effects in GRASP had accounted for the first two effects (improved efficiencies in light use (potential growth rates) and water use) but not the third (improved nitrogen use – for which there had been insufficient evidence in the earlier review by Hall *et al.* 1998). However we now have field measurements on the effects of CO_2 on tropical pastures from OzFACE (the Australian Savanna Free Air CO_2 Enrichment) experiment (Stokes *et al.* 2008; Stokes *et al.* 2005). The GRASP modelling team was consulted throughout the experiment to ensure that the results could be incorporated into their model. Working with Greg McKeon (and others from the Queensland Climate Change Centre of Excellence) we have used the OzFACE data to test, validate and improve how GRASP simulates the effects of CO_2 on pasture growth (Table 2.1, Appendix 6.3).

2.4 Climate change exposure - scenarios and weather data

To represent climate change in simulation analyses it is necessary to first decide which climate scenarios to use, and then how these scenarios should be used to modify the daily weather data that drive the models. For any location there is a great diversity of available GCM (global circulation model) projections representing the combination of GCMs (more than 22), greenhouse gas emissions scenarios and projection dates. For climate adaptation analyses it is essential to test that potential strategies are flexible enough to cover this range of uncertainty. However, it is impractical to use the full range of scenarios in modelling analyses, particularly where analyses (such as adaptation assessments) need to concentrate on large factorial combinations of other factors such as spatial location, land types and land management options within the simulated 'experimental design'.

We therefore developed an approach to summarise the envelope of uncertainty in GCMs and reduce the number of scenarios to be modelled (allowing more of the effort in simulations and data interpretation to be focussed on sensitivities to change and adaption options) (see Appendix 6.4 for full details). For this approach we obtained climate projections from the OzClim database (http://www.csiro.au/ozclim) for 22 GCMs, 3 emissions scenarios (A1FI, A2, and A1B) and 4 dates (2030, 2050, 2070 and 2100). For each location we summarised the bounds of uncertainty in terms of the relationship between projected changes in rainfall and changes in temperature. For each projection date we calculated the mean projected temperature increase and the associated 10^{th}, 50^{th}, and 90^{th} percentile projected changes in rainfall. We then plotted the 10^{th} (red), 50^{th} (grey) and 90^{th} (blue) percentile trajectories of changes in rainfall over time, relative to the associated projected temperature change for each NABRC region (Fig. 2.1). Three key reference scenarios were selected for emphasis, to assist later in interpreting impacts and the effectiveness of adaptation options (Section 2.5). These scenarios were the baseline of current climate (1990, black diamond), and the average temperature for 2070 with the associated 90^{th} (2070H, blue diamond) and 10^{th} (2070L, red diamond) percentile rainfall projections (Fig. 2.1). For each scenario the associated atmospheric CO_2 level was calculated from the average CO_2 projection for the 3 IPCC emissions scenarios used (A1FI, A2, and A1B) on the projection date (Nakicenovic and Swart 2000).

These graphs provide a succinct way of summarising regional patterns of exposure (Figs 1.1 and 1.2) to climate change. All NABRC regions include both the possibility of becoming wetter and the possibility of becoming drier. In the northern band of NABRC regions (top row in Fig. 2.1) the chances of becoming wetter or drier are about equal, whereas across the southern band of regions there is a stronger tendency towards drying trends. The main determinant of differences between GCM projections is differences in relative warming of oceans on either side of the Australian continent: if ocean warming is faster to the west (Indian Ocean) then wetting trends are more likely, but if eastern warming is faster (Pacific Ocean) then drying trends are more likely (Watterson 2012).

Baseline weather data was obtained from SILO (www.longpaddock.qld.gov.au/silo/) for the weather station with the longest record (>120yrs) of good quality data near each modelled NABRC location (Fig 1.3). For future climate scenarios, climate change adjustments were made to the base weather data following the "delta method", as has been used in previous modelling of the region (McKeon *et al.* 2008; McKeon *et al.* 2009). For each daily weather record maximum and minimum temperatures and rainfall were adjusted by the change factors for the scenario, before making matching changes to vapour pressure and pan evaporation (see Appendix 6.4 for details). However, instead of estimating the new evaporation directly from the adjusted temperatures and vapour pressures, estimated evaporations were calculated for both the original (EstEvap1) and modified (EstEvap2) climate, and the final modified evaporation was calculated by multiplying the original evaporation by EstEvap2/EstEvap1.

2.5 Cross-regional overview of ecological vulnerability

The simulation modelling analyses were applied across each of the North Australian Beef Research Council (NABRC) regions (Fig. 1.3) using the envelopes and thresholds approach introduced earlier (Fig. 1.2). The climate change exposure summaries generated above (Fig. 2.1) provided the input driver for the analyses (Fig. 1.2:1) that we now use to assess potential impacts, determinants of sensitivity and effectiveness of adaptation options (Fig. 1.2:2 and 3).

For determining which characteristics make some pastures more sensitive to climate change we considered the following five factors, regional variation (the combination of differences in land type, vegetation and current climate) and four other factors representing variation within regions: land condition (following the A,B,C,D system where A is the best condition and D is very degraded); tree density; soil fertility; and soil water storage capacity (the combined effects of soil texture and depth).

For adaptation strategies we focussed on three broad areas of improved land management: improvements in land condition (particularly improving C condition land to B condition); changes in tree density (as a consequence of fire management, weed/tree control and/or carbon-offset strategies); and changes in stocking rate. For the third option, we considered that stocking rates were reduced to match the safe utilization level (i.e., to the "carrying capacity") in all simulations (and we did not explicitly model the case where stocking rates were maintained at current levels in the face of changing pasture productivity). The other two options represent characteristics of pastures (from the analysis of climate sensitivity above) that can be influenced by land managers. These three options correspond with

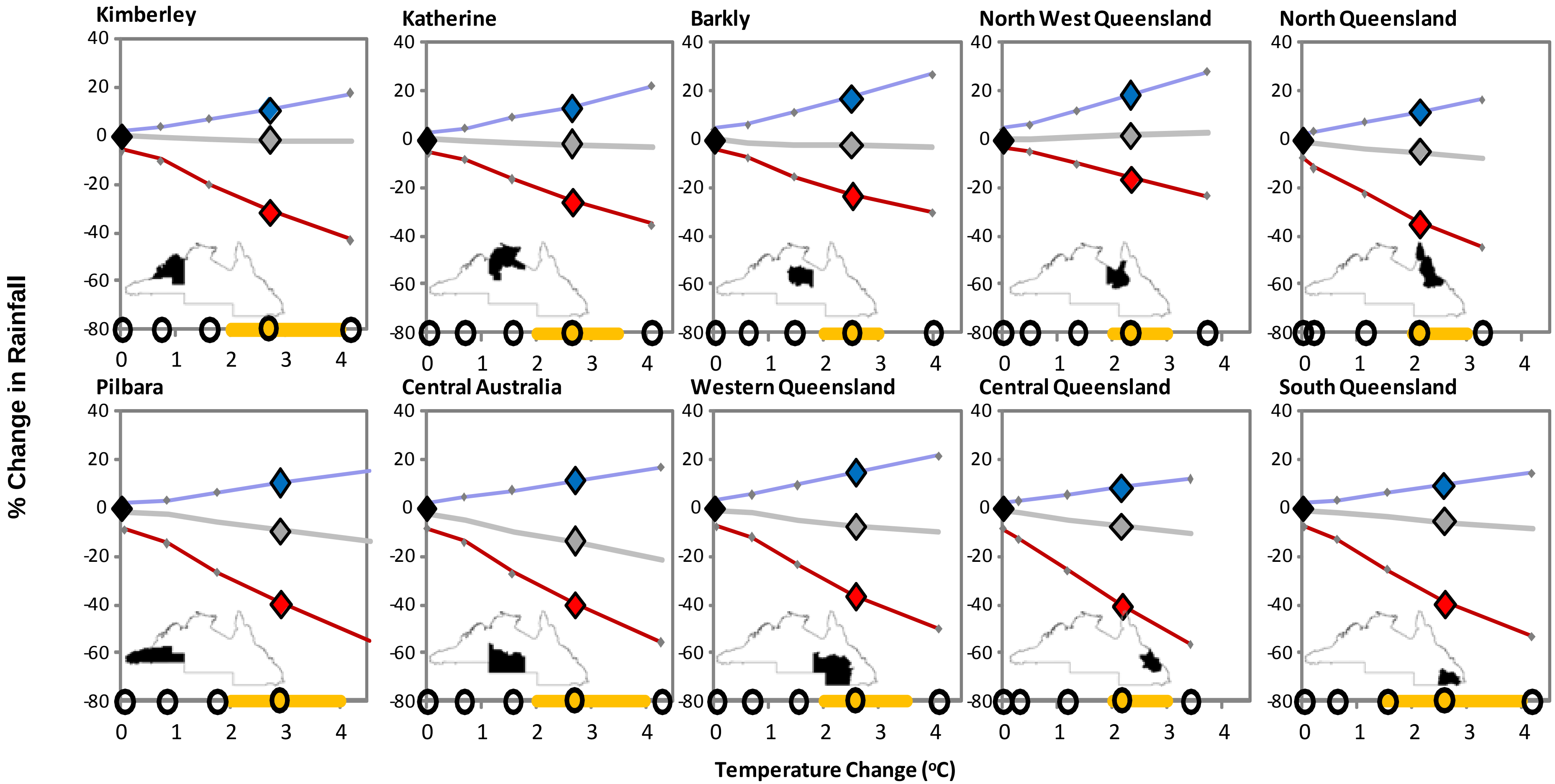

Fig. 2.1: Climate change exposure envelopes summarise the uncertainty in climate projections as the trajectory of rainfall projections along a gradient of climate change (projected change in temperature) for each NABRC region. The upper blue line follows the 90th percentile rainfall against the average temperature projection for each date, the grey line the median rainfall projection, and the red line represents the trajectory of the 10th percentile rainfall projection for each date. The diamonds mark the key reference scenarios: the baseline of current climate (1990, black), and the average projected temperature changes for 2070 with the associated 90th (2070H, blue) and 10th (2070L, red) percentile rainfall projections. Circles mark the progressive average warming for 2020, 2030, 2050, 2070 and 2100 along the x-axis, and the yellow bar the projected range for 2070.

priority areas for improving on-property management covered in the allied project ('Component 1', B.NBP.0616). While that project evaluated the location-specific best management practices for improving grazing land management, our analyses concentrate on evaluating how effective the resulting improvements would be as part of adapting to future climate scenarios.

The simulations were run using the pastoral production model GRASP (Rickert *et al.* 2000), across a full factorial set of model runs that included all combinations of the following factors:

- Climate Change
  Climate scenarios: 3 reference climate scenarios were used for each region consisting of a baseline ('1990') and two future scenarios using for 2070 following wetting ('2070H') and drying ('2070L') trends, using the approach described above. (To generate full response curves along gradients of climate change, intervening scenarios were used to cover all combinations of projected temperature changes for 2030, 2050, 2070 and 2100 with 10^{th}, 50^{th} and 90^{th} percentile rainfalls);
- Variation between regions
  NABRC regions: the diversity of extensive grazing environments across northern Australia was covered using 10 NABRC (excluding the more intensive and fragmented SE Queensland region). GRASP parameter files for a representative pastoral land type for each region (provided by the 'Component 1' B.NBP.0616 modelling team, based on parameter sets from their property-level simulations). No bioeconomic parameters were available for the Pilbara so those for the most similar region, Alice, were used instead. The base parameter set for each region was then modified to represent variation within each region. (This controlled factorial approach allows independent evaluation of how each factor contributes to resulting responses, which is not possible when using different mixes of land-types where contributing factors co-vary and are confounded);
- Variation with regions
- Land condition: four land conditions to represent A, B, C and D condition;
- Trees density: The base tree density was contrasted against a situation with extra trees (the greater of +2 m^2/ha or +~50% basal area) that could occur either by uncontrolled, CO_2-stimulated woody thickening, or management-facilitated changes for carbon credits.
- Fertility: The base level of fertility was contrasted against a lower fertility variant of each site, represented by lowering fertility-related GRASP parameters (6,97,98,99,181) by 20%.
- Plant available soil water storage: The base soils were contrasted against a sandier (or shallower) variant, where water holding characteristics of the top three soil layers were adjusted so as to reduce plant available soil moisture storage (moisture at Field Capacity vs Wilting Point) by 20%.

Each simulation was run over 120-year period (using historic and climate-scenario-adjusted daily weather data for the location), with dynamic land degradation turned off, and stocking rates adjusted each year to target a safe percentage forage utilization. This approach is a representation of 120 separate years under safe stocking for each scenario (rather than a dynamic assessment of stocking rate strategies used in 'Component 1' B.NBP.0616) aimed at providing an indicator of average relative changes in 'carrying capacity'.

As an important caveat it should be noted that confidence in our bioeconomic modelling (this and the following section) is greatest for eastern NABRC regions (in Queensland), declining westwards and is greatest for simulations of pasture production, declining as these are followed through to liveweight gain and enterprise/herd economics. This relates to the availability and quality of data sets to validate and parameterise the models. Also these analyses do not take into account changes in rainfall distribution (greater year-to-year variation, possible changes in seasonal distribution, and more intense rainfall events) and it would be a logical next step to include sensitivity analyses of these effects in future analyses. In particular the projected increase in rainfall variability would likely have a negative influence on carrying capacities (and productivity) under both wetting and drying scenarios. As such all the simulations of projected changes below may have a slightly optimistic bias.

Using the 3 key scenarios for reference (1990, 2070H and 2070L, Fig. 2.1), the potential impacts of change (without adaptation: Fig. 1.2:2) were expressed as the percentage change in pasture production for the climate scenario (2070L: drier or 2070H: wetter) relative to the current baseline (1990). The sensitivity of different pasture types to climate change is marked by the magnitude of responses to the wetting and drying scenarios.

The effectiveness of each adaptation option was expressed as percentage change in pasture production that resulted from applying that management option under each climate scenario (e.g., the improvement in pasture productivity from C condition under the 2070L scenario to B condition under the same climate scenario). The potential impacts without adaptation are marked by the base of the arrows in graphs, and the ends of the graphs show the improved outcome after adaptation for each of the 3 reference scenarios (Fig. 1.2:3). Results from simulations for intervening climate scenarios complete the response curves with and without adaption. Other outputs from the simulations, such as carrying capacity and liveweight gain per ha, were analysed in the same way (Appendices 6.6 - 6.7). (In a related project, B.NBP.0564 ('Climate Clever Beef'), we added an assessment of GHG outcomes to highlight any synergies and conflicts between actions for adapting to climate change and actions for mitigation GHG emissions).

As an indicative threshold of change (Fig. 1.2:4), we used the break-even points from the economic analyses (Section 3.4, Appendix 6.9) to calculate the decline in carrying capacity (combined with the corresponding modelled declines in live-weight gain under drying climate scenarios) below which enterprises with no debt would cease to be profitable. These are marked by the grey band on charts for reference. Note that a range of socio-economic considerations (Fig. 1.2:5) covered in the following two sections indicate that enterprises would likely cease to be viable before this threshold was reached.

The main findings of these simulations are summarized in Table 2.2 and Fig. 2.2 (supported by comparable tables (Appendix 6.5) and figures (Appendix 6.6) for other responses and more detailed tables (Appendix 6.7) in Appendices). These show that overall, the downside risk of climate change (-44% pasture growth, -41% carrying capacity) for pastoral production is slightly higher than the upside risk (+35% pasture growth, +35% carrying capacity) (Table 2.2, Appendix 6.5), magnifying average projected changes in rainfall for northern Australian rangelands (-32% to +12%: Fig. 2.1). There are strong regional differences in simulated impacts with the North Queensland Region showing the least sensitivity to climate change (narrowest range of projected impacts between 2070 L & H scenarios), the South Queensland Region showing the greatest sensitivity (to both positive and negative impacts) and the western half of NABRC regions showing a stronger tendency to overall negative impacts (Table 2.2). Of the various land/pasture characteristics that were tested, trees and soil fertility had a minimal influence on climate change sensitivity, while sandier soils were slightly less sensitive (for both positive and negative impacts) (Table 2.2). Land degradation tended to magnify climate change impacts, with A condition land being the least and D condition the most sensitive, particularly to the negative impacts of drying scenarios (Table 2.2, Appendices 6.5-7). The regions that showed the greatest risk of crossing the 'break-even' threshold under 10th percentile rainfall trajectories, even improving land to 'B condition', were (in decreasing order): the Kimberley, Central Queensland, South Queensland and Western Queensland (Fig. 2.2).

Table 2.2: Climate change impacts (%change for scenario vs 1990) on pasture productivity showing regional variation in impacts, and how differences in pasture characteristics and land condition affect sensitivity to climate change. (Results are for pastures in B condition and averaged across regions, unless otherwise noted.)

Scenario >>	2070L	2070H
Base Veg Chars, B Condition, By Region		
Kimberley (B)	-74%	53%
Katherine (B)	-38%	25%
Barkly (B)	-34%	40%
NW Qld (B)	-2%	25%
N Qld (B)	-15%	32%
Pilbara (B)	-51%	25%
Central Aus (B)	-65%	58%
W Qld (B)	-64%	43%
Central Qld (B)	-77%	50%
S Qld (B)	-80%	78%
B Condition, By Veg Chars (Avgd Regions)		
Avg Base (B)	-42%	40%
Avg Extra Trees (B)	-43%	29%
Avg Lower Fert (B)	-44%	37%
Avg Sandier (B)	-34%	38%
Base Veg Chars, B Condition (Avgd Regions)		
Avg A Condition	-42%	35%
Avg B Condition	-42%	40%
Avg C Condition	**-49%**	29%
Avg D Condition	**-49%**	33%
Base Veg Chars (Avgd Regions* Conditions)		
Avg Base Veg	**-44%**	**35%**

Table 2.3: Effects of adaption options (%change for management action vs no action under comparable conditions) on pasture productivity. Results show how the effectiveness of management actions is altered under different climate scenarios, and how it is affected by pasture characteristics and land condition.

a) Improving Land Condition

Scenario >>	1990	2070L	2070H
C -> B Condition, by Veg Chars (Avgd Regions)			
Avg Base Veg	71%	94%	86%
Avg Extra Trees	70%	90%	73%
Avg Lower Fert	74%	86%	85%
Avg Sandier	83%	115%	87%
Base Veg, by Land Condition (Avg Regions)			
Avg B -> A	24%	24%	20%
Avg C -> B	**71%**	**94%**	**86%**
Avg D -> C	27%	27%	23%

b) Impact of EXTRA Trees

(active planting or NOT controlling thickening)

Scenario >>	1990	2070L	2070H
B Condition, by Veg Chars (Avgd Regions)			
Avg Base Veg	**-28%**	-29%	-31%
Avg Lower Fert	-30%	-30%	-33%
Avg Sandier	-25%	-25%	-27%
Base Veg Chars, by Land Condition (Avg Regions)			
Avg A Condition	-29%	-29%	-31%
Avg B Condition	-28%	-30%	-34%
Avg C Condition	-28%	-28%	-29%
Avg D Condition	-27%	-29%	-30%

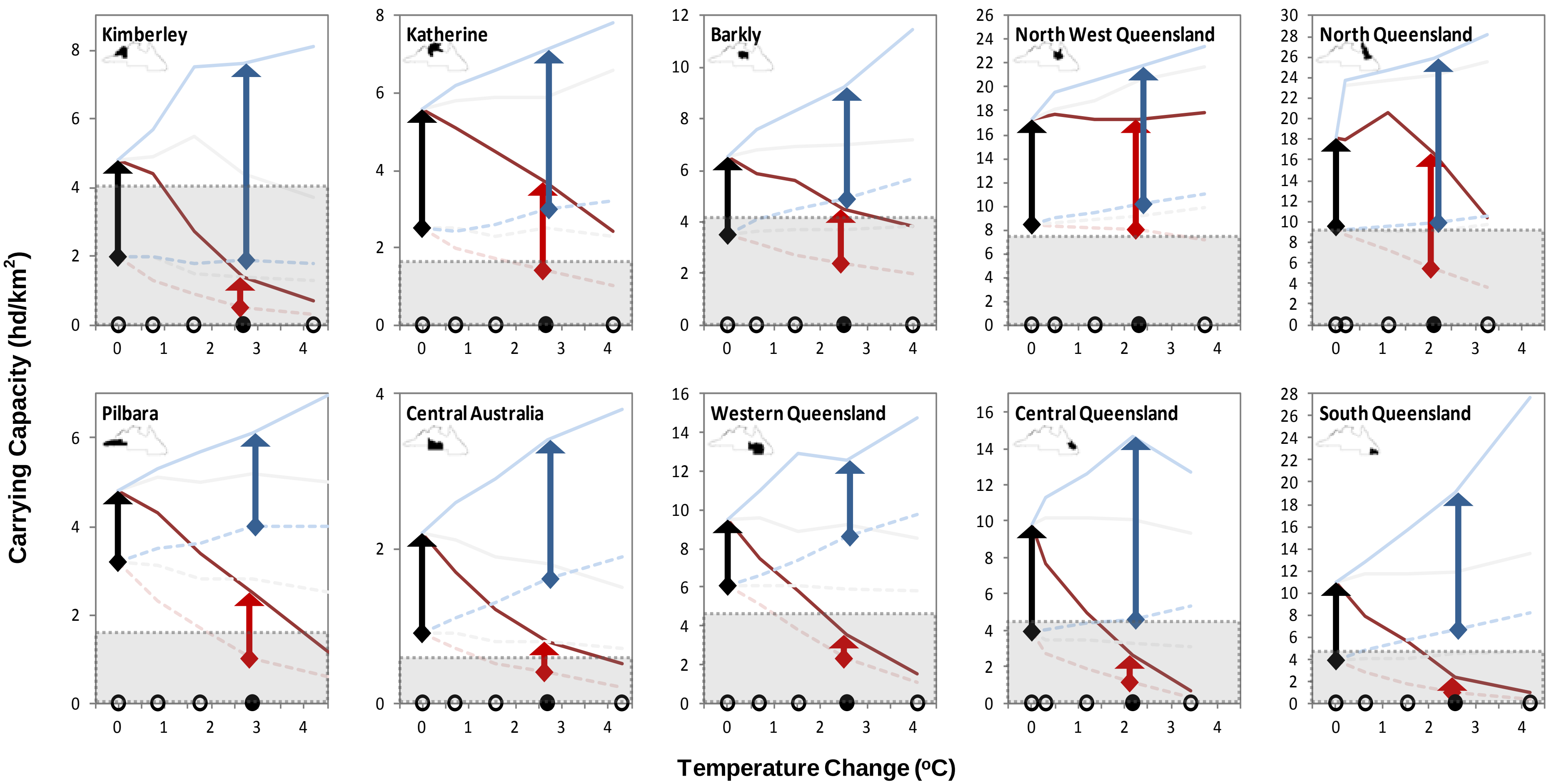

Fig. 2.2: Variation in the impacts of climate change and the effectiveness of adaptation (improving land condition) on carrying capacity (hd/km^2) across northern Australia. Arrows compare the effects of the management action under three reference climate scenarios: the current climate (1990 - black) and 2070 projected temperatures with associated 10th (2070L - red) and 90th (2070L - blue) percentile rainfall projections. The base of each arrow represents each scenario on ‘C condition’ pastures, while the arrows show the response if pastures were improved to ‘B condition’. Responses are shown in relation to projected temperature change (x-axis). Circles along the x-axis mark progressive projected average warming for 1990, 2030, 2050, 2070 and 2100 respectively. Dotted lines cover the full time series of climate scenarios for ‘C condition’ pastures and solid lines the improved (‘B condition’) pastures for 10th (red), 50th (grey) and 90th (blue) percentile rainfall projections. Grey areas mark the break-even threshold of no net profit at 100% equity (Section 3.3).

Of the pasture characteristics evaluated, two (land condition and tree density) can be altered through management as part of adapting to climate change. (It is already implicit in the modelling that other changes, such as adjusting stocking rates and feeding supplements to match pasture growth, are taken to match each scenario, and other management options have been covered in Section 2.2). The biggest benefit in improving land condition (by one 'grade') comes from improving C to B condition, and this tends to produce an enhanced benefit under drying climate scenarios (relative to the benefits under the current climate or wetting scenarios) (Table 2.3). The benefits of improving land condition are greater for sandier soils, but were not influenced much by trees or soil fertility (Table 2.3). The benefits of controlling trees (or the negative impacts of allowing woody thickening or actively planting trees for carbon credits) is very similar across climate scenarios, land conditions and pasture characteristics (Table 2.3). Lower fertility soils are slightly more sensitive to the impacts of extra trees, while sandier soils are slightly less sensitive.

To interpret Fig. 2.2, one of the key indicators is the solid red line, which follows the decline in carrying capacity under the drying scenarios after land has been improved to B condition. The steeper the red line drops off (along the gradient of increasing climate change), the more sensitive the region is to climate change, and the sooner it crosses the break-even threshold (grey area), the more economically vulnerable it is. From this, our results suggest that:

1) the regions that may be both most climate-sensitive and economically vulnerable are the Kimberley, Central Queensland, South Queensland (Maranoa-Balonne) and Western Queensland;
2) some regions are sensitive (steep red line) but less economically vulnerable (less likely to cross thresholds), e.g., Central Australia and Katherine regions;
3) the regions that appear both the least sensitive and least vulnerable are in northern Queensland, i.e., the Northwest Queensland and North Queensland regions.

The size of the black arrow (effect of adaptation option under current conditions) relative to the drop along the solid red line (impacts with adaptation under the drying climate scenarios) indicates the extent to which adaption could offset the negative impacts of climate change.

In summary, the agro-ecological assessment found that overall, the downside risk of declining productivity for the northern beef industry is only slightly higher than the upside risk of improving productivity. Those regions that are currently less productive tended to be more susceptible to the effects of climate change (particularly negative impacts) whereas some of the more productive regions tended to be less sensitive (to either drying or wetting trends). The results reinforce initiatives to improve grazing land management both because pastures in better condition tended to be less sensitive to negative climate impacts, and because associated improvements in productivity could offset declines under drier climate scenarios. Sandier soils (with less capacity to store plant-available water) tended to be less sensitive to climate change and more responsive to improving land condition (but modifying soil properties is not a viable management option). Other sources of local variation in pasture (such as fertility and tree density) had little consistent effect in modifying their sensitivity to climate change or adaptation options.

While changes in projected pasture condition may seem to be largely determined by changes in rainfall, caution needs to be urged that adaptation does not become solely focussed on this challenge. The effects of rising CO_2 and temperature on pasture growth (up to about -40% and +40% respectively by 2070) are large, but opposing and offset each other (Appendix 6.8).

However:

1. the magnitude of CO_2 effects is uncertain;
2. CO_2 effects will plateau off with further rises in atmospheric levels (diminishing benefit for each further increment in atmospheric CO_2);
3. temperature effects on vapour pressure deficit (and water use efficiency) follow an escalating curve (increasing negative effect for each degree of warming at hotter temperatures);
4. once CO_2 levels in the atmosphere stabilise, temperatures (and their negative effects) will continue to rise (whereas there are minimal lags for direct plant responses to CO_2, so no further benefits would accrue).

The implications of this are first, that short term impacts of climate change may be more benign (disproportionate expression of benefits) than those experienced in the longer term (when lagged and escalating negative impacts become more strongly expressed). Secondly, existing efforts to improve land management and strategies for coping with variable rainfall will assist climate adaptation, but are unlikely to be sufficient, and will need to be complimented by strategies for coping with the arising unique new climate challenges (Appendix 6.1, such as rising temperatures and CO_2 levels, for which there is no prior management experience to draw on).

It also important to note the break-even thresholds used here do not include the structural adjustments that enterprises would likely make when faced with large declines in pasture productivity. The thresholds would be indicative of the limits to adaptation that involved only existing BMPs (with slight modification) within the confines of the existing business structure (including property boundaries, infrastructure, and herd structure). But the diversity of enterprises and environments across northern pastoral lands (as indicated for example by the wide range of break-even carrying capacities in Fig. 2.2) indicates that there is a much greater inherent potential to adapt to climate changes if structural changes were made (e.g. consolidation of properties into more extensive enterprises). This added potential would be greater for more productive regions than for less productive regions where enterprises are already near the extensive extremes (and break-even points that are already very low). Past experience of structural adjustment in agriculture suggest that such changes, when necessary, are far more disruptive and difficult to achieve with broader repercussions for regional communities, requiring careful policy consideration.

2.6 References

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3 Economic vulnerability and adaptation

3.1 Introduction

The economic component of the project seeks to place beef enterprises that are located across a broad spectrum of agro-ecological regions into a context of their vulnerability to climate change developments of a scope and nature consistent with the array of climate change projections that were discussed above (Section 2). The regional spread of production enterprise types will be represented in this section by a set of 'representative beef enterprises' that were constructed under the earlier phases of the Northern Grazing Systems (NGS) process for 9 rangeland regions spanning northern Australia (see MLA projects B.NBP.0578 and B.NBP.0616). These NGS regions correspond to the NBRC regions we are using in this report (Fig. 1.3) although there was no specific template model created within the early NGS phases for the WA Pilbara region for the earlier NGS project components (so the Alice Springs / Central Australia template was used instead). The NGS regional models were named after the sub-regions in which they were assumed to be located which differs slightly from the NBRC regional titles – the correspondence being summarised in Table 3.1.

Table 3.1: NGS regions and corresponding NBRC regions.

NBRC	South Qld	North Qld	Central Qld	Western Qld	North West Qld	Katherine	Barkly	Central Aust	Kimberley
NGS	Maranoa-Balonne	Burdekin	Fitzroy Duaringa	Western Qld Blackall	Southern Gulf Normanton	VRD South	Barkly South	Alice Springs	Kimberley Fitzroy River

The vulnerability-adaptation context is firstly supported by consideration of some highlights of a significant 'sector financial situation analysis' that was commissioned by MLA in 2010 (Project B.NBP.0518) – otherwise known as the "McCosker Report" (McCosker *et al.* 2010).

Productivity gains and the ability to adapt to ongoing challenges, of which climate change is necessarily one additional source of pressure, are critical components of beef enterprise survival. The ongoing impetus to retain viable operations in face of the vagaries of competitive markets and cost pressures is briefly considered against the context of the 'terms of trade' trends for beef production. Climate change vulnerability and adaptation prospects can be considered against this broader economic background.

In a relatively open market economy with limited public support, such as the northern beef sector operates within, economic vulnerability is closely tied to economic viability which in turn is largely driven by the capacity of enterprises to make a net profit after costs are met and a competitive return on their capital base. In the remainder of the section, consideration is given to the sensitivity of the baseline net profit projections of the 9 'representative' regional enterprises to changes in the constituent components of the net profit equation. Projected changes in the two key production drivers that are most closely associated with different climate change scenarios - animal growth and carrying capacity of pastures - are contrasted against those results.

3.2 Northern beef situation analysis

The "McCosker Report" (McCosker *et al.* 2010) provides a snapshot of the current financial 'state of play' of beef enterprises across the northern sector with an aim to generate an understanding of the economic performance and issues impacting beef producers at the enterprise level. Based on the principal authors' well-known knowledge of industry economics through the successful RCS consultancy business it complements other official sources of data on industry performance, including those from ABARES and the ABS. The material in the report focuses, in large part, on the RCS Profit Probe database comprised of a large number of RCS clients. Summaries are provided in the report for the broad client base and also for the top 20% of that clientele in terms of an array of profitability metrics. Rather than reproduce large sections of the report, which is in the public domain, this section draws on a few key statistics and observations on status for the average of the whole RCS client sample and the top performing 20% of that sample.

Overall conclusion – the northern beef sector as a whole is generally in the worst financial shape that it has been since the historically significant market slump of the mid-1970s. Across the regions the average return on capital investment (viz. net profit/total capital X 100%) only ranged between 0.3% and 2.0% in 2009, while one half of all enterprises earned <u>negative</u> net profits (i.e. failed to cover all costs) in 5 of the last 7 years covered by the report. These results are generally consistent with the most recent economic data from ABARES for specialist beef enterprises in Queensland, Northern Territory and Western Australia. On that basis, McCosker *et al*. (2010) generally concluded that continued production for many northern enterprises is neither <u>profitable</u> nor <u>sustainable</u>.

Capacity to adjust - Dominant issues underlying that difficult economic context included a range of structural, economic, climatic and policy factors. For example, most existing enterprises were judged to be of inadequate size and unable to reap further economies of size in terms of increased turnover and reductions in production and trading costs. This was exacerbated by a rapid inflation in land prices (250% in a decade) preventing cost-effective property amalgamation coupled to an escalation in variable and overhead costs (100% in a decade). At the same time, and despite some market buoyancy (pre-live export crisis) in recent years, the growth in cattle prices was limited (see *terms of trade* next sub-section). The limited ability of many enterprises to adapt to these economic trends is reflected in an average doubling of debt held per animal carried although some of that rise would have been driven by earlier property amalgamations. Despite more recent favourable seasons, climatic conditions were not particularly favourable across many northern regions in the past decade with many instances of below average annual rainfall – this added to the pressure of rising production costs through reduced herds and increased costs of feeding, transporting and supporting droughted stock. Finally, and particularly for Queensland enterprises, stricter application and enforcing of vegetation management legislation has placed significant curbs on woody plant regrowth control and pasture development options which are two major sources of productivity gain for extensive grazing systems (e.g. Scanlan 1988, Gramshaw and Lloyd 1993).

Higher performers - Although many northern beef enterprises were doing it tough, not all of the McCosker study enterprises fared poorly over the past decade. The dominant characteristic of the top 20% of enterprises were that they were generally larger in terms of land held and livestock carried, and much of their superior economic performance was attributed to increased levels of productivity attained per hectare or per animal rather than any ability to extract price premia per se. These enterprises typically adhered to more conservative stocking rates than the average but yielded higher levels of animal productivity (average 7kg/adult equivalent animal carried) – giving higher average gross margins. Profitability was further enhanced through having lower overhead costs (average 20% less than the total group). These characteristics were summed up in the conclusion that the elite group was on the whole comprised of better land and livestock managers than the average for the sector.

Therefore a broad conclusion to be drawn from this important situation analysis is that under the present climate regime a large section of the existing northern beef enterprises are judged to already be highly vulnerable to any adverse movement in their both production and trading context. Moreover, on the face of the evidence they are seemingly already unable to implement successful adaptation strategies without the added burden of any adverse production consequences of projected climate change. Above average enterprises and managers do exist within the sector and to date they have been adapting to their exposure to market forces, cost and legislative pressures and climatic circumstances – but this may be relative, when considered against ongoing cost adjustment pressures as suggested in the next sub-section.

3.3 Terms of Trade

The preceding section has briefly described the difficult economic position that many northern beef enterprises find themselves in and how the elite (top 20%) have higher levels of productivity. Why reaping continuing productivity gains is so important to economic vulnerability and adaptation success is easily highlighted by considering the real and relative profitability of beef production over time as measured by the beef production 'terms of trade'. These terms are represented by relative movements over time in output and input prices which reflect the effective purchasing power of a kilogram of beef sold in the market. These are illustrated in Figure 3.1 which shows movements in the ratio of the indices of ABARES *beef prices* and *all farm costs* series from 1970-71 through to 2010-11 (base is 1970-71 = 1.00). Also shown is the linear trend which is declining at a cumulative annual rate of ~1.5% which is the root of the so-called *cost-price squeeze*.

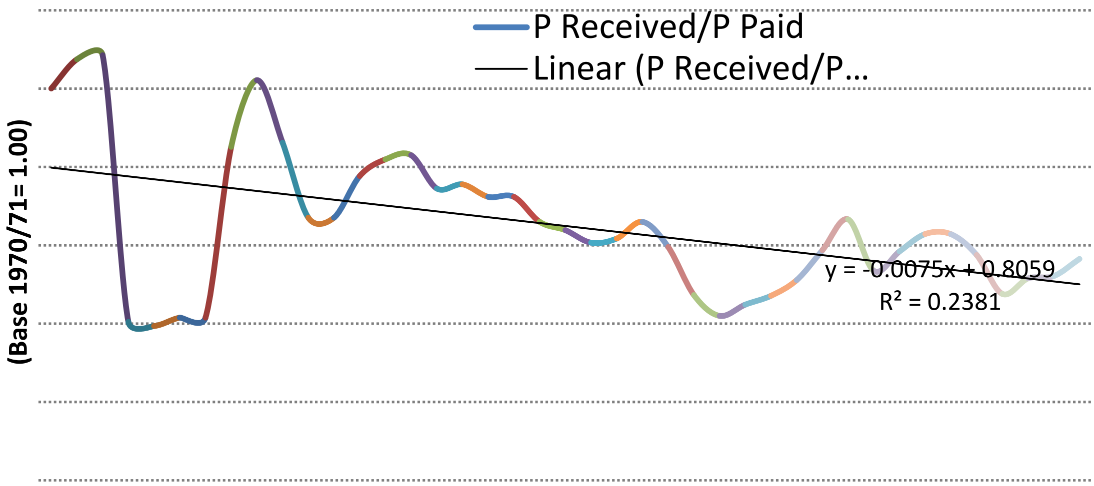

Figure 3.1: Beef terms of trade 1970-71 to 2010-11.

A manipulation of the simple profit equation reveals the central role of productivity in offsetting declines in relative profitability through adverse relative price trends.

$$\text{Profit} = (Pb \times B) - (Pi \times I)$$

Where:
- Pb X B = total revenue
- Pi x I = total costs
- Pb = price of beef
- Pi = price of inputs
- B = total beef output
- I = total inputs (physical)

And:
- Pb/Pi = terms of trade
- B/I = average productivity (physical)

Therefore, if ∆Pb/∆Pi is declining (e.g. at 1.5% annual), net profit can only be maintained at a constant level if physical productivity (∆B/∆I) is increasing at an equivalent rate (in this case 1.5% annual). To some extent, the pressure on enterprises to maintain productivity growth has eased in the last few years where the short term change in the terms of trade has actually been positive (2001-2011 trend ~0.2%) but over the longer period of decades the terms have clearly been adverse and it is unlikely to see a structural change away from that declining trend. Moreover, productivity gains in the northern sector have stalled over the past decade (McCosker *et al.* 2010) and so the respite has been welcome but unlikely to last. An important observation is that while the top 20% of enterprises enjoy a productivity advantage over the rest of the northern beef sector the overall terms of trade in 2010-11 are less than 60% of those for the 1970-71 base period and the elite group does not enjoy that magnitude of productivity advantage. That is, all enterprises are operating in a real profitability context that is considerably less favourable than in earlier decades.

3.4 Regional models and sensitivity to change

The sensitivity to climate change of a series of land and herd management practices recommended to support sustainable resource use has been thoroughly explored using simulation modelling techniques in the parallel MLA-DAFF funded project B.NBP.0616. This modelling was centred on a set of synthetic 'representative' beef enterprises that were defined in the course of a paired series of stakeholder workshops that were held in 9 regions. These regions included – Maranoa-Balonne (Mitchell), Burdekin (Uplands), Fitzroy (Duaringa), Western Queensland (Blackall), Southern Gulf (Normanton), VRD (South), Barkly Tableland (South), Alice Springs (Barrow Creek) and the Kimberley (Fitzroy River) – and can be located within the relevant NBRC regions through Table 3.1. Each of the simulations was set against a baseline scenario which equated to the performance of the 'representative' enterprise under current management and current climatic conditions. These regional baseline enterprises are used as the benchmark against which vulnerability to projected climate change is assessed – the main characteristics of the 'representative' enterprises are summarised in Table 3.2. Economic analyses used a static version of the approach in B.NBP.0616 by constructing analysis templates to explore the sensitivity of enterprises to changes in five key drivers of profitability: carrying capacity and liveweight gain (to link productivity outputs from GRASP simulations); fixed and overhead costs (to represent improvements in business management to control costs); and beef price (combined with costs, to explore the sensitivity to declining terms of trade). Details of this approach are provided in Appendix 6.9.

In each case the 'representative' enterprise is built around a self-replacing breeding herd, the main differences between the regions being the scale of activity and the ability of the enterprise to economically finish stock for various markets. For example, with the exception of the North West Qld/Southern Gulf property, the Northern Territory and WA Kimberley enterprises are considerably larger than the Queensland enterprises which generally account for the larger share of northern range production. The Central Qld/Fitzroy enterprise is focussed on finishing steers to north Asian market specifications (e.g. Japan Ox), whereas the South Qld/Maranoa-Balonne, North Qld/Burdekin, Central Aust/Alice Springs and Kimberley enterprises sell steers off as weaners or yearlings preferring to concentrate on breeding activities rather than attempting to finish animals under difficult environmental conditions and limited markets. The Western Queensland, North West Qld/Southern Gulf, Katherine/VRD and Barkly enterprises are directed to supplying young steers to the live export trade. The opportunity for shifting between these production activities and markets is generally quite limited further heightening their potential vulnerability to structural changes in markets and or shorter term disruptions as, for example, occurred in the live export market in Indonesia in 2011.

Baseline profit projections - the baseline scenario that was established (MLA DAFF B.NBP.0616) for each of the 9 regional 'representative' enterprises gave a projected positive level of net profits in all cases when any debt is ignored. However, even when relatively modest levels of debt are considered the enterprises are quite vulnerable to making net losses on their investment. This is summarised in Table 3.3 for two assumed levels of equity - full equity (i.e. nil structural debt) and 80% equity (debt equivalent to 20% of total capital investment).

Table 3.2: Baseline summary data for NGS 'representative' enterprises in 9 regions.

NBRC region	South Qld	North Qld	Central Qld	Western Qld	North West Qld	Katherine	Barkly	Central Australia	Kimberley
NGS Region	**Maranoa - Balonne**	**Burdekin**	**Duaringa**	**Western Qld**	**Sth Gulf**	**VRD South**	**Barkly South**	**Alice Springs**	**Kimberley**
Land area	15,586ha	24,000ha	14,230ha	16,200ha	166,500ha	4,594km^2	5,000km^2	3,400km^2	2,670km^2
No. Paddocks[1]	7	10	18	15	20	20	20	13	10
Land types	Brigalow/belah Poplar box on duplex Soft mulga on sandplains	Grey clays Yellow earths Red and brown duplex Alluvial	Alluvial brigalow Box flats Narrow-leafed ironbark	Open downs Wooden downs Soft gidyea Boree wooded downs Open alluvial	Open downs Alluvial Red plains Black soils Spinifex ridges	Black cracking clay Good basalt red soil Poor calcareous red soil Spinifex plains	Lateritic red earths Heavy grey earths	Open woodland Mulga Spinifex Alluvial	Pindan Black soils Marine plains
Condition (Av)	B/C (2.5)	B (2.1)	B/C (2.3)	A/B (1.7)	B/C (2.3)	A/B (2.0)	A/B (1.9)	B/C (2.8)	B/C (2.1)
Enterprise type	Breeding cows with steers sold as weaners or yearlings	Breeding cows with steers sold as weaners or yearlings	Breeding cows with steers sold as heavy Ox (3yo)	Breeding cows with steers & heifers sold for trade or live export	Breeding cows with steers & heifers sold for live export	Breeding cows with steers sold for live export	Breeding cows with steers sold for live export	Breeding cows with 60% of steers sold as yearlings and 40% grown out to 2yo	Breeding cows with 25% steers sold as weaners, 25% as yearlings and 50% as 2yo
Total stock carried[2]	1,600AE	2,100AE	1,650AE	1,500AE	1,3850AE	10,850AE	30,000AE	4,000AE	6,400AE
Total value (incl. Livestock)[2]	$7.5m	$7.1m	$16.0m	$7.8m	$27.6m	$57.2m	$85.0m	$7.3m	$5.9m

1. Excludes small holding paddocks, horse yards etc
2. Baseline projection – these values will vary according to the scenarios being simulated.

The projected baseline return on capital invested in the 9 enterprises ranges from 1.1% to 3.5% and, while modest, is generally consistent with the trends identified in the McCosker report (McCosker *et al.* 2010) and ABARES grazing industry statistics (e.g. Thompson and Martin 2011) – if anything it is slightly more conservative than recent ABARES results which projected an average net loss for all northern enterprise with full equity in 2010-11 although the largest size categories (1500-5400 AE) gave similar rates of return (1.8%). Note, that none of these projections specifically allow for the disruption to the live export trade to Indonesia in 2011.

Few cattle enterprises are genuinely free of structural debt (i.e. above trade credit) and the projections in Table 3.3. when assumed equity is reduced to 80% clearly show that debt accumulation and servicing needs have a major bearing on bottom line profitability and, hence, vulnerability. For example, 7 of the 9 'representative' enterprises are projected to either carry a net loss or achieve a rate of return of less than 0.1% on their capital investment. So, the ability of northern beef enterprises to service debt from beef earnings under current management and current climatic conditions is necessarily limited.

Table 3.3: Baseline net profit for NGS 'representative' enterprises in 9 regions.

NBRC region	South Qld	North Qld	Central Qld	Western Qld	North West Qld	Katherine	Barkly	Alice Springs	Kimberley
NGS region	Maranoa	Burdekin	Duaringa	Western Qld	Sth Gulf	VRD	Barkly	Alice Sp.	Kimberley
TGM ('000)	$279.0	$289.6	$417.1	$229.8	$1,460.6	$1,328.8	$2,492.1	$334.6	$403.0
Net Profit ('000)	$113.4	$169.6	$232.1	$161.7	$1,113.3	$1,127.8	$1,338.3	$214.6	$136.0
Total Capital	$10.0m	$8.8m	$17.2m	$9.0m	$32.2m	$66.8m	$96.7m	$10.6m	$10.6m
Rate of return	1.1%	1.9%	1.3%	1.8%	3.5%	1.7%	1.4%	2.0%	1.3%
Net Profit ('000) (80% equity)	-$95.5	$1.6	-$158.8	-$32.8	$514.8	-$316.8	-$592.6	$34.2	-$1.4
Rate of return (80% equity)	-1.4%	0.0%	-1.3%	-0.5%	2.7%	-0.7%	-0.9%	0.6%	0.0%

Terms of trade impacts – the continuing pressure for northern beef enterprises to respond to a chronic cost-price squeeze was highlighted in an earlier subsection (3.3 above), and just now the difficulty of bearing more than modest levels of debt which might, for example, be mandated by a poor season or market disruption has also been noted.

The structural impact of exposure to an ongoing negative trend in terms of trade can be examined by adjusting the benchmark returns and cost parameters within the NGS 'representative' farm models to reflect annual terms of trade decline of a given order. This can be projected out into the future – in this case, to 2070 for which the climate change scenarios discussed before have been constructed. The projections on net profit (at full equity) are presented for a range of annual changes from 0.5% through to 2.5% in Figure 3.2.

To allow a comparison of the different regional models, given the large difference in scale between them, the results have been standardised around changes from the current year base (2012 being 100%). All of the regional models show marked declines in net profitability across the range of terms of trade deterioration rates, noting that the trend in Figure 3.2 is ~-1.5%. Clearly, the South Qld/Maranoa- Balonne, North Qld/Burdekin, Barkly, Central Aust/Alice Springs and Kimberley are particularly affected by worsening terms of trade trends which is largely explained by their market focus and relative revenue to cost ratios. Note, these are extreme projections and are intended to give a guide to sensitivity to trend shifts without offsetting adjustments to scale of management rather than an accurate portrayal of how things might pan out by 2070. The structure of the northern beef industry in 2012 bears little resemblance, of course, to that of 1950 and presumably the structure of 2070 will be much different again. These projections simply highlight how the current structure would be impacted by ongoing cost inflation of the scale seen in the past few decades. However, the projections do suggest that the adjustment imperative will not be trivial.

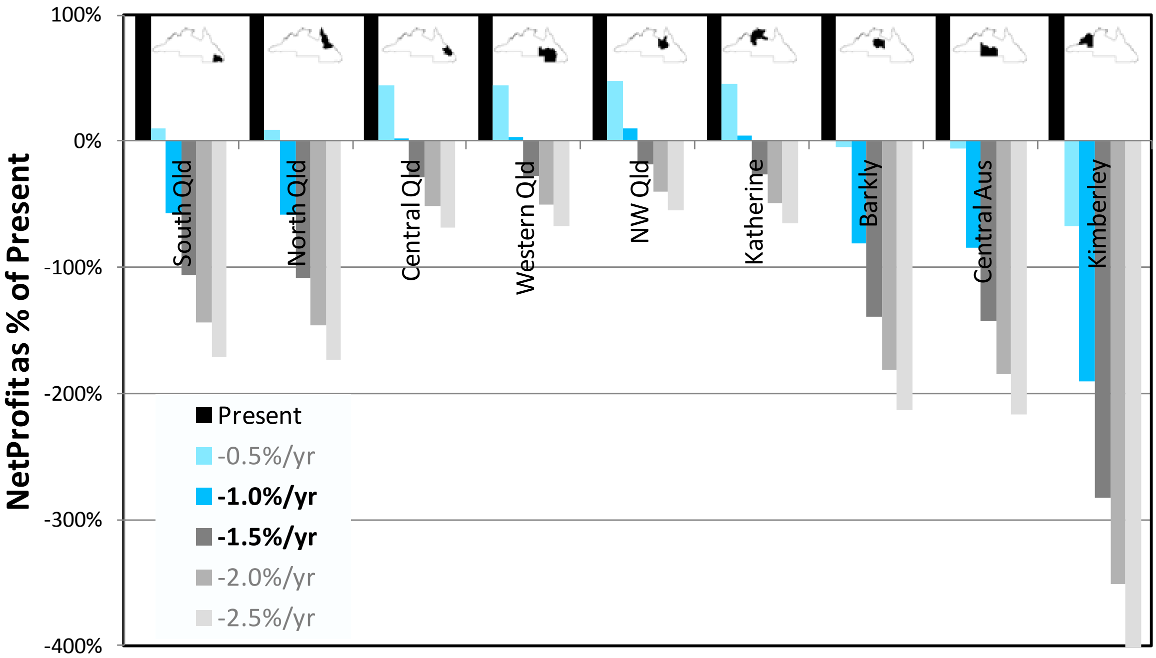

Figure 3.2: Net profit projections to 2070 for 9 'representative' baseline enterprises under a range of declining terms of trade trends (-.5% to -2.5% pa).

Break-even thresholds – if economic vulnerability is taken in its narrowest sense of the capacity of an enterprise to continue to make a positive economic profit over time and/or a competitive return on its capital investment then the conditions under which that capacity is lost will be of singular importance. To examine this profitability threshold or 'break-even' point, a simple sensitivity test was applied to the net profit determining parameters in each of the 9 baseline models – carrying capacity, liveweight gain, variable and overhead costs were varied across an array of values to determine how the net profit estimate responded (see Appendix 6.9 for details). The effect of changing carrying capacity in GRASP is co-determined with changing liveweight gain estimates (achieved through regression of values at the 10th percentile as described in detail Section 2), so the scale shown in the following table (Table 3.4) is simply labelled as 'changes in carrying capacity'.

The' break-even' change in projected carrying capacity relative to that of the current baseline values for the original 9 regional 'representative enterprises and Pilbara enterprise and the additive effects of changing the variable cost and overhead cost parameters is presented in summary form in Table 3.4. The interpretation of the rows in Table 3.4 is that for the South Qld/Maranoa, for example, if carrying capacity were to fall by 41% below the current baseline management level the 'representative' enterprise would make nil net profit. Should variable costs be reduced by 20%, for example through productivity gains, this threshold would not be reached until carrying capacity fell by a further 4%. If overhead cost could be reduced by 20%, for example through general efficiencies or scale improvements, the break-even decline in carrying capacity would be 53% and if this were concurrently achieved with a similar reduction in variable costs the overall decline would be 55%. The average decline threshold for all 9 regions is shown in the last column of Table 3.4 and would be 46% of the current threshold. The effect of changes to variable and/or overhead costs would then range through a further 5% to 12% above the 46% threshold. The Kimberley 'representative' enterprise is the most vulnerable to carrying capacity losses which reflects the low level of animal productivity that is assumed to already prevail under current management and climatic conditions.

Table 3.4: 'Break-even' thresholds for net profit for NGS 'representative' enterprises in 10 regions under variations in projected carrying capacity.

NBRC Region	South Qld	North Qld	Central Qld	Western Qld	North West Qld	Katherine	Barkly	Central Aust	Kimberley	Pilbara	
NGS Regon	Maranoa	Burdekin	Duaringa	W Qld	Sth Gulf	VRD	Barkly	Alice Sp.	Kimberley	Pilbara1	Average
Current Mgmt	-41%	-49%	-44%	-58%	-49%	-71%	-38%	-47%	-12%	-51%	-46%
VC -20%	-45%	-56%	-46%	-61%	-52%	-74%	-47%	-58%	-19%	-61%	-6%
OHC -20%	-53%	-56%	-50%	-63%	-52%	-71%	-42%	-52%	-16%	-57%	-5%
VC -20% & OHC -20%	-55%	-62%	-53%	-66%	-55%	-79%	-57%	-62%	-24%	-66%	-12%

1. Pilbara enterprise is based on the Alice Springs property template as explained in Section 2.5.

3.5 References

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4 Social vulnerability, thresholds and adaptation

4.1 Social Vulnerability

Human adaptation to climate change will make a major difference to the extent of the impacts of climate change. The specific challenge faced by pastoralists within the cattle industry is to build the productivity and profitability of their enterprises in the face of climate uncertainty without depleting the soils on which they depend (McKeon *et al.* 1993). They must anticipate and prepare for climate-driven change and institutions will need to be particularly supportive. However, climate adaptation processes are not straight-forward. Some pastoralists are likely to be more vulnerable than others and will be limited in their ability to cope and adapt (Marshall 2010).

Vulnerability assessments should help decision-makers better understand the nature and complexity of vulnerability. They should also provide insights that can assist in the development of strategies that might minimise vulnerability and maximise opportunities for adaptation. The focus of this section of the study was to understand the nature of vulnerability of pastoralists across northern Australia. People can be vulnerable to change in different ways, however surprisingly little research has been conducted at the individual level. We focus at the individual level because this scale is often over-looked in the development of regional policies, and because the individual scale is necessary to complement other research at other scales and because individual adaptation has spill-over effects to collective action and response.

We use the modification of the IPCC framework to assess vulnerability as described above. The modification establishes that vulnerability within both social and ecological components of a system is a function of both climate sensitivity and adaptive capacity. Hence, in order to assess social vulnerability, we must assess both the sensitivity of people as well as their adaptive capacity. We describe the important components of assessing sensitivity (also known as resource dependency) and adaptive capacity.

4.1.1 The components of resource dependency

How individuals are sensitive to climate changes depends on how dependent they are on a climate-sensitive natural resource. Those that are more dependent on the grazing resource have less psychological, financial and cultural flexibility with which to experiment with their options for the future and are likely to be more vulnerable to changes that occur in the ecological components of the system. Pastoralists can be dependent on a natural resource in economic and non-economic ways. Here we list the important ways that pastoralists can be dependent on a natural resource and thus vulnerable to change.

Attachment to the Occupation:
Pastoralists can be sensitive to change because of their attachment to their occupation (Becker & Carper 1956) When a person with a strong occupational attachment is suddenly faced with the prospect that they are no longer able to continue in their current occupation, or need to redefine what it means to be a 'pastoralist' they not only lose a means of earning an income, they lose an important part of their identity (Minnegal *et al.* 2004). Hence, individuals with a strong identity created around their current resource-harvesting operation are likely to be sensitive to changes in the resource.

Employability:
People living and working in resource dependent communities often have limited experience in other occupations. As a result, they often lack transferable skills and consequently become 'locked' into their occupation (Reed 1999). Pastoralists that are older, have little education or are uninterested in working elsewhere are likely to be especially sensitive to

climate change since they are usually least equipped to take advantage of other employment opportunities (Allison & Hobbs 2004). Employability is assessed using measures of age, education, level of transferrable skills sets and attitude to working elsewhere.

Family:
Pastoralists can be sensitive to change if they have dependents for whom they are responsible. Family members are likely to be most sensitive to loss of income or livelihood. Pastoralists with dependents may be especially sensitive to climate changes since they will be less able to experiment with their options for the future (Poggie & Gersuny 1974). We measure the number of dependents that each pastoralist is responsible for.

Attachment to place:
This concept describes the level of connection that individuals have with their physical community (Twigger-Ross & Uzzell 1996). It describes the identity created around the locality, the sense of pride associated with belonging to the town and the strong friendships and networks that exist within it or connections to ancestors (Gustafson 2001). People will often prefer the stability associated with remaining in the one community, and this can increase their dependency on the natural resource (Fried 1963) and decrease their capacity to effectively respond to climate change.

Formal and informal networks:
Networks can be formal - through legal structures and government agencies, or informal – through friends, families and associates (Fenton 2004). Individuals with stronger, more informed and more effective networks have reciprocal connections of interactions, increased levels of trust and access to information that are exchanged for mutual benefit (Measham *et al.* 2011).

Business size and approach:
The business skills that people possess can be good indicators of their competitive advantage within the resource industry and their level of transferable skills outside of the resource industry (Peluso *et al.* 1994). Often, the extent of business skills present within an individual is correlated with the size of business that they operate. Generally, larger businesses are more likely to buffer themselves from unpredictable problems such as mechanical breakdowns, difficulties with employees and fluctuations in the weather since they can take bigger risks and experiment with their options for the future (Fisher 2001). Business owners in larger businesses are more likely to be strategic, have the capacity to motivate, plan, organise and act and are more likely to be driven by economic incentives to harvest the resource (Stedman 1999). Capital investments, however, may limit flexibility and stifle innovation. We assess business size here using the number of employees (under 'normal' circumstances), number of nectars managed and annual turnover in broad categories.

Financial status and access to credit:
The income and debt levels of pastoralists and their ability to access credit can also significantly influence the extent to which they can effectively respond to change (Humphrey 1995). Pastoralists with a lower financial status often lack the flexibility with which to successfully absorb the costs of change and are often reluctant to take on further risks. Those with higher financial status or access to credit are more likely to be able to diversify (Ogburn 1972).

Income diversity:
Individuals with income derived from multiple resource types or sectors are likely to be less sensitive to resource impacts from climate change. In many regions, individuals tend to diversify their income sources to spread risk, manage seasonality, increase flexibility, achieve stability, and better cope with shocks in any one system. For example, a pastoralist

may also operate a small farm, shop or chandlery in addition to their cattle business. These individuals have more options for responding to climate-induced changes to key resources, and thus will be less sensitive to climate changes than those who derive most of their income from a single enterprise.

Local environmental knowledge:
Some individuals have invested substantially into developing local environmental knowledge and can detect subtle changes in resource condition over time. However, this investment usually means that individuals are less likely to move and develop it again elsewhere (Carroll *et al.* 2000). While individuals with high levels of local knowledge are often well-adapted to current conditions, they are likely to be especially sensitive to resource changes. In this study we ask pastoralists to describe whether they monitor soil condition as a proxy for local knowledge.

Environmental awareness, attitudes, beliefs:
Environmentally educated and aware resource-users tend to be more flexible and supportive of resource-protection strategies (Marshall *et al.* 2007). Pastoralists that have higher environmental awareness can develop identities such as 'land steward', which makes them less dependent on traditional resource management practices, and more willing to adopt new practices that promote sustainability. Here we ask respondents for the extent to which they see themselves as responsible for the future productivity of their land.

Resource Use:
The interaction between pastoralists and the grazing resource is likely to be a strong predictor of dependency. In this study we asked pastoralists to describe how variable their stocking rate was over the last twelve months.

4.1.2 The components of adaptive capacity

Adaptive capacity is a description of the potential or preconditions necessary to cope with novel situations and enable adaptation without overly losing options for the future (Nelson *et al.* 2007). For the most part, these 'pre-conditions' reflect learning, the flexibility to experiment and adopt novel solutions, and the ability to respond generally to a broad range of challenges (Levin *et al.* 1998; Gunderson 2000). Characteristics that contribute to adaptive capacity include possessing creativity and innovation (for identifying solutions or adaptation options), testing and experimenting with options, recognising and responding to effective feedback mechanisms, employing adaptive management approaches, possessing flexibility, being able to reorganise given novel information, managing risk and having necessary resources at hand (Marshall *et al.* 2011).

At the individual scale, adaptive capacity has been more comprehensively operationalised according to four measurable attributes reflecting an individual's skills, circumstances, perceptions and willingness to change (Marshall & Marshall 2007). They encompass: a) how risks and uncertainty are managed, b) the extent of skills in planning, learning and reorganising for change, c) the level of financial and psychological flexibility to undertake change; and d) the level of anticipation of the need and willingness to contemplate and undertake change. We refer to these four dimensions as a basis from which to examine the capacity to undertake change, and correspondingly, assess social vulnerability.

4.1.3 Methods

Survey development
Survey questions were developed so as to quantify a pastoralist's resource dependency, and capacity to adapt to climate variability (Appendix 6.10). Some questions within the survey, such as 'in what year were you born?', required simple answers. Some questions

such as, ‘are you employed as a land manager on someone else’s land?’ required a ‘yes’ or ‘no’ answer. Answers to most questions, however, were expressed as a statement and reflected an attitude, opinion or stance. For example, one statement was, “I do not talk about strategies to survive drought much with others”. Respondents were asked to rate how strongly they agreed with each statement using a 5-point rating scale (1=strongly disagree, 2=disagree, 3=neutral, 4= agree, 5=strongly agree). This scale builds upon the Likert scale (Likert 1932) and is especially useful in quantifying and comparing attitudes, since results can be standardized and contrasted. Respondents were asked to leave a question blank if they preferred. Responses for negative statements were reversed prior to analysis. An initial version of the survey was pilot-tested with 10 pastoralists in their homes to ensure that the questions were readable and unambiguous.

Survey administration
An intensive media campaign commenced the survey administration phase to introduce the research to pastoralists across northern Australia. Grazing families also received a personal letter informing them of the research and inviting them to participate. Names, addresses and telephone numbers of pastoralists were obtained from the yellow pages; an online business directory. Within two to three weeks of receiving the letter, pastoralists received a telephone call and were again invited to participate in the research. Some pastoralists were happy to complete the survey immediately, and others made an appointment at a more convenient time. Of the 308 pastoralists that were contacted, 32 refused to participate in the research. Our sample of 240 pastoralists thus represents 78% of those contacted.

Data analyses
Quantitative data were analysed using standard statistical techniques (using SPSS®). A ‘weighted mean’ or F-score was calculated for each component of resource dependency, adaptive capacity and climate awareness. Correlations between adaptive capacity and resource dependency conducted using Pearson Correlations of the F-scores for each conceptual variable.

Types of vulnerability were identified used K-means clustering, and results were considered for up to ten clusters. Most information about vulnerability was gained from specifying four clusters. An analysis of variance F statistics was used to provide information about each variable's contribution to the separation of the types. Bonferroni adjustments were made to offset the chance of a false rejection of the null hypothesis in the number of separate tests.

We did not want to represent vulnerability as a standard mean and standard error for the population, because we were worried that this would not reflect the full range of diversity among resource-users. Instead, we chose to represent vulnerability of resource users on the rangelands using the concept of ‘types’. Typing people provides an opportunity to understand social heterogeneity within a population. It also provides an opportunity to directly ‘match’ various potential adaptation options to the full range of individual ‘vulnerability types’ on the rangelands and savannas.

4.1.4 Results

We identified four types of pastoralists according to their vulnerability to climate change (Table 4.1). The two most vulnerable types were also the most prevalent within the sample. The main type of pastoralist represented 43% of the sample. This type was vulnerable because they had low skills for planning, experimenting, reorganising and learning and low interest in adapting to the future. They were 59 years old on average and were only weakly networked within the industry. Their businesses were generally relatively small (mean size was 72,728ha, 1.9 employees, 4,600 head of cattle and a business turnover between $1M-$5M).

The next main second type of pastoralist representing 41% of the sample was vulnerable because they managed risk and uncertainty poorly and were not strategic in their business. They were 51 years on average. Their businesses were medium sized (mean size was 111,634ha, 3.4 employees, 7,000 head of cattle and a business turnover between $1M-$5M).

Together, these two main types of pastoralists represented nearly 85% of the sample. Only 15% of pastoralists appeared to have higher levels of resilience to change. One of these types of pastoralist, representing 13.4% of pastoralists, had a stronger psychological and financial buffer, they were well net-worked and tended to operate large businesses (mean size was 364,639ha, 8.9 employees and a business turnover between $1M-$5M). The other main type, representing only 2.6% of the sample, managed risk well, liked to experiment with options and were interested in change. Their mean age was 41 years old. They were well networked and used technology. They also operated large businesses and saw themselves as responsible for the future productivity of their land.

Pastoralists with most resilience were located in the Burdekin River Catchment (Table 4.2). None were located in the Gulf country. Please note that equal numbers of pastoralists were not sampled within each of the seven regions.

Table 4.1: The four main types of pastoralists based on their vulnerability to climate change.

N=232	**Cluster One**	**Cluster Two**	**Cluster Three**	**Cluster Four**
Numbers of People	**31 (13.4%)**	**6 (2.6%)**	**100 (43.1%)**	**95 (40.95%)**
RISK	.67630	1.46228 Manages risk well	-.05768	-.20124 Manages risk poorly
PLAN	-.08211	.72139 Likes to experiment	-.10054 Doesn't experiment	.09851
COPING	.42102 More likely to cope	-.87522	.09739	-.18931
INTEREST	.04376	.94812 Interested in change	-.13929 Less interested in change	.10262
Identity	.83484 Strong identity	1.11073 Strong identity	-.14170 Low identity	-.07211
Employability	-.74297 Mean age= 52	1.19598 Mean age= 41	-.02157 Mean age = 59	.14578 Mean age = 51
Networks	.78091 Strong	.95230 Strong	-.18120 Weak	-.08357
Dependents	4.03 With kids	1.00	.07 No kids	4.20
Approach	.57002	.91606 Use technology	-.06656	-.14282 Not strategic
Business size	10.11315 Size= 364,639 ha Employees= 8.9 cattle= 12,000, income= $1-5M	.03144 BIG H=218,428 Employees = 6.3, cattle=2000, income=>$5M	-.16686 SMALL 72,728, Employees = 1.9, cattle 4,600, income=$1-5M	.03057 Medium 111,634, Employees = 3.4, cattle = 7,000, income=$1-5M
Environmental Awareness (1-5)	4.71	5.00 Highly green	4.58	4.46
Are you the owner?	1.58 Manager/ Owner	1.17 Manager	1.76 Owner	1.76 Owner
% family income from cattle	100%	100%	80-99%	80-99%

Table 4.2: The number of pastoralists within each vulnerability type for each region across northern Australia.

	Cluster				Total
	1	2	3	4	
Roma	3	0	21	17	41
Fitzroy River	3	1	13	4	21
Gulf region	0	0	2	6	8
Victoria River, NT	1	0	0	1	2
Alice and NT	2	0	2	1	5
Kimberley, WA	1	0	5	1	7
Burdekin	20	4	56	64	144
Total	30	5	99	94	228

4.1.5 Discussion of vulnerability across northern Australia

Our results suggest that there are several ways in which pastoralists can be vulnerable to climate change. Pastoralists can be vulnerable because of a high level of resource dependency and/or a low level of adaptive capacity. The most common ways in which pastoralists across northern Australia were vulnerable were their management of risk and uncertainty, their planning, experimenting, reorganising and learning skills, their level of interest in change, networks, business size, and environmental awareness.

The most important finding from this section suggests that only 15% of pastoralists have the capacity to currently prepare for climate changes. Most pastoralists across northern Australia are unlikely to adapt to climate changes or to the strategies promoted to assist in climate adaptation. Unless the vulnerability of pastoralists is reduced, climate adaptation planning processes are unlikely to be successful.

4.2 Thresholds and barriers to change

4.2.1 Introduction

Thresholds of coping

Resource managers planning for climate adaptation are likely to require knowledge of the current capacity of a resource system to absorb change, what the current trajectory is for the system and what is needed to guide the current trajectory onto a more desirable pathway. Identifying thresholds of coping and measuring the proximity of social systems to them are vital pieces of information for climate adaptation planning because social systems that are distant from their thresholds should be able to absorb change, and should be more easily directed onto a planned pathway (Olsson *et al.* 2006; Adger *et al.* 2011). The challenge is to recognise what the thresholds look like and measure their distance.

Socio-ecological systems possess marked thresholds which determine whether they will switch from a ‘desirable’ state into an ‘undesirable’ one (Walker & Meyers 2004). Systems can shift dramatically and often irreversibly between states, depending on how close they are to their ‘thresholds’ and how large the change-event is (Folke *et al.* 2002; Folke 2003). A sufficiently large change event can cause a system to switch to an alternate state if the thresholds of coping are reached and exceeded. For example, a thriving agricultural community can become a “ghost-town” when markets or environmental conditions fail to keep communities viable (Carpenter & Gunderson 2001). Once the threshold is crossed it is difficult to reverse back to the original state (e.g. from a ghost town into a thriving community once more). Such negative shifts from ‘desirable’ to ‘undesirable’ states represents loss of system resilience, and whether a system is heading for collapse is important to know for planning purposes.

Researchers often argue that there is no point in actually measuring thresholds. Measurements of thresholds typically have low precision and shift with time due to the inherent complexity and dynamic behaviour of social systems. In fact, thresholds are believed to change so rapidly that it is difficult to design assessment programs that can develop as quickly as thresholds change (Berkes & Jolly 2001; Folke *et al.* 2002). Instead, developing social tools that focus on building adaptive capacity and identifying desirable trajectories rather than defining, measuring and predicting where social thresholds lie might be more useful. Pastoralists with higher levels of adaptive capacity should be able to move thresholds further away and make them more or less difficult to reach (Walker & Meyers 2004). Yet, we also argue that knowledge of the proximity of thresholds distinguishing between desirable and undesirable regimes – and the nature of such thresholds - are important for prioritising adaptation planning. For example, pastoralists that are close to their thresholds of coping might be given urgent attention if maintaining industry resilience in the face of climate change within a specific region is important.

Our research suggests that the thresholds of coping strongly reflect the level of climate sensitivity (or resource dependency) of pastoralists. Pastoralists that are more dependent upon the grazing resource are likely to be more sensitive to changes. These pastoralists are likely to be closer to their thresholds of coping. However, we also recognised that what was a threshold for one person was not necessarily a threshold for another. Thresholds are very much an individually-set construct; even for economic values. For example, whilst a poverty threshold of $20,000 annual income might be a useful point in space to describe poverty for Australians, many people will be able to live well beneath this amount and report high standards of well-being, whereas others will be unable to cope.

Social thresholds are particularly difficult to define and set. Using our list of factors that define resource dependency, we think that we can impart a solid understanding of what thresholds of coping might look like within the northern cattle industry. Some thresholds might be about identity, whilst others might be about place attachment, employment, lifestyle, or environmental awareness. For example, some pastoralists may be close to their thresholds of coping if they have high occupational identity, and experience a change event that directly threatens their identity as a pastoralist or ability to continue within their occupation Similarly, pastoralists may be close to their thresholds if they have high place attachment and they experience a change event that directly threatens their ability to remain working and living in their 'place'. Other pastoralists may be close to their thresholds if they are poorly networked within the industry and the change event directly threatens their ability to identify and capitalise on other opportunities. The social impacts that are associated with each threshold will also be important to acknowledge such as psychological impacts, loss of livelihood, family breakdown, loss of connection with community and the like.

Barriers to change

An important component to understanding climate adaptation processes is to recognise that some pastoralists will put up "barriers to change" (Walker & Meyers 2004). These pastoralists may be unable to cope and adapt to the impacts of climate change such as environmental degradation or suffering cattle. Importantly, they will also resist climate adaptation strategies that are presented by either government or industry to assist them in the adaptation process. Developing an industry-wide response or climate adaptation plan becomes ineffective.

We think that the description of pastoralists' resource dependency acts not only to describe their climate sensitivity and proximity to the thresholds of change, but acts also to identify the likely "barriers to change" that can be expected in any region or industry. For example, pastoralists may be aware that they are rapidly approaching a threshold of coping because of an impending or actual change event and will resist the event so as to protect themselves. Their resistance is often regarded as a sign of non-compliance or stubbornness, and they are frequently described as erecting “barriers to change”. We propose that they resist entering a particular new territory because it risks that they will reach their thresholds of coping and enter into an ‘undesirable’ state.

Change events that threaten pastoralists ability to cope and adapt will be resisted. Our aim in this part of the study was to identify what the likely “barriers to change” would be for the northern cattle industry. Knowledge of the range of likely barriers may provide a basis from which a suite of adaptation strategies could be designed with a likely probability of being accepted. We assessed the climate sensitivity of pastoralists across northern Australia according to each dimension of resource dependency and made an assessment about how many pastoralists were close to their thresholds of coping given a change event occurring that directly meant that the proximity to a certain threshold might be affected.

4.2.2 Results and Discussion

We found that a majority of pastoralists were close to a range of thresholds (Table 4.3). The most important threshold for pastoralists across northern Australia was the threshold affecting occupational identity. Other important thresholds of coping included those associated with attachment to place, extent of formal and informal networks and number of dependents. These results suggest that the sorts of impacts and strategies that are likely to ‘push’ pastoralists towards their thresholds of coping include those that threaten identity such as those that encourage leaving the industry or conducting business in ways that do not concur with how they see traditional roles of grazing. Other strategies that are likely to push pastoralists across their thresholds include those that threaten whether they can remain in the same place, or threaten the financial security of families.

Each of the thresholds we have identified in Table 4.3 are also likely to adequately represent the likely barriers to change within the industry. As pastoralists feel threatened that their thresholds may be reached as a result of a certain change event, they are likely to erect barriers to it. For example, our results suggest that occupational identity as well as place attachment are important thresholds and are likely to represent significant barriers to change. Choosing to change occupation or place can represent a ‘self-concept’ change with an ‘old’ self being replaced by a ‘new’ self. There is strong evidence to suggest that control over whether this change occurs is important for psychological and emotional well-being (Fried 2000). Unwanted and uncontrollable change resulting in the loss of continuity may cause grief, a strong sense of loss, psychological impacts and in extreme cases, suicide. In Australia suicide in rural areas amounts to one person every three days (Hogan ref). Suicide is known to be especially severe during drought periods where agricultural people doubt their capacity to remain viable and grieve their loss of identity. Typically, climate adaptation planning has not considered these elements in their design, but our results suggest that without their consideration, many strategies and policies are likely to be resisted or rejected.

The properties that enable people to push their thresholds of coping away and be adaptable, flexible and prepared for change and uncertainty are only just recently receiving attention within the literature (e.g.(Walker & Meyers 2004). However, because social thresholds are not easily observable and are highly context-specific they are rarely successfully ‘measured’ and even more seldomly predicted (Berkes & Folke 1998; Adger 2000). Our results suggest that the identification, assessment and prediction of the capacity of resource-users to cope with climate adaptation strategies and climate impacts can be relatively simply achieved.

Table 4.3: The nature of likely thresholds of coping within the cattle industry and the proportion of individuals that are proximate and somewhat proximate to them.

Thresholds	**Example statement**	**% Strongly agree**	**% Agree & strongly agree**
		Proximate to thresholds	**Some proximity to thresholds**
Threats to identity	I love being a cattle grazier	62.4%	92.6%
	Being a grazier is a lifestyle – it is not just my job	51.9%	80.5%
Threats to continuing in the same place	I would never want to move from this region	29.4%	54.6%
Threats to securing employment elsewhere	I would (not) happily consider another occupation if the need arose	23.6%	39.1%
Access to networks (informal)	I (do not) discuss approaches for climate adaptation with other cattle graziers	16.4%	31.4%
Access to networks (formal)	I (do not) discuss approaches for climate adaptation with government agencies and researchers	33.6%	65.0%
Threats to dependents	How many children do you have living at home? (>2, >0)	14.5%	58.0%
Inability to manage business	I am more of a lifestyle grazier and focus less on making a profit	7.6%	19.5%
Inability to use local knowledge	I (do not) continually record the condition of my land so that I can recognise important changes	8.3%	22.1%

4.3 Minimising the vulnerability of pastoralists

Desirable climate adaptations are those that are planned and which will benefit both society and ecosystems. Yet our results suggest that adoption of climate adaptation strategies within the cattle industry is likely to be low since only 15% of the industry of the industry has the capacity to change. One possibility to assist the industry is to enhance the adaptive capacity of pastoralists. Another will be to reduce the level of resource dependency within the industry. However, both of these endeavours are likely to be expensive and will require substantial amounts of time. We consider here how vulnerability to change (or the antonym;

resilience) might be managed as effectively as possible, given knowledge of what makes pastoralists vulnerable. We looked at the relationships that existed between components of climate sensitivity and adaptive capacity (Table 4.4), and whilst we do not attribute causality between the factors, we suggest that a significant relationship might indicate an opportunity to manipulate adaptive capacity.

Results suggest that many dimensions of resource dependency were highly correlated with many dimensions of the capacity to change (Table 4.4). For example, place attachment had a negative relationship with the capacity to change. Whilst place attachment may bring resources such as networks, social capital, local knowledge and a sense of well-being into a region (Pelling & High 2005), our results suggest that it may also act to render resource-users highly dependent on remaining where they currently are, regardless of the untenability of the location. In these instances, individuals that are highly attached to their place are likely to be highly sensitive to changes; especially those associated with impacting on place. Our results suggest that individuals with high place attachment, for instance, have very little interest in change, and tend to have poor planning and risk management skills. The challenge here is to understand the nature of the relationship between adaptive capacity and resource dependency and recognise when resource dependent factors act to enhance adaptive capacity, and when they act as barriers to change.

Related to place attachment is the extent to which individuals are networked within their industry and beyond. Social networks have been shown in a range of settings to be important for adaptation purposes (Wolf *et al.* ; Folke *et al.* 2005). Our results have also found that the extent to which individuals were networked was a positive influence on the capacity to change (Table 4.4). Our results suggest that individuals that were well embedded within the broader community were more exposed to novel ideas and opportunities and appeared to be in a stronger position to adapt. The challenge here is too assist resource-users to develop internal and broader networks that can support novel adaptation strategies. Facilitating networking opportunities might be useful, as might strategies that involve including a diversity of people including women within the industry to assist with providing novel ideas or act as change agents or facilitators (Nielsen & Reenberg).

A strategic approach to doing business (Marshall *et al.* 2009) was also identified as important in influencing the capacity to change (Table 4.4). These results support the important work of others working in climate adaptation (Cinner *et al.* 2009; Cinner *et al.* 2011). The challenge is to encourage resource-users to invest in the development of their strategic skill sets so as to develop their capacity to undertake a range of climate adaptation strategies. In Australia, these responsibilities might be imparted to local Natural Resource Management authorities with the expertise to roll-out workshops that enhance the capacity of resource-users to manage their land more sustainably.

We also found that local environmental awareness and how users interact with a resource (e.g. variability in stocking rates) were significantly and positively correlated with at three dimensions of the capacity to change (Table 4.4). These results suggest that another challenge will be to improve environmental awareness and the extent of environmental monitoring within an industry to encourage an increase in the capacity to change. Our results suggest that resource-users who use dynamic stocking rates may in fact be better acquainted with the need to adapt – perhaps because they are more aware of environmental degradation processes and the limitations of the environment to sustainably provide benefits (Olsson *et al.* 2010).

The technical aspects of resource dependency (whether pastoralists were likely to access climate technology and expertise) were also significant influences on capacity to change in this study, suggesting that if pastoralists could be encouraged to use climate technologies (Marshall *et al.* 2011), then transformational capacity might be enhanced on at least three dimensions (Table 4.4). This remains the next challenge. Resource-users that use technologies, such as seasonal climate forecasts, to help them make decisions regarding the future are more likely to have an interest in change and develop the appropriate planning skills.

Income diversity did not influence adaptive capacity in this study. Yet, the literature abounds with advice to diversify in order to increase resilience. For a pastoralist to be resilient, they must have the capacity to change. Our results suggest that whilst diversification may create options to adapt (Cinner *et al.* 2011), having options does not necessarily mean that the capacity to capitalise on those options exists. This is because adaptive capacity is the potential to mobilise existing resources necessary for adapting to change and is not simply a description of the resources at hand (Nelson *et al.* 2007). Our results suggest that other factors are much more important in influencing adaptive capacity.

Governments, communities and other institutions that support primary industries are likely to have a vital role to play in assisting resource industries to undertake a range of adaptations (Marshall *et al.* 2010; Stokes & Howden 2010). Future research might identify and test the significance of other influences on adaptive capacity. For example, how people embedded within different institutional contexts are enhanced or restricted in their capacity is important for learning across scales. Creating supportive policy environments that enable lower-risk change pathways and that provide well-matched incentives for effective change are other important research (Brooks & Adger 2004; Brooks *et al.* 2005).

Table 4.4: The relationship between resource dependency and each of the four dimensions of adaptive capacity within pastoralists of northern Australia.

Resource Dependency	RISK	PLAN	COPE	INTEREST
Identity	.249**	.286**	.108	.057
Place	-.147*	-.208**	.106	-.304**
Employability	-.080	.237**	.010	.213**
Networks	.066	.317**	-.008	.378**
Dependents	.059	.017	-.051	.105
Strategic Approach	.148*	.477*	-.023	.519**
Business Size	.081	.146	.119	.054
Local Knowledge	.060	.123	-.013	.111
Greenness	.255**	.178**	.080	.214**
Resource Use	.233**	.347**	.114	.248**
Owner/Manager	.018	-.048	-.046	.007
%Income from cattle	.073	.024	.051	.059
Use of technology	.111	.256**	-.067	.631**

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5 Conclusions

5.1 Synthesis of vulnerability and adaptation recommendations

This project aimed to assist the northern beef industry to prepare for the future by evaluating vulnerability to climate change and ways of enhancing adaptive capacity. To do this we conducted a cross-regional analysis of the northern beef industry that systematically analysed agro-ecological, economic and social dimensions of vulnerability and adaptability by addressing two fundamental questions (Fig. 1.1):

1) What are the key factors that contribute to some places/enterprises/people being more vulnerable to climate change?
2) Based on this understanding, what adaptive actions can moderate these sensitivities and impacts to improve the resilience of the northern beef industry?

We conclude here with a synthesis of the findings, in relation to these guiding questions, and their implications for planning adaptation strategies. This includes feedback from a strategy workshop that was held with representatives of peak industry and government (RD&E and policy) bodies at the end of the project (Table 5.1). Our intention is not to prescribe what adaptation strategies others should follow. Rather we recognise that there are many organisations already actively working in this area and would see this report as a resource that can stimulate thinking and feed into planning approaches within those organisations.

There are a diverse suite of factors that contribute to how sensitive different parts of the pastoral industry will be to climate change. Some of these (such as the soil properties, and attachment to place and occupation) will be difficult to alter, but are still important to recognise for the role they play in determining overall differences in vulnerability. Others (such as land condition, strategic skills, networking and climate knowledge) have greater potential to be influenced, and indicate opportunities where adaptation efforts could be targeted to reduce climate sensitivity and/or offset negative impacts (Table 5.1a, Fig. 1.1). These opportunities would include supporting efforts to improve land condition, control the spread of trees and weeds, develop strategic business skills, improving networks (between and among pastoralists and government agencies), and enhance the ability to monitor and respond to environmental changes (Table 5.1b). Most of these avenues are already being pursued to some extent in existing (or planned) activities targeting climate adaptation or otherwise improving resilience in the beef industry. These activities can be considered in four main areas:

Risk management:
One of the key focus areas is improving risk management capabilities. This includes the Risk Matrix method (Cobon *et al.* 2009) and similar approaches that look to convert generic climate change information into practical location- and industry-specific challenges that could result from climate change. There is also a need to put these climate risks in context relative to: other challenges that producers are responding to; how well past experience of climate and market variation equips them to deal with emerging climate risks in the short and medium term; and the likely relative advantage of climate change risks for the north when compared with the less favourable projections for agriculture in most of the south of the country.

Best management practice (BMP):
There is a currently a strong emphasis on adoption of BMPs aimed at improving both the sustainability and profitably of beef enterprises (including the NGS approach). These target most of the bio-economic sources of vulnerability identified here. More recently, internet-based remote assistance and other approaches to improving decision making have been trialled to support the extension of BMPs.

Communication:
There are a range of approaches that have been used to improve the communication of climate challenges in a more accessible way. One of the more innovative of these is the Climate Dogs approach (http://www.dpi.vic.gov.au/agriculture/farming-management/weather-climate/understanding-weather-and-climate/climatedogs) which uses animated working dogs to simply the complex processes that drive variability, and builds on

Table 5.1: Summary of information for adaptation planning (including input from strategy workshop) summarising: a) sources of vulnerability and potential targets for improving adaptability (*), b) current or planned activities by government agencies and peak industry bodies to assist adaptation and c) priorities for future efforts to assist the northern beef industry to better cope with climate challenges. (There is not a 1:1 correspondence between sources of vulnerability and actions/priorities across rows.)

Sources of Vulnerability / Resilience	Strategies & Actions (Current & Planned)	Adaptation Priorities
Agro-ecological + Better land condition* [– Greater climate variability] – Animal heat stress* – Increasing trees* – Biosecurity (weeds, pests & disease)* [+ Sandier soils]	**Risk-management** • Risk matrix approach • Define local practical risks • Define risk relative to: - other challenges - past experience of climate & markets - other regions (north vs south)	**Immediate co-benefits (low regrets)** • Strategic capacity (85% are vulnerable) • Existing overlapping BMPs • Seasonal (including trend) forecasting
Economic [– Cost-price squeeze] – Debt levels +/– Market changes (increasing protein demand, live export) + Productivity (sustainable)*	**Best Management Practice** • Focus on near future • Remote (internet) assistance • Improved decision making (e.g., attachment to livestock)	**Medium-term** • Managing gradual transition e.g., “Learning from History” • Enhance industry networks • Identify “climate analogues” • R&D of adaptation options • Monitor (uncertain) changes • Identify opportunities and threats (north vs south) • Supporting policy (facilitate change, reduce barriers and conflicts) (e.g. identity)
Social + Strategic skills (incl. risk management, planning, business approach) * + Formal networks* – Apathy (burnout, uncertainty, regulation overload, disinterest) + Environmental awareness and monitoring change* + Knowledge of climate technologies* [–/+ occupational identity] [– Place attachment]	**Communication** • Climate Dogs • Climate Futures • Regional fact sheets • Climate Champions • Communities of Practice	**Long-term (not a priority yet)** • Security of carbon stocks • Regional infrastructure • Shifts in market access
	Technical • Climate data • Pasture and enterprise modelling • Decision support	**Engagement** • Clarify messages • Place/industry specific information • Emphasise what IS known (not just uncertainty) • Target next generation of managers (e.g., consider a qualification/standard for entry to industry)

+ indicates characteristics contributing to resilience; – indicates sources of vulnerability;

* indicates quality could be targeted to enhance adaptability; [...] indicates limited ability to influence;

this to explain how climate change is changing these important rain-generating processes. It is now being extended to other states. The Representative Climate Futures (RCF) approach (Whetton *et al.* 2012) simplifies climate scenarios into a few categories with qualitative (and quantitative) descriptions that are independent of GCM projections. (Our climate gradient approach can be converted to these RCFs for simplified communication (Webb *et al.* 2011), but the coarseness of RCF categories lacks the resolution required for cross-regional comparisons).

Technical improvements:
Ongoing technical refinements aim to improve many aspects of climate data (projections, downscaling, and generating modified daily weather data), its use in improved models and analyses of climate impacts and effectiveness of management actions, and the possibility of ultimately building decision support tools from these.

Combining these activities into strategies that effectively enhance the capacity of the industry to deal with future challenges is more difficult. In the past we have emphasised the need for a long-term strategic approaches to adaptation that build on a sequence of prerequisites: confidence that the climate really is changing; the motivation to change to reduce risks or seize opportunities; demonstrating the benefits of adaptation options; supporting transitions to new management (or land use) practices; building capacity for land managers to develop and implement adaptation strategies; adapting regional transport and market infrastructure; and monitoring to provide early detection of uncertain projected change, and effective management responses (Howden *et al.* 2007b; Stokes and Howden 2010; McKeon *et al.* 2009). Ideally the beef industry would be broadly engaged and represented throughout this process, providing input in the early stages of development so that support and options are appropriate by the time they are implemented.

However, in light of the diversity among producers (and particularly the small proportion with strong strategic skills) indentified in this report, we suggest that a range of approaches will be required to accommodate these differences. Furthermore there are numerous contributors to apathy that could create a barrier to strategic engagement including burnout from too much communication and consultation, passive and active disinterest in climate science, regulatory overload, and inaction in response to climate change uncertainty (Table 5.1). The idealised long-term strategic approach may therefore only be effective for engaging with a minority of producers. It will need to be complemented by approaches that are compatible with managers for whom engagement, adoption and change in management is more likely to occur as result of short-term (less than 18 months) tactical decisions made in response to immediate challenges. Case studies of management change in Australian agriculture suggest this may be how widespread adoption is most likely to occur e.g., *Bos indicus* bloodlines were rapidly incorporated across northern beef herd in the 1970s following failures of tick control measures, 40 years after research into these breeds with industry leaders began (Parsonson 1998, McKeon, pers. com.). Importantly however, for such options to be available for adoption when widely demanded, they still have to be developed (by researchers working with industry leaders) and proven (by early adopters, once viable), starting well in advance. The initial priorities for adaptation are therefore likely to focus on options with the most immediate benefit, while simultaneously planning ahead strategically for what will be required next, and assisting a broader proportion of the beef industry to become involved in the development of adaptation options (Table 5.1c).

One of the clearest short-term priorities to emerge is the need to assist the 85% of the industry who are most vulnerable to change to improve their strategic business skills. In particular, there are likely to be substantial benefits from developing scenario planning skills that equip pastoralists to cope with emerging uncertain challenges by conceiving of future scenarios and working through possible plans to respond and reorganise accordingly. Strategies to increase their strategic capacity might include workshops that address generic business skills, as well as creating opportunities for industry members to learn from each other. This might include web-based activities (e.g. face-book, twitter, blogging, webinars, email news), community activities (Climate Dogs, Climate Futures, Climate Champions, Communities of Practice), facilitated networking opportunities (e.g. mini-conference style meetings, web-based communities) as well as the opportunity to interact and learn from formal members of the industry (e.g. researchers, policy makers, peak industry bodies) through webinars, newsletters, regional fact sheets or special events. Many industry members will be reluctant to become involved in such activities, and further research is needed to identify and test the effectiveness of a range of factors that could be important in improving strategic capacity for these individuals. For example, it may be worth targeting the next generation of managers, who are still developing their management approaches and will have to deal with the longer-term effects of climate change. In some countries a qualification standard is required to be able practice agriculture and this could be considered for future managers locally, as one way of accelerating a foundational level of capacity in the industry on which to build.

The other short-term priority is to focus on management practices that have immediate co-benefits (irrespective of climate change), that can be promoted by emphasising the immediate benefit. This is the emphasis of existing activities promoting best management practice (BMPs) described above. However, BMPs need to be forward-looking, not just drawing on past experience but anticipating how they may need to be modified to meet future challenges (the approach taken in this and the related B.NBP.0616 projects). There are strong synergies between existing BMPs and adaptation and mitigation options. However, some conflicts can be anticipated where the trade-offs will need to be managed, especially in the areas of fire management and the control of woody vegetation (native and weeds).

Of the existing BMPs the one with the strongest overlaps with climate adaptation is managing seasonal variability. This should provide a strong foundation for building preparedness for climate change because: in the short-term managers are likely to be more concerned about coping with year-to-year variation, while climate change is not yet pushing extremes much outside bounds of past experience; accounting for year-to-year differences builds in some automatic tracking of the initial impacts of climate trends; these approaches encourage a shift from less flexible management styles to ones where managers adaptively monitor and respond to changes; and managing for extreme events is already important in agriculture and will become more so as extreme events become more common under climate change (Stokes and Howden 2010). An understanding of the climate processes that create variability, seasonal forecasting and their application to risk-based management decision-making also provide a foundation for progressively incorporating the influence of climate trends, as these trends become more apparent (e.g., Climate Dogs mentioned above).

Development of new options (beyond co-benefits of existing options) will need to consider the (sometimes long) lead times from initiating development to adoption and impact, to ensure action is taken in time to meet the demands when required for shorter-term tactical adoption. Despite future uncertainty, there are a number of medium-term (within ten years) considerations that can be anticipated with sufficient confidence to require action to begin now (Table 5.1). Whatever change occurs, there will be benefits for all those involved in supporting industry resilience from enhancing networks: among pastoralists, among government agencies (policy, extension and research), and between industry and government. The enormous diversity of land types and climates in which pastoralism occurs indicates that this is an extremely adaptable land use and that the industry as a whole has a wealth of experience to draw upon in adjusting to local shifts in future climate and vegetation. Broadening existing localised networks would allow people to more easily access expertise from those further away, who may have experience relevant to future needs under climate change. This process could be facilitated by identifying "future analogue locations", where current enterprise structures and practices may be useful in preparing for similar future climate and vegetation in another region. Government policies are more likely to support effective adaptation if policymakers, researchers and industry cooperate to ensure developing new policy and research. This includes consideration of potential trade-offs and conflicts in related policy areas (especially those pertaining to drought, water, mitigation and vegetation management) to ensure they do not unnecessarily constrain the flexibility of land managers to adapt to future changes (both within existing property boundaries and broader regional structural adjustment).

Monitoring provides a useful response to uncertainties about medium-term climate trends, since it provides a means of detecting early changes that are location and industry specific. This includes property and regional-level monitoring of weather data, pasture and enterprise productivity, and tracking any spread of pests, weeds and diseases. Past experience in Australian rangelands has shown episodes of rapid degradation (over a decade or less) have tended to occur where there were delays in reducing stocking pressures to match relatively small cyclical declines in productivity associated with climate variability (McKeon *et al.* 2004). This highlights that a key threat during the early stages of gradual climate change trends will be ensuring that timely actions are taken to adjust stocking rates to gradually changing productivity of pastures, to avoid the risk of a widespread degradation episode (or lost opportunities) that delayed action could bring. Most long-term considerations are not a priority for action yet. The exception is the long-term security of carbon stocks and associated risks of decline (drying climates, fire regimes) that should be considered as part of any mitigation practices based on biosequestration. Monitoring activities should also take into account longer-term considerations (such as evaluating effectiveness of initial adaptation actions), and re-evaluate priorities if necessary.

Many of these recommendations support existing initiatives to improve resilience in the beef industry, adding further motivation for efforts to improve stocking rate management, land condition and climate variability (although these will need to be complemented by adaption options for coping with additional, unique new climate challenges such as coping with greater heat stress for livestock and people). Results also highlight the benefit of improving strategic planning skills and networking among producers. However efforts to build producer capacity are likely to more effective if they accommodate individual differences and develop a range of approaches suited to the particular needs of different groups.

5.2 Success in achieving objectives

The procedural contractual objectives of the project were listed in the introduction (Section 1.2). Here we briefly summarise how the material presented in this report met each of these objectives.

1. *Incorporated the effects of CO_2 on pasture production (including OzFACE results) into the modelling framework*.
   We improved the way in which CO_2 effects are represented in GRASP by updating previous approaches to include the benefit of CO_2 in improving nitrogen use efficiency of pastures (an effect observed in experiments but that had not previously been represented in GRASP) (Section 2.3). This improved approach was used in both 'Component 1' and 'Component 2' of the project (although a more conservative approach was used in 'Component 1' B.NBP.0616). Since GRASP does not include a full nitrogen cycling sub-model the nitrogen use efficiency benefit is not represented mechanistically, but by adjusting parameters that determine the limit to which nitrogen can be diluted in grasses before growth stops.

2. *Identified effective responses for supporting producers to adapt successfully to a changing and more variable climate*.
   Property-level management options for adapting to specific climate challenges were identified in an initial review and refined with producer input at each of the regional NGS workshops (Section 2.2, Appendix 6.2). Broader approaches to supporting adaptation across the industry were analysed in each of the agro-ecological (Section 2), economic (Section 3) and social (Section 4) sections. The conclusions above provide a synthesis of our recommendations (Section 5.1).

3. *Extrapolated regional and property-level results to evaluate climate change impacts across the north, using the best available climate projections*.
   A cross-regional analyses using GRASP simulations for each NABRC region explored climate change impacts, sensitivities and effectiveness of broad adaptation options (Section 2.5) using parameter sets (GRASP MRX files) from the property-level analyses in 'Component 1' B.NBP.0616.

4. *Identified thresholds beyond which incremental adaptation is unlikely to be adequate*.
   Although economic viability of an enterprise is a relative construct – i.e. determined by individual expectations and preferences, social norms and acceptable levels of reward for effort or investment – it is reasonable to conclude that one extreme limit is the point at which current or incremental management is no longer capable of generating positive levels of net profit or returns to capital investment consistent with safe alternatives (e.g. bank deposits). Despite operating in highly variable markets and agro-climatic conditions, the majority of northern beef enterprises yield relatively limited economic returns under contemporary management systems and current climatic circumstances. In fact, many have operated at an economic loss over the past decade (McCosker Report, ABARES). Using economic model templates developed for 9 agro-ecologically separated regions of the northern grazing lands (MLA-DAFF funded project B.NBP.0616) it was possible to identify thresholds at which projected economic returns fell to zero for a range of 'representative' beef enterprises in these regions (Section 3.4). These break-even points were largely based on changes to projected carrying capacity, which are in turn co-determined by changes in animal productivity. The relevant declines ranged between -12% and -71% across the 9 rangeland regions and averaged -46%. That is, on average, carrying capacity could decline by almost one half before the average enterprise from the range considered yielded an economic loss – however, for some regions (e.g. the Kimberley where land condition is relatively poor, this margin is considerably less and for other regions (e.g. VRD) it is much more accommodating.

5. *Identified conditions / regions where incremental adaptation may be insufficient to offset climate impacts*.
   Projected climate change, although important, is an additional stressor for profitable pastoral production in northern Australia. The economic position of many northern beef enterprises is already weak under contemporary management systems and current climatic conditions. For example, a recent beef sector situation analysis (McCosker Report) suggested that around one half of all beef enterprises failed to earn a positive economic return in 6 of the last 7 years to 2010-11 (Section 3.2). Moreover, in the face of a longer term declining trend in 'terms of trade' for beef production of around -1.5% pa, productivity gains critical to retaining profitability have stalled further exposing of northern beef enterprises to viability risks. It is noted that another MLA-funded project has been commissioned to specifically address this issue – viz Project B.BSC.0107: A scoping study with CSIRO's Sustainable Agriculture Flagship to identify and implement sustainable development pathways for the northern beef industry aligned with NABRC RDE priorities. These productivity gains which have been based on a mix of research-derived technologies and the application of improved land and herd management practices, have typically represented the principal form of incremental adaptation in the

sector. All of the regions studied were generally sharing a limited capacity for further adjustment, although the modelling results did suggest that some of the regions had a wider margin for change than others (e.g. contrast the relative break-even points for the Kimberley and VRD). The conclusion is necessarily reached that many northern beef enterprises already possess limited scope for incremental adaptation to adverse movements in marketing and production trends that are already apparent. Projected climate change for these enterprises is simply an additional source of stress to be accommodated (Figs. 2.1). The regions that showed the greatest risk of crossing the 'break-even' threshold under 10th percentile rainfall trajectories, even improving land to 'B condition', were (in decreasing order): the Kimberly, Central Queensland, South Queensland and Western Queensland (Fig. 2.2).

6. *Identified coping mechanisms for the northern beef industry*.
   In Section 4 we identified all the reasons why pastoralists might not cope with change and some mechanisms to assist them navigate through change. Property-level adaptation options were reviewed and then discussed with producers at each regional NGS workshop (Section 2.2) and the collated (Appendices 6.1 and 6.2).

7. *Provided draft input for use in forming a strategic industry response plan*.
   This report itself provides a resource that can assist organisations working with the northern beef industry develop their own climate change response strategies. Following the framework (Fig. 1.1) and approach (Fig. 1.2) outlined in Section 1, we used the information in this report as the basis for presentations and discussions at the industry strategy workshop noted below.

8. *Presented project findings to peak industry bodies to help identify potential strategies and options for adapting to a changing and more variable climate*.
   The project findings (as presented in this report) were presented and discussed at a strategy workshop with representatives of peak industry and government organisations held at the end of the project (Section 5.1). The feedback from the workshop was incorporated into the synthesis above (Section 5.1).

5.3 Key messages

Despite using the best available data and modelling tools, there are still many uncertainties and caveats in this report. Such uncertainties are likely to persist into the future (even with improved data and analyses) so it is important that adaptation approaches are flexible and robust enough to accommodate this uncertainty. In this sense, the analyses and the results presented should certainly NOT be used as 'predictions' of the future. Rather they should be used as indicative of the types of future challenges and opportunities climate change is likely to bring, serving as a resource for scenario planning to ensure adequate measures and adaptation options are available to deal with such situations where and when they arise.

The agro-ecological assessment found that, overall, the downside risk of declining productivity for the northern beef industry is only slightly higher than the upside risk of improving productivity. Those regions that are currently less productive tended to be more susceptible to the effects of climate change (particularly negative impacts) whereas some of the more productive regions tended to be less sensitive (to either drying or wetting trends). The results reinforce initiatives to improve grazing land management both because pastures in better condition tended to be less sensitive to negative climate impacts, and because associated improvements in productivity could offset declines under drier climate scenarios. Sandier soils (with less capacity to store plant-available water) tended to be less sensitive to climate change and more responsive to improving land condition (but modifying such soil properties is not a viable management option). Other sources of local variation in pasture (such as fertility and tree density) had little consistent effect in modifying their sensitivity to climate change or adaptation options.

While changes in projected pasture condition may seem to be largely determined by changes in rainfall, caution needs to be urged that adaptation does not become solely focussed on this challenge. Temperature and CO_2 effects are large and counter-opposing but CO_2 benefits are less certain and will rise less quickly over time, whereas negative temperature impacts (via vapour pressure deficit) are lagged and escalate with increased warming. This implies that existing efforts to improve land management and strategies for coping with variable rainfall will assist climate adaptation, but are unlikely to be sufficient, and will need to be complimented by strategies for coping with the arising unique new climate challenges (such as rising temperatures, for which there is no prior management experience to draw on).

Many northern beef enterprises are struggling to adapt to pressures being placed on them by contemporary market and climatic trends – many already lack economic resilience and are struggling to integrate productivity enhancing technologies and practices into their current production management systems. Without such adaptive economic capacity, these enterprises will find the task difficult to maintain relative profitability over time. Projected climate change has generally adverse implications for carrying capacity and animal productivity which are two critical drivers of beef enterprise profitability. This further exacerbates what is already a difficult situation.

There is a natural dispersion of capabilities and performance around any industry average and the northern beef sector is no exception. A recent beef sector situation analysis (McCosker Report) identified relative performance differentials for the top 20% of enterprises of 7kg per animal carried, larger scales of operation, higher gross revenues and lower costs in the order of 20% below the average. This higher performing group was more conservative in their stocking rates, had higher levels of animal productivity and were generally rated as better animal and financial managers than the norm. Nevertheless, all enterprises have been facing the same terms of trade trends over time and these are presently around 50% of the level experienced in the early 1970s.

If adapting successfully to both contemporary market and production trends and allowing for additional imposts of climate change requires major structural change of existing production systems the investment implications are extremely important. The sector has relatively limited capacity to handle even modest declines in business equity – that is, the ability to service debt from existing beef returns is limited and relative small declines in equity place an average beef enterprise much closer to the break-even margin of profitability.

In the social component of the project we set out to understand and assess the vulnerability of pastoralists across Northern Australia to climate variability and change as a basis for climate adaptation planning. Through our analysis we were able to identify the thresholds to change and the barriers that would most likely inhibit change processes. Most importantly, we were able to identify the factors and processes that could minimise vulnerability and enhance the resilience of the industry. Our approach was to interview 240 pastoralists across northern Australia by telephone. The key findings were as follows:

Vulnerability is a function of both climate sensitivity and adaptive capacity. We assessed the climate sensitivity of pastoralists as the levels of:

- (i) occupational identity,
- (ii) family circumstances,
- (iii) place attachment,
- (iv) employability,
- (v) formal and informal networks,

(vi) business approach,
(vii) business size,
(viii) income diversity,
(ix) environmental awareness,
(x) local environmental knowledge.

We assessed the adaptive capacity of pastoralists as the levels of:
(i) management of risk and uncertainty,
(ii) skills for planning, experimenting, reorganising and learning,
(iii) psychological and financial buffers,
(iv) interest in adapting to the future.

The vulnerability of the sample of pastoralists was high. One type of pastoralist representing 43% of the sample was vulnerable because they had low skills for planning, experimenting, reorganising and learning and low interest in adapting to the future. They were 59 years old on average and were only weakly networked within the industry. Their businesses were generally small (mean size was 72,728ha, 1.9 employees, 4,600 head of cattle and a business income between $1M-$5M). A second type of pastoralist representing 41% of the sample was vulnerable because they managed risk and uncertainty poorly and were not strategic in their business. They were 51 years on average. Their businesses were medium sized (mean size was 111,634ha, 3.4 employees, 7,000 head of cattle and a business income between $1M-$5M). Together, these two main types of pastoralists represented nearly 85% of the sample. Only 15% of pastoralists appeared to have higher levels of resilience to change.

In our interpretation of the thresholds to change, we recognised that what was a threshold for one person was not necessarily a threshold for another. Thresholds are very much an individually-set construct. We think that identifying the proximity to thresholds may best be achieved by understand the sensitivity of pastoralists to change. For example, some pastoralists may be close to their thresholds of change if they have high occupational identity, and the change event directly threatens their ability to continue within their occupation. Other pastoralists may be close to their thresholds if they have high place attachment and the change event directly threatens their ability to remain working and living in their ‘place’. Other pastoralists may be close to their thresholds if they are poorly networked within the industry and the change event directly threatens their ability to identify and capitalise on other opportunities.

Barriers to change were also able to be identified on the basis of the sensitivity of pastoralists to change. For example, pastoralists with high levels of occupational identity would be less likely to adopt strategies that threaten how they see themselves in their occupational role. Similarly, pastoralists with a lifestyle approach would erect barriers around proposed adaptation strategies that threatened their sense of lifestyle.

Adaptive capacity was highly correlated with many aspects of climate sensitivity. Of those aspects that could be best managed we found that pastoralists that had higher adaptive capacity had stronger networks, a strategic approach to their business, had high environmental awareness and had high local environmental knowledge. Importantly, income diversity, business size and whether pastoralists were owners or managers did not directly influence their capacity to adapt. Income diversity and business size provide options for adaptation, but do not influence the capacity with which adaption processes proceed.

The implications of our social research suggest that any investments into the development of adaptive capacity of pastoralists across northern Australia would heighten the success of any climate adaptation planning. We think that assisting pastoralists to develop their networks, strategic interest, environmental awareness and knowledge (through monitoring soil condition for example) is likely to be highly useful.

Many of these findings support existing initiatives to improve resilience in the industry, adding further motivation for efforts to improve stocking rate management, improve land condition and manage climate variability (although these will need to be complemented by adaption options for coping with additional, unique new climate challenges). Results also highlight the benefit of improving strategic planning skills and networking among producers. However efforts to build producer capacity are likely to more effective if they accommodate individual differences and develop a range of approaches suited to the particular needs of different groups.

5.4 References

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6 Appendices

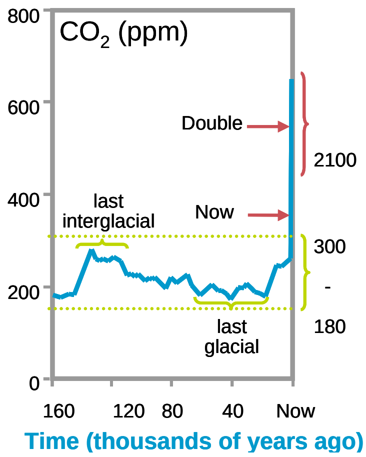
6.1 Appendix 1 - Synthesis document on climate change impacts and adaptation options in rangelands

Preparing the Northern Beef Industry for Future Climate Challenges

Livestock production is the dominant land use, both nationally and globally, much of it in harsh and variable environments that are unsuitable for other uses. The risks of climate change are now adding to existing climate challenges. Climate change could impact the amount and quality of produce, reliability of production and the natural resource base on which agriculture depends. In order to continue to thrive in the future, livestock industries need to anticipate these changes, be prepared for uncertainty, and develop adaptation strategies now. There will be new challenges and new opportunities, both of which will require proactive planning to modify existing management guidelines and to develop and implement appropriate new responses.

While climate change will have some direct effects on livestock, the dominant influences will be through changes in plant growth and the timing, quantity and quality of forage availability. Climate change will involve a complex mix of responses to (1) rising atmospheric carbon dioxide (CO_2) levels, (2) rising temperatures, (3) changes in rainfall and other climate factors, and (4) broader issues related to how people collectively and individually respond to these changes (Table 1). Each of these influences of climate change is summarized briefly below.

1) Rising atmospheric carbon dioxide

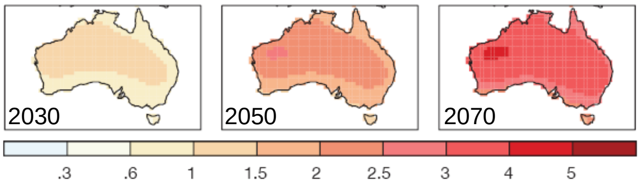


The most certain aspect of the changing environment for future livestock production is the rising level of CO2 in the atmosphere. Already, CO2 levels are almost 40% higher than in pre-industrial times, and are still rising exponentially.

Plants are therefore already growing in CO2-enriched environments and rising levels of CO2 will further benefit plants by allowing them to use water, nutrient and light resources more efficiently. In rangelands, the biggest benefit of CO2 is likely to be improvements in plant water use, which allows pastures to grow more using the same amount of water. However, the trade-off is that increases in pasture production come at the expense of reduced forage quality, since grasses grown at high CO2 have lower protein content and lower digestibility. There could also be changes in vegetation because higher CO2 levels favour trees and legumes.

While CO2 will largely have a positive effect on pasture growth, these benefits will taper off at higher CO2 levels and much of the maximum potential benefit is already being experienced from increases in CO2 that have already occurred. In contrast, many of the negative aspects of climate change and its impacts on agricultural systems lag at least several decades behind the rises in greenhouse gases (GHG) that cause them, and those impacts continue to become more negative as GHG levels rise.

2) Temperature change



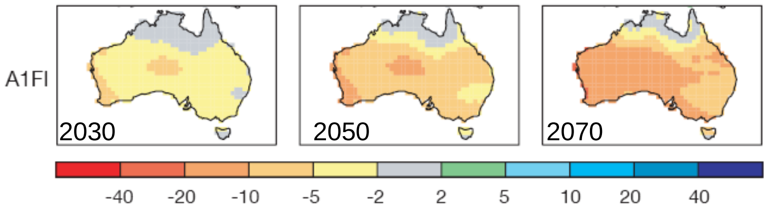
The next most certain aspect of climate change is rising global temperatures, which is the primary effect of increasing GHG levels on the climate. Because of past GHG emissions, some future warming is unavoidable and global average temperatures could well increase by 4ºC or more this century. Warming will be greater towards the interiors of continents (away from the moderating effects of oceans). Each 1ºC increase in temperature will cause a warming in climate that would be roughly similar to moving about 145 km (or about 2º in latitude) closer to the equator.

In climates where low temperatures limit pasture growth during winter, rising temperatures could extend the length of the growing season and reduce frost damage. However, increased plant growth in the cooler months could reduce water availability and pasture growth through the remainder of the growing season. Warmer conditions also tend to reduce forage quality and increase the risks of plant heat stress. Furthermore, greater vapour pressure deficits (the 'dryness' of the air) will adversely affect plant growth by increasing evaporation and lowering water use efficiency, offsetting some benefits of higher CO2.

Livestock will be exposed to greater risks of heat stress, particularly in locations where they are concentrated such as feedlots, and water demand would increase (by about 13% for a 2.7ºC increase in temperature). This will also mean that livestock will be unable to travel as far from watering points in rangelands, concentrating grazing pressure and risks of soil degradation near watering points while areas further from water are left under-utilized.

Under warmer conditions, tropical grasses, weeds, pests and diseases are likely to expand into cooler, southern regions. This could increase the costs of control and damage from pests (e.g., cattle ticks) and alter the species composition of pastures (e.g. increases in less nutritious tropical grasses).

3) Rainfall and other climate changes



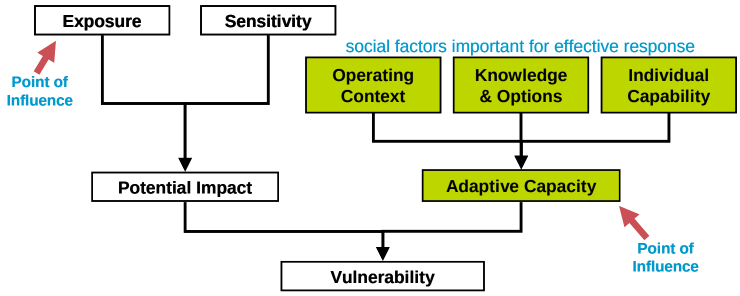
Changes in rainfall could have the greatest affect on livestock production systems in some locations, but they are likely to be one of the most geographically variable aspects of climate change. At a global scale, higher temperatures are expected to intensify the hydrological cycle (more evaporation and more intense rain). As a general global pattern, regions near the equator are expected to get wetter and mid-latitudes (such as most of Australia) are more likely to become drier. But, at the enterprise scale, local factors such as topography and changes in wind patterns and storm tracks can redistribute rainfall between regions. Climate change projections at local/enterprise scales will therefore always involve large uncertainties. An essential element in adapting to climate change will be to accept the inherent uncertainty and develop approaches that can cope with these risks.

Changes in pasture production tend to magnify changes in rainfall, particularly in more arid regions. For example, pasture growth would decline by more than 10% for a 10% decline in rainfall. River flows are even more sensitive to changes in rainfall (e.g. a 10% change in rainfall can alter runoff by 30-40%) which could affect beneficial flooding (e.g., in the Channel Country).

Seasonal patterns of forage quality and availability are also likely to be affected by climate change. For example, declines in spring and autumn rainfall would tend to shorten growing seasons. In contrast, warmer temperatures could allow spring growth to start earlier in cool climates, and CO2 could delay water use, prolonging growth at the end of the wet season. Fire regimes and the fire management will be affected not only by changes in seasonal fuel loads and curing, but also changes in temperature and humidity (which could shorten the period when conditions are suitable for prescribed burning).

Increases in rainfall intensity are likely to increase soil erosion by increasing runoff, particularly where drying climates reduce protective vegetation cover. Erosion and management risks will likely be further increased by greater year-to-year variability in rainfall. Maintaining perennial grass cover will become even more important.

4) Broader context



Livestock production systems will also be affected by a broad set of societal responses related to climate change, including economic and policy considerations. For example, markets for livestock products will be affected by global competitors (and how they are affected by and respond to climate change), changing demand for livestock products (e.g., concerns over ruminant methane emissions), and the emerging biofuel industry (which competes with the livestock industry for grain). Climate change will also influence patterns of land use and competition between different land uses.

The ultimate impacts of climate change will be strongly modified (for both better and worse) by the way in which producers, governments and supporting organisations respond to these challenges. It is just as crucial to understand what helps and hinders people in adapting effectively, as it is to understand the biophysical aspects of climate change. Successful adaptation will require (1) the availability of effective adaptation options, (2) capability of enterprise managers to implement these options and (3) a policy and institutional environment that promotes the development, evaluation and adoption of practicable adaptation strategies. Vulnerability to climate change can be reduced by preparing, evaluating and implementing adaptation strategies that limit the risks of negative impacts while taking advantage of new opportunities.

In the short term, many adaptation options are likely to correspond strongly with efforts to promote existing ‘best management practices’ (BMP) that are both economically and environmentally sustainable (Table 2). This would include practices such as managing diet quality (using diet supplements, legumes and choice of introduced pasture species), matching stocking rates to pasture production, adjusting herd management to altered seasonal patterns of forage production, using fire to control woody thickening, arranging water points to even out grazing pressure, and monitoring the spread of pests, weeds and diseases. Enhancing such practices should be an initial priority because they provide an immediate and ongoing benefit, irrespective of whether climate change occurs. A broad array of adaptation options will be needed to deal with geographic differences in grazing resources, culture, institutions, economies and impacts of climate change. In more arid environments, where coping with climate variability is already a management priority, building capacity to cope with climate variability can serve as a strong starting foundation in preparing for climate change. Over the longer term, it will also be necessary to develop new management options that are better suited to emerging novel climate conditions.

This project aims to help the beef industry prepare for climate change by:

- working with the industry to identify promising adaptation options, including improvements to existing best practice guidelines;
- evaluating the impacts of alternative climate change scenarios and how adaptation measures can reduce these impacts (and take best advantage of new opportunities);
- determining which pastoralists will be most vulnerable to climate change and why; and
- assisting peak industry organisations and agencies to develop approaches that will support the northern beef industry in adapting to future climate challenges.

Table 1: Summary of climate change impacts on livestock production systems

Plants & Natural Resources	Livestock
Carbon dioxide	
Increased pasture growth per unit of available water and nitrogen (and light) Reduced forage quality (protein and digestibility) Prolonged moisture availability (and growth) at end of wet season from water savings Species-specific CO_2 responses cause shifts in vegetation composition (e.g., favour nitrogen-fixers and deep-rooted plants)	No direct effects
Temperature	
Reduced water use efficiency and increased evaporation Decreased forage quality (digestibility) Earlier start to spring growth in cooler climates Southern expansion of weeds, and pasture species (e.g., less nutritious tropical grasses)	Increased heat stress and greater water requirements Livestock concentrate more around water points Southern expansion of tropical pests and diseases
Rainfall and other changes in climate	
Changes in forage production magnify percentage changes in rainfall Changes in seasonal rainfall affect seasonality of forage availability (e.g., declining spring/autumn rainfall would reduce the length of growing seasons) Increased rainfall intensity and interannual variability create greater challenges for managing forage supplies and limiting soil erosion Greater risks of flooding (and saltwater intrusion)	Changes affect availability of water for livestock
Broader context and other issues	
Uncertainty over climate change impacts and adaptation options could create reluctance and delays in taking pre-emptive action, exacerbating impacts Changes in regional/international competition from geographic differences in effects of climate change (magnitude of impacts/benefits and adaptability of beef industry) Changing demand for livestock products as a result of climate change and consumer attitudes to GHG-efficiency of food products Cost-price squeeze from GHG reduction measures that increase input and processing costs (indirect) Potential shifts in land use and competition between land uses (e.g., expansion of cropping into pasture areas, less productive cropping lands converting to pasture, loss of land for carbon sequestration and renewable energy generation) Conflicts and synergies with other public and private policies and initiatives (especially drought, water, natural resource and GHG emission policies)	

Table 2: Options for adapting to climate-change in the livestock industry.

Adaptation option
Grazing and pasture management
Introduce stocking rate strategies that are responsive to seasonal climate forecasts and track longer term climate change trends Redefine safe stocking rates and pasture utilization levels for climate change scenarios Improve on-property water management, particularly for pasture irrigation Improve nutrient management using sown legumes and phosphate fertilisation where appropriate Develop 'climate-ready' forage species that will be better suited to future projected climate conditions Develop software to assist proactive decision making at the on-farm scale Accept climate-induced changes in vegetation and modify management accordingly Expand routine record keeping of weather, pests and diseases, weed invasions, inputs and outputs Diversify on-farm production and consider alternate land uses
Managing pests, diseases and weeds
Improve predictive tools and indicators to monitor, model and control pests Increase the use of biological controls (with caution) Incorporate greater use of fire and alternative chemical and mechanical methods for controlling weeds and woody thickening
Livestock management
Select animal lines that are resistant to higher temperatures but maintain production Adjust use of supplements and planted pasture species to offset declines in diet quality Modify timing of mating, weaning and supplementation based on seasonal conditions Provide extra shade using trees and constructed shelters
Broad-scale adaptation
'Mainstream' climate change considerations into existing government policies and initiatives (particularly those relating to drought, GHG emissions and natural resource management) Encourage uptake of 'best practice' in livestock enterprises (and evaluate current recommendations to ensure benefits will continue under future climate scenarios) Work with the livestock industry to evaluate potential adaptive responses to the system-wide impacts of a range of plausible climate change scenarios Provide adequate buffering to buffer early adopters from adaptation failure Modify transport networks to support changes in agricultural production systems Continuously monitor climate change impacts and adaptation responses adjusting actions to support and ensure effective and appropriate adaptation

6.2 Appendix 2 – Potential adaptive responses to specific climate-related management challenges/opportunities

Collected from workshops with pastoralists in the NGS focus regions.

Changes in pasture productivity

a) wetter

intensify production
shift to greater emphasis on fattening (relative to breeding)
(requires regional infrastructure change, e.g. meatworks)
targeted establishment of legumes/forage species to improve pastures

b) drier

consolidate properties
move to less intensive production systems
shift to greater emphasis on breeding and less on fattening

c) more variable rainfall

flexibility, responsive stocking rates

d) general approaches to prepare for uncertainty in the trend of future rainfall

expand routine on-property record keeping (weather and vegetation etc.) including monitoring points (land condition, woody weeds etc.)
adjust stocking rates based on seasonal climate forecasts (including trends)
redefine safe utilization levels / long-term stocking rates for land types (including infrastructure improvements)
Improve utilisation of pastures remote from water
Greater importance of maintaining and improving vegetation cover and land condition

Shifts in seasonality of pasture production (& fire weather)

adjust mating and weaning times (controlled mating & supplementation)
adjust when feed supplements are provided
adjust timing of prescribed burning

Lower forage quality (protein & digestibility)

increase use of supplements
plant legumes and other suitable introduced pasture species
(consider threats of introduced species escaping or causing problems)
add urea to drinking water

Vegetation change (& woody thickening)

control woody vegetation with fire (and mechanical, herbicide control)
consider fewer more intense burns to control woody plants
consider trade-offs between intensified production (which puts a greater premium on forage) and forage availability as fuel for prescribed fires
plant pasture species to improve pasture productivity
breed and select new ‘climate-ready’ pasture plants/varieties
accept some vegetation change is inevitable and adjust management
protect pastures (to suppress woody establishment)
expand routine on-property record keeping to monitor and detect changes

Southern expansion of tropical pests, weeds and disease
weed control measures (biocontrol, mechanical, herbicide, fire)
expand routine on-property record keeping
improve regional monitoring to detect spread of pests
develop and use predictive models to monitor, model and control pests

Greater animal and human heat stress
(including greater water requirements & reduced travel from water)
provide extra shade (trees and structures) especially in yards & feedlots
handle stock at later (cooler) times of the day
    erect light in stock yards to allow work in the evening/night
(animals adapt to being night-time (dawn & dusk) grazers under hot conditions)
match provision of shade & water to calving times
use existing hardier breeds of cattle
select heat-tolerant cattle lines (that maintain production & quality)
add extra water points
improve on-property water management

Other (rainfall variability, intensity, erosion risk)
supplement income with off-farm sources e.g., off-property work, off-farm investment (passive income stream) – a current trend in central Australia
diversify sources of on-farm income
change turn-off times to match higher cattle prices (more consistent income)
consider alternative land uses
expand record-keeping (business inputs, outputs and responses to change)
further encourage uptake of Best Management Practices (BMP)
    (e.g. soil erosion, variability, soil C)
evaluate BMPs for suitability under future climate scenarios
encourage flexible management approaches to cope with uncertainty
look at opportunities to improve soil carbon (with overlapping goals for C/GHG mitigation credits/offsets, improving land condition and improving productivity)

6.3 Appendix 3 – Incorporating experimental CO_2 results into GRASP modelling

Over the past few decades, results of many of the major Australian rangeland experiments have been incorporated into improving GRASP. As with all of these previous cases, the first major task has been to use the collected experimental data to calculate and recompile the field measurements in terms of metrics that can be directly compared to the output that GRASP produces (e.g., measures of water and nitrogen pools in the same soil layers and plant fractions that GRASP uses). Using the OzFACE data we compiled the following data sets 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);
and 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). Other GRASP parameters were calculated directly from further analysis of the experimental measurements.

Our main interest was in ensuring that GRASP accurately reflects the stimulating effect of CO_2 in increasing pasture production. The additional data sets helped to ensure that underlying processes (such as altered patterns of water and nitrogen use by plants) were being properly captured in the model (Fig. 6.3.1). To have confidence in using the model to extrapolate the experimental results to other rangeland locations, we needed to be sure not just that we were simulating the right final outcome (i.e., change in pasture productivity), but also that we were getting this result by correctly simulating the underlying mechanisms.

Elevated levels of CO_2 benefit plant growth by increasing the efficiency with which they use light, water and nitrogen resources. Previous representations of CO_2 effects in GRASP had accounted for the first two effects (improved efficiencies in light use (potential growth rates) and water use) but not the third (improved nitrogen use – for which there had been insufficient evidence in the earlier review Hall *et al.* 1998). Comparisons with the OzFACE data showed that CO_2 effects were being under-represented by and did not account for the experimental results showing improved nitrogen use (allowing grasses to grow until nitrogen was diluted to a lower level) under elevated CO_2. Changing critical nitrogen parameters in GRASP allowed us to better represent the observed changes in N use in OzFACE and represent the greater benefit of CO_2 to grass production (Tables 2.1 and 6.3.1).

Based on the GRASP parameterization of OzFACE (Table 1), GRASP simulated a 25.4% increase in pasture production (for the elevated 550 ppm treatment relative to the 375 ppm ambient control), duplicating the strong response observed over the 6 years of the OzFACE experiment (Table 2). Previous experimental data (from C4 grasses growing in mixed C3-C4 communities in FACE experiments in temperate environments) has suggested weaker responses of about a 20% increase in production for C4 grasses exposed to this level of elevated CO_2 Nowak *et al.* 2004. We had suspected that the run of years during OzFACE had been particularly favourable for a strong CO_2 effect (with some moderate drought years where improvements in water use would be most beneficial). Running the GRASP simulations over the full 116 year weather record for the OzFACE site (Yabulu weather station, northeast Queensland) confirmed this, producing an average 20.9% response to elevated CO_2 – i.e., the response in the particular run of years over which the experiment was conducted was about 25% higher than would be expected on average, and helps explains the strong response observed in the experiment.

Table 6.3.1: Comparison of the effects of CO_2 in stimulating aboveground grass production from FACE experiments and GRASP simulations. Growth responses are expressed as the percentage increase at 550 ppm CO_2 relative to 375 ppm (the OzFACE treatments). The top row gives the growth responses of C4 grasses from other FACE experiments (in mixed C3-C4 grass communities in temperate climates). The next three rows compare OzFACE experiment measurements with GRASP simulations over the duration of the experiment. The next four rows compare the alternate representations of CO_2 effects in GRASP over a 116-yr period (using the parameterizations listed in Table 1). The last two rows compare the new recommended parameterization against the previously-used one for an 'Average Native Pasture' (ANP – the base standard GRASP land type) using weather data from Charters Towers.

Site	CO2 Parameters	Period	Growth response
FACE C4 grasses (Nowak et al. 2004)			**~20%**
OzFACE	(field measurements)	2001-06	**36.3%**
OzFACE	Howden 99	"	**7.2%**
OzFACE	OzFACE	"	**25.4%**
OzFACE	DAQ139	1891-2006	**31.1%**
OzFACE	Howden 99	"	**4.7%**
OzFACE	OzFACE	"	**20.9%**
OzFACE	Recommend	"	**15.4%**
ANP	Howden 99	"	**2.2%**
ANP	Recommend	"	**15.3%**

Several adjustments were made to the final recommended parameterizations of CO_2 effects (Table 1). First, many FACE experiments show declining N availability (decrease to parameter #99) over the first several years of the experiment. This process, known a Progressive N Limitation, is likely an artefact of FACE experiments where a sudden increase in CO_2 at the start of the experiment causes a strong plant growth response that temporarily 'locks-up' N in plant material and litter. Once the ecosystem and N cycling is back in equilibrium with the higher CO_2 level, N mineralisation from plant litter would come to more closely match plant N uptake again. In the absence of solid evidence of the long-term equilibrium effects of CO_2 on N cycling and N availability (parameter #99) we recommend at the moment that this parameter be left unchanged. Furthermore, since the OzFACE responses are at the upper end of responses reported from other data sources, the conservative approach is to downgrade these responses to what is more typically reported. The effect on transpiration efficiency (parameter #7) is reduced to what has been used before and the effects on improved nitrogen use efficiency and leaf nitrogen dilution are also reduced (parameters #101 & 102) (also taking into account that progressive nitrogen limitation is likely to exaggerate plant nitrogen dilution relative to equilibrium conditions). Sensitivity tests of these two nitrogen parameters showed that almost all the effect of improved nitrogen efficiency is captured by parameter #101 (%N at zero growth) and that changes to parameter #102 (%N at maximum growth) only accounted for 0.5% of the increase in pasture growth, i.e., it is the ability of grasses to continue growing and diluting N to lower levels under elevated CO_2 that accounts for the extra growth response captured in the new representation of CO_2 effects and observed in experiments. We will likely make further refinements to these initial recommendations through the duration of this project as we start to include these improvements in simulations across a more diverse array of rangeland environments and land types.

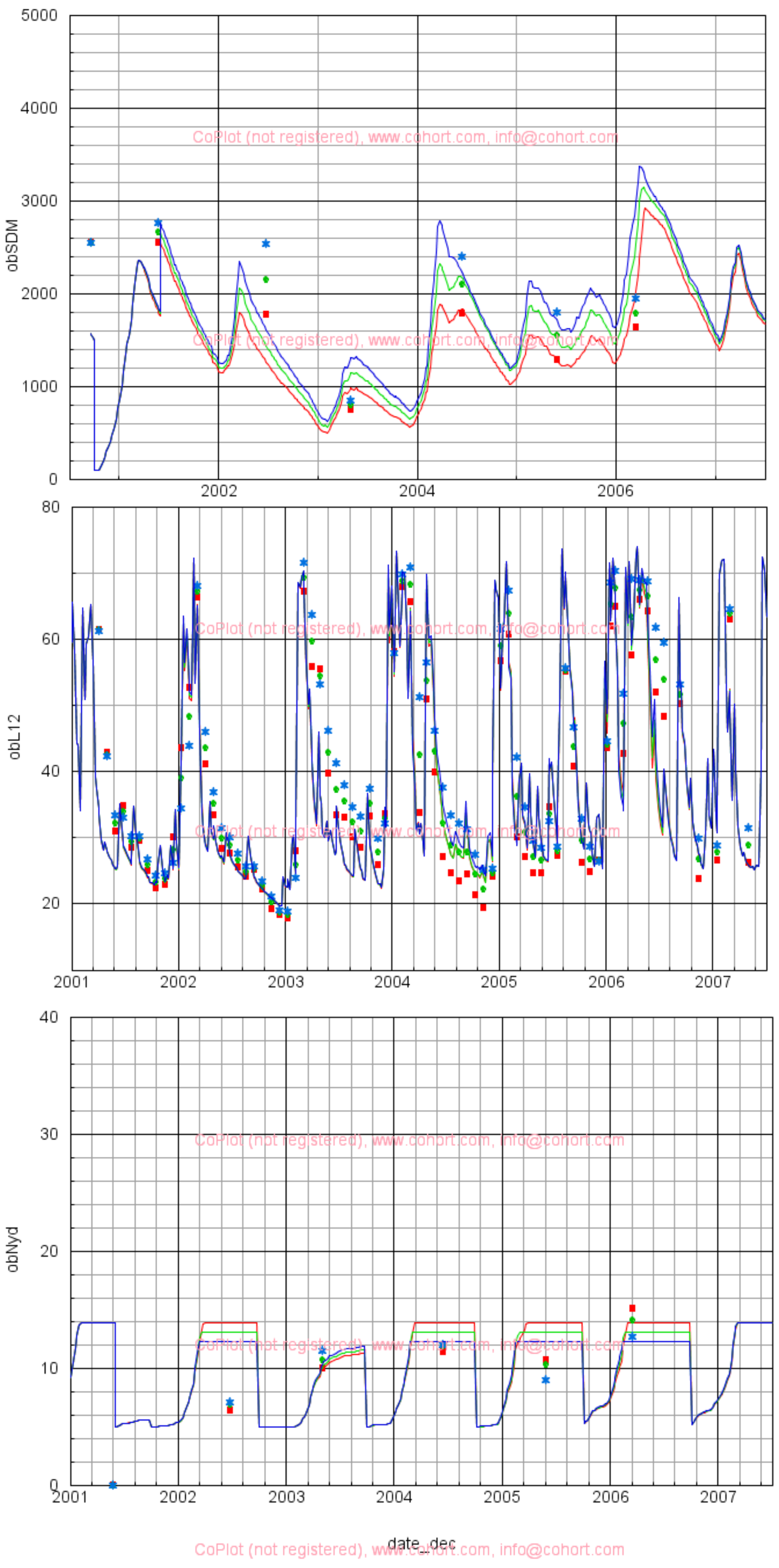


Figure 6.3.1: Comparison of experimental observations of the effects of CO_2 on tropical pastures from the OzFACE experiment with GRASP simulations of the experiment for (a) standing dry matter, (b) soil moisture in the grass rooting zone (layers 1 & 2), and (c) pasture nitrogen.

While these changes improve how GRASP can be used to simulate CO_2 effects there are a number of remaining issues and responses that are still not captured in the model. Some of the more important of these are:

1) Experimental data show that plant water savings under elevated CO_2 accumulate in stored soil moisture through the growing season and are then used at the end of the growing season. This effect is not duplicated in GRASP simulations where water savings are used immediately such that simulated fluctuations in soil moisture show no difference between CO_2 treatments (Fig. 6.3.1b). This suggests that some process other than increased water use efficiency at the leaf level is affecting patterns of water use. While we have discussed options for forcing this behaviour in GRASP, we would prefer to have a mechanistic explanation of the process before trying to replicate it in the model.

2) Dynamic changes in vegetation composition are not dealt with in the model. Climate change and CO_2 effects can change the tree-grass balance, the mix between C3 and C4 grasses and shifts between species within the same functional group. If such changes can be anticipated, they can be represented using existing approaches to represent vegetation differences in GRASP – but GRASP cannot be used to dynamically simulate and 'predict' what vegetation changes could occur. Together with Joe Scanlan, we are at least considering some simple approaches to dynamically model CO_2 effects on trees.

3) Experimental data shows that elevated CO_2 (and increased temperatures) reduce forage quality by reducing digestibility and protein content. The effects of reduced diet quality on cattle liveweight gains are not included in the model.

4) GRASP does not have a full dynamic nitrogen model. The improvements in nitrogen use efficiency under elevated CO_2 are therefore implemented by adjusting nitrogen dilution parameters. Further experimental data would be needed to validate whether this approach accurately represents pasture responses across a full range of fertility conditions (for very infertile to very fertile pasture/land types).

5) The approach for representing intermediate levels of CO_2 (other than the traditional double of CO_2 from 350 to 700 ppm used in the past), assumes linear adjustments to each process affected (water and nitrogen use efficiency, and seasonal start-up growth). While this is an improvement in allowing actual projected levels of CO_2 to be simulated, the linear response is a simplification, when CO_2 responses are known to follow a curve of declining returns. This interpolation approach therefore will only be correct at 350 and 700 ppm, and will be slightly conservative between these values. Extrapolations outside this range (above and below) should be avoided and will tend to over-estimate CO2 effects with escalating errors the further the CO2 level is from the calibration references of 350 and 700 ppm.

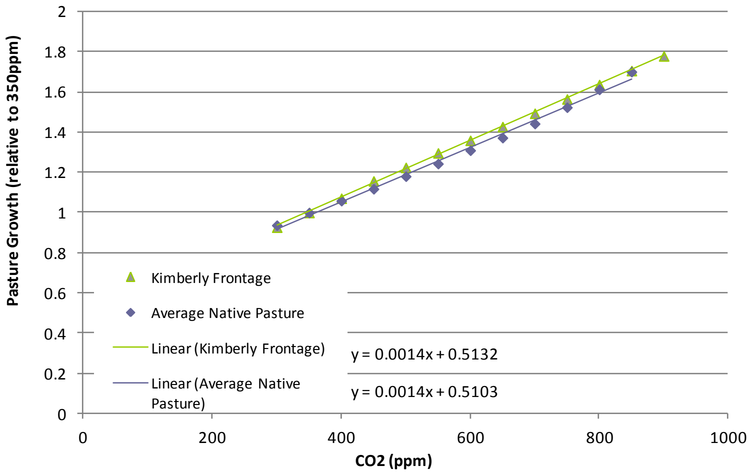


Figure 6.3.2: Linear simulated responses of pastures (Kimberly Frontage and Average Native Pasture) to a gradient of increasing CO_2 (using current Kimberly weather data).

6.4 Appendix 4 – Climate change envelopes and weather adjustments

The approach to selecting climate scenarios that represent trajectories of change and envelopes of uncertainty consists of the following steps:

1) Extract climate change projections from the OzClim database for each rainfall station location for 22 GCMs (excluding BCCR BCM2.0, which performs too poorly). Only SRES scenarios A1FI, A2 and A1B are used, since other scenarios are now deemed seem unrealistically optimistic (assuming). This still includes a scenario (A1B) where substantial action is taken to curb emissions by the end of the century.

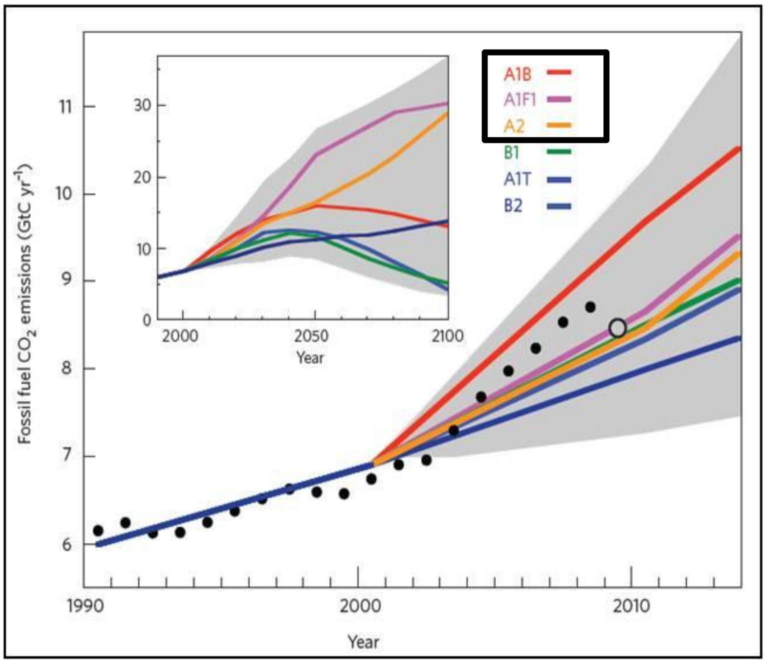


Fig 6.4.1. Measured CO_2 emissions against IPCC GHG emissions scenarios (SRES) which, together with global policy developments since the SRES scenarios were developed, indicate that some emissions scenarios are unrealistically optimistic and would bias the range of uncertainty downwards.

2) For each location, plot projected changes in rainfall against projected changes in temperature to quantify the dependence between these two variables. Plot lines showing median, 90th percentile, median and 10th percentile projections in rainfall for each projection date (2030, 2050, 2070 and 2100) as a function of the average project temperature change for that date. Expressing climate scenarios in terms of a gradient of temperature change provides an absolute and more permanent reference for results than explicitly referring to dates. This is because projections for a given location are likely to change as they improve over time. By referencing the scenarios in terms of the actual climate change factors, the results can continue to be used at a later date, and can be interpreted in the light of how strongly future, improved projections support the selected scenarios. The temperature axis provides a compound proxy for the combined effects of:
   a) the amount of GHG emissions,
   b) the sensitivity of the global climate (or modelled projection) to GHG increases, and
   c) time (the duration of global warming) – all of which contribute to increases in temperature (along this proxy gradient of climate change).

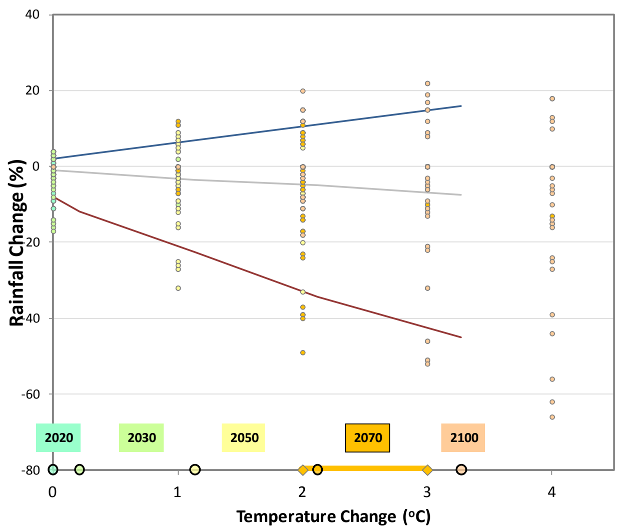


Fig. 6.4.2: Climate exposure envelopes summarise the diversity of climate projections (dots, colour-coded by date following the dates along the x-axis) as the trajectory of rainfall projections along a gradient of climate change (projected change in temperature). The upper blue line follows the 90th percentile rainfall against the average temperature projection for each date, the grey line the median rainfall projection, and the red line represents the trajectory of the 10th percentile rainfall projection for each date. Climate change along the temperature gradient represents the combined effects of total global GHG emissions, the sensitivity of globe to those emissions, and time. Projections are for Charters Towers, NE Queensland.

3) Three key scenarios are selected for emphasis along the percentile lines. These scenarios are a baseline of no change (historic weather record for location), the 90th percentile change in rainfall associated with the average 2070 temperature projection, and the 10th percentile rainfall projection associated with the 2070 temperature. The median projection is purposely excluded to emphasise the range of uncertainty, a crucial aspect of developing robust adaptation strategies.

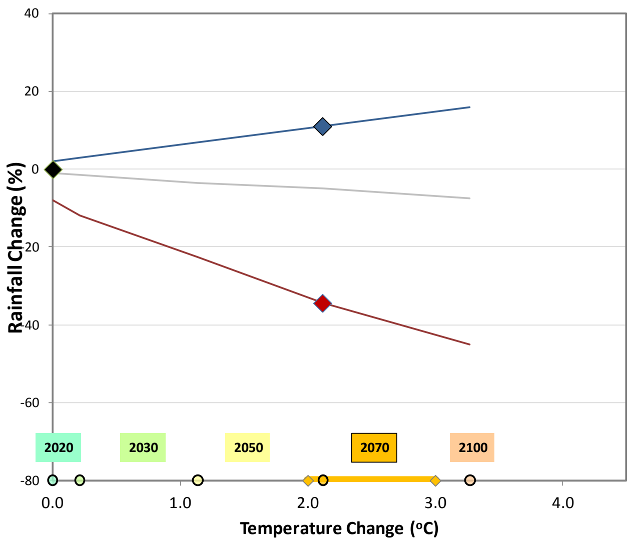


Fig 6.4.3. Example of selected 3 key reference scenarios and envelopes of GCM uncertainty along a gradient of climate change.

For clearer communication to a non-technical audience, these key scenarios can be expressed using a Representative Climate Futures (RCF) approach. RCFs provide simple verbal descriptions to describe a small set of climate scenarios (such as "hotter, drier" or "much hotter, wetter"), together with some indication of how strongly that scenario is supported by current climate change projections (Webb et al. 2011, Whetton et al. 2012). Importantly, the storylines (and their associated evaluations of likely impacts and adaption options) remain constant points of reference over time. Instead the level of support for different storylines (and emphasis on 'most likely' storylines) for a given location can be updated as climate projections improve over time.

4) For each scenario, changes in temperature and rainfall are applied to historic daily weather records using the "delta method" by a) adding the temperature change factor to the maximum and minimum temperature for each day, b) multiplying each day's rainfall by projected rainfall change multiplier, and c) recalculating the vapour pressure and pan evaporation based on the new maximum and minimum temperatures. This followed the approach used previously for GRASP climate change analyses in the region (). However, instead of estimating the new evaporation directly from the altered temperatures and vapour pressures, estimated evaporations were calculated for both the original (EstEvap1) and modified (EstEvap2) climate, and the final modified evaporation was calculated by multiplying the original evaporation by EstEvap2/EstEvap1. (This was to accommodate very dry regions like Alice Springs where we found the equations for estimated pan evaporations sometimes deviated from observed measurements within the existing daily weather records). Only annual (rather than monthly/seasonal) change factors are used because there is sufficient confidence in seasonal changes (such as redistribution of early and late season rainfall) to include this in models at this stage (CSIRO and Australian Bureau of Meteorology 2007). It may only add 'noise' and distortion to the simulations, confounding simulation 'treatments' and making them more difficult to interpret. We therefore prefer to apply annual changes uniformly across seasons. Subsequent sensitivity analyses could be conducted to determine the implications of relative seasonal redistributions of rainfall (without confounding these seasonal changes with any overall annual changes in rainfall etc.)

   We initially explored several other statistical options for using GCM climate change factors, such as weather generators, but none of these preserved the patterns and cycles of year-to-year variation in rainfall. In the extensive pastoral industry this variation in rainfall, such as the El Nino – Southern Oscillation cycles, is one of the major challenges for land and cash-flow management. It is therefore important to preserve these weather patterns in simulations, particularly when they are being used to assess the effectiveness of alternative management options.

   The QCCCE team conducted a parallel project tasked with providing a consistent approach for generating climate change weather data for simulation analyses. However their approach was not suitable because:

   a) their project ran concurrently and only produced recommendations after our analyses were underway;
   b) it did not fit with our approach for selecting climate scenarios (which were not linked to specific individual GCM projections, but rather an aggregate analysis of GCMs); and
   c) climate sensitivities are highly situation-specific for different agricultural practices, so the aspects of climate change (and required climate generating approach) that each project needed to focus on were different.

6.5 Appendix 5 – Summaries for additional climate impacts and adaptations

Table 6.5.1: Responses for carrying capacity:

a) Climate change impacts (%change for scenario vs 1990) showing regional variation in impacts, and how differences in pasture characteristics and land condition affect sensitivity to climate change.

b) Effects of adaption options (%change for management action vs no action under comparable conditions) showing how effectiveness is altered under different climate scenarios, and how it is affected by pasture characteristics and land condition.

(Results are for pasture in B condition and averaged across regions, unless otherwise noted).

a) Climate Impact (%change vs 1990)

	Scenario >>	2070L	2070H
a1	Base Veg Chars, B Condition, By Region		
	Kimberley (B)	-71%	58%
	Katherine (B)	-34%	27%
	Barkly (B)	-31%	42%
	NW Qld (B)	0%	25%
	N Qld (B)	-8%	43%
	Pilbara (B)	-48%	27%
	Central Aus (B)	-64%	55%
	W Qld (B)	-63%	33%
	Central Qld (B)	-73%	50%
	S Qld (B)	-78%	74%
a2	B Condition, By Veg Chars (Avgd Regions)		
	Avg Base (B)	-38%	42%
	Avg Extra Trees (B)	-39%	28%
	Avg Lower Fert (B)	-42%	37%
	Avg Sandier (B)	-28%	38%
a3	Base Veg Chars, B Condition (Avgd Regions)		
	Avg A Condition	-40%	34%
	Avg B Condition	-38%	42%
	Avg C Condition	**-47%**	26%
	Avg D Condition	**-47%**	31%
a4	Base Veg Chars (Avgd Regions* Conditions)		
	Avg Base Veg	**-41%**	**35%**

b) Adaptation Effectiveness

- Improving Land Condition

	Scenario >>	1990	2070L	2070H
b1	C -> B Condition, by Veg Chars (Avgd Regions)			
	Avg Base Veg	104%	136%	131%
	Avg Extra Trees	102%	133%	107%
	Avg Lower Fert	111%	126%	128%
	Avg Sandier	118%	162%	131%
b2	Base Veg, by Land Condition (Avg Regions)			
	Avg B -> A	41%	38%	33%
	Avg C -> B	104%	136%	131%
	Avg D -> C	31%	31%	26%

- Impact of EXTRA Trees

(active planting or NOT controlling thickening)

	Scenario >>	1990	2070L	2070H
b3	B Condition, by Veg Chars (Avgd Regions)			
	Avg Base Veg	-28%	**-29%**	-31%
	Avg Lower Fert	-30%	**-29%**	-33%
	Avg Sandier	-24%	**-23%**	-26%
b4	Base Veg Chars, by Land Condition (Avg Regions)			
	Avg A Condition	-29%	-29%	-30%
	Avg B Condition	-28%	-29%	-35%
	Avg C Condition	-27%	-28%	-28%
	Avg D Condition	-27%	-28%	-29%

Table 6.5.2: Responses for liveweight gain / ha:

a) Climate change impacts (%change for scenario vs 1990) showing regional variation in impacts, and how differences in pasture characteristics and land condition affect sensitivity to climate change.

b) Effects of adaption options (%change for management action vs no action under comparable conditions) showing how effectiveness is altered under different climate scenarios, and how it is affected by pasture characteristics and land condition.

(Results are for pasture in B condition and averaged across regions, unless otherwise noted).

a) Climate Impact (%change vs 1990)

	Scenario >>	2070L	2070H
a1	Base Veg Chars, B Condition, By Region		
	Kimberley (B)	-124%	113%
	Katherine (B)	-45%	34%
	Barkly (B)	-55%	79%
	NW Qld (B)	-18%	44%
	N Qld (B)	-44%	75%
	Pilbara (B)	-61%	28%
	Central Aus (B)	-71%	63%
	W Qld (B)	-93%	74%
	Central Qld (B)	-102%	92%
	S Qld (B)	-110%	156%
a2	B Condition, By Veg Chars (Avgd Regions)		
	Avg Base (B)	-65%	74%
	Avg Extra Trees (B)	-70%	58%
	Avg Lower Fert (B)	-71%	70%
	Avg Sandier (B)	-48%	63%
a3	Base Veg Chars, B Condition (Avgd Regions)		
	Avg A Condition	-61%	58%
	Avg B Condition	-65%	74%
	Avg C Condition	**-91%**	69%
	Avg D Condition	**-108%**	99%
a4	Base Veg Chars (Avgd Regions* Conditions)		
	Avg Base Veg	**-68%**	**67%**

b) Adaptation Effectiveness

- Improving Land Condition

	Scenario >>	1990	2070L	2070H
b1	C -> B Condition, by Veg Chars (Avgd Regions)			
	Avg Base Veg	207%	1108%	217%
	Avg Extra Trees	265%	-962%	205%
	Avg Lower Fert	260%	-177600%	231%
	Avg Sandier	222%	670%	212%
b2	Base Veg, by Land Condition (Avg Regions)			
	Avg B -> A	59%	75%	45%
	Avg C -> B	207%	1108%	217%
	Avg D -> C	76%	-307%	49%

- Impact of EXTRA Trees

(active planting or NOT controlling thickening)

	Scenario >>	1990	2070L	2070H
b3	B Condition, by Veg Chars (Avgd Regions)			
	Avg Base Veg	-44%	**-56%**	-45%
	Avg Lower Fert	-49%	**-64%**	-48%
	Avg Sandier	-35%	**-42%**	-36%
b4	Base Veg Chars, by Land Condition (Avg Regions)			
	Avg A Condition	-41%	-48%	-41%
	Avg B Condition	-42%	-51%	-48%
	Avg C Condition	-51%	-168%	-46%
	Avg D Condition	-62%	225%	-52%

6.6 Appendix 6 – Graphs of additional impact and adaption responses

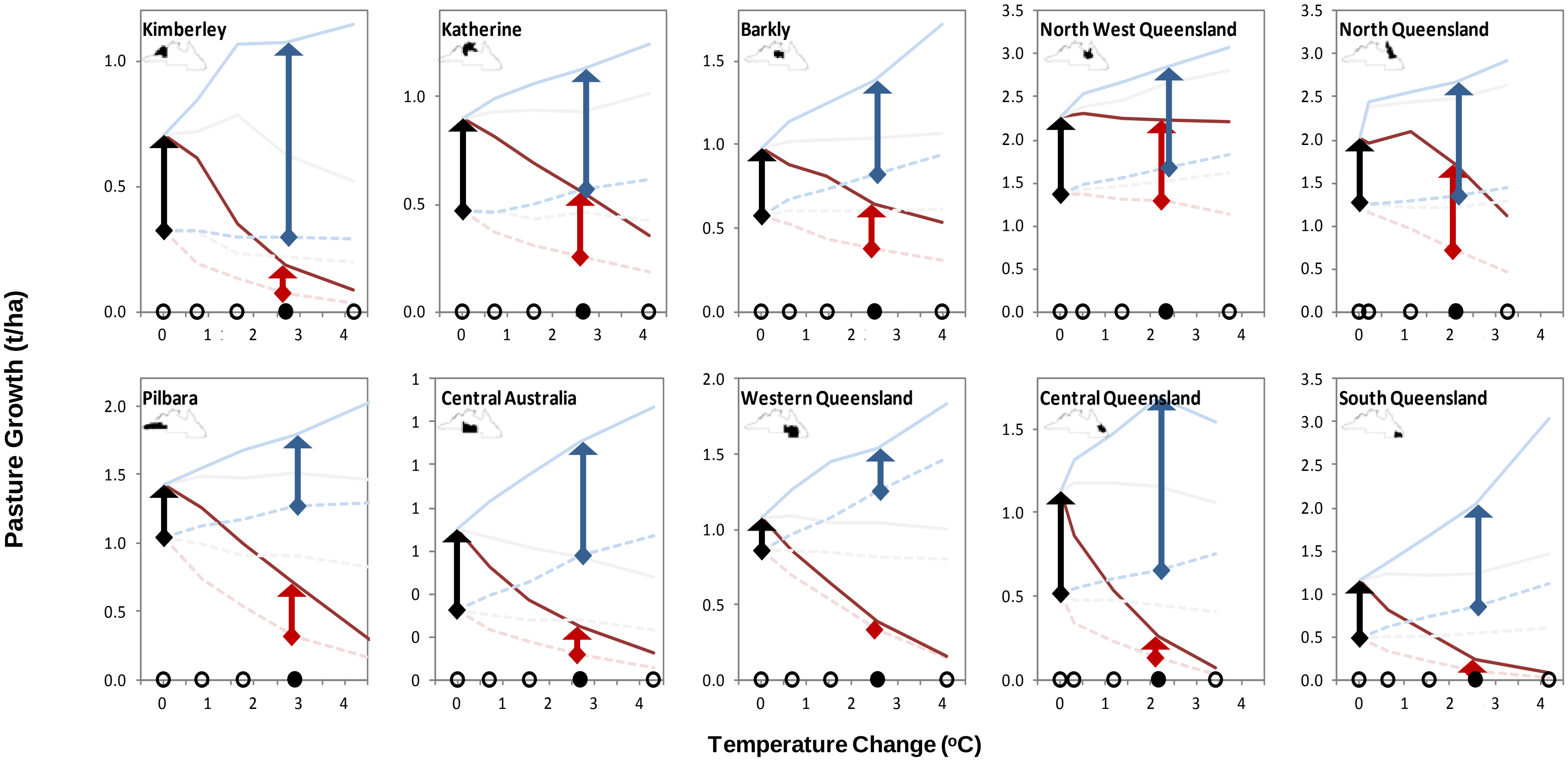


Fig. 6.7.1: Variation in the impacts of climate change and the effectiveness of adaptation (improving land condition) on pasture growth (t/ha) across northern Australia. Arrows compare the effects of the management action under three reference climate scenarios: the current climate (1990 - black) and 2070 projected temperatures with associated 10th (2070L - red) and 90th (2070L - blue) percentile rainfall projections. The base of each arrow represents each scenario on 'C condition' pastures, while the arrows show the response if pastures were improved to 'B condition'. Responses are shown in relation to projected temperature change (x-axis). Circles along the x-axis mark progressive projected average warming for 1990, 2030, 2050, 2070 and 2100 respectively. Dotted lines cover the full time series of climate scenarios for 'C condition' pastures and solid lines the improved ('B condition') pastures for 10th (red), 50th (grey) and 90th (blue) percentile rainfall projections.

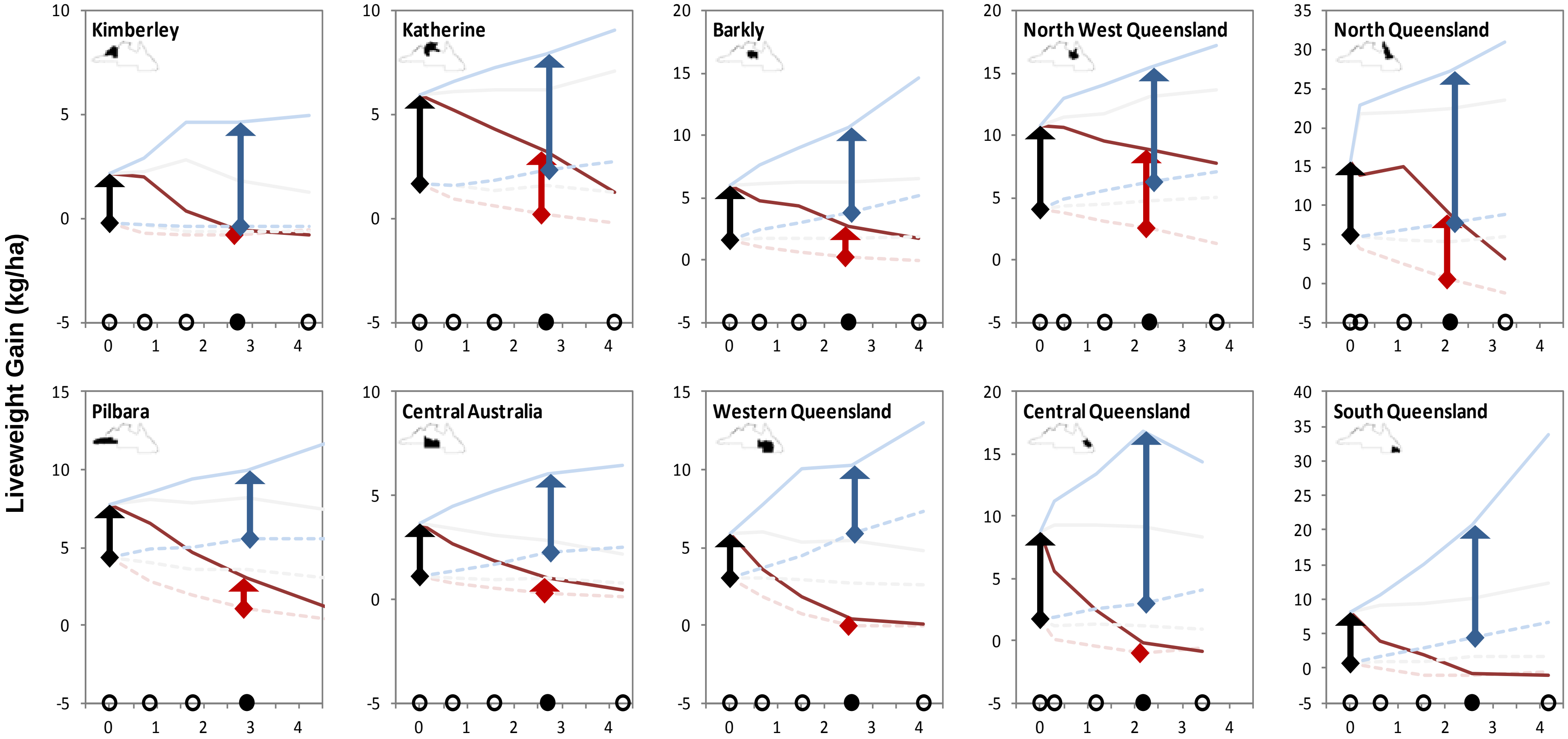


Fig. 6.7.2: Variation in the impacts of climate change and the effectiveness of adaptation (improving land condition) on liveweight gain (kg/ha) across northern Australia. Arrows compare the effects of the management action under three reference climate scenarios: the current climate (1990 - black) and 2070 projected temperatures with associated 10th (2070L - red) and 90th (2070L - blue) percentile rainfall projections. The base of each arrow represents each scenario on 'C condition' pastures, while the arrows show the response if pastures were improved to 'B condition'. Responses are shown in relation to projected temperature change (x-axis). Circles along the x-axis mark progressive projected average warming for 1990, 2030, 2050, 2070 and 2100 respectively. Dotted lines cover the full time series of climate scenarios for 'C condition' pastures and solid lines the improved ('B condition') pastures for 10th (red), 50th (grey) and 90th (blue) percentile rainfall projections.

6.7 Appendix 7 – Additional detailed tables of impacts and adaptation effects

Table 6.7.1: Pasture growth responses. Additional detail for the summary tables of climate change impacts and adaptation analyses showing factorial combinations prior to averaging (All responses are for B condition pastures unless otherwise noted.)

Climate Scenario Impact (%change vs 1990)

Land Type>>	Base		Extra Trees		Lower Fertility		Sandier Soils	
Scenario >>	2070L	2070H	2070L	2070H	2070L	2070H	2070L	2070H
Kimberley (B)	-74%	53%	-74%	11%	-73%	41%	-75%	16%
Katherine (B)	-38%	25%	-47%	26%	-44%	27%	-26%	22%
Barkly (B)	-34%	40%	-44%	33%	-31%	46%	-27%	43%
NW Qld (B)	-2%	25%	-8%	21%	-3%	21%	-1%	26%
N Qld (B)	-15%	32%	-25%	13%	-26%	16%	-7%	23%
Pilbara (B)	-51%	25%	-59%	23%	-53%	34%	-49%	31%
Central Aus (B)	-65%	58%	-63%	54%	-65%	52%	-62%	60%
W Qld (B)	-64%	43%	-66%	41%	-63%	52%	-56%	60%
Central Qld (B)	-77%	50%	-76%	44%	-75%	52%	-70%	40%
S Qld (B)	-80%	78%	-83%	77%	-81%	73%	-66%	89%
Avg A Condition	-42%	35%	-42%	32%	-43%	34%	-36%	36%
Avg B Condition	-42%	40%	-43%	29%	-44%	37%	-34%	38%
Avg C Condition	-49%	29%	-49%	27%	-47%	29%	-44%	35%
Avg D Condition	-49%	33%	-50%	28%	-48%	31%	-44%	34%
Avg (Region*Cond)	**-44%**	**35%**	**-45%**	**30%**	**-45%**	**34%**	**-38%**	**36%**

Adaptation Effectiveness - Improving Land 1 Condition Class

Land Type>>	Base			Extra Trees			Lower Fertility			Sandier Soils		
Scenario >>	1990	2070L	2070H	1990	2070L	2070H	1990	2070L	2070H	1990	2070L	2070H
Kimberley (C->B)	119%	148%	261%	138%	96%	109%	116%	120%	207%	177%	146%	164%
Katherine (C->B)	92%	119%	98%	83%	72%	108%	70%	71%	85%	110%	131%	104%
Barkly (C->B)	72%	74%	69%	93%	64%	76%	69%	81%	75%	68%	85%	64%
NW Qld (C->B)	65%	73%	69%	70%	86%	74%	62%	70%	67%	78%	92%	74%
N Qld (C->B)	59%	144%	100%	65%	131%	63%	89%	146%	96%	67%	162%	86%
Pilbara (C->B)	38%	122%	40%	48%	111%	51%	50%	113%	58%	73%	156%	47%
Central Aus (C->B)	117%	105%	92%	129%	138%	106%	106%	82%	84%	201%	143%	216%
W Qld (C->B)	25%	18%	23%	28%	14%	34%	23%	18%	29%	27%	22%	30%
Central Qld (C->B)	118%	104%	160%	77%	81%	101%	118%	103%	142%	92%	121%	129%
S Qld (C->B)	142%	121%	143%	101%	86%	97%	131%	92%	145%	150%	178%	165%
Avg B -> A	24%	24%	20%	23%	25%	26%	23%	24%	20%	25%	22%	24%
Avg C -> B	**71%**	**94%**	**86%**	**70%**	**90%**	**73%**	**74%**	**86%**	**85%**	**83%**	**115%**	**87%**
Avg D -> C	27%	27%	23%	26%	28%	25%	24%	26%	22%	25%	27%	26%

Adaptation Effectiveness - Impact of Extra Trees (active planting or NOT controling thickening)

Land Type>>	Base			Lower Fertility			Sandier Soils		
Scenario >>	1990	2070L	2070H	1990	2070L	2070H	1990	2070L	2070H
Kimberley (B)	-48%	-48%	-62%	-45%	-38%	-59%	-52%	-44%	-55%
Katherine (B)	-22%	-34%	-21%	-20%	-11%	-27%	-20%	-27%	-21%
Barkly (B)	-44%	-52%	-47%	-49%	-56%	-53%	-37%	-42%	-35%
NW Qld (B)	-11%	-17%	-14%	-14%	-15%	-15%	-15%	-9%	-12%
N Qld (B)	-15%	-25%	-27%	-26%	-28%	-28%	-7%	-18%	-12%
Pilbara (B)	-24%	-36%	-25%	-22%	-38%	-32%	-19%	-32%	-25%
Central Aus (B)	-37%	-33%	-38%	-40%	-29%	-34%	-31%	-29%	-32%
W Qld (B)	-29%	-33%	-30%	-31%	-34%	-38%	-27%	-30%	-32%
Central Qld (B)	-54%	-51%	-56%	-45%	-52%	-56%	-39%	-48%	-44%
S Qld (B)	-43%	-52%	-43%	-41%	-42%	-44%	-40%	-50%	-38%
Avg A Condition	-29%	-29%	-31%	-31%	-31%	-33%	-25%	-25%	-26%
Avg B Condition	-28%	-30%	-34%	-30%	-28%	-36%	-24%	-24%	-26%
Avg C Condition	-28%	-28%	-29%	-30%	-29%	-30%	-24%	-25%	-28%
Avg D Condition	-27%	-29%	-30%	-28%	-30%	-31%	-26%	-27%	-28%
Avg (Region*Cond)	**-28%**	**-29%**	**-31%**	**-30%**	**-30%**	**-33%**	**-25%**	**-25%**	**-27%**

Table 6.7.2: Stocking rate responses. Additional detail for the summary tables of climate change impacts and adaptation analyses showing factorial combinations prior to averaging (All responses are for B condition pastures unless otherwise noted.)

Climate Scenario Impact (%change vs 1990)

Land Type>>	Base		Extra Trees		Lower Fertility		Sandier Soils	
Scenario >>	2070L	2070H	2070L	2070H	2070L	2070H	2070L	2070H
Kimberley (B)	-71%	58%	-69%	12%	-71%	44%	-73%	19%
Katherine (B)	-34%	27%	-45%	25%	-42%	26%	-20%	22%
Barkly (B)	-31%	42%	-43%	32%	-28%	45%	-25%	42%
NW Qld (B)	0%	25%	-8%	18%	-3%	18%	0%	24%
N Qld (B)	-8%	43%	-19%	12%	-26%	15%	1%	27%
Pilbara (B)	-48%	27%	-58%	25%	-53%	39%	-46%	33%
Central Aus (B)	-64%	55%	-57%	43%	-60%	53%	-61%	56%
W Qld (B)	-63%	33%	-66%	40%	-62%	55%	-52%	59%
Central Qld (B)	-73%	50%	-72%	39%	-71%	55%	-67%	32%
S Qld (B)	-78%	74%	-81%	72%	-80%	69%	-61%	88%
Avg A Condition	-40%	34%	-40%	31%	-41%	32%	-33%	35%
Avg B Condition	-38%	42%	-39%	28%	-42%	37%	-28%	38%
Avg C Condition	-47%	26%	-47%	25%	-46%	26%	-41%	30%
Avg D Condition	-47%	31%	-48%	26%	-46%	29%	-42%	31%
Avg (Region*Cond)	-41%	35%	-42%	29%	-43%	32%	-34%	35%

Adaptation Effectiveness - Improving Land 1 Condition Class

Land Type>>	Base			Extra Trees			Lower Fertility			Sandier Soils		
Scenario >>	1990	2070L	2070H	1990	2070L	2070H	1990	2070L	2070H	1990	2070L	2070H
Kimberley (C->B)	140%	180%	300%	160%	167%	123%	127%	150%	227%	208%	150%	193%
Katherine (C->B)	124%	164%	137%	110%	100%	150%	90%	100%	118%	146%	168%	144%
Barkly (C->B)	86%	88%	88%	118%	75%	96%	89%	100%	93%	84%	100%	83%
NW Qld (C->B)	106%	116%	115%	118%	135%	123%	103%	110%	111%	125%	139%	119%
N Qld (C->B)	89%	207%	162%	96%	186%	93%	143%	210%	148%	107%	238%	141%
Pilbara (C->B)	50%	150%	53%	57%	114%	67%	64%	113%	79%	86%	163%	68%
Central Aus (C->B)	144%	100%	113%	180%	200%	122%	114%	100%	109%	200%	133%	250%
W Qld (C->B)	56%	52%	47%	62%	44%	76%	46%	45%	62%	63%	64%	70%
Central Qld (C->B)	151%	136%	220%	92%	117%	129%	145%	144%	203%	117%	150%	167%
S Qld (C->B)	189%	167%	189%	137%	140%	129%	177%	111%	193%	197%	227%	220%
Avg B -> A	41%	38%	33%	39%	37%	43%	37%	38%	32%	42%	33%	40%
Avg C -> B	104%	136%	131%	102%	133%	107%	111%	126%	128%	118%	162%	131%
Avg D -> C	31%	31%	26%	30%	32%	29%	29%	30%	26%	28%	32%	27%

Adaptation Effectiveness - Impact of Extra Trees (active planting or NOT controling thickening)

Land Type>>	Base			Lower Fertility			Sandier Soils		
Scenario >>	1990	2070L	2070H	1990	2070L	2070H	1990	2070L	2070H
Kimberley (B)	-46%	-43%	-62%	-41%	-30%	-57%	-51%	-40%	-55%
Katherine (B)	-21%	-35%	-23%	-18%	-5%	-27%	-20%	-27%	-21%
Barkly (B)	-43%	-53%	-47%	-49%	-58%	-53%	-37%	-41%	-33%
NW Qld (B)	-8%	-16%	-14%	-13%	-13%	-14%	-15%	-4%	-12%
N Qld (B)	-14%	-24%	-33%	-31%	-29%	-34%	-3%	-18%	-12%
Pilbara (B)	-25%	-40%	-26%	-22%	-35%	-34%	-18%	-33%	-27%
Central Aus (B)	-36%	-25%	-41%	-40%	-33%	-35%	-33%	-29%	-36%
W Qld (B)	-28%	-34%	-25%	-30%	-34%	-41%	-27%	-33%	-34%
Central Qld (B)	-53%	-50%	-56%	-39%	-50%	-58%	-35%	-43%	-41%
S Qld (B)	-42%	-50%	-42%	-39%	-37%	-43%	-37%	-47%	-36%
Avg A Condition	-29%	-29%	-30%	-31%	-31%	-33%	-24%	-24%	-25%
Avg B Condition	-28%	-29%	-35%	-30%	-27%	-38%	-22%	-22%	-26%
Avg C Condition	-27%	-28%	-28%	-29%	-28%	-29%	-25%	-26%	-27%
Avg D Condition	-27%	-28%	-29%	-29%	-29%	-30%	-25%	-25%	-26%
Avg (Region*Cond)	-28%	-29%	-31%	-30%	-29%	-33%	-24%	-23%	-26%

Table 6.7.3: Liveweight gain responses. Additional detail for the summary tables of climate change impacts and adaptation analyses showing factorial combinations prior to averaging (All responses are for B condition pastures unless otherwise noted.)

Climate Scenario Impact (%change vs 1990)

Land Type>>	Base		Extra Trees		Lower Fertility		Sandier Soils	
Scenario >>	2070L	2070H	2070L	2070H	2070L	2070H	2070L	2070H
Kimberley (B)	**-124%**	**113%**	-476%	119%	-159%	123%	-150%	36%
Katherine (B)	**-45%**	**34%**	-68%	37%	-64%	39%	-28%	26%
Barkly (B)	**-55%**	**79%**	-90%	85%	-55%	102%	-42%	72%
NW Qld (B)	**-18%**	**44%**	-29%	35%	-22%	34%	-12%	38%
N Qld (B)	**-44%**	**75%**	-53%	31%	-60%	32%	-19%	49%
Pilbara (B)	**-61%**	**28%**	-67%	26%	-63%	46%	-59%	36%
Central Aus (B)	**-71%**	**63%**	-71%	52%	-74%	51%	-68%	69%
W Qld (B)	**-93%**	**74%**	-99%	90%	-98%	120%	-74%	95%
Central Qld (B)	**-102%**	**92%**	-136%	108%	-106%	105%	-92%	57%
S Qld (B)	**-110%**	**156%**	-150%	259%	-116%	159%	-87%	166%
Avg A Condition	**-61%**	**58%**	-65%	58%	-65%	58%	-51%	55%
Avg B Condition	**-65%**	**74%**	-70%	58%	-71%	70%	-48%	63%
Avg C Condition	**-91%**	**69%**	-113%	89%	-100%	85%	-78%	68%
Avg D Condition	**-108%**	**99%**	-166%	152%	-125%	120%	-92%	90%
Avg (Region*Cond)	**-68%**	**67%**	**-75%**	**65%**	**-73%**	**68%**	**-55%**	**61%**

Adaptation Effectiveness - Improving Land 1 Condition Class

Land Type>>	Base			Extra Trees			Lower Fertility			Sandier Soils		
Scenario >>	1990	2070L	2070H	1990	2070L	2070H	1990	2070L	2070H	1990	2070L	2070H
Kimberley (C->B)	-964%	-32%	-1456%	-127%	23%	-168%	-305%	-4%	-602%	-327%	7%	-531%
Katherine (C->B)	261%	1304%	235%	309%	-1567%	342%	246%	-2900%	252%	305%	585%	239%
Barkly (C->B)	283%	846%	178%	-2330%	-149%	392%	357%	#DIV/0!	227%	209%	442%	141%
NW Qld (C->B)	160%	239%	145%	195%	410%	164%	154%	242%	141%	179%	250%	152%
N Qld (C->B)	150%	1856%	254%	195%	-1761%	157%	283%	-2700%	245%	170%	695%	215%
Pilbara (C->B)	78%	184%	80%	89%	192%	95%	100%	178%	122%	134%	240%	94%
Central Aus (C->B)	241%	253%	171%	306%	460%	177%	230%	196%	152%	381%	345%	362%
W Qld (C->B)	93%	-1075%	74%	109%	-113%	117%	84%	-155%	100%	98%	146%	106%
Central Qld (C->B)	423%	-81%	462%	-5080%	1%	608%	667%	-59%	463%	265%	-187%	322%
S Qld (C->B)	949%	-16%	369%	-834%	36%	353%	1234%	11%	394%	731%	-204%	410%
Avg B -> A	**59%**	**75%**	**45%**	63%	88%	64%	54%	83%	43%	61%	52%	53%
Avg C -> B	**207%**	**1108%**	**217%**	**265%**	**-962%**	**205%**	**260%**	**-177600%**	**231%**	**222%**	**670%**	**212%**
Avg D -> C	**76%**	**-307%**	**49%**	124%	-57%	69%	82%	-100%	53%	64%	337%	45%

Adaptation Effectiveness - Impact of Extra Trees (active planting or NOT controling thickening)

Land Type>>	Base			Lower Fertility			Sandier Soils		
Scenario >>	1990	2070L	2070H	1990	2070L	2070H	1990	2070L	2070H
Kimberley (B)	-90%	52%	-90%	-115%	13%	-102%	-116%	11%	-103%
Katherine (B)	-30%	-59%	-28%	-26%	-16%	-36%	-27%	-37%	-26%
Barkly (B)	-62%	-91%	-61%	-74%	-105%	-71%	-52%	-64%	-41%
NW Qld (B)	-17%	-28%	-22%	-22%	-26%	-23%	-22%	-11%	-18%
N Qld (B)	-25%	-38%	-44%	-45%	-46%	-45%	-8%	-31%	-19%
Pilbara (B)	-33%	-43%	-34%	-29%	-47%	-44%	-25%	-40%	-36%
Central Aus (B)	-48%	-47%	-52%	-52%	-46%	-41%	-40%	-43%	-43%
W Qld (B)	-37%	-95%	-31%	-40%	-218%	-49%	-32%	-44%	-40%
Central Qld (B)	-72%	394%	-69%	-60%	129%	-72%	-48%	-162%	-52%
S Qld (B)	-71%	41%	-59%	-72%	10%	-60%	-58%	-187%	-49%
Avg A Condition	-41%	-48%	-41%	-45%	-52%	-44%	-34%	-37%	-34%
Avg B Condition	-42%	-51%	-48%	-46%	-53%	-52%	-31%	-39%	-35%
Avg C Condition	-51%	-168%	-46%	-62%	26200%	-49%	-45%	-88%	-42%
Avg D Condition	-62%	225%	-52%	-77%	72%	-59%	-55%	-245%	-46%
Avg (Region*Cond)	**-44%**	**-56%**	**-45%**	**-49%**	**-64%**	**-48%**	**-35%**	**-42%**	**-36%**

6.8 Appendix 8 – Effects of individual temperature, evaporation, vapour pressure, CO_2 and rainfall components of climate change responses

Table 6.8.1: This analysis tested individual components of climate change responses separating out and comparing:

1) Individual components of temperature (direct effects on plant growth limitation, effects on vapour pressure, changes in evaporation), CO_2 and rainfall;
2) The grass basal area (GBA) growth model (usually only runs to "boot-up" growth and produce some leaf area) vs normal growth (dominated by the transpiration * transpiration efficiency model);
3) The Kimberly frontage MRX vs the Average Native Pasture MRX.

Results are expressed as the percentage change in pasture production in response to the individual components of climate change.

a) **Dominant effect of Temp is VPD** for Tsp/VPD & Evap for GBA growth models

b) **GBA model less sensitive** to all component effects (CO2, Rain, Temp)

c) The Kimberly frontage landtype (MRX) is more sensitive than Average Native Pasture

Land type>>	**Kimbly_Frontage**		**AvgNtvPast_NGS**	
Growth Model >>	**Norm_Gr**	**GBA_Gr**	**Norm_Gr**	**GBA_Gr**
Separated Climate Component Effects				
CO2 654ppm_only	42.9%	5.0%	37.6%	5.8%
Rain +0%_only	0.0%	0.0%	0.0%	0.0%
Rain +11%_only	30.2%	8.7%	26.6%	7.5%
Rain -29%_only	-69.5%	-27.0%	-52.4%	-24.5%
T +2.7oC_only (1)	-1.4%	0.6%	-3.3%	0.4%
Evap_only	-8.7%	-7.9%	1.1%	-6.1%
VPD_only (2)	-34.2%	0.0%	-31.7%	0.0%
T,Ev&VPD (no Rn or CO2)	-41.5%	-7.2%	-33.2%	-5.7%
Combined Climate Scenario Effects				
+2.7C +0%Rn +CO2	-9.4%	-2.6%	-10.7%	-0.3%
+2.7C +11%Rn +CO2	23.3%	6.3%	17.3%	7.3%
+2.7C -29%Rn +CO2	-74.2%	-30.2%	-55.7%	-25.4%

(1) adjusted VP so VPD at higher temp = base VPD (at unadjusted temp)

(2) adjusted VP so VPD (at unadjusted temp) = VPD for higher temp (+2.7oC)

Comined effects very roughly additive (usually within 15%)

Add independent components to test for additivity:

T_only + Ev_only + VPD_only	-44.3%	-7.3%	-33.9%	-5.7%
Sc1 added T,R,CO2 cmpts	1.4%	-2.2%	4.4%	0.1%
Sc2 added T,R,CO2 cmpts	31.6%	6.5%	31.0%	7.5%
Sc2 added T,R,CO2 cmpts	-68.1%	-29.2%	-48.0%	-24.4%

6.9 Appendix 9 – Details of economic analyses

The bio-economic component of this project has provided a biophysical assessment of climate change impacts with and without adaptation, and has canvassed several attributes that increase risk and sensitivity of beef enterprises to projected climate change. To define where these changes may approach thresholds that may limit the ongoing viability of beef enterprises (with and without adaptation, see Fig. 1.4), the following economic assessment has been used.

Within the comprehensive range of bio-economic evaluations that were undertaken in 'Component 1' (B.NBP.0616), the ecological and economic implications of a series of land and herd management strategies (notably - stocking rate manipulation, wet season spelling and prescribed fire for regrowth control) were canvassed using modified variants of the GRASP pasture simulation model (McKeon et al. 1990) and the CSIRO ENTERPRISE herd economic model (MacLeod and Ash 2002). These strategies for sustainable resource use were considered within the context of a synthetic 'representative' beef enterprise that was assumed to be located in each of 9 regions of northern Australia (corresponding with the NABRC regions, excluding the Pilbara, above and Appendix A). The definition and calibration of each synthetic enterprise was structured around the consensus of industry representatives reached in the course of a series of paired workshops in each region which include:

- Maranoa (Mitchell)
- Burdekin (Uplands)
- Fitzroy (Duaringa)
- Western Qld (Blackall)
- Southern Gulf (Normanton)
- VRD (South)
- Barkly Tableland
- Alice Springs (North)
- Kimberley (Fitzroy Crossing)

The strategies were examined using simulations based on contemporary climate records of recent 25-28 years duration and a series of projections for 2030 and 2050. The outcomes are summarised in the 'Component 1' final report (B.NBP.0616).

For 'Component 2' (this report) the socio-economic focus has been more closely focussed on exploring the adaptive capacity of beef enterprises in the target regions. To address this, the economic modelling task has been built on the same baseline 'representative' enterprises that were created for 'Component 1'. It seeks to examine the sensitivity of the economic performance metrics (notably total gross margin and net profit) for those enterprises to changes in herd productivity and input-output price ratios (a measure of economic efficiency) that might be encountered under the projected climate change scenarios and/or increasing or decreasing management efficiency that might reflect managers' decision-making efforts to cope with the evolving climate outcomes. The singular and apparently narrow focus on these few central profit metrics recognises that survival of the business unit in the strict economic sense requires the enterprise generating sufficient revenue to retain or grow its' asset structure over time – this requires it to meet the full level of costs (both variable and overhead) to allow a surplus of resources for such purposes. In effect, to make a profit and positive and competitive return on the capital investment that constitutes the enterprise.

Modelling approach and structure

The general structure of the modelling approach is presented in Fig. 3. The core of the approach is an Excel® based template which is composed of several worksheet modules. The first module reconstructs the herd structure of each the 9 regional 'representative' enterprises based on general herd demographic and management data using data sourced from the 'Component 1' Enterprise models – data for all 9 enterprises is loaded and an individual regional enterprise is mimicked by selecting a 1-9 code which is filtered through a lookup table to input the relevant data for that region. A second module which contains data on total land area, effective access and up to 3 component land types - including carrying capacity and projected liveweight gain (averages ex-GRASP) - combines such data with the herd structure data to build the total herd carried and projects animal turnoff and injection by numbers, stock classes etc. Input-output prices and inputs employed by animal class types are sourced from a third module, and supplementary feeding types and rates from a fourth module, to place values on the different animal flows within the regional enterprises in a fifth reconciliation module which input to a sixth economic profitability metrics module to give a summary of the economic outcome - an array of metrics is available, but the key metrics are total gross margin (revenue less direct costs) and net economic profit (gross margin less overhead costs). Finally, the key to the scenario testing is a seventh module containing an array of 2-way ('what-if') data tables which consider the impact of the value of a particular parameter changing through a range - in this case 80%-120% of the baseline value. For the present, the impact is assessed on total gross margin and net economic profit.

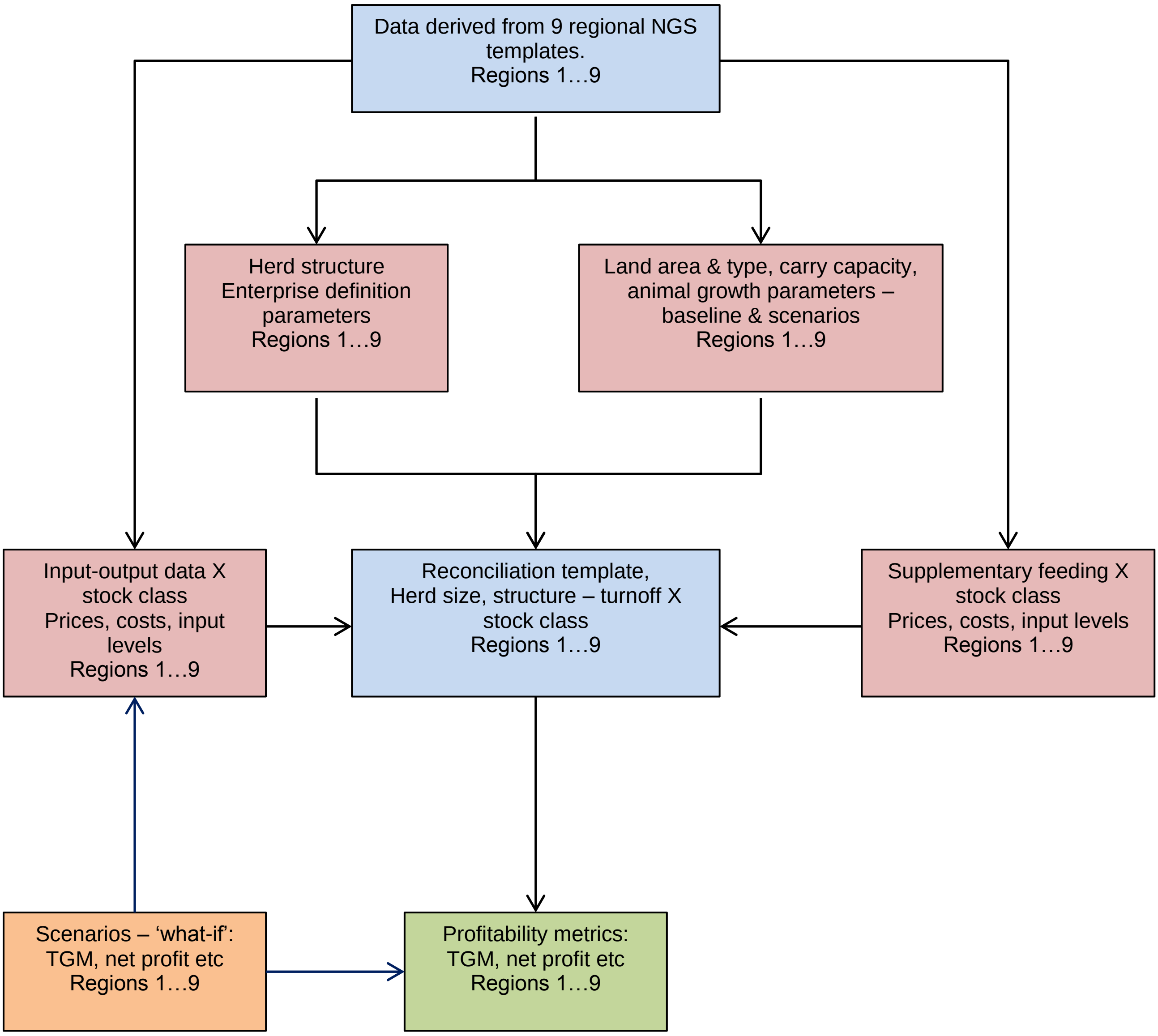


Fig. 6.9.1: Thematic of economic modelling approach.

The scenarios that are considered (initially) include variations in (Table 2):

- Liveweight gain (steer & breeder – kg/hd/yr).
- Carrying capacity (Ha or km^2/AE)
- Average beef price ($/kg liveweight)
- Total direct costs ($/hd/animal class)
- Total overhead costs ($/enterprise)

The first two reflect response to climate change, the last three to management adaptation.

Example - Fitzroy Region (Duaringa)

Application of the modelling template is briefly presented for the Fitzroy case study used in 'Component 1'. This is a self-replacing breeding herd rearing steers for turnoff at Japan Ox weight at around 2-2.5 yo. The property is 14,230ha of mixed native pasture and some timber regrowth. Pastures are a range of good to poor condition with an estimated (GRASP) average carrying capacity of 8 ha/A. There are 10 age cohorts of breeders and 2 age cohorts of steers assuming average liveweight growth of 160-190kg/head/yr. Average branding rates and male and female mortality rates are estimated (Enterprise regressions) respectively to be 80% (2yo+ breeders), 2.3% and 2.0%. Beef is valued at ~$1.55-1.80/kg liveweight across the classes, average direct cost is ~$8.50-35.00/hd steers to breeders and total overheads are ~$185,000 (~$13/ha).

Mean baseline total gross margin (TGM) and net economic profit (NP) are estimated to be $400,205 and $215,215 respectively giving an average rate of return after costs of 0.9% on a total investment of almost $16 million assuming 100% equity. Note, this would fall to -0.4% if the equity only fell to 90% giving an indication of the economic 'vulnerability' of this particular enterprise.

Table 6.9.1: Summary of economic scenarios

Parameter	% Δ	-20%	-15%	-10%	-5%	0%	5%	10%	15%	20%
1. LWG	TGM	$287,484	$314,598	$345,877	$371,111	$400,205	$418,802	$441,143	$466,707	$472,865
	NP	$102,494	$129,608	$160,887	$186,121	$215,215	$233,812	$256,153	$281,717	$287,875
2. CC Ha/AE	TGM	$333,504	$348,004	$363,823	$381,147	$400,205	$421,268	$444,672	$470,829	$500,256
	NP	$148,514	$163,014	$178,833	$196,157	$215,215	$236,278	$259,682	$285,839	$315,266
3. Beef price	TGM	$302,923	$327,243	$351,564	$375,884	$400,205	$424,525	$448,846	$473,166	$497,487
	NP	$117,933	$142,253	$166,574	$190,894	$215,215	$239,535	$263,856	$288,176	$312,497
4. Direct cost	TGM	$500,256	$470,829	$444,672	$421,268	$400,205	$381,147	$363,823	$348,004	$333,504
	NP	$225,227	$222,724	$220,221	$217,718	$215,215	$212,712	$210,209	$207,706	$205,203
5. OH cost*	NP	$252,213	$242,963	$233,714	$224,464	$215,215	$205,965	$196,716	$187,466	$178,217

*By definition changing overhead cost has no effect on TGM.

The baseline values are obviously the same as those in the 0% change column. Should either liveweight gain or carrying capacity fall or increase under projected climate change the TGM and NP both fall or increase as this change in growth flows through to fertility, mortality and turnoff numbers and weights. While falls of as much as 20% reduce NP by between 25% and 50%, it is not enough to drive projected NP to zero or less for this enterprise.

Increases in beef prices and falls in direct cost, induced perhaps by more effective management, increase both TGM and NP – and vice versa. Again falls in price or increases in direct costs of up to 20% are still not enough to remove the underlying profitability of the model enterprise. Changing overhead costs by definition has no impact on TGM, but inversely affects the estimated NP when they are increased or reduced. Again, shifts in the range of up to +20% are still not sufficient to remove the underlying profitability of this model enterprise.

Under both sets of scenarios, the conclusion could be drawn that the enterprise is potentially resilient to projected climate change impacts on animal productivity or carrying capacity and would benefit considerable from increased economic management while having a buffer against adverse market trends (e.g. continuing negative real cost-price trends).

This is an example of the approach and its potential application – similar analyses were conducted for the remaining 8 regions. While there were regional variations in sensitivity of the various regional models to changes of these parameters, they generally followed the same pattern.

Calculating Break-even Thresholds

Break-even analyses were undertaken with each of the 9 regional template models to provide a bio-economic metric of a 'threshold' of viability which is essentially the approximate limit to the level of productivity decline that an enterprise could sustain under the impacts of drying climate scenarios. The economic model (above) accommodates independent adjustments of carrying capacity and liveweight gain (lwg/hd). However, in GRASP simulations along gradients of climate change, the changes in these two components of productivity are tightly linked. This relationship was quantified for each region by regressing the percentage change in lwg/hd against the percentage change in carrying capacity for the set of drying climate change scenarios (10^{th} percentile rainfall projections and associated changes in temperature for 2030, 2050, 2070 and 2100: Fig. 2.1). The fitted regression multiplier for each region is given below (Table 6.9.2).

Table 6.9.2: Multiplier for each region linking percentage changes in liveweight gain per head to percentage changes in carrying capacity for declining productivity along a temporal gradient of drying climate (from GRASP modelling output).

NABRC Region	South Qld	North Qld	Central Qld	Western Qld	NW Qld	Katherine	Barkly	Central Aus	Kimberley	(Pilbara)
NGS Name	Maranoa	Burdekin	Duaringa	Western Qld	Sth Gulf	VRD - Sth	Barkly - Sth	Alice Springs	Kimberley	Pilbara
Linkage multiplier	-0.72	-0.43	-0.52	-0.23	-0.41	-0.28	-0.55	-0.17	-1.00	-0.12

Note that the regression lines were forced to have zero intercept (i.e., the percentage change in both variables is 0 when no change occurs). Note also that carrying capacity is expressed as area/hd in order to obtain a linear relationship.

This inherent linkage from the GRASP modelling was incorporated into economic break-even analyses by forcing the lwg/hd to follow the changes in carrying capacity, e.g., if carrying capacity (area/hd) was changed by 10%, then lwg/hd was changed by 10% * linkage multiplier. All subsequent references to changing in carrying capacity in the economic model imply that corresponding linked changes in lwg/hd have also been made.

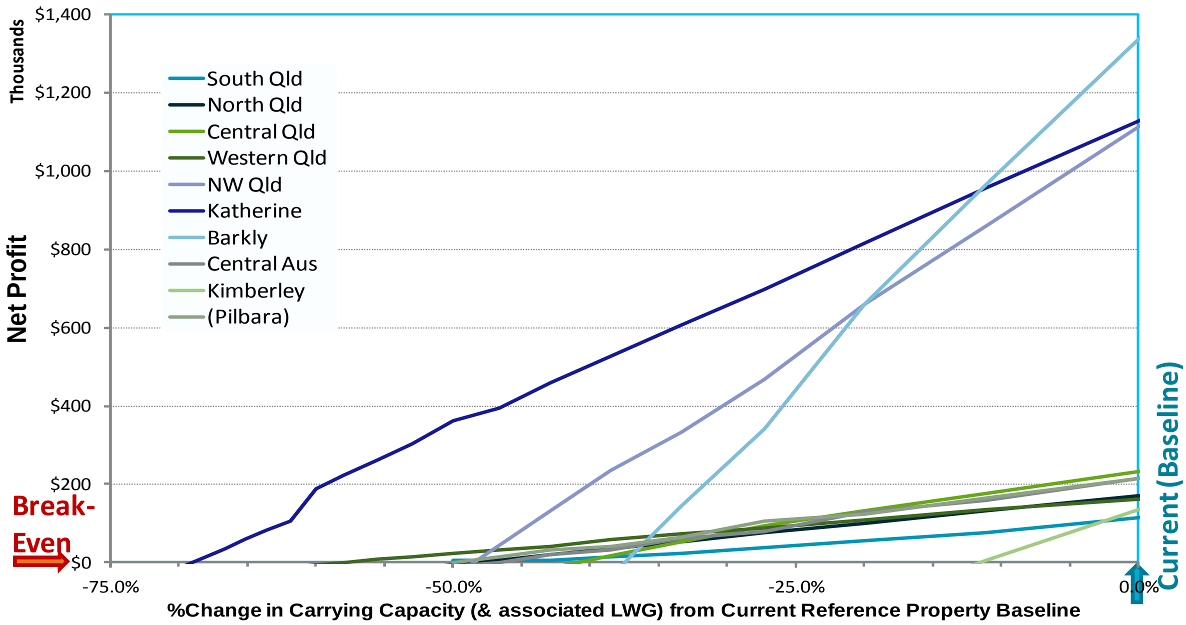


Figure 6.9.2: Declines in net profit (at 100% equity) as a function of declining carrying capacity (and associated linked declines in liveweight gain – Table 6.9.1) for representative properties in each region.

Note that the x-axis intercept gives the break-even threshold as the decline in productivity below which there is no profit. (The y-axis intercept gives current profit of the enterprise and the slope of the line the sensitivity of the business to declining productivity). Carrying capacity here is expressed as hd/area to obtain a linear relationship.

To calculate the break-even threshold ($0 net profit at 100% equity), the net profit for the enterprise in each region was calculated across a range of declining carrying capacity (and associated decline in lwg) and a regression line was then used to calculate the intercept (percentage decline in carrying capacity at which net profit was $0) (Fig. 6.9.2).

References

McKeon, G.M., K.A. Day, S.M. Howden, J.J. Mott, D.M. Orr, W.J. Scattini, and E.J. Weston (1990). Northern Australian savannas: Management for pastoral production. *Journal of Biogeography* 17, 355-372.

MacLeod, N.D., and A.A. Ash (2001). Development of a spreadsheet herd dynamics model to assess the economic value of forecasts in extensive grazing enterprises. *Oceans to Farms Project Report No.6*, CSIRO Sustainable Ecosystems, Brisbane and Townsville.

6.10 Appendix 9 – Questionnaire used for surveys in social section

Survey questionnaire to assess how well the northern beef industry is prepared to cope with climate- and other challenges. (Conducted with 240 pastoralists across the NGS regions).

The beef survey for beef enterprises

Interviewer: ______________________
Interviewee: ______________________
(Gender: M / F)
Date: ______________________

Hello! My name is ______________________, I am from the CSIRO team who are researching the northern cattle industry. Do you remember receiving a letter from us in the mail? We are hoping to speak with 50 beef producers in the region and 300 nationally about their plans for the future. Your information will help us advise government and the cattle industry to help people like you deal with environmental changes more easily.

Would you mind if I asked you some questions? (Is there a more appropriate time to call you?). Please remember that your responses remain confidential.

PART A About You

1. Are you managing the property for someone else? ______ *Owner / Manager*
2. How long you have been grazing cattle? ______ *years*
3. How long have you grazed in this region? ______ *years*
4. How many generations of your family have worked as graziers? ______
5. How many of your family members are cattle graziers? ______ *people*
6. Have you ever completed any trade certificate or degree? ______ *Yes / No*

   What? ______________________

7. Have you ever worked outside of the grazing industry? ______ *Yes / No*

   Where? ______________________

8. What would you do if you could no longer be a cattle grazier? ______
9. Do you mind telling me in what year you were you born? ______ *19* ______
10. How many children do you have living at home? ______ *People*
11. How many hectares of land do you manage? ______ ha
12. How many additional people are employed on your property ______ *People*
13. Approximately, how many head of cattle do you run? ______ *Head*
14. How variable is this number? E.g. over the last **10years**, what were the minm and maxm that you ran?

    minm ______________ to maxm ______________

15. Over the past 5 years what % of your FAMILY income came from cattle?

    1-20% 21-40% 41-60% 61-80% 81-100%

16. What are your other sources of FAMILY income? ____________________

17. On a scale of 1-5, would you say you have a strong financial buffer in case of emergencies? (for example, can you access finance easily if you need to?)

    1. Not at all 2. a little 3. depends 4. possibly 5. definitely

18. To what extent would you say your 'bank manager' has a large influence on your business decisions?

    1. None at all 2. a little 3. depends 4. a little 5. a large extent

19. Approximately, how much income does your business turnover each year?

    <$150K $150K-$500K $500K-$1M $1M-$5M >$5M

PART B This section is about how you manage climate challenges

Before we start – is there any over-arching comment you would like to make about climate change?

____

____

____

____

The following is a list of statements. We would like to know how much you agree with each one. Could you please use the following 5-point scale to indicate how much you agree or disagree with each statement: where 1=strongly disagree, and 5=strongly agree.

(1=strongly disagree, 2=disagree, 3=unsure, 4=agree, 5=strongly agree)

How strongly do you agree with each of the following statements?
strongly disagree - strongly agree

20.	I do not believe that future climate will be any different from my past experience	1	2	3	4	5
21.	If the climate changes, there is much that I can do to respond to the impacts	1	2	3	4	5
22.	If the climate changes, is there much I can do to respond to the opportunities	1	2	3	4	5
23.	How I approach present climate challenges will be sufficient for dealing with any future climate challenges, should they occur	1	2	3	4	5
24.	The best approach for dealing with climate change, should it occur, is to pick the most likely impacts and concentrate on coping with these	1	2	3	4	5
25.	Before I would start to develop plans for a changing climate, I would first need accurate predictions of what might happen	1	2	3	4	5

26.	I have a broad understanding of the ways in which projected changes in climate could influence my business (+ly & -ly)	1	2	3	4	5
27.	Climate change is NOT an important consideration when developing options for *my cattle business*, relative to other current issues	1	2	3	4	5
28.	Climate change should be an important consideration when developing *policies and regulations* for the beef industry relative to other current issues	1	2	3	4	5
29.	I think that immediate policy action is needed to prepare for climate change and its influence on beef production in this region	1	2	3	4	5
30.	Climate impacts are unlikely to manifest in this region for some time	1	2	3	4	5
31.	I am interested in learning about climate change and its impacts on the beef industry	1	2	3	4	5
32.	I discuss approaches for climate adaptation with government agencies and researchers	1	2	3	4	5
33.	I discuss approaches for climate adaptation with other cattle graziers	1	2	3	4	5
34.	I always assume the worst (e.g. approaching drought) when I make land management decisions	1	2	3	4	5
35.	I believe that opportunity comes from taking calculated risks	1	2	3	4	5
36.	I don’t really believe in long-term planning – things are too uncertain	1	2	3	4	5
37.	I like to experiment with new ways to graze cattle	1	2	3	4	5
38.	I am prepared to take advantage of a particularly good season	1	2	3	4	5
39.	We rely on drought assistance to get us through drought years	1	2	3	4	5

Financial, attitudinal and emotional flexibility

40.	I have always grazed cattle in (generally) the same way	1	2	3	4	5
41.	Regardless of what happens, we have made sure that we are financially secure	1	2	3	4	5
42.	I am less likely to survive drought compared to other cattle graziers I know	1	2	3	4	5
43.	I am interested in learning new skills	1	2	3	4	5
44.	I feel confident that I already have the skills to manage for long-term drought	1	2	3	4	5
45.	I love being a cattle grazier	1	2	3	4	5
46.	Being a grazier is a lifestyle – it is not just my job	1	2	3	4	5

47.	I have many options available to me other than being a grazier	1	2	3	4	5
48.	I make decisions about my land based on market prices	1	2	3	4	5
49.	I make decisions about my land based on what I think the following season might be like	1	2	3	4	5
50.	I continually record the condition of my land so that I can recognise important changes	1	2	3	4	5
51.	I have some very strong friendships in this community	1	2	3	4	5
52.	I would never want to move from this region	1	2	3	4	5
53.	I always access expertise (e.g. consultant) before I make an important business decision	1	2	3	4	5
54.	I always know how much money comes in and out of my business each month	1	2	3	4	5
55.	I have a documented business plan	1	2	3	4	5
56.	I am more of a 'lifestyle' grazier and focus less on making a profit	1	2	3	4	5
57.	I have calculated my production costs	1	2	3	4	5
58.	My current land management practices will not impact on my future productivity	1	2	3	4	5
59.	My land condition is not related to the way I use the land, but rather to the local environment, climate and geology	1	2	3	4	5
60.	I like to think of myself as responsible for the future productivity of my land	1	2	3	4	5
61.	I make decisions about my land independently of others	1	2	3	4	5
62.	I have good networks to access government agencies and government assistance	1	2	3	4	5
63.	I would happily consider another occupation if the need arose	1	2	3	4	5
64.	I am unlikely to *move* elsewhere to graze cattle if conditions become unsuitable here	1	2	3	4	5
65.	If needed, I am prepared to completely change the way I manage my property in order to survive as a grazier	1	2	3	4	5
66.	I already access scientific technology and expertise relating to the climate (e.g. forecasts)	1	2	3	4	5
67.	I would like more access to climate technology and expertise	1	2	3	4	5
68.	The important thing for me is to minimise my losses during bad seasons	1	2	3	4	5
69.	Even if I knew drought was likely to occur, there is not much I could do about it	1	2	3	4	5
70.	I could minimise the environmental impact of cattle if I knew whether the next season is likely to be wet or dry	1	2	3	4	5

71.	I have not increased my fencing over the past 5 years to manage any erosion prone areas I might have on my property	1	2	3	4	5
72.	I have increased my fencing over the past 5 years to allow for increases in cattle numbers	1	2	3	4	5
73.	I do not use a set pasture utilisation target when adjusting stocking rates?	1	2	3	4	5
74.	I have increased the number of watering points on my property over the last 5 years	1	2	3	4	5
75.	I do not have a well developed or documented weed, pests and diseases plan for my property	1	2	3	4	5

PART C In this section, I would like to discuss with you the sorts of plans you might have for the future.

76. Have you made any major changes on your property over the past *five* years in terms of:
    a. Technology and management ____________________
    b. Diversification ____________________
    c. Changes in land use ____________________
    d. Infrastructure (fences/watering points) ____________________

77. Apart from grazing, are there other resources that exist on your land that may be profitable?
    a. What are these and do you think you might pursue them as a business?

    ____

    ____

    b. *If yes,* how have you found out /will you find out information about these?

    ____

    ____

I would now like to present you with 6 possible scenarios for the future. We are keen to know how you would approach each challenge or opportunity, IF these situations were to occur.

Situation 1: More Rain

78. Faced with a <u>long term</u> **<u>improvement</u>** in pasture growth, what would you ASPIRE **to do? Would you….**

a.	*Do nothing(keep cattle numbers static)*	*YES/UNSURE/NO*
b.	*Increase cattle numbers*	*YES/UNSURE/NO*
c.	*Move from breeding cattle to fattening*	*YES/UNSURE/NO*
d.	*Increase cattle numbers and infrastructure such as fences, watering points, etc*	*YES/UNSURE/NO*

e. *Consider diversifying the business beyond cattle* — *YES/UNSURE/NO*

f. *Sell all the cattle and consider another livelihood* — *YES/UNSURE/NO*

g. *Sell the property and move elsewhere* — *YES/UNSURE/NO*

h. *Retire* — *YES/UNSURE/NO*

i. *Other* ______________________________

____

____

79. What would stop you from achieving your aspiration?

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SITUATION 2: Less Rain

80. Faced with a long term *decrease* in pasture growth due to lower rain, what would you ASPIRE to do? Would you….

a. *Do nothing* — *YES/UNSURE/NO*

b. *Run breeds that are more resistant to drought* — *YES/UNSURE/NO*

c. *Move towards breeding cattle only (less fattening)* — *YES/UNSURE/NO*

d. *Decrease cattle numbers only* — *YES/UNSURE/NO*

e. *Amalgamate with other properties to reduce stocking rates* — *YES/UNSURE/NO*

f. *Increase supplementary feeding of herd* — *YES/UNSURE/NO*

g. *Implement strict controlled breeding based on feed availability* — *YES/UNSURE/NO*

h. *Increase infrastructure such as fences, watering points, etc.* — *YES/UNSURE/NO*

i. *Sell all the cattle and consider another livelihood* — *YES/UNSURE/NO*

j. *Sell the property and move elsewhere to continue grazing* — *YES/UNSURE/NO*

k. *Retire* — *YES/UNSURE/NO*

l. *Other* ______________________________

____

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81. What would stop you from achieving your aspiration?

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____

SCENARIO 3: Increasing Heat Stress

82. If temperatures rise such that the water demands of your herd increase due to a long term rise in animal heat stress, what would you ASPIRE to do? Would you….

a.	*Do nothing*	*YES/UNSURE/NO*
b.	*Increase watering points (regardless of cost)*	*YES/UNSURE/NO*
c.	*Encourage more trees*	*YES/UNSURE/NO*
d.	*Decrease stocking rates*	*YES/UNSURE/NO*
e.	*Run breeds that are more resistant to drought*	*YES/UNSURE/NO*
f.	*Balance stress performance with productivity and meat quality*	*YES/UNSURE/NO*
g.	*Sell all the cattle and consider another livelihood*	*YES/UNSURE/NO*
h.	*Sell the property and move elsewhere to continue grazing*	*YES/UNSURE/NO*
i.	*Retire*	*YES/UNSURE/NO*
j.	*Other* ____________________	

83. What would stop you from achieving your aspiration?

SITUATION: Changing Seasons

84. Faced with a long term increase in rainfall variability (e.g. a change in the timing and duration of rainfall across seasons), what do you ASPIRE to do? Would you….

a.	*Do nothing*	*YES/UNSURE/NO*
b.	*Increase infrastructure such as watering points*	*YES/UNSURE/NO*
c.	*Fatten or breed cattle*	*YES/UNSURE/NO*
d.	*Be flexible in the stocking rates*	*YES/UNSURE/NO*
e.	*Conduct strict controlled breeding*	*YES/UNSURE/NO*
f.	*Increase supplementary feeding of herd*	*YES/UNSURE/NO*
g.	*Sell all the cattle and consider another livelihood*	*YES/UNSURE/NO*
h.	*Sell the property and move elsewhere to continue grazing*	*YES/UNSURE/NO*
i.	*Retire*	*YES/UNSURE/NO*
j.	*Other* ____________________	

85. What would stop you from achieving your aspiration?

____

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SITUATION 5: Increasing Pests, Weeds, Diseases

86. Faced with an increase in the numbers of pests, weeds or diseases over the longer term, what would you ASPIRE to do?

a.	*Do nothing*	*YES/UNSURE/NO*
b.	*Run breeds that are more resistant to disease*	*YES/UNSURE/NO*
c.	*Implement more stringent weed control strategies*	*YES/UNSURE/NO*
d.	*Make better use of fire management strategies*	*YES/UNSURE/NO*
e.	*Amalgamate with other properties to reduce stocking rates*	*YES/UNSURE/NO*
f.	*Reduce stocking rates*	*YES/UNSURE/NO*
g.	*Use controlled burns to control woody weeds*	*YES/UNSURE/NO*
h.	*Sell all the cattle and consider another livelihood*	*YES/UNSURE/NO*
i.	*Sell the property and move elsewhere to continue grazing*	*YES/UNSURE/NO*
j.	*Retire*	*YES/UNSURE/NO*
k.	*Other* ______________________________	

____

____

87. What would stop you from achieving your aspiration?

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SITUATION 6: Erosion

88. Faced with increasing problems with soil erosion on your property (as a result of drought and wind storms), what do you ASPIRE to do?

a.	*Nothing*	*YES/UNSURE/NO*
b.	*Decrease cattle numbers*	*YES/UNSURE/NO*
c.	*Increase supplementary feeding of herd*	*YES/UNSURE/NO*
d.	*Increase infrastructure such as fences, watering points, etc*	*YES/UNSURE/NO*
e.	*Fence cattle away from erosion sensitive areas on the property*	*YES/UNSURE/NO*
f.	*Better manage wet season spelling strategies*	*YES/UNSURE/NO*

g.	*Intensively plant more trees in vulnerable areas*	*YES/UNSURE/NO*
h.	*sell all the cattle and consider another livelihood*	*YES/UNSURE/NO*
i.	*sell the property and move elsewhere to continue grazing*	*YES/UNSURE/NO*
j.	*Retire*	*YES/UNSURE/NO*
k.	*Other* ______	

89. What would stop you from achieving your aspiration?

______

______

______

90. Faced with a situation where you feel like you should be considering changes in order to maintain your profits or longer-term sustainability, how important would you rate each of the following factors in preventing you from changing,

on a scale of 1-4 where 1=not at all important, 4=very important …

a.	*It is too hard for me to change what I do*	*1*	*2*	*3*	*4*
b.	*Any change would limit me in other areas*	*1*	*2*	*3*	*4*
c.	*The relevant rules and regulations are incompatible with my aspirations*	*1*	*2*	*3*	*4*
d.	*I am not convinced that change will be more profitable*	*1*	*2*	*3*	*4*
e.	*I do not think that rain will increase*	*1*	*2*	*3*	*4*
f.	*I do not see any urgency for me to change*	*1*	*2*	*3*	*4*
g.	*My family would not be supportive of change*	*1*	*2*	*3*	*4*
h.	*Change for more productive times is too risky*	*1*	*2*	*3*	*4*
i.	*I need advice on how to implement change*	*1*	*2*	*3*	*4*

91. Have you ever noticed parts of your property that might have degraded and not be so profitable?

Yes / No details ______

92. Do you think you could estimate the time lag that exists between recognising that environmental conditions are changing on your land and a decrease in **profits**?

______ *Years*

93. In your experience, do you think you could estimate the time lag that exists between a decrease in **profits** and actually changing your land management strategy?

______ *Years*

Measure of Success

94. Overall, COMPARED TO OTHERS YOU KNOW how successful do you think you have been in the past at managing climate events such as drought – on a scale of 1-10, where 1= dismally unsuccessful and 10= extremely successful. You may want to measure success as minimising the (environmental and financial) losses that could be expected during a drought

1 2 3 4 5 6 7 8 9 10

PART D Advice for Climate Adaptation Planning

In these last few questions, we hope to get some advice from you for climate adaptation purposes.

95. Who are the key PEOPLE or ORGANISATIONS that you rely on to gain information about cattle grazing in a changing environment? (*prompt for individuals, organisations or information sources (e. g. policies, materials, websites etc*)

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96. What sort of information would you like to help you make decisions about the future?

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97. We would be delighted to circulate the results of our survey to you. We are also very keen to follow key individuals into the future and see what they do, what their challenges are and what opportunities they find. Would you be interested in being part of this research on an ongoing basis? At this stage, we hope to contact you every 3-5 years and do a (shorter) survey with you. Of course, you would be free to leave the research at any time. *Please confirm full name, address and phone*

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Email: ______________________________

THANK-YOU SO MUCH FOR YOUR HELP!