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The climate change risk management matrix for the grazing industry of northern Australia

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Abstract. The complexity, variability and vastness of the northern Australian rangelands make it difficult to assess the risks associated with climate change. In this paper we present a methodology to help industry and primary producers assess risks associated with climate change and to assess the effectiveness of adaptation options in managing those risks. Our assessment involved three steps. Initially, the impacts and adaptation responses were documented in matrices by 'experts' (rangeland and climate scientists). Then, a modified risk management framework was used to develop risk management matrices that identified important impacts, areas of greatest vulnerability (combination of potential impact and adaptive capacity) and priority areas for action at the industry level. The process was easy to implement and useful for arranging and analysing large amounts of information (both complex and interacting). Lastly, regional extension officers (after minimal 'climate literacy' training) could build on existing knowledge provided here and implement the risk management process in workshops with rangeland land managers. Their participation is likely to identify relevant and robust adaptive responses that are most likely to be included in regional and property management decisions. The process developed here for the grazing industry could be modified and used in other industries and sectors.

By 2030, some areas of northern Australia will experience more droughts and lower summer rainfall. This poses a serious threat to the rangelands. Although the impacts and adaptive responses will vary between ecological and geographic systems, climate change is expected to have noticeable detrimental effects: reduced pasture growth and surface water availability; increased competition from woody vegetation; decreased production per head (beef and wool) and gross margin; and adverse impacts on biodiversity. Further research and development is needed to identify the most vulnerable regions, and to inform policy in time to facilitate transitional change and enable land managers to implement those changes.

Additional keywords: impact, adaptation, vulnerability, policy, decision making, adaptive action.

Introduction

Importance of agriculture

The grazing industry in Australia is a predominant land use of the rangelands along with traditional ownership and national parks and occupy 6.7 million km^2 or around 85% of the land area in Australia (National Land and Water Resources Audit 2001).

Agriculture contributed Au$36.1 billion or ~2% of gross domestic product (GDP) in Australia in 2006–07 (ABS 2007), around two-thirds of agricultural products were exported (DAFF 2007) and agricultural products accounted for ~18% of total Australian merchandise exports (ABARE 2007). Over the period 2004–07 the beef industry accounted for ~21% and the sheep industry (wool and sheep meat) for ~8% of all agricultural production in Australia.

Using Queensland as the example State, the domestic livestock (sheep and cattle) in the State are forecast (2008–09) to contribute 29% of the state's primary industries gross value of production (DPI&F 2008). Their collective contribution to the Australian economy is forecast (2008–09) to be Au$3.54 billion (DPI&F 2008).

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Drought has a major impact on the Australian economy, which was highlighted in 2002–03 with a 19 percent fall in the value of agricultural production which led to a decline in Australia's GDP growth of ~1% (Lu and Hedley 2004).

Effect of climate change on agricultural resources and productivity

Climate change is projected to have a significant adverse impact on Australia's agricultural production and exports (IPCC 2007; Stern 2007; Garnaut 2008). Australian production of beef, sheep meat and wool could decline by 5–11% by 2030 relative to the reference case (Heyhoe *et al*. 2008, reference case is 'business as usual' in the absence of any impacts from climate change, external changes or new policy changes). In northern Australia, the decline in beef production is expected to be 3.5% by 2030 (Heyhoe *et al*. 2008).

Again using Queensland as an example State, the impact of climate change in Queensland's rangelands is unclear, with wide uncertainties reported in projections of the growth of pasture, beef liveweight gain and livestock carrying capacities (Hall *et al*. 1998). This uncertainty was associated with choice of rainfall scenarios in the modelling simulations used. The climate change impacts also varied considerably across the state depending on whether moisture, temperature or nutrients were the limiting factors. Studies in regional Queensland show less variability in pasture growth and production projections than the state-wide study (Cobon *et al*. 2005; Cobon and Toombs 2007, 2008); however, regional projections of climate change include additional uncertainty associated with spatial downscaling from larger scale global circulation models (Charles *et al*. 1999).

The rangelands in Australia support vast natural plant and animal biodiversity which is likely to be highly vulnerable to climate change. The rate of environmental change associated with the changing climate is predicted to be faster than any change in the past so adequate response through adaptive evolution is unlikely for most species and fragmentation of natural landscapes presents formidable barriers to natural migration (Hughes 2003).

The interactions between human induced changes in different climate variables and the effects on biological processes are often complex and difficult to interpret accurately. For example, a rise in carbon dioxide concentration is likely to increase pasture growth but this benefit maybe offset by reduced rainfall and higher temperatures decreasing non-structural carbohydrate concentrations and digestibility in tropical grasses (Howden *et al*. 1999; Crimp *et al*. 2002; IPCC 2007).

Uncertainty – climate projections and biological processes

The most recent comprehensive best estimate projections for Australia in 2030 indicate a rise in average temperature of 0.7–1.2°C, little change in annual rainfall in the far north and decreases of 2–5% elsewhere, and 2% increased potential evapotranspiration (CSIRO and Bureau of Meteorology 2007). There is uncertainty associated with these projections due to differences between models and uncertainty in the likely green house emissions in future years.

Gaps in our understanding of some biological process (e.g. relationship between CO_2 level and vegetation growth) and problems associated with accurately representing complex systems in modelling limit our capacity to understand the 'real impacts and most effective adaptive responses' of climate change (McKeon *et al*. 2009, this volume).

Importance of commencing adaptation now

Despite the lack of accurate future climate details and understanding of some biological processes, adaptation needs to occur now because past emissions of greenhouse gases have already committed Australia to further warming (Solomon *et al*. 2007) and these emissions are continuing to increase (Raupach *et al*. 2007). Risk assessment allows informed decisions to be made even where knowledge is limited.

Australian agricultural businesses have been surveyed with respect to climate change impacts on farm management and production (ABS 2008). As a result of perceived climate change impacts on their agricultural business, nearly half the respondents have already changed management practices.

The Australian Federal and State governments' policy responses to climate change have focused on mitigation (e.g. National Greenhouse Response 1992, Australian Government 1992; National Greenhouse Strategy 1998, Commonwealth of Australia 1998; Queensland ClimateSmart 2050, State of Queensland 2007) although it's recognised that adaptation actions were important in enhancing resilience to climate change (e.g. ClimateSmart Adaptation 2007–12, DNRW 2007).

The availability and implementation of adaptation options will influence the ability of the grazing industry to ameliorate the impacts of, or potentially benefit from, climate change (Stokes *et al*. 2008). Early work describing likely changes in grazing management indicated a wide variety of responses that can assist with adapting to climate change (e.g. McKeon *et al*. 1993). There have been more studies completed since then and many of these are referenced in the adaptation matrix reported later in this paper. Under moderate climate change these adaptation options are likely to be a key component in effectively coping with climate change (Easterling *et al*. 2007).

Adaptation responses are important because the climate has already changed and these changes are likely to continue even if mitigation strategies are highly effective. An effective broad-scale adaptive response is most likely if the impacts of climate change are considered in decisions at all levels across a variety of sectors (e.g. agriculture, health, infrastructure, energy, transport).

The Australian CSIRO and the Bureau of Meteorology have recently detailed climate change projections for regions of Australia (CSIRO and Bureau of Meteorology 2007) but the challenges for rangeland science are, for a range of spatial scales, to: (1) assess these projections in terms of impacts on rangeland grazing systems and their management; (2) develop effective adaptation responses and assess vulnerability; (3) enhance the capacity of regional extension to inform decision makers; and (4) inform policy of priorities for action.

Process to facilitate self action

Completing a risk assessment can help identify the climate change impacts of most importance (impact risk) and the areas of greatest vulnerability (e.g. high potential impact with a low capacity to adapt). Risk is the product of consequence and likelihood (Jones 2001). Although there is some understanding of the range of potential consequences of climate change for the grazing industry (e.g. decreases in pasture growth) understanding of the magnitude and/or likelihood of these consequences is less well developed.

The aim of this paper is to demonstrate a methodology for assessing the risk of climate change to the grazing industry in northern Australia. We developed matrices of the impacts of changes in climate (rising CO_2, temperature, rainfall, etc.) on key elements of the grazing industry (including pasture growth, water availability and gross margin) and of adaptation responses to each of those impacts. We modified a risk management framework (AGO 2006) to complete an assessment for the grazing industry of northern Australia of the risk, vulnerability and priorities for action (managerial and policy).

Methods

Adaptation and risk assessment

The word 'adaptation' is used in this paper to include the actions of adjusting practices, processes, and capital responses to the actuality or threat of climate change (Adger *et al*. 2007). It refers to planned or autonomous adjustments in the system (natural, production, human) and can reduce harmful effects or exploit opportunities (IPCC 2007).

The effective and successful implementation of adaptive responses involves risk assessment and four other preconditions that are required in the adaptation process (Warrick 2000). Implementation of adaptation measures is a continuous cycle of:

- gathering information;
- assessing the risks and developing responses;
- including the responses in normal decision making processes ('mainstreaming' adaptation);
- monitoring and evaluating the success and ongoing need of those responses (and of adaptation responses in other areas);
- raising awareness of future climate and the risks and opportunities; and
- building capacity to respond to those risks and opportunities.

The adaptation process is a model for communicating climate change risks and adaptive responses to a range of decision makers who are likely to implement them in management decisions or in government policy (e.g. land managers, regional groups, industry bodies, State and National governments).

The risk matrix used was derived from the Ansoff Product-Market Growth Matrix model (Ansoff 1957). This model hypothesises that the element of risk increases the further the strategy moves away from known quantities. For example, in a matrix illustrating consequences and likelihood of climate change, the risk increases as the consequences increase and the likelihood of occurrence becomes more certain. The risk matrix can help identify, prioritize, and manage key risks on a range of levels (e.g. business, industry, sector, state, country or global scale).

Workshops to develop matrix

In a series of seven workshops in Brisbane, we modified a generic risk management framework (AGO 2006) which provided the guidance and ground rules to complete a risk assessment for the northern Australian grazing industry. These workshops were completed in five distinct steps:

Step 1 - At the beginning of the first workshop it was essential to develop a common understanding of the scope of the assessment, identify the climate change variables that were important to the grazing industry, articulate how the climate variables were assumed to change in the future, assess the level of confidence in the projections for each variable, and identify the important components (or elements) of the grazing industry;

Step 2 - In all workshops, we evaluated the impacts by using a modification of the risk management framework (AGO 2006) and the expert knowledge of the workshop participants to complete separate impact and adaptation matrices;

Step 3 - completing a risk assessment of the impacts to identify those of most importance (impact risk);

Step 4 - completing a risk assessment of the impacts and adaptive responses to identify areas of greatest vulnerability (e.g. high potential impact with low capacity to adapt); and

Step 5 - preparing the risk statements that can identify the nature and level of risk, the need for, and timing of the response and the nature of useful adaptation responses.

Step 1 - Establishing the risk assessment boundaries

Scope of the assessment

The geographical boundary was defined as the rangelands in northern Australia (north of 29°S) within a timeframe of 2030.

Key variables of climate change for the grazing industry

The workshop participants identified 13 key variables of climate change with the potential to have a significant impact on the grazing industry. This list was not considered to be exhaustive but nonetheless adequate to provide a useful risk assessment overview of the grazing industry in northern Australia. The variables of climate change and the level of confidence in the projections we assigned (based on Cai *et al*. 2005; also see the following section) are presented in Table 1.

Table 1. The components of climate change of importance to the grazing industry and the level of confidence in the climate change projections (source Cai *et al*. 2005)

Variable of climate change	Level of confidence
Elevated CO_2	Very high confidence
Increased evaporation	Very high confidence
Higher minimum temperature	High confidence
Less frost	High confidence
Higher maximum temperature	High confidence
More days over 35°C	High confidence
More droughts	Medium to high confidence
Increased storm intensity – same total rainfall	Medium to high confidence
Decrease in winter rainfall	Medium to high confidence
Decrease in summer rainfall	Medium to high confidence
Increased storm frequency – same total rainfall, local flooding	Moderate confidence
More wildfires	Moderate confidence
Higher peak wind speeds	Moderate confidence

Level of confidence in climate change projections

To help assess the impact of each climate variable independent of the others we defined the level of confidence in the climate change projections for each climate variable (Table 1). The range in projections reflects uncertainty due to the various emissions scenarios and model differences. Generally there is more confidence in temperature projections than in rainfall projections, and more confidence in broad-scale average changes than in regional changes (CSIRO and Bureau of Meteorology 2007; IPCC 2007). We used four levels of confidence in assigning the 2030 projections to the climate change variables, namely: very high confidence (more than 90% probability); high confidence (~90% probability); medium to high confidence (more than 70% probability); and moderate confidence (more than 50% probability).

Extent of change in climate variables

To help identify the impacts of climate change it was necessary to define how much each climate variable was expected to change in the future. Climate change projections for 2030 (CSIRO and Bureau of Meteorology 2007) were used as a guide to assess the impacts of the changing climate. The impacts were developed assuming climate in northern Australia is projected to become warmer (0.7–1.2°C), with more hot days (+5 to 40 days/year over 35°C) and fewer cool nights (0 to –12 nights/year under 0°C), higher potential evaporation (2%), higher carbon dioxide concentrations (70–100 ppm) and little change in rainfall (annual, summer and autumn) in the far north, and decreases of 2–5% elsewhere (annual, summer and autumn). These changes are relative to 1961–1990 values and there are differences between regions and seasons.

Elements of the grazing industry

The elements of the grazing industry we identified covered economic, natural resource and social aspects. They were: pasture growth, woody vegetation, surface cover, water availability, pasture nutrition, plant available water capacity, sediment generation, wind erosion, environmental stress for animals, animal diseases, production (wool and beef; per head and per hectare), costs above the consumer price index (CPI)*, gross margin (relative to CPI), prices (relative to CPI), biodiversity and rural human health. Of these, we identified pasture growth, surface cover, production per head (wool and beef), gross margin and biodiversity as key elements important for economic, environmental and social well being in the grazing industry.

Step 2 - The impact and adaptation matrices

The matrices of climate change impacts and of adaptation responses consisted of the climate change variables (y-axis) and key elements of the grazing industry (x-axis) (see Tables 2 and 3 for layout). The workshop participants 'populated' each cell in the impact matrix by discussing and coming to consensus on the expected impact of each climate change variable for each key element, independent of other influences. The steps to populate each cell in the impact matrix (Table 2) consisted of verbally agreeing and then listing the following items:

(1) the direction (increase or decrease) and extent of the impact ignoring all other influences;
(2) whether the impact was negative or positive;
(3) a statement describing the direction and extent of the impact; and
(4) a statement describing the overall impact of climate change for each element (bottom row of matrix).

Once the impacts had been assessed each cell in the adaptation matrix (Table 3) was populated through agreement on an adaptive response(s) for each climate change variable and each key element of the grazing industry.

Step 3 - Risk assessment of the impact

Risk is defined as a hazard or the chance of a loss, but the analysis of risk may also identify opportunity and gain (rather than just fate and loss). Our risk assessment of the impacts of climate change involved understanding the potential consequences and the likelihood of these consequences occurring. Categories of consequence and likelihood were developed and one category from each was assigned to every cell in the impact matrix, which together provided an indication of impact risk. The level of impact risk can be used to identify priorities for action, which can be useful in the absence of a full vulnerability assessment.

Level of consequence of the impact

The level of consequence was determined by modifying the work of AGO (2006). Each cell in the impact matrix was assigned one of the following consequence categories: catastrophic, severe, major, moderate and minor for negative impacts, and phenomenal, extreme, major, moderate and minor for positive impacts. To help determine the consequence level for each cell in the impact matrix we needed to define and provide an example for each category. This task was made easier by listing some impacts associated with climate change (Appendix 1) and assigning an event that could be associated with each consequence category (Appendix 2). By completing this task it was easier to associate the impact with a likely consequence.

The catastrophic and minor categories were defined first to help set the consequence boundaries. A catastrophic rating was considered to be an unprecedented event in Australian agricultural history and was defined as a complete loss of capability to supply animal products and/or loss of export and domestic markets. It was thought to be caused by either one of/or a combination of the following: exotic disease; a long-term 'super' drought (no surface water for agriculture); price of methane emissions exceeds industry value; global anti-meat cultural change; or market collapse caused by global depression or world war. The events and definitions for the other consequence categories are shown in Appendix 2.

Likelihood of an impact arising

The likelihood of an impact occurring was assigned to one of five categories (AGO 2006). At the extreme ends of the scale were impacts that were almost certain to happen and those that were extremely unlikely to happen. The names for the likelihood categories were: Almost certain, Likely, Possible, Unlikely and Rare.

*Consumer price index is a measure of the average price of consumer goods and services purchased by households.

As part of the likelihood assessment we also considered how often the impact might occur. Some impacts may happen only once, such as the permanent loss of an endangered animal or a plant species. Others were thought of as recurring events such as reduced income or ground cover caused by drought. The scale used to help rate the likelihood of both single and recurrent events is shown in Appendix 3 (see AGO 2006).

Impact risk

Once the categories of consequence and likelihood were developed one category from each was assigned to every cell in the impact matrix, which together provided an indication of impact risk. The levels for negative and positive impact risk were: extreme, high, medium and low and are shown in Table 4 (adapted from AGO 2006).

The assessment of impact risk was shown by the shading in each cell of the impact matrix (see Table 2). The darker the shading the greater the impact – negative impacts were shaded in brown and positive impacts in blue. The reason for cells without shading is described within each of those cells.

Priority for action

In the absence of a full vulnerability assessment, which in this case is provided later in the paper, the level of impact risk can be used to identify priorities for action. For example, a climate change impact that is almost certain to occur and has the potential for catastrophic consequences could be regarded as an extreme impact risk requiring urgent attention (see Table 4). The suggested association between level of impact risk and priorities for action for the grazing industry are provided below (adapted from AGO 2006).

Extreme – This level of impact risk demands urgent attention at the most senior leadership levels of industry and government. Effective responses are always transformational and not part of routine action.

High – This level of impact risk needs attention at senior levels of industry executives, agency management and policy development. More senior industry and government representatives need briefing. Effective responses are usually transformational and not generally incremental routine action.

Medium – This level of impact risk needs close monitoring and reporting on at senior levels (Industry executives, agency senior management, Pastoral Co. Boards, NRM group executives). Effective responses may be incremental and part of routine action.

Low – This level of impact risk requires they be maintained under review but existing controls should be sufficient and no further action is required unless the status changes.

Step 4 - Risk assessment of the potential impact and adaptive response (vulnerability)

Vulnerability is the degree to which a system is exposed, its sensitivity, and its adaptive capacity (IPCC 2007, see Fig. 1). Adaptive capacity is the ability of a system to adjust to climate change (including climate variability and extremes), to moderate potential changes, to take advantage of opportunities, or to cope with the consequences (IPCC 2007).

Vulnerability to climate change reflects situations where components of a natural or production system are: (1) likely to be more highly exposed to climate change; (2) relatively sensitive to adverse climate change; and (3) have adaptive mechanisms that are either ineffective or unlikely to be applied at the necessary scale.

To assess vulnerability, the workshop participants collectively agreed on the capacity of each key element of the grazing system to adapt to each variable of climate change. Adaptive capacity was considered to be either low, medium or high, and together with the previously compiled assessment of impact risk, a measure was derived of low, moderate or high vulnerability (Table 5).

Vulnerability assessed in this way was shown by the shading in each cell of the adaptation matrix (see Table 3; darker colouring of the cell indicates greater vulnerability; white cells reflect either positive consequences, insignificant impact or unknown or opposing processes in Table 2).

Step 5 - Writing the risk statement

The impact risk and vulnerability can be described in the form of risk statements that are useful when advising management and informing policy. A risk statement provides the descriptive information required for a reasoned and defensible assessment of the nature and level of risk, the need for and timing of the response and the nature of useful adaptation responses. They may result in the modification of existing strategies and plans, the development of new plans, the allocation of resources and responsibilities for the plans and their implementation.

A statement describing the risk of more and prolonged drought to the northern Australian grazing industry was prepared as an example for this paper.

Evaluating the risk assessment process and validating the matrices with stakeholders

A ‘matrix’ workshop was held in Longreach (western Queensland, September 2008) over a two day period to: (1) provide an evaluation of the risk assessment process for delivering climate change impacts and adaptations; (2) validate the content of the existing matrix; and (3) populate a new matrix with regional content. The participants were seven scientists/extension officers from Queensland government agencies and a natural resource management group, two land managers and one agribusiness consultant (G. Stone, unpublished). Their expertise included the disciplines of pasture ecology and agronomy, economics, agribusiness, animal nutrition, soil processes and grazing property management.

An introductory talk on climate change was provided to the participants that covered global, national, state and regional climate variability, and climate change trends and projections. Past and current research was also presented on topics such as the varying effects of CO_2, temperature and rainfall on pasture growth, pasture quality and animal production. The workshop participants were then provided with copies of the current impact and adaptation matrices.

The facilitator led a discussion of the impact of each climate variable on pasture growth (first column of matrix), the impact of CO_2 on each grazing element (first row of matrix) and the response required to adapt to each of these impacts. Consensus among participants provided validation of the current matrices. Later the extreme and high impact cells were discussed and validated, in all ~100 cells from each matrix.

Table 2. Impacts and the level of impact risk associated with climate change for key elements of the grazing industry in northern Australia[#]
CPI, Consumer Price Index

Climate change variable	Pasture growth	Surface cover	Wool per head	Beef per head	Gross margin (relative CPI)	Biodiversity
1. Elevated CO_2	Moderate increase in pasture growth due to CO_2 fertilisation (Refs 2a, 6a, 16a, 17h, 19b, 20a, 21a, 24a, 26a, 31a)	Minor increase in surface cover (Refs 6a, 16a, 19b, 20a, 31a)	Minor decrease in wool per head due to decreased pasture nutrition (Refs 19b, 20a, 21a)	Minor decrease in beef per head due to decreased pasture nutrition (Refs 19b, 20a, 21a, 25a)	Gross margin decreased (weed control, emissions trading and flow-on effects) (Refs 17b, 30a)	Changes in species composition and structure for plant species (Refs 17b, 17h, 21a, 27d)
2. Increased evaporation	Decrease in pasture growth (Refs 6a, 9a, 14a, 16a, 17b, 25a)	Decrease in surface cover (Refs 9a, 16a)	Decrease in wool per head (Refs 17b, 17h, 21a, 27a)	Decrease in beef per head (Refs 6a, 9a, 17b, 17h, 27a)	Decrease in gross margin (Refs 16a, 17b, 17h, 22a, 27a, 30a)	Changes in species composition and structure for plant and freshwater dependent species (Refs 1b, 8a, 11a, 12a, 17b, 17h, 27d)
3. Higher minimum temperature	Moderate increase in pasture growth (Reference 23c - increasing CO_2 may increase frost damage) (Refs 2a, 6a, 9a, 14a, 17h, 19a, 21a, 25a, 26a)	Increased surface cover (Refs 6a, 9a, 19a, 25a)	Increase in wool per head (Refs 19a, 19b, 26a, 27a)	Increase in beef per head (Refs 9a, 19a, 19b, 24a, 26a, 27a)	Increased gross margin (Refs 19b, 22a, 27a)	Changes in insect and plant species composition (Refs 17b, 17h, 27d)
4. Less frost	Increase in pasture growth during winter (Refs 2a, 6a, 9a, 14a, 17h, 19a, 21a, 25a, 26a)	Increased surface cover (Refs 9a, 19a, 25a)	Increase in wool per head (Refs 19a, 19b, 26a, 27a)	Increase in beef per head (Refs 9a, 19a, 19b, 24a, 26a, 27a)	Increase in gross margin (Refs 19b, 22a, 27a)	Changes in insect and plant species composition (Refs 17b, 17h, 27d)
5. Higher maximum temperature	Decrease in pasture growth (Refs 6a, 9a, 14a, 16a, 17b, 19b)	Decrease in surface cover (Refs 6a, 9a, 16a, 19b)	No significant effect on mature animals (Expert Opinion)	Decrease in beef per head (Refs 6a, 9a, 17b, 17h, 25a, 27a)	Decrease in gross margin (Refs 16a, 17b, 17f, 17g, 17h, 19b, 21a, 22a, 27a, 29a, 30a)	Changes in amphibian, insect and plant species composition (Refs 1b, 8a, 11a, 12a, 17b, 17h, 27d,30a)
6. More days over 35°C	Decrease in pasture growth (Refs 6a, 9a, 14a, 16a, 17b, 19b)	Decrease in surface cover (Refs 6a, 9a, 16a, 19b)	No significant effect on mature animals (Expert Opinion)	Decrease in beef per head (Refs 6a, 9a, 17b, 25a, 27a)	Decrease in gross margin (Refs 16a, 17b, 17f, 17g, 17h, 19b, 21a, 22a, 27a, 29a, 30a)	Changes in plant structure and species composition (Refs 17b, 17h, 27d, 30a)
7. More droughts	Severe reduction in pasture growth (Refs 6a, 9a, 14a, 16a, 17b, 17h, 19b, 21a, 24a, 25a)	Severe reduction in surface cover (Refs 6a, 9a, 16a, 19b, 25a)	Severe decrease in wool per head (Refs 17b, 17h, 21a, 27a)	Severe decrease in beef per head (Refs 6a, 9a, 17b, 17h, 25a, 27a)	Severe decrease in gross margin (Refs 16a, 17b, 17h, 19b, 21a, 22a, 24a, 26a, 27a, 28a, 30a)	Major changes in plant and animal species composition (Refs 1b, 8a, 11a, 12a, 17b, 17h, 21a, 26a, 27d)
8. Increased storm intensity - same total rainfall	Decrease in pasture growth (Refs 9a, 14a)	Decrease in surface cover (Ref. 9a)	Decrease in wool per head (Expert Opinion)	Decrease in beef per head (Ref. 9a)	Decrease in gross margin e.g. loss of stock and property damage (Refs 17b, 30a)	Changes in insect and plant species composition; siltation of waterholes (Refs 8a, 11a, 17b, 17h, 27d)
9. Decrease in winter rainfall	Minor decrease in pasture growth (Refs 6a, 9a, 14a, 16a, 17b, 17h, 19b, 21a, 24a, 25a)	Minor decrease in surface cover (Refs 6a, 9a, 16a, 19b, 25a)	Decrease in wool per head (Refs 17b, 21a)	Minor decrease in beef per head (Refs 6a, 9a, 17b)	Minor decrease in gross margin (Refs 16a, 17b, 17h, 19b, 21a, 22a, 24a, 30a)	Major changes in plant and animal species composition (Refs 1b, 8a, 11a, 12a, 17b, 17h, 21a, 27d)
10. Decrease in summer rainfall	Severe reduction in pasture growth (Refs 6a, 9a, 14a, 16a, 17b, 17h, 19b, 21a, 24a, 25a)	Severe reduction in surface cover (Refs 6a, 9a, 16a, 19b, 25a)	Decrease in wool per head (Refs 17b, 21a)	Decrease in beef per head (Refs 6a, 9a, 17b)	Severe decrease in gross margin (Refs 16a, 17b, 17h, 19b, 21a, 22a, 24a, 28a, 30a)	Changes in plant and animal species composition (Refs 1b, 8a, 11a, 12a, 17b, 17h, 21a, 27d)
11. Increased storm frequency - same total rainfall, local flooding	Decrease in pasture growth (Refs 9a, 14a)	Increase in surface cover (Ref. 9a)	Increase in wool per head (Ref. 27a)	Increase in beef per head (Refs 9a, 27a)	Increase in gross margin (Expert Opinion)	Changes in plant and animal species composition (Refs 1b, 8a, 11a, 17b, 17h, 27d)
12. More wildfires	Increase in pasture growth (Ref. 25a)	Decrease in surface cover (Expert Opinion)	Increase in wool per head due to flush of green feed of higher quality (Ref. 27a)	Increase in beef per head due to flush of green feed of higher quality (Ref. 27a)	Decrease in gross margin (Refs 17b, 17i - loss of income due to stock losses and property damage)	Changes in plant structure and species composition (Refs 17i,17h)
13. Higher Peak Wind Speeds	Decrease in pasture growth due to higher evaporation and erosion of topsoil especially in arid and semi-arid regions (Expert Opinion)	Decreased surface cover due to higher evaporation, erosion of topsoil, enhanced detachment and stacking of detached litter (Expert Opinion)	Small decrease in wool per head due to environmental stresses, i.e. harsher environment (Expert Opinion)	Decrease in beef per head due to environmental stresses, i.e. harsher environment (Expert Opinion)	Decrease in gross margin (Ref. 30a - especially in relation to increased storm and cyclone intensity)	Damage to some tree and animal species (Refs 8a, 11a - Increased evaporation due to higher wind speeds leads to a reduction in the biodiversity in waterholes in the dry season)
Overall estimate for the Risk Averse (based on rows above and other related columns)	Reduction in pasture growth (*)	Decrease in surface cover (*)	Decrease in wool per head (*)	Decrease in beef per head (*)	Decrease in gross margin (*)	General negative long-term effects on ecosystem function (*)

(*) Based on references in the above cells and expert opinion.

(*continued next page*)

Table 2. (*continued*)

LEVEL OF CONFIDENCE IN PROJECTIONS

- Very high
- High
- Medium to high
- Moderate

LEVEL OF NEGATIVE IMPACT

Likelihood	Negative consequences				
	Minor	**Moderate**	**Major**	**Severe**	**Catastrophic**
Rare	Low	Low	Low	Low	Low
Unlikely	Low	Low	Medium	Medium	Medium
Possible	Low	Medium	Medium	High	High
Likely	Low	Medium	High	High	Extreme
Almost certain	Low	Medium	High	Extreme	Extreme

LEVEL OF POSITIVE IMPACT

Likelihood	Positive consequences				
	Minor	**Moderate**	**Major**	**Extreme**	**Phenomenal**
Rare	Low	Low	Low	Low	Low
Unlikely	Low	Low	Medium	Medium	Medium
Possible	Low	Medium	Medium	High	High
Likely	Low	Medium	High	High	Extreme
Almost certain	Low	Medium	High	Extreme	Extreme

Numbers in the cells refer to the list of references in Appendix 4.

#The complete table containing all 19 elements of the grazing industry is provided on the journal's website as Accessory Publication.

Table 3. Adaptation responses and vulnerability to climate change for key elements of the grazing industry in northern Australia[#]

TGP, Total Grazing Pressure; BMP, Best Management Practice; CPI, Consumer Price Index; ENSO, El Niño Southern Oscillation; MJO, Madden Julian Oscillation; PDO, Pacific Decadal Oscillation

Climate change variable	Pasture growth	Surface cover	Wool per head	Beef per head	Gross margin (relative CPI)	Biodiversity
1. Elevated CO_2	Manage cattle/sheep to utilise extra pasture; Maintain cattle/sheep for pasture recovery; Monitor C_3/C_4 ratio (Refs 5a, 9a, 18a, 20a, 22a, 23a, 27a, 31a, 32a)	Manage cattle/sheep/fire to maintain existing cover; Maintain cattle/sheep for pasture recovery (Refs 9a, 23a, 27a, 32a)	Use supplements and rumen modifiers; Use early season growth and destock sooner; Lengthen recovery time of pastures; Monitor C_3/C_4 ratio (Refs 5a, 18a)	Use supplements and rumen modifiers; Use early season growth and destock sooner; Lengthen recovery time of pastures; Monitor C_3/C_4 ratio (Refs 5a, 18a)	Monitor feed availability, quality and C_3/C_4 species and trade animals before critical thresholds are reached: Use feedlots to finish animals (Refs 5a, 5b, 17j, 18a, 23a)	Manage invasive plant species; maintain refugia (Refs 20a, 23a)
2. Increased evaporation	Decrease cattle/sheep in the warm/dry season to maintain pastures, maintain groundcover to preserve soil moisture, tree strips to reduce landscape evaporation (Refs 9a, 17h, 18a, 20a, 22a, 23a, 27a)	Decrease pasture utilisation to maintain ground cover (Refs 9a, 14a)	Increase shade for animals, e.g. plant/retain suitable trees for shade; Increase number of water points (Refs 20a, 23a)	Provide shade for animals where required; Increase number of water points; Use adapted animal breeds (Refs 20a, 23a)	Combination of the adaptation responses (to the left)	Manage invasive plant species; maintain refugia (Refs 20a, 23a)
3. Higher minimum temperature	Manage cattle/sheep to utilise extra pasture; Maintain cattle/sheep for pasture recovery (Refs 9a, 18a, 20a, 22a, 23a, 27a, 32a)	Manage cattle/sheep to maintain existing cover; Maintain cattle/sheep for pasture recovery (Refs 27a, 32a)	Manage sheep in winter to utilise extra pasture; Maintain sheep for pasture recovery; Monitor micron of wool; Use mulsing and fly-resistant bloodlines (Refs 18a, 21a, 22a)	Manage cattle in winter to utilise extra pasture; Maintain cattle for pasture recovery; Use tick/fly resistant breeds/bloodlines (Refs 9a, 14a, 22a, 23a, 27a)	Use BMP to monitor incidence of disease in winter; Use insect baiting programs in winter before numbers build-up; Monitor micron of wool in winter (Refs 23a, expert opinion)	Manage invasive plant species; maintain refugia (Refs 20a, 23a)
4. Less frost	Manage cattle/sheep to utilise extra pasture; Maintain cattle/sheep for pasture recovery (Refs 18a, 19a, 20a, 27a, 32a)	Manage cattle/sheep to maintain existing cover; Maintain cattle/sheep for pasture recovery (Refs 27a, 32a)	Manage sheep in winter to utilise extra pasture; Maintain sheep for pasture recovery; Monitor micron of wool; Use mulsing and fly-resistant bloodlines; Offset by decrease in winter rainfall (Refs 9a, 14a, 18a, 21a, 22a)	Manage cattle in winter to utilise extra pasture; Maintain cattle for pasture recovery; Use tick/fly resistant breeds/bloodlines; Offset by decrease in winter rainfall (Refs 9a, 14a, 22a, 23a, 27a)	Combination of adaptation responses (to the left)	Manage invasive plant species; maintain refugia (Refs 20a, 23a)
5. Higher maximum temperature	Decrease cattle/sheep in the warm/dry season to maintain pastures; manage utilisation early in the growing season (Refs 9a, 18a, 20a, 22a, 23a, 27a, 32a)	Decrease TGP to maintain cover (Refs 23a, expert opinion)	Implement BMP, e.g. lamb in autumn; Wean in late winter/early spring; Shear in spring; Use Merinos breed for harsh conditions; Manage non-domestic grazing pressure (Refs 21a, 22a, 23a, expert opinion)	Implement BMP, e.g. use controlled joining to calve in autumn; Use adapted breeds (Ref. 23a)	Monitor fringe pasture and animal species for mortality and production; Identify and use better adapted species/breeds. Use feedlots to finish animals (Refs 5a, 5b, 17g, 17j, 18a, 23a)	Manage invasive plant species; maintain refugia (Refs 20a, 23a)
6. More days over 35°C	Decrease cattle/sheep in the warm/dry season to maintain pastures; manage utilisation early in the growing season (Refs 9a, 18a, 20a, 22a, 23a, 27a, 32a)	Decrease TGP to maintain cover (Refs 23a, expert opinion)	Implement BMP, e.g. lamb in autumn; Wean in late winter/early spring; Shear in spring; Use Merinos breed for harsh conditions; Manage non-domestic grazing pressure (Ref. 23a)	Implement BMP, e.g. use controlled joining to calve in autumn; Use adapted breeds (Ref. 23a)	Monitor fringe pasture and animal species for mortality and production; Identify and use better adapted species/breeds; Use feedlots to finish animals (Refs 5a, 5b, 17g, 17j, 18a, 23a)	Manage invasive plant species; maintain refugia (Refs 20a, 23a)
7. More droughts	Decrease cattle/sheep to maintain pastures; manage climate variability, e.g. MJO, ENSO, PDO to help adjust animal numbers; Manage non-domestic grazing pressure (Refs 9a, 17h, 18a, 20a, 22a, 27a, 28a, 32a)	Decrease TGP to maintain cover; manage climate variability, e.g. MJO, ENSO, PDO to help adjust animal numbers (Refs 20a, 23a, expert opinion)	Decrease sheep to utilise less pasture; Decrease sheep for pasture recovery; Use climate forecasts to destock early (Refs 20a, 21a, 23a)	Decrease cattle to utilise less pasture; Decrease cattle for pasture recovery; Wet season spelling of pastures; Use climate forecasts to destock early (Refs 20a, 23a)	Combination of adaptation responses (at left); Explore alternative land-use; Grants for adaptation; Loans for further education and business development (Refs 5b, 17j, 23a, expert opinion)	Manage invasive plant species; maintain refugia - especially wetlands (Refs 20a, 23a)
8. Increased storm intensity - same total rainfall	Decrease cattle/sheep in the warm/dry season to maintain pastures; Maintain biomass for optimal infiltration (Refs 9a, 14a, 17h, 18a, 27a)	Decrease TGP to maintain cover; Use erosion mitigation strategies (Refs 23a, expert opinion)	Decrease sheep to utilise less pasture; Decrease sheep for pasture recovery (Refs 9a, 14a, 22a, 23a, 27a)	Decrease cattle to utilise less pasture; Decrease cattle for pasture recovery (Refs 9a, 14a, 22a, 23a, 27a)	Maintain cover to maximise water infiltration into soil; Use other erosion mitigation strategies (Refs 20a, 23a)	Manage invasive plant species; maintain refugia (Refs 20a, 23a)

(*continued next page*)

Table 3. (*continued*)

9. Decrease in winter rainfall	Decrease cattle/sheep in the warm/dry season to maintain pastures; manage climate variability, e.g. ENSO & PDO to help adjust animal numbers (Refs 9a, 17h, 18a, 20a, 23a, 27a)	Decrease TGP to maintain cover (Refs 23a, expert opinion)	Decrease sheep in winter to utilise less pasture; Decrease sheep for pasture recovery; Offset by decrease in frost and higher min temp (Refs 9a, 14a, 22a, 23a, 27a)	Decrease cattle in winter to utilise less pasture; Decrease cattle for pasture recovery; Offset by decrease in frost and increase in min temp (Refs 9a, 14a, 22a, 23a, 27a)	Monitor feed availability and quality and trade animals before critical thresholds are reached; Use seasonal forecasts in decision making; Develop and use viable systems that manage non-domestic animals (Refs 5a, 5b, 17j, 20a, 23a)	Manage invasive plant species; maintain refugia (Refs 20a, 23a)
10. Decrease in summer rainfall	Decrease cattle/sheep to maintain pastures; manage climate variability, e.g. MJO, ENSO, PDO to help adjust animal numbers; Manage non-domestic grazing pressure (Refs 9a, 17h, 18a, 20a, 22a, 23a, 27a, 28a, 32a)	Decrease TGP to maintain cover; manage climate variability, e.g. MJO, ENSO, PDO to help adjust animal numbers (Refs 20a, 23a, expert opinion)	Implement BMP, e.g. lamb in autumn; Wean in late winter/ early spring; Shear in spring; Use Merinos breed for harsh conditions; Manage non-domestic grazing pressure (Ref. 23a)	Implement BMP, e.g. use controlled joining to calve in autumn; Use adapted breeds; Manage non-domestic grazing pressure; Wet season spelling of pastures (Ref. 23a)	Monitor feed availability and quality and trade animals before critical thresholds are reached; Use seasonal forecasts in decision making; Develop and use viable systems that manage non-domestic animals; Use feedlots to finish animals; Explore alternative land-use in marginal areas (Refs 5a, 5b, 17j, 18a, 20a, 23a)	Manage invasive plant species; maintain refugia (Refs 20a, 23a)
11. Increased storm frequency - more floods, same total rainfall	Maintain biomass and groundcover for optimal infiltration; manage climate variability, e.g. MJO, ENSO, PDO to help adjust animal numbers (Refs 9a, 17h, 20a, 23a)	Maintain cover for optimal infiltration (Refs 9a, 14a)	Decrease sheep to utilise less pasture; Decrease sheep for pasture recovery (Refs 9a, 14a, 22a, 23a, 27a)	Decrease cattle to utilise less pasture; Decrease cattle for pasture recovery (Refs 9a, 14a, 22a, 23a, 27a)	Monitor C_3/C_4 ratio of pasture species and soil erosion; Use erosion mitigation strategies (Refs 5a, 5b, 17j, 18a)	Manage invasive plant species; maintain refugia (Refs 20a, 23a)
12. More wildfires	Fire preparedness; Rotate paddocks of heavier grazing as fire breaks (Refs 18a, 17h)	Decrease TGP to maintain cover; Use erosion mitigation strategies; Use controlled fires (Refs 23a, expert opinion)	Decrease sheep to utilise less pasture; Decrease sheep for pasture recovery (Refs 9a, 14a, 22a, 23a, 27a)	Decrease cattle to utilise less pasture; Decrease cattle for pasture recovery (Refs 9a, 14a, 22a, 23a, 27a)	Plan controlled burning to balance feed quantity and quality and to provide fire breaks for wildfires; Use fire ploughing around paddock boundaries; Re-outfit rural fire brigades (Refs 5b, 17i, 17j, 23a)	Increase patchiness and reduce extreme intensity and size; manage refugia (Refs 20a, 23a)
13. Higher peak wind speeds	Provide shelter belts (Refs 17h, 18a, 23a, expert opinion)	Decrease TGP to maintain cover (Refs 23a, expert opinion)	Provide shelter belts; Property planning and animal management (Refs 17h, 18a, expert opinion)	Provide shelter belts; Property planning and animal management (Refs 17h, 18a, expert opinion)	Combination of adaptation responses (to the left)	Manage invasive plant species; maintain refugia; monitor for invasive insect biota (Refs 20a, 23a)

LEVEL OF CONFIDENCE IN PROJECTIONS

Very high
High
Medium to high
Moderate

LEVEL OF VULNERABILITY TO CLIMATE CHANGE

Potential impact	**Adaptive capacity** Low	Medium	High
Extreme	High	High	Moderate
High	High	High	Moderate
Medium	Moderate	Moderate	Low
Low	Low	Low	Low

Numbers in the cells refer to the list of references in Appendix 4; White cells reflect either positive consequences, insignificant impact or unknown or opposing processes in Table 2.
[#]The complete table containing all 19 elements of the grazing industry is provided on the journal's website as Accessory Publication.

Table 4. Impact risk assessed by the product of consequence and likelihood of climate change (adapted from AGO 2006)

Likelihood	Consequences*				
	Minor	Moderate	Major	Severe	Catastrophic
Rare	Low	Low	Low	Low	Low
Unlikely	Low	Low	Medium	Medium	Medium
Possible	Low	Medium	Medium	High	High
Likely	Low	Medium	High	High	Extreme
Almost certain	Low	Medium	High	Extreme	Extreme

*Consequences for negative impact risk are shown.

Table 5. Vulnerability to climate change as a function of adaptive capacity and impact

Impact	Adaptive capacity		
	Low	Medium	High
Extreme	High	High	Moderate
High	High	High	Moderate
Medium	Moderate	Moderate	Low
Low	Low	Low	Low

Results

Impact risk

The text within the impact matrix (Table 2) show the direction, and in some cases extent of the climate change impact on each element of the grazing industry. The shading in the impact matrix is a measure of impact risk.

The proportion of cells with negative impact within the impact matrix was 68% of the total (brown shading). Of these, 30% had either an extreme or high negative impact and 38% had either low or medium. 'Drought' had either an extreme or high impact on 17 of the 20 grazing elements, and 'lower summer rainfall' on 18 of the 20.

The proportion of cells with positive impact within the impact matrix was ~32%. Of these, 2% had either an extreme or high positive impact; and 30% had either low or medium. Increased CO_2, higher minimum temperatures, less frost and increased storm frequency were most associated with positive impacts for pasture growth and quality.

For the key elements of the grazing system, the overall negative impact of climate change was high for surface cover, gross margins and biodiversity (see bottom row of Table 2). A lack of surface cover caused by increased evaporation, temperatures, storm intensity, wildfires and peak wind speeds, and lower rainfall can be associated with major erosion events, loss of topsoil and slow pasture recovery. Low gross margins can be associated with high stocking rates, low surface cover, resource degradation, high farm debt resulting in unviable enterprises needing significant financial assistance and industry restructuring. Biodiversity in the rangelands has reached its current expression in response to low and variable rainfall but is likely to be sensitive to more extreme droughts, decreased rainfall (summer and winter) and more wildfires.

Pasture growth was assessed as an overall medium negative impact which is likely to reduce pasture availability and digestibility and potential feed intake of animals in dry seasons. The drying associated with higher evaporation, temperatures and

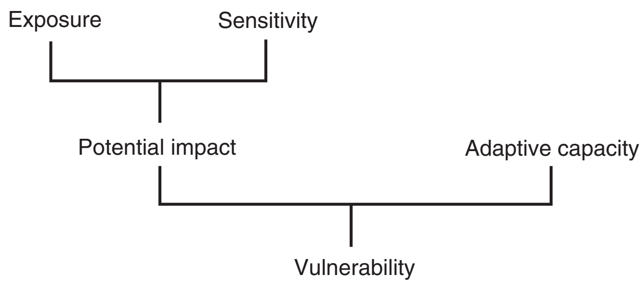

Fig. 1. Components of vulnerability to climate change (redrawn from Allen Consulting 2005).

lower rainfall was expected to be ameliorated by increases in CO_2, minimum temperature, less frost and more wildfires (i.e. by reducing shrub and tree competition). Production of wool and beef per head was assessed as having a low negative impact because of an overall low sensitivity to the direct effects of climate change.

The overall assessment of pasture nutrition and selling price indicated a positive impact. Pasture nutrition was likely to increase because of less pasture growth, resulting from increased potential evaporation, higher minimum temperature, less frost, increases in storm intensity and frequency and decreases in rainfall, more wildfires and higher peak wind speeds. The direct impact of single climate variables on selling price was not clear, however overall, selling prices were thought to increase (relative to CPI) because of greater demand for meat protein and natural fibre from a wealthier and larger global population.

The direct impact of higher minimum temperature on the occurrence of animal disease, more droughts on gross margin and biodiversity, and lower winter rainfall on biodiversity were all classed as extreme risk. Higher minimum temperatures may facilitate the introduction and distribution of exotic animal disease from northern shorelines, and the southward spread of existing domestic diseases and their vectors. More severe and prolonged droughts are likely to cause severe reductions in farm income requiring government assistance and industry restructuring. More droughts with lower winter rainfall are likely to result in severe stress, leading to changes in plant and animal species composition (see Table 2).

Overall assessment of impact risk

An overall risk assessment for each key element was made by the authors to summarise the interaction and combined effects of the single climate variables (see 'bottom line' of Table 2). While there were beneficial and detrimental effects (i.e. positive and negative impacts), the overall risk assessment represents the dominating influences. The integrated assessment and the individual cells provide a basis for considering adaptation and vulnerability.

Vulnerability

The text within the adaptation matrix (Table 3) shows some responses required to help land managers adapt to climate change. They are not considered to be exhaustive nor will they be relevant to all businesses and regions. The shading in the adaptation matrix is a measure of vulnerability (combination of impact and adaptive capacity). Assessments of extreme or high vulnerability are most likely to be associated with a need for transformational adaptive responses. An example of a transformational response would be a change in grazing enterprise from wool to beef production. Transformational responses are in contrast to incremental responses that may be already part of routine management.

'More droughts' and 'lower summer rainfall' were assessed as the climate change variables that were likely to cause the biggest concerns for the grazing industry. These climate change variables were found to make the majority of elements highly vulnerable. This occurred for all key elements (i.e. pasture growth, surface cover, production per head, gross margin and biodiversity), despite the fact that there was only moderate confidence in the projections for these climate variables.

'More days over 35°C' and 'higher potential evaporation' were also associated with either high or moderate vulnerability for a large majority of elements, and particularly for pasture nutrition, surface water availability and environmental stress for animals. This vulnerability was due to a combination of medium to high impact, and low to moderate adaptive capacity.

The vulnerability ranking (highest to lowest) for the key elements was biodiversity, surface cover, gross margin, pasture growth, beef production per head and wool production per head.

Risk statement

An example of a statement describing the risk of more and prolonged drought to the northern Australian grazing industry is:

> *The extreme risk to the grazing industry is that more and prolonged drought could lead to lost viability of grazing enterprises in marginal regions and loss of biodiversity in fragile ecosystems. This level of risk requires an immediate response from the most senior levels of industry leadership, agency management, policy development and government representatives. This risk can potentially be mitigated through application of seasonal and decadal climate variability technologies, more certainty in regional climate change projections and analysis for policy makers on exceptional circumstance reform, adaptation grants, time limited income support and exit grants to leave the land.*

Evaluating the risk assessment process and validating the matrices with stakeholders

The workshop at Longreach provided validation for the content of some cells in the impact and adaptation matrices. In addition the participants indicated that the matrices and the risk assessment process were valuable tools to help understand complex subject matter and to identify impacts, adaptive responses and priorities for action. The participants also provided additional content for some cells in the matrices that was practical and relevant to the region. These insights reflected their experience and highlighted the importance of conducting workshops in the regions to identify adaptive responses that are most relevant and likely to be used in decision making. These additional insights were recorded and may form the basis of a matrix applicable specifically to central-west Queensland (G. Stone, unpublished).

Discussion

Overall risk of climate change

The risk assessment reported here showed an overall detrimental impact of climate change on the northern Australian rangelands. More droughts and lower summer rainfall were the major cause of down-side risk across the 20 grazing elements investigated. The overall impact of climate change was detrimental for all but three grazing elements: pasture nutrition, animal disease and selling prices (above CPI). Allowing for regional differences, pasture nutrition may benefit from climate change, although this is likely to be offset by reductions in growth, availability and feed intake. The incidence of animal disease may decline overall, however, higher minimum temperatures and less frost are likely to facilitate their movement south. Selling prices may rise although this key element is very difficult to assess because of international influences and is likely to be offset by reductions in animal productivity.

Response to increased vulnerability

The high potential impact and low adaptive capacity to longer, more frequent and more pronounced droughts is likely to make the grazing industry highly vulnerable to climate change. Although some native pasture ecosystems are considered to be resilient to grazing (Orr and Holmes 1984), 'super droughts' may cause ecosystem decline to the extent that survival of long-lived perennial pasture and tree species is threatened. Therefore it is likely that existing incremental adaptive responses (e.g. climate forecasting, adjusting stock numbers to feed reserves and early destocking combined with policy reform measures) will no longer be sufficient for the industry to remain sustainable in the long term. However, in the short-medium term, linking management decisions to climate forecasts in some regions may guide land managers in the correct direction (McKeon *et al*. 1993). The monitoring and the anticipation of seasonal climate variability will improve the basic climate knowledge in the regions (extension officers, land managers, NRM officers) and facilitate response to and understanding of climate change. In addition there is a need to monitor and evaluate the changes in levels of risks and suitability of adaptation responses.

Need for transformational change

Depending on the success of incremental adaptation the industry may need to be proactive and strategic and make major changes in enterprises, land use and human and social capital (transformational responses, e.g. diversification, land use change) to create new options to remain viable in the medium to long-term. The industry has already been exposed to transformational change and therefore has the expertise and experience to shift to alternative grazing enterprises. For example, large fluctuations in the relative value of beef and wool have occurred since the early 1970s leading to changes in type of enterprise. In 1974, the United States and Japan imposed beef import restrictions (Daly 1983; 71% drop in market price between 1973 and 1975). The decision to shift from beef to wool in the mid-1970s may also have been assisted by the introduction of the wool reserve price scheme in the early 1970s. The demise of the wool reserve price scheme in 1991 provided the economic stimulus for enterprise shift from wool to beef (Bardsley 1994). These shifts were made easier because of the existence of an alternate enterprise with established markets, there was experience in the alternative enterprise, the infrastructure was available and there was a strong belief that the change was necessary (McKeon *et al*. 1993). The challenge will be to identify those regions most in need of transformational change and the role for policy (structural adjustment), new technologies and adaptive capacity.

Importance of summer pasture growth

In the rangelands of northern Australia, the amount and timing of rainfall in summer is a key driver of vegetation growth (pastures, shrubs and trees), quantity of surface water supplies, animal production and profitability. The grazing industry (arid and semi-arid rangelands) is already highly sensitive to low and variable summer rainfall. In the absence of effective adaptive responses, climate change is likely to make sustainable management more difficult. Because of relatively low capacity to adapt to lower summer rainfall, the 'pasture growth' element was assessed as likely to be highly vulnerable to climate change.

Management to reduce impact of pests and diseases

Managing infrequent events that have the potential to severely impact either natural resources or animals requires planning, expertise and alert/response systems. The impact of exotic disease is limited by quarantine and physical barriers but the potential exists for exotic disease to have a major impact in extensive areas where it is difficult to regulate animal movement. The increases in winter temperature in particular, together with less frost and higher peak wind speeds have the potential to facilitate the southward movement and winter survival of insect vectors and wind-borne diseases (Sutherst 2001). The continued exclusion of some exotic diseases under climate change conditions will depend on strict border surveillance, recognition of entry point hotspots, community identification of disease symptoms and rapid and efficient implementation of well thought-out and tested biosecurity plans. Some diseases already endemic in Australia may be currently constrained by low winter temperatures. Restricting the southward movement of these diseases will depend on continued restrictions to animal and plant movement, vaccination, monitoring and biosecurity responses and programs that limit population explosions of parasites (e.g. sheep blowfly, cattle tick) and other insect vectors.

Management to reduce impact on biodiversity

The most vulnerable natural plant and animal species are likely to be those with long generation times, low mobility and small or isolated range (Hughes 2003). Fauna that are dependent on water holes for maintenance of populations may be threatened by higher evaporation and changes in flow regime (Cobon *et al*. 2006). Increased drought may result in changes in vegetation composition in grassland, savanna and wetland communities, with more adapted species (including weeds) displacing less adapted species (Kriticos *et al*. 2003*a*, 2003*b*). Many existing activities may assist to preserve biodiversity such as fencing riparian areas, maintaining or restoring connectivity in the landscape, erosion mitigation, maintaining environmental flows, reduced land clearing and preventing introduction of potentially invasive species.

Management of impact on surface soil cover

The amount of surface cover on the soil is a useful indicator of rangeland condition (Tothill and Gillies 1992) and together with pasture tussock health drives recovery in good seasons. More droughts, lower summer rainfall, higher evaporation and temperature, more wildfires and higher peak wind speeds are likely to drive greater exposure of the soil surface. Low surface cover exposes the soil to water and wind erosion and reduces water infiltration and soil moisture content. Loss of topsoil reduces vegetation growth and increases sediment loads in watercourses. Existing adaptive responses such as adjusting stock numbers to feed reserves, early destocking, managing total grazing pressure, use of climate forecasts and use of erosion mitigation strategies will help maintain surface cover.

Global influences

Gross margins on extensive grazing properties are largely driven by growth of pasture, animal production per head, costs of production and market prices. The three former elements are highly vulnerable to climate change and the fourth (market prices) is largely driven by global forces (through demand and supply) that are sensitive and exposed to climate change. Development of effective national and international policies will be important under these global influences.

In summary, the biophysical components of the grazing system (surface water availability, plant available water, wind erosion, animal disease) and costs are likely to be highly vulnerable in some regions. Future actions required to reduce vulnerability include: increasing water storage facilities and/or reducing evaporative loss, maintaining good surface cover and plant basal area, improving disease recognition and border surveillance, adopting labour saving technologies, and facilitating property amalgamation.

The risk statements – informing plans, policies and strategies on adaptation

It is useful when advising management and informing policy of risks and vulnerabilities to describe them in the form of risk statements. The risk statement provides descriptive information extracted from the impact and adaptation matrices, and the risk assessment process. The justification for the risk statement provided in this paper is that more droughts are likely to be associated with extreme risk of losing enterprise viability in marginal areas and reductions in biodiversity within fragile ecosystems. There is high risk of reduced growth of pastures, surface cover, surface water availability and animal production, and increased resource degradation.

Grazing enterprises already in marginal regions are likely to be highly vulnerable to climate change. Managing seasonal and decadal climate variability is likely to be an effective response in the short term. However, the uncertainty of regional rainfall projections makes the identification of the most marginal areas difficult. Analyses of regional impacts are needed for policy makers to better assess the need for financial assistance from governments and industry restructuring. The risk statement for this climate change issue can be useful for 'mainstreaming' adaptation into plans, policies and strategies.

Evaluation and monitoring for feedback and change

The analysis of impacts and adaptation to climate change is a complex and daunting subject to discuss in detail, particularly for the land managers. The *Climate Change Risk Management Matrix* provided a process to systematically outline important climate risks for the grazing industry that could potentially be acted upon at the regional scale. The matrices provided an organised approach to identify positive and negative impacts associated with climate change and management responses that would achieve some degree of adaptation.

The matrix approach has also been tested with climate change risk assessment of Queensland's wine industry, but has not been validated with industry representatives (J. Scanlan, unpublished). A matrix approach was also used in regional planning in far north Queensland with the tourism industry to identify likely impacts of climate change and options for adapting to those impacts. In these examples, the process did not include risk assessment, but was found to be a helpful process for people with limited knowledge of climate change to look at the likely impacts and adaptation options (Department of Local Government, Planning, Sport and Recreation 2007; Tourism Queensland 2008). The approach was very useful in raising awareness of how climate change was likely to affect their industries and in preparing for the next stage of risk assessment.

Awareness raising and capacity building

Governments have committed to have the impacts of climate change considered in decisions at all levels across a variety of priority sectors (DNRW 2007). A major challenge exists for agricultural extension to communicate trends and change in climate to the rangeland community (McKeon *et al*. 2009, this volume). One method that has proved effective is 'learning by participating' (Woodhill and Robins 1998). The risk management matrix is a participatory approach and has proved to be a useful tool to: (1) effectively assess the complexity in the grazing system; (2) handle uncertainty in the climate projections; (3) be used by extension personnel with land managers in regional areas; (4) identify a more comprehensive range of adaptations than are typically explored by scientists which provides a practical and realistic assessment of risk and vulnerability (see also Howden *et al*. 2003, Stokes *et al*. 2008); (5) help address the issue of 'cynicism' regarding the influence humans play in changing the climate; and (6) bridge the disconnect between science and the knowledge required for informed and effective on-ground responses. With some initial training, the matrix can easily be operated by a range of stakeholders, extension officers, natural resource officers and scientists to better prepare different regions and ecosystems for the changing climate. The process has the potential to be modified and used in other industries (e.g. horticulture, cropping) and sectors (e.g. health, transport, infrastructure).

Building the knowledge and tools

During the process of populating each cell in the matrices, it was apparent that our scientific understanding in some areas was limited and in some cases we were forced to make 'educated guesses'. We also identified areas where opposing biophysical processes made 'expert analysis' difficult. In these cases, more field experimentation and/or simulation modelling using systems analysis will be required to provide better estimates of climate change impacts. This topic is discussed in more detail in the companion paper (McKeon *et al*. 2009, this volume).

The following areas in the matrices were difficult to populate using our current knowledge and grazier experience and require further research:

(1) biological and bio-economic processes such as CO_2 and effects on trees, tree/grass relationships; temperature and effects on animal production, gross margin, and biodiversity;
(2) interactive effect of climate variables: separating the single effect of climate variables from the combined effect of all climate change variables on single elements of grazing helped understanding, but may not be critical to decision makers (e.g. higher storm frequency and intensity may produce more surface water but the greater impact comes from higher temperatures which reduces overall surface water availability);
(3) climate variables can have both detrimental and beneficial effects on elements of the grazing system (e.g. higher minimum temperature will increase the length of the growing season in winter to benefit animal production but higher maximum temperature will be detrimental to animal production in summer);
(4) determining the combined effect of climate change when the effect of single climate variables on a grazing element is a mixture of both beneficial and detrimental (e.g. tree/grass balance – 11 of the 13 climate variables had a beneficial effect of providing relatively more grass but the overriding effect was the increase in trees provided by higher CO_2);
(5) changing management to adapt to one impact may have detrimental effects in other areas (e.g. changing from *Bos taurus* to *Bos indicus* breeds to adapt to higher temperatures may reduce productivity);
(6) regional and vegetation differences (e.g. in northern savannas, nitrogen rather than rainfall limits pasture growth; the use of fire varies across the rangelands; the importance of surface water availability varies from low in the Great Artesian Basin to high in other areas; and climate change projections vary regionally from little change to drier);
(7) over-estimating the importance of some climate variables (e.g. impact of higher peak wind speed is mainly a problem in desert and mulga areas);
(8) rural health, costs (above CPI) and biodiversity; and
(9) analysis and interpretation of whole system performance.

Research, monitoring and understanding uncertainty

This study has provided an overview of climate change impacts and possible adaptive responses for the northern Australian rangelands. Although some state and national studies have been completed recently (Heyhoe *et al*. 2008; McKeon *et al*. 2008, 2009, this volume; Stokes *et al*. 2008), little research and development has been completed to detail the extent of climate change impacts at the regional scale. Studies at this scale are necessary before land managers are likely to have the confidence and motivation to initiate actions other than incremental responses. For land and water managers to better understand the bio-physical processes and develop more effective adaptation actions to manage climate change, they need: better information about climate change projections at the regional scale; expanded collection of natural resource and agricultural production data; and calibrated models and decision tools.

Despite the uncertainty of climate change projections, there is little room for complacency about potential impacts. Understanding uncertainty is important in developing adaptive management programs that contain a balanced mixture of adaptive action and continued monitoring. Uncertainty is not an excuse for inaction. To manage uncertainty, stochastic methods have been used in the quantification of climate risk for water resources (Preston and Jones 2008) and these methods may also be useful in assessing biophysical and bio-economic risk for the grazing industry.

Implementation of adaptation measures

There is a strong rationale for an increasing focus on adaptation of agriculture to climate change (Howden *et al*. 2007). Our study developed important items for the implementation of adaptation responses by the grazing industry including: risk assessment, risk statements, the regional evaluation and feedback, proposed training and tools. In this paper we have documented: (1) the foundation for adaptive management responses relevant to the grazing industry at the regional scale that can be incorporated into policy (local, state, national), natural resource plans and institutions; and (2) the need for 'climate literacy' training to be provided for regional extension officers to facilitate implementation of the climate change risk management matrix process in regional centres.

We also suggest that adaptation also includes a change in attitude and receptivity to deal with climate change.

Limitations and benefits of the risk assessment process

To populate the entire matrix required some knowledge of the process and of the impacts of climate change within a particular industry or region. Regional extension officers may need some training in climate, climate change and the interactions with the grazing system so they can adequately facilitate the matrix process with land managers.

The size of the matrix can be a benefit and a limitation. It was regarded as beneficial because it attempts an expert analysis of all the key components of grazing and climate change. A limitation for regional implementation, however, is the resource commitment required to complete the whole matrix. Regional assessments could be 'scaled down' to focus only on the key climate variables and grazing elements for the region (e.g. a 3×6 matrix). Other elements of the matrix are relevant across the whole industry and may not need to be reassessed at the regional level (e.g. exotic disease). Thus regional groups can build upon the experience of previous groups and that reported in this paper.

Despite being only 'two-dimensional', the risk assessment approach has the advantage of simplicity and its ease of use by decision makers (e.g. land managers). It has potential application to other industries, particularly those that have not previously considered climate impacts. Other more complex tools can also be used to inform the risk assessment process (e.g. results from modelling analyses).

In summary, the matrix proved a useful tool to unravel the complexities of the grazing system and evaluate uncertain climate projections to provide outcomes for decision makers in planning for climate change.

Conclusion

The description of methodology and content of the climate change risk management matrices have provided the foundation (process and technical knowledge) to build upon and complete risk assessments for regional areas. The process was simple and allowed for a systematic analysis of a large and complex issue that can be a daunting subject for land managers. The matrices identified the impacts and adaptive responses, and the risks associated with exposure, sensitivity and adaptive capacity. Building capacity of regional stakeholders to use this tool will provide the means for participation, development of adaptive responses and action by land managers.

The impact risk and vulnerability assessments indicated that drought and lower summer rainfall have the potential to drive the industry in some regions into transformational change. Incremental responses used in the past may be adequate in the short to medium-term, however, it is likely that transformational responses may be necessary in the long term. Further research is required to identify these regions and inform policy in time to implement transitional change to maintain a healthy industry and natural resource base.

The risk assessment process was useful to rank and identify the key risk areas, and help prepare risk statements to assist mainstreaming adaptive responses into plans, policies and strategies.

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Appendix 1. List of impacts developed to assist in defining consequence categories

Reduction in methane emissions (30%)	Temperature heat index	Mining
Exotic disease	Work force reduction (skilled, unskilled)	Cost price squeeze – viability
Woody weed explosion	Chemical residues	Environmental pressure
Desertification	Genetic modification debate	Animal welfare
Water quality and supply/artesian	Government policy (vegetation management, leases)	Trade barriers
Loss of surface water supply	Land management failure	Globalisation
Other weed invasion	Perception of poor management	Increase in interest rates
Market collapse	Feral animals and macropods	Global depression
Consumption reduction	Loss of feedlot industry	Drought
Communities change	Loss of drought aid	Reduction in pasture quality
Change in species mix	Loss of topsoil	Value of the Australian dollar
Temperature dynamic	Fuel prices	
Marginal lands	Displacement industries (carbon offsets and biofuels)	

Appendix 2. Consequence categories for climate change on the grazing industry in northern Australia

Consequence category	Description of likely consequence	Examples of the impact
Catastrophic	Inability to supply product with a considerable loss of export and domestic markets (Event is unprecedented)	- Exotic disease - Long-term super drought – No surface water for agriculture - Price of methane emissions exceeds beef industry value - Global anti-meat cultural change - Market collapse (e.g. global depression, world war affecting clients)
Severe	Inability to fully supply export and domestic markets for 5 years More than a half of the properties become unviable, with limited restructuring opportunities (Event example: economic impact of the federation drought)	- Woody weed explosion on a regional basis - Increases in tree density by 30% - Government intervention (legislation) - Loss of topsoil - Interest rate increase up to 20% - Trade barriers - Exchange rate goes to US $1.10 (depending on other currencies) - Prolonged (and repeated) drought
Major	Inability to fully supply export and domestic markets for 2–5 years Increasing rate of properties becoming unviable with significant industry restructuring (Event example: 1970s beef slump)	- Global consumption reduction - Environmental pressures - Animal welfare lobbying to shut down abattoirs or changing policies on farm management - Interest rate increase up to 12–15% - Prolonged drought
Moderate	Inability to fully supply export and domestic markets for 6–24 months More marginal properties become unviable with some industry restructuring (Event example: pesticide residue mid 1980s)	- Loss of feedlot sub-sector - Pesticide residues - Reduced pasture growth - Response to perceived or real management issues (such as land clearing, genetic modification, use of pesticides etc.) - Fuel prices double - Local reduction in consumption - Drought
Minor	Gross margins reduced by more than consumer price index More marginal properties become unviable (Event example: impacts are largely regional)	- More difficult to meet terms of trade due to issues such as compliance, market fluctuations, disease, animal health legislation etc. - Reduction of exceptional circumstances/drought support - Locust/army worm type of outbreak - Flood - Small changes in terms of trade - Feral animals and macropod - Mining - Labour shortage - Pasture species/quality change (adaptation options)

Appendix 3. Likelihood of recurrent and single events occurring given that the climate changes (source AGO 2006)

Rating	Recurrent events	Single event
Almost certain	Could occur several times per year	More likely than not - Probability greater than 50%
Likely	May arise about once per year	As likely as not - 50/50 chance
Possible	May arise once in 10 years	Less likely than not but still appreciable - Probability less than 50% but still quite high
Unlikely	May arise once in 10 years to 25 years	Unlikely but not negligible - Probability low but noticeably greater than zero
Rare	Unlikely during the next 25 years	Negligible - Probability very small, close to zero

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