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Potential impacts of projected climate change on safe carrying capacities for extensive grazing lands of northern Australia

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Abstract: Climate change has the potential to significantly affect the productivity of the extensive grazing lands of northern Australia. One area that may be impacted is the estimated safe carrying capacity of grazed pastures. This is being examined within the Northern Grazing Systems program being coordinated by Meat and Livestock Australia. Here we report the potential impact of different climate scenarios on the safe carrying capacities of grazing lands using the GRASP pasture simulation model.

GRASP has previously been used to investigate many aspects of grazing land management, from estimating 'safe' carrying capacities through to impacts of projected climate change. The model has been adapted to more realistically represent the process of pasture degradation. Additionally, growth parameters were modified to represent the effects of elevated CO_2. These changes are described.

The updated model has been used to estimate impacts of projected climate change on pasture condition, soil loss and animal production for a range of land types and locations across northern Australia. Initial simulations were undertaken for the Maranoa and Fitzroy regions of Queensland and the Victoria River District of the northern Territory.

The working definition employed for a 'safe' carrying capacity is the fixed stocking rate that would maintain good pasture condition (at least 70% perennials average) over a 30-50 year period. The simulation runs are based on current climate and two possible 'future climates' selected from 392 files per region provided by the Queensland Climate Change Centre of Excellence. Mean values of temperatures and rainfall for all files were compared with the current climate file, and ranked in terms of change in temperature and change in rainfall. The selected files represented (1) 3^{o}C increase with decile 9 rainfall; (2) 3^{o}C increase with decile 1 rainfall. These represented upper and lower limits of the degree of change in rainfall at a temperature increase that is plausible by 2050.

For nitrogen-limited land types, estimated safe carrying capacities actually improved or experienced no change for the two future climates. By contrast, the safe carrying capacities for some other land types decreased by more than 50%, especially under the 3^{o}C increase in temperature with decile 1 rainfall. Pasture production responses tended to be proportionally greater than the projected changes in rainfall, as were carrying capacities but to an even greater extent.

Some reasons for the variable responses and implications for the extensive grazing industries are discussed.

Keywords: *climate change, safe carrying capacity, extensive grazing lands*

1. INTRODUCTION

Some potential impacts of climate change on the extensive grazing lands of northern Australia have been highlighted by McKeon *et al.* (2009). Identified gaps for further work were the effects of enhanced CO_2 on forage production and the effects of climate change on long-term carrying capacities of pastures. Considerable uncertainty remains about the direction and magnitude of changes in rainfall in northern Australia, although the range of possible changes has been defined (data provided by the Consistent Climate Scenario Project, undertaken by Queensland Climate Change Centre of Excellence (QCCCE) and funded by the Commonwealth Department of Agriculture, Fisheries and Forestry Australia's Farming Future – Climate Change Research Program). Webb *et al.* (2011) have examined some of the responses of pastures for a range of climate projections showing differences among land types for different response variables (e.g. pasture growth, soil loss). Such preliminary analyses are necessary to examine the range of possible impacts to enable land managers and government agencies to consider what adaptation actions should be considered.

From 2009, Meat and Livestock Australia (MLA) has supported the Northern Grazing Systems (NGS) project that is being undertaken by CSIRO, and Queensland, Northern Territory and Western Australian agencies involved in grazing management activities. The ramifications of the potential impacts of climate change for current management practices relating to stocking rate, pasture resting and use of prescribed fire were identified as important topics of research for the NGS project.

The results presented here builds upon the work of McKeon *et al.* (2009) by using new climate change projections and a modified approach to determining 'safe' carrying capacity. Simulations of the response of different land types in the Northern Territory and Queensland were undertaken to investigate the impacts of selected climate projections on pasture growth and 'safe' carrying capacities.

2. METHOD

The GRASP pasture simulation model has been widely used to examine many aspects of pasture management in northern Australia (e.g. Rickert *et al.* 2000; McKeon *et al.* 2009). The model has been recently modified to enable certain aspects of grazing management to be simulated in a more realistic manner (see Scanlan *et al.* 2011, this volume). To represent the effects of elevated CO_2, a number of parameters within the GRASP model were adjusted (C.S. Stokes and G.M. McKeon, pers. comm.) based on recent experimental data (Stokes *et al.* 2005) and a review of other experiments.

Two land types from the Victoria River District (VRD) in the Northern Territory and two from the Fitzroy region of central Queensland were selected to study the potential impacts of selected climate projections. The black cracking clay (VRD) and brigalow/blackbutt land types (Fitzroy) are highly productive land types (Whish 2011), with average annual pasture production in excess of 3000 kg/ha (Table 1). By contrast, the Humbert (VRD) and narrowleaf ironbark land types (Fitzroy) are much less productive at around 1400 kg/ha and 2100 kg/ha respectively.

A number of definitions exist of 'safe' carrying capacity. Scanlan *et al.* (2010) developed a method using the GRASP model to simulate the percentage perennials in pastures over a 30-year period as the fixed stocking rate increased. This was done by running the GRASP model for a particular combination of land type and climate projection many times with the fixed stocking rate progressively increasing in each run. The model outputs presented here are mean pasture production and mean percent perennials over the 30-year simulation period, and estimated safe carrying capacities. Safe carrying capacity (for the period simulated) is the fixed stocking rate that maintained the desired pasture condition throughout the simulation period, presented as adult equivalents (AE) per 100 ha (an AE is a 450 kg steer). For pastures that are initially in good condition, 'desired percentage perennials' is 80% although other values have been used (e.g. 70% in Scanlan *et al.* 2010); for pastures in poor condition, the safe carrying capacity is that which allowed some improvement in condition or at least no further deterioration.

The selection of climate files followed that used by Webb *et al.* (2011) and the same approach was used by Pahl *et al.* (2011, this volume). Projected climate data were provided by the QCCCE Consistent Climate Scenarios Project funded by the Commonwealth Department of Agriculture, Forestry and Fisheries. For each location, we obtained 392 projected climate files, each representing a particular combination of global circulation model, CO_2 emissions scenario, sensitivity to CO_2 and date. From this wide array of projected climate files available, two were selected. Initial selection was for all files that gave an increase in temperature of approximately $3^{o}C$. For those files, we ranked them in order of increasing negative impact on rainfall and selected two files - one having decile 9 rainfall and the other decile 1 rainfall.

Table **1.** Mean climate parameters for baseline and projected climate files used in simulations of land types in the VRD of Northern Territory and the Fitzroy region of Central Queensland.

Simulations - VRD	Code	Annual rainfall (mm)	Mean annual temperature (°C)	Pan evaporation (mm/day)	Radiation (MJ/m^2 /day)	Vapour pressure deficit (kPa)
1 Current rainfall and CO_2	Base	624	26.4	7.67	21.6	16.8
2 Increase temperature with decile 9 rainfall at ~540 ppm CO_2	+3ºC Dec 9 R	802	28.8	8.00	22.1	17.9
3 Increase temperature with decile 1 rainfall ~540 ppm CO_2	+3ºC Dec 1 R	620	29.1	8.41	21.3	19.4
Simulations - Fitzroy						
1 Current rainfall and CO_2	Base	711	22.2	5.46	19.9	18.4
2 Increase temperature with decile 9 rainfall ~540 ppm CO_2	+3ºC Dec 9 R	684	24.6	5.95	19.8	21.4
3 Increase temperature with decile 1 rainfall ~540 ppm CO_2	+3ºC Dec 1 R	503	25.1	5.85	20.0	21.4

3. RESULTS

3.1. Overview

Simulated pasture production under current and projected climates is shown in Table 2. The enhanced CO_2 under current climate led to increased mean pasture growth in all land types (data not shown). These production results are similar to those produced under the projected climate data using the decile 9 rainfall. By contrast, estimated growth using decile 1 climate file rainfall was lower than for current climate and current CO_2 levels, except for the brigalow/blackbutt land type.

Table **2.** Mean pasture production (kg/ha/yr) for three simulations for land types in the VRD and Fitzroy region during 1980-2010.

Simulations	VRD- Black cracking clay	VRD - Humbert	Fitzroy - Brigalow / blackbutt	Fitzroy -Narrow-leaved ironbark
1. Current rainfall and CO_2	3196	1350	3667	2077
2. Increase temperature with decile 9 rainfall ~540 ppm CO_2	3640	1488	3948	2209
3. Increase temperature with decile 1 rainfall ~540 ppm CO_2	2818	1083	3857	1951

For all simulations, the simulated percent perennials remained at the maximum (90%) up to a threshold stocking rate, above which the percent perennials decreased (Figure 1). Under current climate conditions, this threshold for the Humbert land type in the VRD was ~2 AE/100 ha while at the other extreme, it was 32 AE/100 ha for brigalow/blackbutt in Fitzroy. At stocking rates lower than these threshold values, utilisation rates were sufficiently low that pasture condition remained excellent. This reflected the different productivities of the land types. Once the threshold was exceeded, the percent perennials decreased quickly as stocking rate increased further. This resulted from an initial decline in pasture condition during the simulation period which then led to decreased pasture production. Because stocking rate was held constant and the pasture production is reduced, utilisation necessarily increases with a further reduction in pasture condition; eventually leading to a significant decline in condition and limited pasture growth. At some high stocking rate, the percent perennials reached a relatively stable lower value. For all land types, that lower limit was around 10% perennials. This asymptote results from presenting the mean percent perennials for simulations commencing at 90% perennials, with a rapid decline to the minimum possible (1%) over the first 12 years of the 30-year simulation period. For the sake of presentation, graphs in Figure 1 were truncated before all land types and region combinations reached this figure.

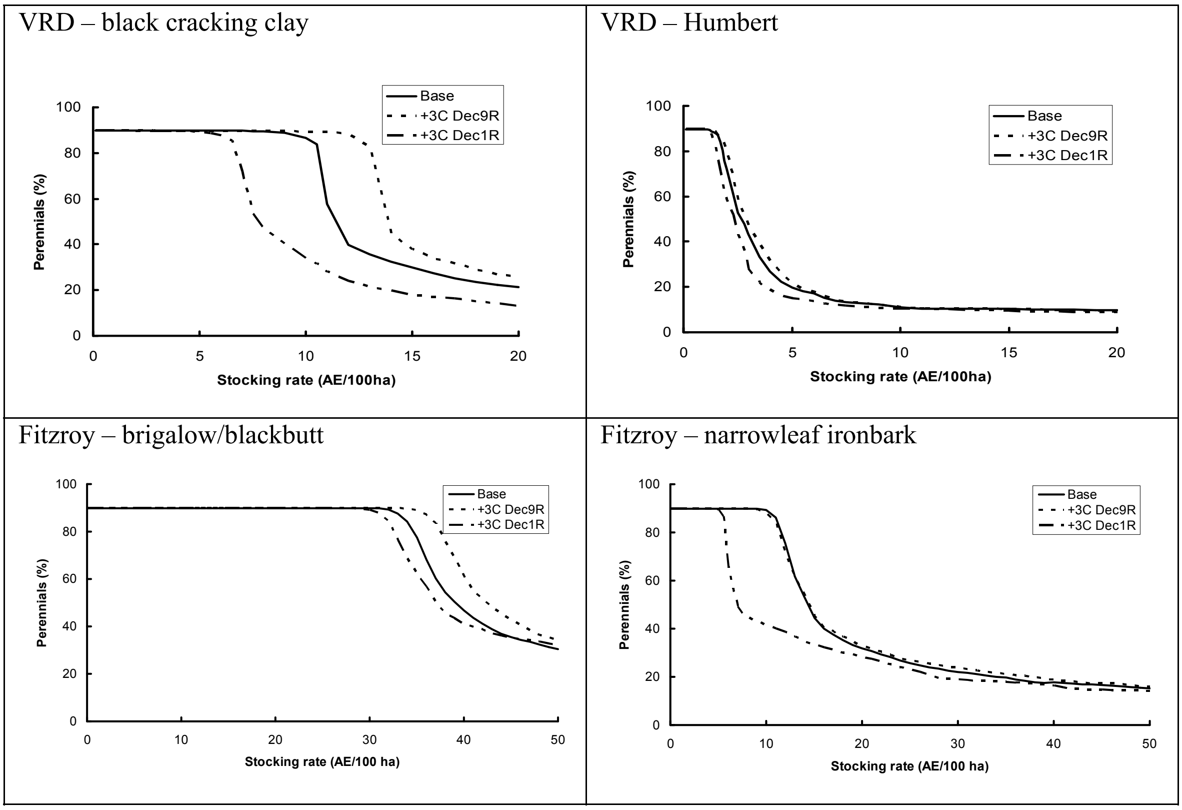

Figure 1. Mean percent perennials over the simulation period (1980-2010) in selected land types in the VRD and Fitzroy region for a range of stocking rates.

The effects of changing climate on rainfall, pasture growth and safe carrying capacities can be seen in Figure 2. In the VRD under decile 9 rainfall scenario, pasture growth increased by a smaller percentage than rainfall; safe carrying capacity increased by a greater percentage than either rainfall or pasture growth. For decile 1 rainfall scenario, safe carrying capacity in fertile conditions was reduced to a greater extent than expected based on rainfall alone; the reduction in poorer land types was not as large as expected based on the reduction in rainfall.

In the Fitzroy region, safe carrying capacity for decile 9 rainfall scenarios is similar to or slightly greater than under current conditions, despite a small reduction in rainfall. Under decile 1 rainfall scenario, the reduction in pasture growth is less than the reduction in rainfall relative to current conditions. For the fertile site, safe carrying capacity is not reduced as much as rainfall, but for the less fertile site, the impact on safe carrying capacity is greater than the reduction in rainfall.

For very infertile land types, where annual growth is limited by nitrogen availability in most years, the increased growth rate due to elevated CO_2 more than compensated for the reduced rainfall, and thus pasture growth increased, even under decile 1 conditions (data not shown). In both locations, the mean change in pasture growth is not a good predictor of the change in safe carrying capacity.

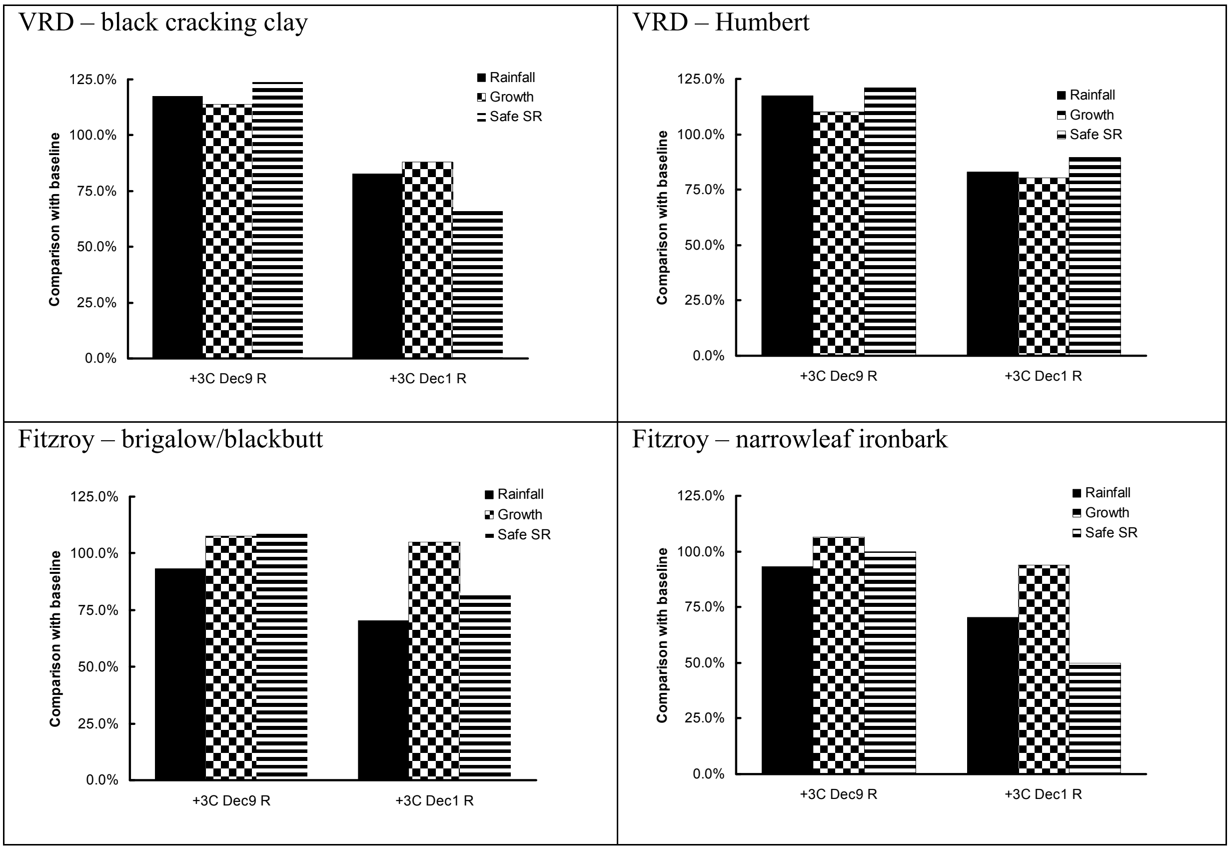

Figure 2. Relative changes in rainfall, pasture growth and safe carrying capacity for land types in the VRD and Fitzroy region compared with the baseline of current conditions.

4. DISCUSSION

There is not a direct, fixed relationship between simulated change in pasture production due to climate change and the associated change in estimated safe carrying capacity (using the definition in this paper). The assumption of a fixed relationship between pasture production and safe carrying capacity has been used under current climatic conditions to estimate carrying capacities for a variety of land types (e.g. by Johnston *et al.* 1996; Day *et al.* 1997). However, this approach should be used with caution when assessing the likely impact of climate change. Land types will differ in their responses to climate change, and the direction and magnitude of change will also differ between the climate change projections being evaluated.

Some preliminary patterns are suggested for the regions studied here. If rainfall increases in fertile land types, the combination of higher rainfall and higher growth parameters due to elevated CO_2 may increase safe carrying capacity (assuming current pasture and stock management practices remain the same). The safe carrying capacity may increase for these fertile land types even if the rainfall declines by a small percentage. In moderately fertile land types, the counteracting influences of small decreases in rainfall and enhanced growth parameters due to elevated CO_2 may result in little or no net effect. For poor land types, moderate reductions in rainfall may have little negative effect on safe carrying capacity. A major proviso is that the reduced nitrogen concentration in pasture growth under elevated CO_2 conditions (Stokes *et al.* 2005) does not directly influence the carrying capacity and that the only influence is due to changes in pasture production.

There is likely to be substantial variation between different regions across northern Australia in the response to climate change. In part this is due to differences in the climate projections, with some regions less likely to experience decreases in rainfall than others. When this is combined with the differences between land types mentioned above, generalisations are fraught with danger. The approach used by Webb *et al.* (2011) is to evaluate the range of possible outcomes (between the 10^{th} and 90^{th} percentile of climate change predictions). Any suggested adaptation measures should be robust enough to cope with a range of possible future climates; attempting to optimise adaptation measures for the median effect could possibly be maladaptive if the actual climate that is experienced is substantially different from the median.

A number of factors not examined in this study are likely to have an impact on safe carrying capacity under climate change. The first is that the 'change factor approach' used to develop future climate projections used in this study does not result in different numbers of rain days per year: changes in rainfall are calculated by applying a multiplier to the existing rainfall patterns. In the current runoff-soil loss model in GRASP (based on Scanlan *et al.* 1996), rainfall intensity is an important factor in estimating runoff and its estimation is based on the magnitude of daily rainfall. A new method developed by G. Fraser (pers. comm.) could overcome this limitation.

Another relevant factor over much of northern Australia is the presence of trees in many land types. Webb *et al.* (2011) have reported considerable impacts of climate change and trees on pasture growth in some land types. It is likely that these production impacts will influence safe carrying capacities. However, it cannot be assumed that the changes in safe carrying capacity will follow the same pattern as change in pasture production, as shown by this study.

Much more work will be required to evaluate the interactions of climate change and the important characteristics of land types across northern Australia. Results from such work will inform the adaptation measures developed to cope with the potential adverse effects and the potential opportunities brought about by climate change. It is clear that simulation modelling using tools such as GRASP has a critical role to play in investigating adaptation strategies and the potential impacts of climate change on Australia's northern cattle industry.

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