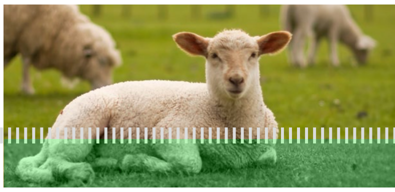
Chapter 4. Sheep & Beef

Hill country sheep and beef: impacts and adaptations to climate change



Mark Lieffering AgResearch

Paul Newton AgResearch

Frank Li AgResearch

Ronald Vibart AgResearch

Abstract

In this chapter we explore the impacts of climate change on hill country sheep and beef enterprises in three regions: Southland, Hawke's Bay and Waikato. Daily time-step climate projections were used in a biophysical pasture simulation model to generate 20-year time periods of monthly pasture growth rates centred around 1990 and 2040. Changes in average annual pasture production by 2040 were modest and largely positive while changes in seasonality – primarily increased spring growth and reduced autumn and summer growth – were evident at all sites. In addition, variability in annual and seasonal production increased in Hawke's Bay. The current pasture growth data were then used in a farm systems model to generate current gross margins using average farming management systems for the three regions. These average systems were then applied to the future pasture growth rates and future gross margins were determined. 'Business-as-usual' management resulted in reduced (Hawke's Bay) unchanged (Waikato) or increased (Southland) gross margins in 2040. The farm systems were then adapted to the future growth curves: the tactical adaptations used were not outside the biologically feasible options possible today but did involve changes in reproductive efficiency and animal growth rates that are only currently achieved on the highest performing farms. Adaptations to the 2040 conditions resulted in unchanged (Hawke's Bay) or increased (Waikato and Southland) gross margins. This leads to the conclusion that, based on the farm management assumptions outlined in the chapter, hill country enterprises in the three regions examined here are likely to continue being viable in the near future. It is important to note that while our analyses show that tactical adaptations may be sufficient to deal with climate change to 2040, we optimally adapted the modelled farm systems; there are many reasons why such optimal adaptations might not be achieved on-farm. Finally, as part of our analyses, we presented the concept of climate analogues to further explore adaptation options: preliminary findings indicated for example that pasture growth curves in future Southland may be similar to those found near current Masterton; while no New Zealand analogues were found for Hawke's Bay. Analogues can provide useful information on future opportunities and constraints.

Contents

1 Introduction

1.1 Context

With annual exports of about NZ$5.5 billion, meat is New Zealand's second-largest food export, accounting for nearly 13% of total merchandise exports (Beef+LambNZ 2011). By volume, about equal amounts of sheep meat (lamb and mutton) and beef meat are exported (350,000 tonnes; (Beef+LambNZ 2011). In addition, sheep raised on hill country are a source of wool – which in 2010 was worth NZ$500 million (Beef+LambNZ 2011). It is estimated that approximately 80% of New Zealand's pastoral land is used to raise sheep and beef animals with this land typically being hilly or rolling. Hill country is found throughout New Zealand under a range of climatic conditions and the animals are raised using a variety of management regimes. However, most of these systems are extensive, with low inputs (e.g., fertiliser and purchased feed) meaning their profitability and sustainability are particularly sensitive to environmental conditions. Consequently, any future changes in climate are potentially of high interest to this sector.

Previous studies (see Section 3) have suggested that, depending on location, climate change is likely to have both positive and negative effects on sheep and beef farming. However, little work has been done at the farm scale. In this chapter we use a simulation model to predict pasture growth under future climate scenarios and then use these data to examine the impacts on farm profitability. The reader is referred to Chapter 3 (Dairy) for a detailed review of current literature on the potential impacts of climate change on pasture (Section 2) and an extensive listing of possible adaptation options (Section 4) that may be used to reduce these impacts. To avoid repetition, this extensive review is not reproduced here. However, it should be noted that not all the potential adaptations suggested in Chapter 3 for dairy situations are viable options for hill country pastures. This is discussed further in Section 8 of this chapter.

1.2 A changing environment

Chapter 2 describes the projected climate changes for New Zealand. It details how the changes in climate are driven by increasing concentrations of greenhouse gases (GHGs) in the atmosphere, the most important of these being carbon dioxide (CO_2). Carbon dioxide is of particular relevance to our biologically-based industries because as well as having an indirect effect through its role as a GHG, it also has a direct effect on plants (as it is the raw material of plant growth that is fixed during photosynthesis). Changes in the atmospheric CO_2 concentration have been shown to have marked impacts on pasture ecosystems including effects on production, feed quality, animal intake (Newton et al. 2011) and soil fertility (Gentile et al. 2012). While climate (temperature and rainfall) changes will differ from region to region, the increasing concentration of atmospheric CO_2 is a global change: the majority of CO_2 emissions are in the Northern Hemisphere but atmospheric CO_2 is relatively well-mixed and, with a lag of a few months, New Zealand experiences the same atmospheric CO_2 conditions as the northern regions despite having an insignificant (compared to the rest of the world) CO_2 emission rate. Because projected temperature changes for New Zealand are lower than the global average projection (NIWA 2011; Chapter 2), and because CO_2 increases will always keep pace with the rest of the world then there is added importance in accurately characterising the CO_2 impact on our agricultural systems. To date, this impact has not been satisfactorily evaluated (see Section 3). Projected changes in CO_2 are shown in Figure 4.1 (Denman et al. 2007). Recent analysis shows that actual emissions are tracking at the high end of these IPCC projections and that the growth rate in emissions from 2000 to 2008 was 21% higher than the rate between 1990 and 1999 (Dolman et al. 2010).

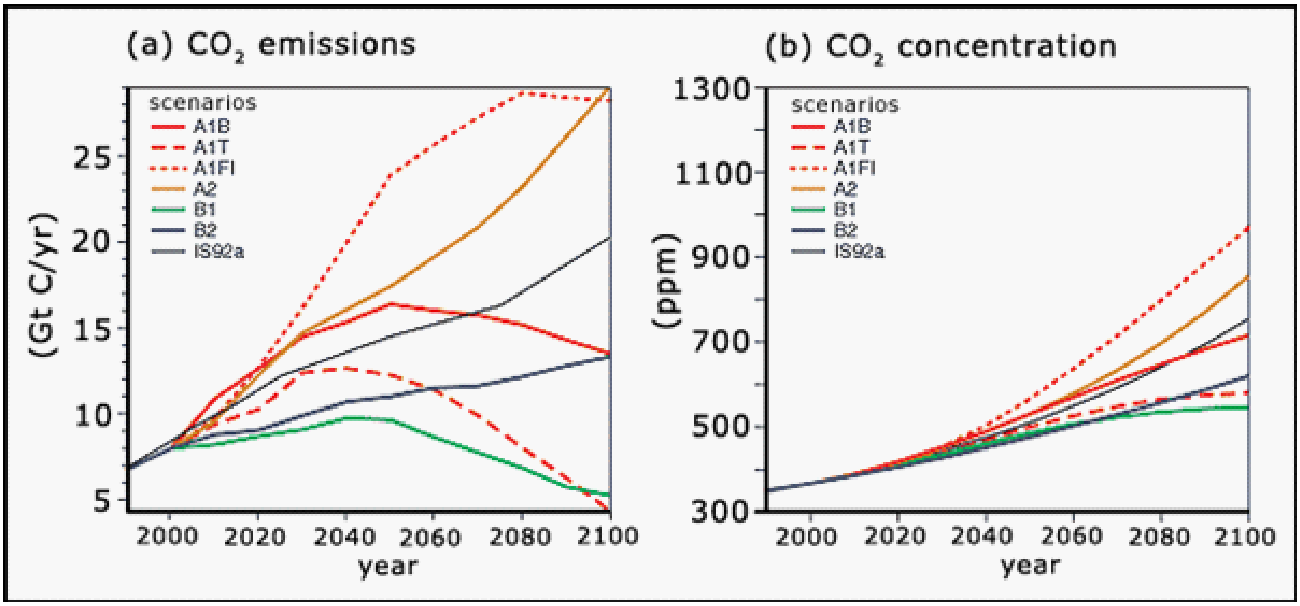


Figure 4.1. Projected CO_2 emissions and concentrations assuming various socio-economic scenarios used in the IPCC Fourth Assessment Report. (a) Emissions. (b) Concentrations. (Source http://www.ipcc-data.org/ddc_co2.html; accessed 20 April 2012.)

2 A review of the effects of a changing environment

Potential impacts of temperature, rainfall and CO_2 on pasture are thoroughly reviewed in Chapter 3 (Section 3). In general, the effects of temperature and soil moisture responses are well characterised and we have high confidence that we can simulate these effects using ecosystem models. We are less certain about the impacts of elevated CO_2, in fact, the response to elevated CO_2 is frequently identified as the major source of uncertainty in simulating the impacts of global change (Lobell & Field 2008; McKeon et al. 2009; Muller 2011; Rotter et al. 2011). In this chapter, we provide some additional information on CO_2 effects and describe how these have been included in our ecosystem model and how these responses have been validated.

The impacts of elevated CO_2 on pasture have been reviewed recently (Newton et al. 2011). In this chapter we present only the main points from Newton et al's review: the references and analyses supporting these main conclusions may be found in the original report. Much of the data relating to grazed pastures comes from a New Zealand experiment (known as the New Zealand Free Air CO_2 Enrichment or NZFACE experiment) in which the ambient air was enriched with CO_2 raising it from the current concentration of 380 ppm to 475 ppm – i.e., looking into the future perhaps 30-60 years hence (note where 475 ppm falls on the projected rises shown in Figure 4.1). This New Zealand experiment is the only one in the world to include grazing animals and provides a unique opportunity to test our models used to simulate future farm performance (Figure 4.2).

Figure 4.2. Aerial view of a single ring in the NZFACE also showing the bulk tank used to store liquid CO_2.

2.1 *Some potentially important effects of elevated CO_2*

2.1.1 Pasture production

Newton et al. (2011) summarised the responses of 16 experiments on grassland and scaled the results to a common CO_2 enrichment level of 550 ppm to make comparisons easier. This is the concentration expected at some time between 2040 and 2070 (see Figure 4.1) assuming a linear response to CO_2 emissions. At this concentration of CO_2, the average response in aboveground growth in 'ideal' growth room conditions was 22% and for field experiments about 10%. Note that the lower response in the field reflects limitations in other factors (e.g., nutrients) that constrain the potential response to CO_2.

While responses in the field are generally lower than found in growth room experiments, in some years strong responses to CO_2 can be expressed. In the NZFACE for example, the range of response in annual yield was from -5% to +74% (scaled to 550 ppm). Clearly, understanding the circumstances under which strong responses to CO_2 are expressed could provide a major bonus to pastoral agriculture.

2.1.1.1 Soil fertility

Under elevated CO_2 conditions, plants can be co-limited by phosphate (P) and nitrogen (N) so that under ambient conditions plants response to both N and P independently but under elevated CO_2 a response to N requires adequate P.

2.1.1.2 Animal intake

Animal intake can be reduced on herbage grown at elevated CO_2 concentrations, so that increases in DM do not necessarily flow through into greater animal performance. This appears to be because of lower feed quality of individual species (higher NDF for example) and, in diverse swards, a shift in botanical composition to species of lower palatability

Changes in secondary compounds, such as tannins, are also likely.

2.1.1.3 Soil carbon and greenhouse gas emissions

The evidence for New Zealand is that elevated CO_2 concentrations will result in increased accumulation of soil C under grasslands.

In an indoor feeding trial and a trial under grazing methane production by sheep per unit of DM ingested was found to be lower under elevated CO_2. However, nitrous oxide emissions may increase.

3 Understanding responses to a changing environment: the importance of models

Experiments are an essential tool for understanding the effects of climate change. However, we cannot do enough experiments to cover the range of potential environmental changes nor cover the range of pasture types and enterprises in New Zealand. To overcome this problem, computer models of pasture ecosystems can be used that enable the results to be extended to new situations (Thornley & Cannell 1997; Medlyn et al. 2011). For this approach to be useful we have to ensure that the models produce 'realistic' simulations. In Section 5.2.4 we show how we have done this – but first we will describe some of the main modelling and impact studies already available for New Zealand.

3.1 *MAF Technology report (1990)*

The MAF Technology Report 1990 (Korte et al. 1990) was the first report to use computer modelling to generate predictions of forage supply. Changes in seasonal pasture growth rates due to climate change were simulated using a mechanistic model and a database (regression) model. The strength of this report was that the forage supply data were then fed into models of the sheep, beef and dairy sectors to give production outputs.

With hindsight it is clear that the limitations of the approach of this impacts assessment were that:

- the mechanistic model was inadequate to capture the interactions of the main drivers (CO_2, temperature, water)
- an average change in pasture growth curves was used, thus masking potential changes in variability
- the impact of pests and diseases was not taken into account
- the animal production models were not designed to test changes in management and so were unable to look at current and potential adaptation.

3.2 Climpacts report (2001)

A prediction of impacts of climate change (including elevated CO_2) on pasture production was included in the 2001 Climpacts report (Clark & Newton 2001). The simulations were for four sites and produced changes in seasonal production. The model used was mechanistic but did not capture the biogeochemical feedbacks from elevated CO_2. In addition, the simulations stopped with average seasonal pasture production changes and did not use this information to generate projections for animal production.

3.3 Ecoclimate report (2008)

This assessment (Wratt et al. 2008) covered the whole of New Zealand, using interpolated climate projections. Pasture production was calculated on an annual basis using a simple predictive relationship between growth, soil moisture, temperature, and soil particle size. Metabolisable energy for animal production was then calculated using a value for digestibility taken from the long-term average assessed by remote sensing. These projections were scaled to animal production in each region using production figures from 2001–2. The strength of this approach was that it allowed coverage of the whole country and provided a net outcome at a national level. The climate scenarios used were also the most recently available and the economic analysis was comprehensive. Limitations of the approach were that forage supply was not simulated using a mechanistic model and did not include the potential impacts of elevated CO_2. This was a 'top-down' approach that used annual mean predictions making it eminently suitable for general economic analysis – but not for on-farm assessment.

4 Approaches to adaptation

As set out in Chapter 1, a simple three-category framework can be used to examine adaptation options to climate change. Briefly, these are:

Tactical adaptations which involve modifying the existing production system using current management options.

Strategic adaptations which involve changing to another known production system, or making substantive changes to current systems, where practices and technologies are well known.

Transformational adaptations which involve innovation to develop completely new production systems or industries.

Under current climatic conditions, hill country farming is an exercise in tactical decision making. Farming enterprises are viable across a large range of climate and soil types in New Zealand. Consequently, we might expect that many changes predicted for the future will be managed using methods currently employed in farm practice today. We have explored some of these options (particularly the management of stock) in our modelling exercise; however, there is an endless range of management combinations that could be invoked so to focus on 'actual' effective responses we have explored the use of analogues, or what Ramírez-Villegas et al. (2011) have described as 'finding tomorrow's agriculture today'. This approach attempts to find current situations that have a high similarity to the predicted futures (Section 4.1); where these can be found within New Zealand it implies that farming methods are available to cope with the predicted future although profitability may change.

Other kinds of adaptation do not necessarily involve land managers. There is a class of adaptation that can be described as 'future-proofing currently important technologies' that is the domain of the scientist and agribusiness (Newton et al. 2007). Many important technologies such as plant cultivars, biocontrol agents, herbicides and nitrification inhibitors may be expected to have a different efficacy under changed climatic conditions. It seems only prudent to ensure that this efficacy is maintained or enhanced (Newton et al. 2007).

The purpose of work on impacts and adaptation is to provide information that is useful for decision making (Willows & Connell 2003). In this case, specifically to assist in decisions which are likely to be influenced by climatic change. It can be argued (Pannell 2010) that on-farm management decisions do not fall into this category because the capacity of farmers to adapt is sufficient to deal with the relatively slow rate of change in the environment and the uncertainty in the direction and amount of change. Where on-farm adaptation is called for, the advice is to encourage adaptations that are suitable to counteract climate variability until such time as the manifestations of climate forecasts or climate changes become more evident (Howden & Stokes 2010). However, there are also decisions that are being made now that should take account of long-term climate changes. These would include aspects of regional management such as investment in infrastructure including specifically agricultural investments such as processing plants; they would also include decisions on property purchases which would involve not only the purchaser but probably also a financial lender such as a bank. While our focus in this report is at the farm level, the future for regions is made up of the sum of individual impacts and an understanding of farm-level responses is a pre-requisite for the kind of regional impact analysis that might guide long- term investment decisions.

4.1 Analogues

In our modelling we have taken climate change projections and 'translated' these into pasture production. We then made an initial study of how effective current management is under the changed situation and what changes might be required to 'optimise' the system under future conditions. This is a theoretical exercise and does not take account of human factors that might influence on-farm decision making. One way that we can improve the reality of our analysis is to use analogues (i.e., find current situations that match the future situations for the site of interest) and compare the management decisions actually taken in each situation. The use of climate analogues is a developing methodology in adaptation research (Ramírez-Villegas et al. 2011). Where possible it is important to go beyond simple comparisons of climate and look at the agricultural performance – this is described by Ramírez-Villegas et al. (2011) as looking '... through the eyes of the crop'. In this report, we are in a strong position to do this: first, we are producing pasture growth rate curves which translate the climate projections into an agronomically relevant form; and second, we can compare the predicted pasture growth rate curves with different locations throughout New Zealand because pastoral agriculture is widespread across a range of environmental conditions. We have used pasture growth curves from a range of sites throughout the country (see Figure 4.3). The growth curves for these sites (Figure 4.4) show marked differences in seasonal patterns of production emphasising the diversity of environments that are used for pastoral agriculture in New Zealand, and, by implication, the diversity of systems that are already employed to match the different timing and amount of feed supply. However, these growth curves provide no information on variability in feed supply which can be an important driver of farm performance and is a caveat to our analogue comparison that we discuss later in the chapter (Section 7.4).

Figure 4.3. New Zealand sites used for the analogue comparison (black dots) and the sites modelled in this chapter (blue triangles).

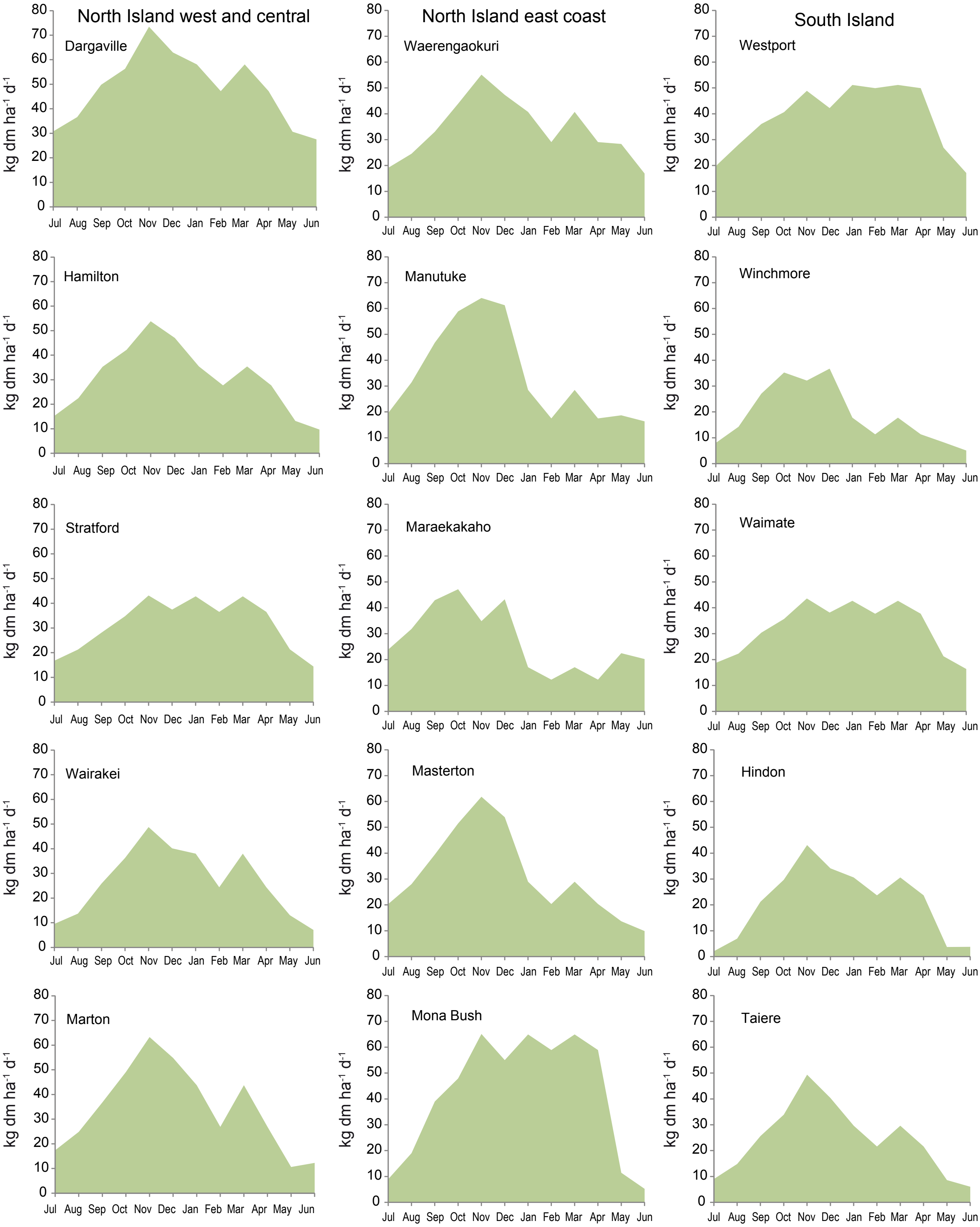


Figure 4.4. Average annual pasture growth curves (in kg dm ha^{-1} d^{-1}) for sites used in the analogue analysis. Data are generated using the APSIM model; details are given in Li et al. (2011). Graphs are grouped into North Island west and central, North Island east coast, and South Island (note: Mona Bush is in the North Island east coast column to balance column lengths). The sites are a mix of flat and hill country landforms.

4.1.1 Analogue methodology

To test whether parts of the country were already experiencing similar pasture growth curves to those projected for our target regions in the future, we compared sites using Lin's concordance correlation coefficient ('CCC) (Lin 1989; Lin 2000). The coefficient has two components: first, is the standard Pearson correlation coefficient (***r***) which tests for a linear relationship between points (monthly growth rates in our case); and the second term (C_b), tests for departure of the relationship from a 1:1 line. In essence the first term is comparing the shape of the seasonal growth curve and the second term is testing the total amount grown. The test was applied using Genstat (version 13.2) (Payne et al. 2010). Guidelines regarding the strength-of-agreement criteria have been set out by McBride (2005): coefficients between 0.90 and 0.95 are deemed to have 'moderate' agreement, between 0.95 and 0.99 'substantial' agreement and coefficients greater than 0.99 'almost perfect' agreement. The analogue exercise was carried out only for the high (A2) climate change scenario.

5 Modelling protocol

5.1 Introduction

Modelling the impacts and adaptations of hill country farming enterprises to projected future climates involved three stages:

1. Daily time-step historical climate and future projections for three locations and two climate change scenarios were used (the Primary Sector Adaptation Scenarios (PSAS), see Chapter 2).
2. These climate data were then used in a biophysical pasture growth model to determine current and future pasture growth rates with monthly growth rates generated for 20-year time slices centred around 1990 and 2040.
3. The monthly pasture growth rates were then used in a farm systems model to determine the feasibility of the current and adapted farm system under future climates.

5.2 Methods

5.2.1 Locations and farm systems

Hill country farms are found in a wide range of geographical and climatological regions leading to a wide range of production systems. To deal with this variation in climate and production systems, organisations such as MPI and Beef+LambNZ use regionally based farm types or farm classes when collating production and other statistics. For example, the 12 MPI model farms are representative of their farm type within each region and are based on information drawn from between 15 and 45 farms (depending on the model) and a wide cross-section of agribusiness representatives (MPI 2012d). Data from these model farms are then combined to generate a national sheep and beef farm model. Table 4.1 shows the 12 regional model farms and their weighted contribution to the national model.

As discussed in Section 1.1, the geographic spread and variability of hill country farms in New Zealand makes it difficult to describe the potential impacts of climate change on these enterprises and discuss potential adaptation measures. For the modelling exercise we therefore chose three representative farm types that together account for nearly 70% of New Zealand's sheep and beef stock units. In the South Island, we modelled an extensive type of finishing-breeding operation (BLNZ Class 6; corresponding in part to MPI monitoring farm type 'Southland/South Otago hill country'; hereafter referred to as 'Southland'). This is the dominant sheep and beef farm class in the South Island and accounts for 21% of New Zealand's sheep and beef stock units. For the North Island, two farm types were modelled: 'North Island hard hill country' and 'North Island hill country' (BLNZ Classes 3 and 4 respectively). The 'Hard hill country' category corresponds in part to the MPI monitor farm category 'Central North Island hill country sheep and beef' (hereafter 'Waikato') and accounts for 14% of New Zealand's sheep and beef stock units. The 'Hill country' category corresponds in part to the MPI monitor farm 'Hawke's Bay/Wairarapa sheep and beef' (hereafter 'Hawke's Bay') and accounts for 32% of sheep and beef stock units. We present a more detailed description of the locations and farm systems that were modelled in the model results (Sections 6.1, 6.2, and 6.3 for Southland, Hawke's Bay and Waikato respectively).

Table 4.1. Regional model farms and their weighted contribution to the national model.

Model farm	*Weighting (%)*
Canterbury/Marlborough hill country	4
Canterbury/Marlborough breeding and finishing	14
Hawke's Bay/Wairarapa hill country	16
Central North Island hill country	12
Gisborne hill country	6
Western lower North Island	4
Northland	9
Otago dry hill	4
South Island high country	2
Southland/South Otago intensive	15
Southland/South Otago hill country	7
Waikato/Bay of Plenty intensive	7

5.2.2 Climate modelling

Historical and projected climate data were derived as described in Chapter 2. For each of the three locations daily climate data were provided for 1971 to 2050 with the first 28 years being re-analysed historical data for the Virtual Climate station location specified for each modelled farm. These data were used for the pasture modelling (Section 5.2.3). Two climate change scenarios were examined: the IPCC A2 and B1 scenarios (hereafter 'high' and 'low' respectively). As the 'current' climate was also modelled, there are slight differences in the climatic variables for 1990 between the two scenarios (Chapter 2).

5.2.3 Pasture modelling: model description

To simulate pasture ecosystems we used the AgPasture module operated in APSIM (Agriculture Production System Simulator; Keating et al. 2003). APSIM links AgPasture to other modules which provide climate data, soil water and nutrient dynamics, plant and animal organic matter returns, and manipulation of grazing management. AgPasture was developed from the EcoMod pasture model (Johnson et al. 2003; Johnson et al. 2008) and has been shown to simulate pasture systems in New Zealand accurately across a wide range of soil types and climates (Li et al. 2011).

The processes used to simulate plant growth in AgPasture are given in detail in Li et al. (2011) and are only outlined here. AgPasture models plant growth at the individual species level and is able to simulate grass-legume swards – an essential attribute for modelling pastures in New Zealand. Potential growth is calculated (see Johnson et al. 2003; Johnson et al. 2008) and then reduced depending on the availability of water and nutrients to give the actual growth. Plant water demand is calculated using the method of Penman & Monteith and the limitation due to water then calculated from the ratio of actual plant water uptake to water demand. Plant nitrogen (N) demand and N-deficit effects are quantified using the concept of critical N concentration (Lemaire & Salette 1984; Ghannoum et al. 2007). Competition among species for light, water and nutrients are explicitly modelled for the individual species, and pasture properties are then calculated by aggregating the species' responses.

The effects of increasing atmospheric CO_2 concentration were included by re-parameterising three key functions: plant photosynthesis and respiration (fC_p), plant N demand (fC_n) and plant stomatal conductance (fC_s). The parameter values, which depended on the atmospheric CO_2 concentration, were taken from experimental data from the NZFACE experiment (Von Caemmerer et al. 2001; Newton et al. 2010) and other relevant literature.

In terms of pasture composition, for the Southland and Hawke's Bay farms a combination of *Lolium perenne* (ryegrass) and *Trifolium repens* (white clover) were used. For Waikato, a pasture composed of ryegrass, white clover and *Paspalum dilatatum* (paspalum) was simulated.

5.2.4 *Pasture modelling: model validation*

Typically, models are validated by comparing long-term pasture data from a specific site with simulations made for that site. To validate against climate change parameters, model results need to be compared against data of pasture grown under variable climates and future atmospheric CO_2 concentrations. Clearly, it is not straightforward to find data for pasture grown under future CO_2 concentrations. Fortunately, we do have a long-term dataset from the NZFACE experiment that provides data for each harvest taken over an 11-year period. We were able to set up the model for the conditions of the NZFACE experiment and compare the actual and modelled data. As far as we are aware, this kind of detailed year-by-year comparison has not been attempted previously – although there are examples where model performance under climate change has been evaluated using a single total or average measure (Pinsonneault et al. 2011).

Details of the NZFACE experiment can be found in the literature covering soil characteristics (Ross et al. 2004), botanical composition (Edwards et al. 2001) and management (Newton et al. 2006; Newton et al. 2010). CO_2 enrichment is achieved by releasing CO_2 into the ambient air stream from a circle of pipes across 12-m diameter areas – a technique known as Free Air Carbon Dioxide Enrichment (Lewin et al. 1994). Briefly, the experiment is set up on a Pukepuke black sand soil on the Flock House experimental farm in the Rangitikei. Annual mean precipitation is 884 mm (1979–2008), and annual mean temperature is 12.9°C. The pasture is botanically diverse containing legumes, C3 and C4 grasses, and broadleaf weed species. Fertiliser is applied to maintain adequate levels of phosphate, potassium and sulphate based on annual soil sampling and established guidelines (Cornforth & Sinclair 1984) but N inputs are solely from N-fixation by legumes. Sheep graze the experiment when the aboveground herbage mass reaches 180–200 g DM·m^{-2} and graze down to a target residual of 50–70 g DM·m^{-2}. Until April 2001, the rings were mob grazed, with animals having free access to all rings. Thereafter, animals were confined within individual rings for the duration of the grazing period to ensure that nutrients were returned within the treatment areas (Newton et al. 2010).

We found that the most accurate simulations were achieved by including all of the parameter changes i.e., adjustments needed to be made for photosynthesis and respiration (fC_p), plant N demand (fC_n) and stomatal conductance (fC_s). The comparison of observed and actual data is shown for total annual production in Figure 4.5 and for season (month) in Figure 4.6. The response to CO_2 is shown in Figure 4.7. In addition the model also matched the experimental data in predicting an enhanced flux of N through the system and increases in the pools of carbon and N in the soil (Ross et al. 2004; Newton et al. 2010). As our model is able to simulate pasture production at sites around New Zealand that differ in temperature and rainfall (Li et al. 2011) we have some confidence in projections of these environmental variables, the validation against the NZFACE data gives us further confidence that the model contains the mechanisms necessary to simulate future changes in CO_2 and climate.

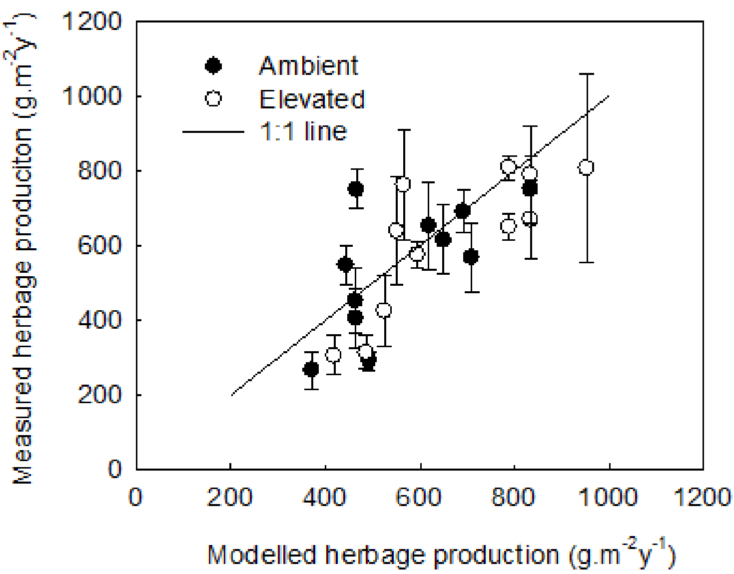


Figure 4.5. The relationship between modelled and measured annual herbage production in the NZFACE. Under ambient CO_2 (black circles) r^2 = 0.433, p =0.028; under elevated CO_2 (open circles) r^2 = 0.568, p =0.007.

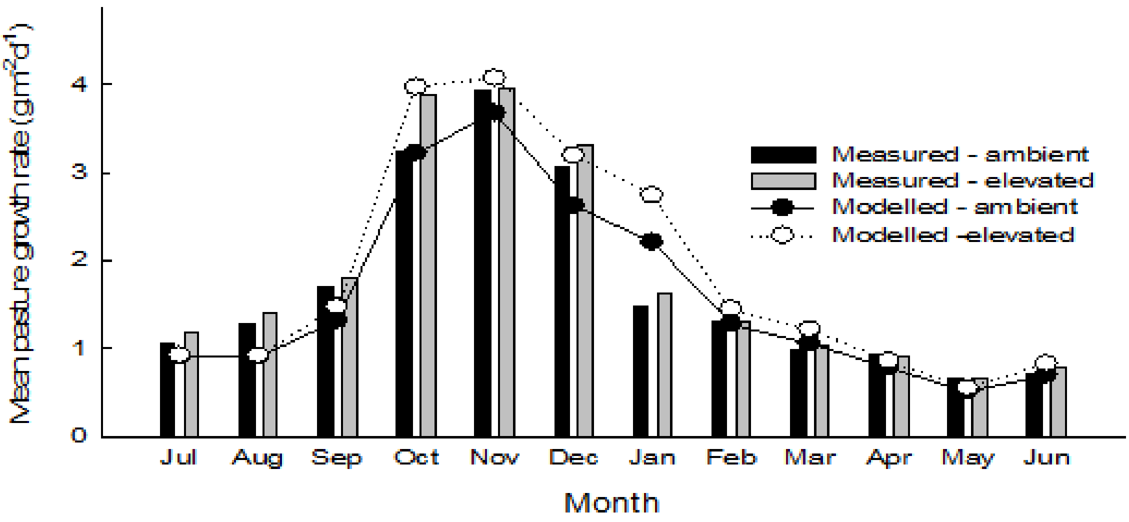


Figure 4.6. Modelled and measured monthly means of daily pasture growth rates in the NZFACE. Modelled and measured are highly correlated (r^2 = 0.920 for ambient, and 0.906 for elevated, respectively; both with $p < 0.001$). The seasonal pattern of CO_2-enhanced increase of daily pasture growth rate is also significantly correlated between modelled and measured (r^2 = 0.579, p = 0.004).

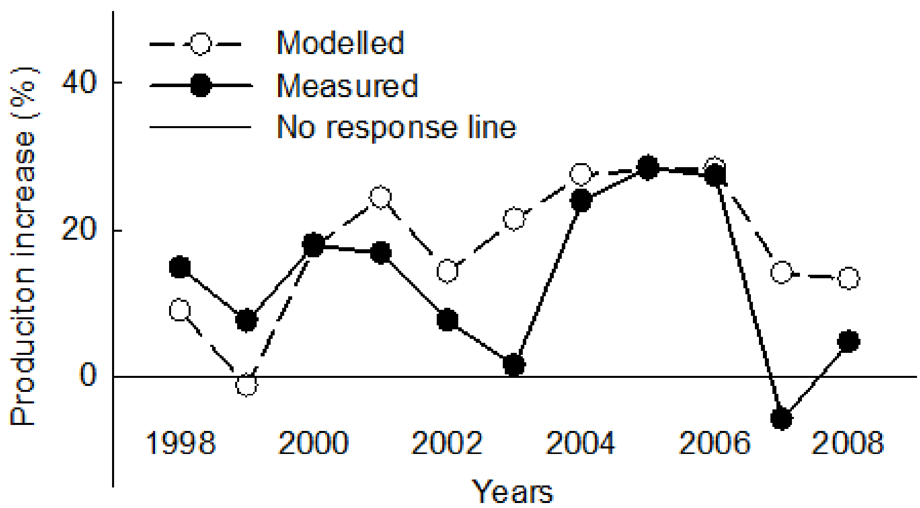


Figure 4.7. Modelled and measured response of annual herbage production to elevated CO_2 in the NZFACE. There was a significant correlation between the modelled and measured data (r^2 = 0.569, p = 0.007).

5.2.5 Importance of topography

The climate change projections at the notional farm locations were generated by a Regional Climate Model (RCM) with bias correction and further downscaling (Chapter 2). This provides information at the meso-scale, with climate averaged for a 5-by-5 km grid around the site. However, there is finer scale micro-climatic variability within hill country farms where the elements of aspect, slope and altitude have marked influences on pasture productivity. At this stage the meso-scale climate changes have not been translated into differences in micro scale climate – although it is quite possible that there may be an interaction where the relative effects of climate change are expressed differently on areas of different slope and aspect. A preliminary study where we changed temperature and incident solar radiation for different slopes and aspects (together with the differences in soil properties) produced pasture growth projections that were sufficiently different to those resulting from the meso-scale climate projections to suggest future work on this issue would improve the accuracy of the simulations. In the absence of information on future climate changes specific to slope and aspect, our simulations of hill and rolling blocks differ only in soil properties. For the Southland farm, two different 'blocks' were modelled: a flatter rolling block (70% of the farm area) and a steeper hill block (30% of the area). For the Waikato farm, the steeper hill block comprised 80% of the farm and a flatter, rolling block 20%. For both locations the soil properties of the rolling and hill blocks were parameterised using data from soils typical of the area. For the Hawke's Bay farm only a single hill block was modelled.

5.2.6 Pasture modelling: simulations

The daily climate files for the three locations and two climate change scenarios were used to determine daily pasture growth rates for the historical time period (using re-analysed RCM data) as well as into the future. The model was run from 1971 to 2050 with the daily pasture output data from the appropriate time slices being used to calculate monthly pasture growth rates. These were used in the farm system modelling (Section 5.2.7). The simulation started in 1971 and ran continuously in order to 'spin-up' the various model components, especially those that take a long time to change, such as soil organic matter dynamics.

5.2.7 Farm system modelling

The whole-farm system model Farmax® Pro (version 6.3.74.1, www.farmax.co.nz) (hereafter Farmax) was used to examine the effects of the projected pasture growth rates on the feed flow and profitability of sheep and beef farming enterprises in Southland, Hawke's Bay and Waikato. A three-step iterative process was used to examine future farming feasibility. For each enterprise, an average farming system based on the current MPI model farm was developed for the current average monthly pasture growth curves obtained from the pasture simulation outputs described in Section 5.2.3 ('A' in Figure 4.8). The specific management systems for each of the localities are presented in Section 6. This average farming system was then applied to the individual monthly pasture growth curves for each of the 20 years in the 1980–1999 time slice (hereafter referred to as '1990') with the same stock policies being used in each year. The farm started and ended each July year with no conserved feed: feed shortages were alleviated by buying-in hay, and feed surpluses converted to hay (which was sold). The window for haymaking was fixed though the actual timing was changed each year to best cope with excess pasture. This method enabled a net energy balance (metabolisable energy in the feed) of the farm to be calculated for each year. Where the amount of hay made was in excess of that normally made in the average year, the extra hay was assumed to be used to contract graze dairy heifers and appropriate adjustments made to calculate a theoretical gross margin for each year. The 10th, 50th and 90th percentiles (***p10th***, ***p50th*** and ***p90th*** respectively) of the 20 years of gross margins were then determined and a coefficient of decile deviation (a measure of variability) calculated as:

(***p90th – p10th***) /(***p50th***)

The second step in the analysis was to apply the current 1990 average farm management system to the individual monthly pasture growth rates for each of the years in the 2030–2049 period (hereafter '2040') (labelled '1' in Figure 4.8). The same rules regarding feed shortages and surpluses were applied and energy balances and gross margins calculated. The energy balances of the farm management system applied to current and future conditions (labelled '2' in Figure 4.8) were compared and a decision was made whether adaptation was necessary. If the average future farming system had a different energy balance, then adaptation was required to deal with the different amounts of available feed (Table 4.2). These adaptations included changes in stock number, reproductive efficiency and animal growth rates. Changing stock number is a reactive short-term response, while changing reproductive efficiency (pregnancy, lambing/calving and weaning percentages) is a longer term strategic adaptation. Altering animal growth rates combines both short and long term strategies: the short-term being an increased plane of nutrition; the longer-term being achieved through selection and breeding. Changes in the seasonality of feed supply, as shown by the average monthly pasture growth rates, were managed by adapting the timing of events such as lambing/calving and hay cutting. As there are multiple ways that a farm could deal with energy shortages or surpluses, only one combination of these changes was implemented and a new average farm system was developed. The choices made and implemented in Farmax were kept within the bounds of currently achievable targets. The specific changes in the management system for each of the enterprises are outlined in Section 6.

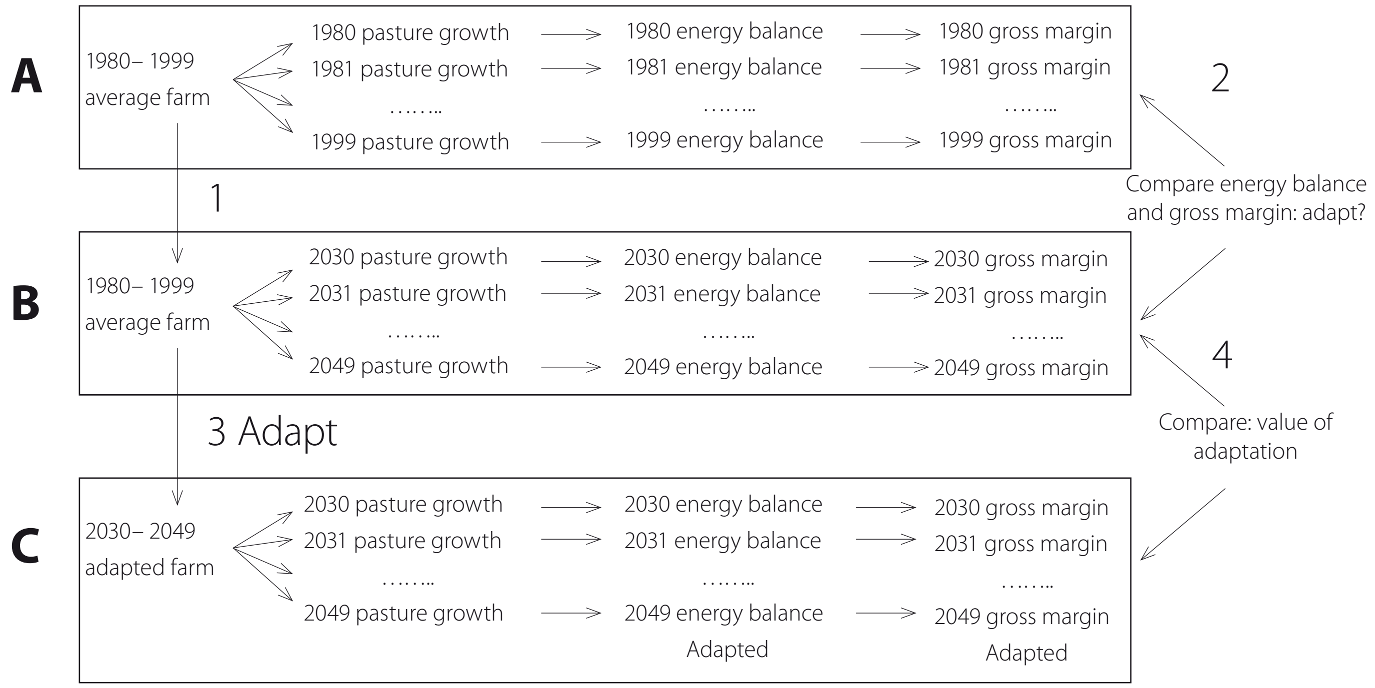


Figure 4.8. Schematic of the farm system impact and adaptation process. A - Current farming system under the historical climate for the 1990 period. B - Current farming system under the projected climate for 2040 period. C - Adapted farming system under the projected climate for the 2040 period. See text for further details.

Table 4.2. Adaptations used in Farmax to balance feed supply and demand.

Supplemental feed	Purchase feed (hay/balage) Sell excess feed (hay/balage)
Stock numbers	Buying/selling stock Contract grazing
Timing of operations	Lambing date Feed conservation date (hay cutting) Weaning date
Reproductive efficiency[1]	Pregnancy % Weaning % Lambing/calving %

[1] The values used in this study did not exceed values already achieved on high-performing farms of this type.

The third step was to apply the new, 'adapted' system to each of the individual years/months in the 2040 time period (labelled '3' in Figure 4.8) and again the annual energy balances and gross margins calculated. As in the previous steps the same rules regarding feed shortages and surpluses were applied. A comparison of gross margins for the adapted (stage C) and non-adapted (stage B) (labelled '4' in Figure 4.8) indicated the value of the adaptation. Note that for these calculations, all revenues and costs were held to current monetary values.

In summary, for each farm system, this process resulted in three different gross margins:

- the current farming system under the historical climate for the 1990 period (A in Figure 4.8)
- the current farming system under the projected climate for 2040 period (B in Figure 4.8)
- an adapted farming system under the projected climate for the 2040 period. (C in Figure 4.8).

A stocking unit (SU) was defined according to the feed consumed on farm including supplemental feed; 1 SU = 550 kg DM consumed. Note that farm system modelling was carried out for the 'high' (A2) scenario only.

We decided to analyse the farming systems as both farm annual energy balances and gross margins for a number of reasons. On a year to year basis, farming is essentially an exercise in matching the energy demand of the management system in place (largely determined by the stock policies) and the pasture production as determined by the weather. By keeping the stocking rates and reproductive efficiencies of the animals constant for each 20-year period and stipulating that the farms started the year without any conserved feed (buying-in when necessary and selling any hay made), we effectively converted each year's weather into an energy balance. Under such rules, for an ideal farm, the energy balance should be above but close to neutral. This means that most of the feed that is grown is converted into high value product (meat and wool) rather than made into lower value hay (or resulting in excessive amounts of hay being bought in). These energy balances will then be reflected in the annual gross margins which we present as the final outcome of matching energy supply and demand.

When seasonal pasture growth rates are not sufficient to meet the average farm system's energy demands, real-world farmers have multiple options ranging from buying-in feed, to selling lambs earlier, to culling capital stock. In the case of the simple rules used in our analysis, the gross margins will be negatively impacted because imported feed will need to be bought in; it must be remembered that other management options may impact the gross margin differently. Conversely, where there is excess feed, then additional income can be gained from increased production by increasing stock energy demand. As in the case of feed shortages, farmers in the real world have different ways to achieve a neutral energy balance which typically involve short-term trading of stock to increase demand. In our model we assumed that additional short-term contract grazing of dairy heifers was used to manage feed surpluses. In some cases, where the non-adapted farm system had trouble dealing with feed surpluses, the use of these simple rules led to gross margins that are likely to be unrealistic: it should be remembered that the values presented in this report are relative to the system under investigation.

6 Modelling results

6.1 Southland

6.1.1 Farm location and description

The Southland MPI model farm represents over 700 farms situated on moderately rolling clay downlands to steeper hill country in South Otago and Southland. Typically, soils in this region are characterised as deep, alluvial and loessic in nature, which provides for a high water holding capacity and relatively reliable summer pasture production in the absence of irrigation. Conversely, wet winters can cause severe pugging and restricted vehicle access across pastures. The model farm has an area of 723 effective hectares of mostly improved pastures on the rolling land with the balance in steeper, hill land tussock blocks. In terms of stocking policy the model farm is considered a finishing-breeding operation (BLNZ class 6), based on a flock of breeding ewes with some lambing hoggets (most lambs are finished on farm) and a herd of breeding cows with most calves finished on farm. Dairy cow grazing is included in this model but continues to diminish (MPI 2012c). Opening stock numbers, stocking policies and reproductive efficiencies are presented in Table 4.5. For the purpose of generating the climate change projections, the model farm was assumed to be located near Lumsden, northern Southland; though this area is drier than the rest of Southland it typifies the wider Southland/Otago region in terms of pasture production.

6.1.1.1 Climate projections

Table 4.3 shows some of the current and projected low and high scenario climate changes for the Southland site. Atmospheric CO_2 concentration was 353 ppm in 1990, and projected to increase to 491 ppm in 2040 for the high scenario and to 463 ppm in 2040 for the low scenario.

The annual mean temperature for both scenarios was about 10°C in 1990, with increases by 2040 of 1.4°C for the high and 0.9°C for the low scenarios. Projected annual precipitation in the high scenario increased, but in contrast to temperature, the increases were different across seasons, with larger increases in winter (23 mm) and spring (42 mm), but less in summer (15 mm) and autumn (22 m) in 2040 (data not shown).

Table 4.3. Projected changes in climate and atmospheric CO_2 concentration (averaged over 20 years) for Southland.

Parameter	**IPCC scenarios**	**1990**	**2040**
CO_2 (ppmv)	High	353	491
	Low	353	463
Radiation (MJ m^{-2} y^{-1})	High	4737	4710
	Low	4753	4749
Mean annual temperature (°C)	High	9.9	11.3
	Low	9.9	10.8
Mean annual precipitation (mm)	High	975	1069
	Low	998	1024

Together with an increase in average temperature, the projections were for more hot days with daily maximum temperature higher than 30°C increasing from 0.4 days in 1990 to 3.5 days in 2040 (Table 4.4). The frequency of rain storms also increased slightly with the number of days with more than 25mm of rain increasing from 6 days in 1990 to 8 days in 2040.

Table 4.4. Extreme weather events in the high scenario for Southland for 1990 and 2040: average number of days per year with: daily maximum temperatures greater than specified; daily minimum temperatures less than specified; and days with total rainfall more than specified.

Parameter		**Time period (days)**	
		1990	**2040**
Daily maximum temperature greater than (°C)	>28	3.3	8.7
	>30	0.4	3.5
	>32	0.1	0.4
	>34	0	0.1
Daily minimum temperature less than (°C)	<2	107.1	68.9
	<0	57.8	30.7
	<-2	23.5	8.9
	<-4	6.3	0.7
	<-6	0.5	0
Days with rainfall of (mm)	>100	0.1	0.1
	>75	0.2	0.3
	>50	1	1.2
	>25	6.2	8.3
	>10	29.5	32.7

6.1.1.2 Pasture growth projections

Total annual pasture production for the low and high climate change projections are shown in Figure 4.9. For the low scenario pasture production increased from about 8500 kg DM ha^{-1} y^{-1} in 1990 to about 9500 kg DM ha^{-1} y^{-1} in 2040. For the high scenario in 2040, pasture production increased more than in the low scenario (to about 10,000 kg DM ha^{-1} y^{-1}). Inter-annual variation did not change much from current levels in either scenario.

There were marked changes in the monthly average daily growth rates, particularly for the high scenario (Figure 4.10). For example, spring pasture growth rates (September to November) were nearly 30% greater in 2040 compared to 1990. In addition, and probably more importantly, the inter-annual variation in the summer month growth rates increased markedly in the future.

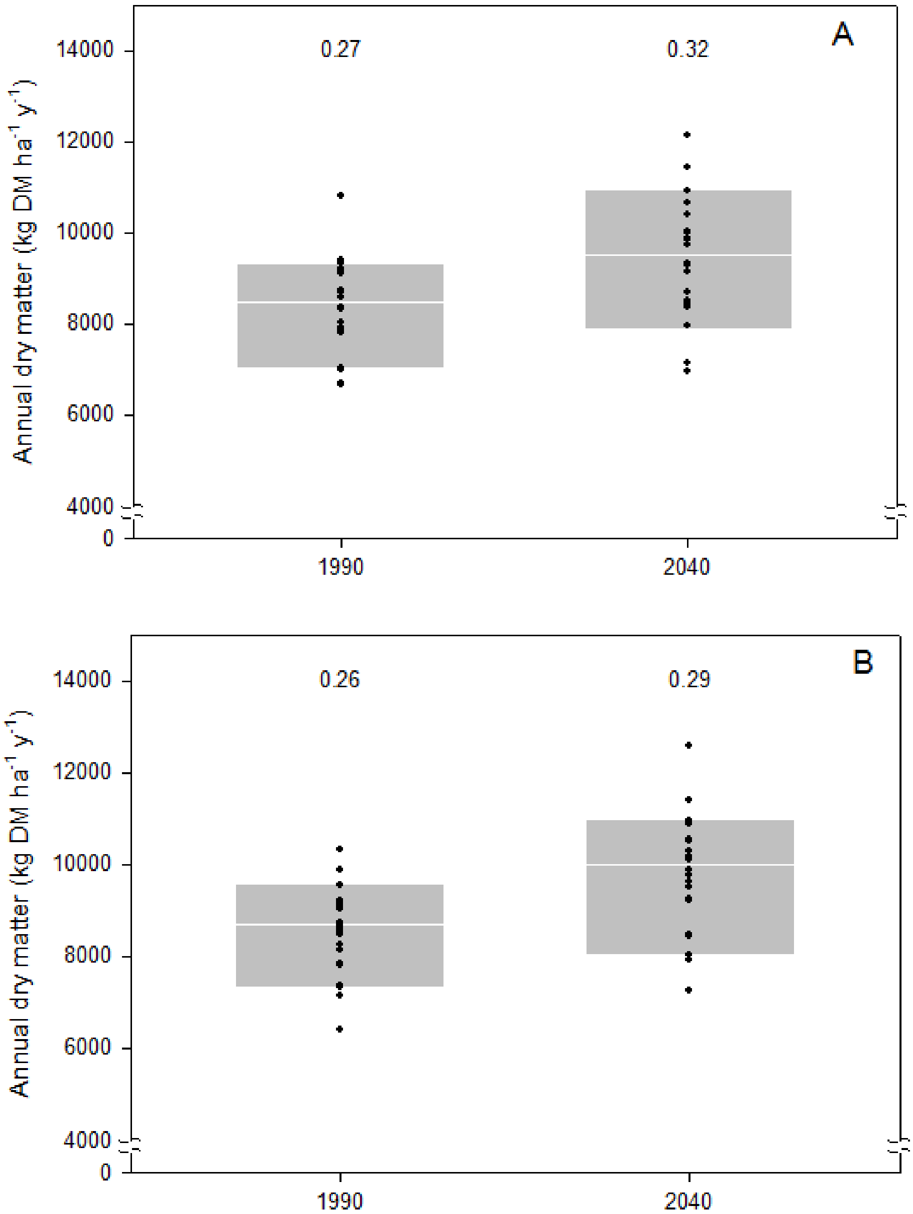


Figure 4.9. Boxplots of annual DM production in Southland for the periods 1980–1999 (labelled '1990') and 2030–2049 ('2040') for two scenarios. (A) Low climate change scenario. (B) High climate change scenario. The bottom boundary of the box indicates the 10th percentile, the line within the box marks the 50th percentile (median), and the upper boundary of the box indicates the 90th percentile. The individual annual DM production values are also shown, with the variability indices for each period shown above the boxplots (see text for details).

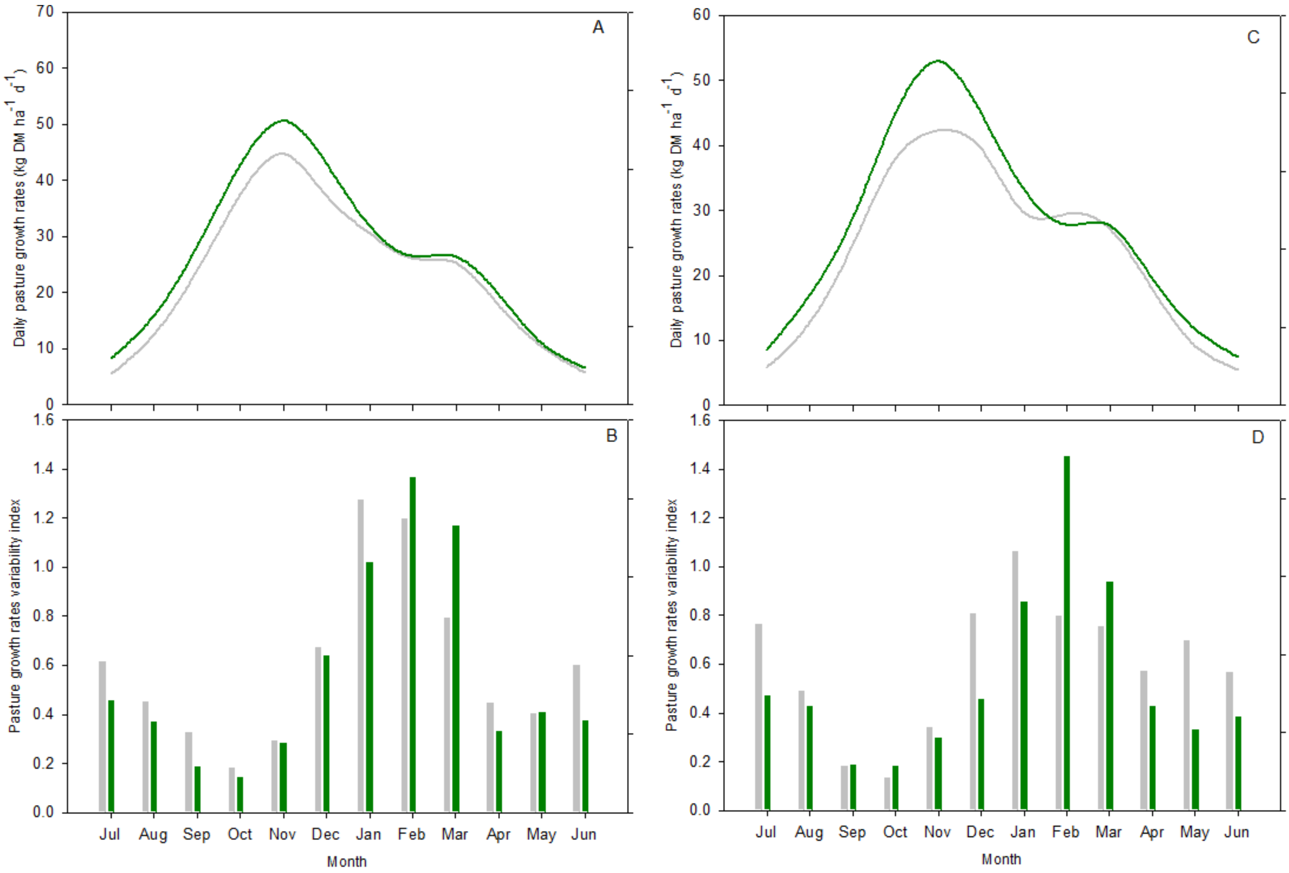


Figure 4.10. Average monthly pasture growth rates in Southland for low (A) and high (C) climate change scenarios for the 1990 (grey lines) and 2040 (green lines) time periods. Variation in the 20-year monthly growth rates are shown in (B) and (D) respectively (see text for calculation details)Farm systems modelling.

6.1.1.3 Farm systems modelling

As described in Section 5.2.7 (and illustrated in Figure 4.8), the feasibility of farming under the high climate change scenario and changes needed to adapt the management for the different future pasture growth patterns were determined using an iterative approach and the Farmax decision support package.

Table 4.5 details some of the physical indicators and measures of reproductive efficiency for the 1990 and 2040 Southland farm systems optimised for the pasture growth curves under the high scenario (Figure 4.10) while Figure 4.11 shows the gross margins in 1990 and 2040 for both the non-adapted and adapted farming systems.

The current 1990 farm had 12.5 SU ha^{-1} as a mixed sheep and beef finishing system with a small contribution to farm income coming from a deer enterprise. Based on DM intake, the current 1990 farm comprised an animal species ratio of 72:25:3 (sheep:cattle:deer) including Romney ewes, Angus x Hereford cows, and Red deer. A similar species ratio (73:24:3) was assumed for the 2040 farming system.

Under 1990 pasture growth conditions, this system had a median gross margin of about NZ$800 ha^{-1}, with only one year in the 20-year period showing a negative gross margin ('1990' in Figure 4.11). When this management system was applied to the pasture growth rates projected for the 2040 time period, the gross margin increased by about 30% to just over NZ$1000 ha^{-1} ('2040' in Figure 4.11). However, an analysis of the energy balance of the 1990 management system run under 2040 pasture growth rates (data not shown) indicated that even though the gross margin increased significantly, there was still surplus pasture which could be turned into product (meat and wool). Therefore, changes were made to the management system to match the new feed supply curve which focussed on increasing the demand for feed in the spring by increasing stocking rate and reproductive efficiency. These changes are outlined in Table 4.5. Ewe pregnancy, lambing and weaning percentages were increased from 167%, 134% and 130% respectively, to 202%, 186% and 182%, respectively for the 1990 and 2040 farming systems. This increased overall ewe reproductive efficiency (lamb weaning weight per kg ewe mated) by 33%; corresponding ewe mating weights slightly increased from 64.9 to 65.1 kg LW. Cow reproductive efficiencies were also increased, but to a lesser extent: the corresponding pregnancy, calving and weaning percentages were increased from 92%, 88%, and 87% respectively, to 95%, 92% and 91% respectively, increasing overall cow reproductive efficiency by 5%.

Table 4.5. Main physical indicators and measures of reproductive efficiency of the Southland farm modelled for 1990 and 2040 (high scenario) time periods. Output from Farmax.

Parameter	***Time period***	
	1990	***2040***
Mean pasture production[1]	8549	9879
Stocking (SU ha^{-1})	12.5	14.7
Sheep, opening numbers (head)	0.1	0.4
Ewes	4061	4236
Ewe hoggets	1181	1233
Rams	48	50
Total sheep	*5290*	*5519*
Cattle, opening numbers (head)	6.3	0.7
Cows	93	98
1-yr heifers	38	42
2-yr heifers	28	32
1-yr steers	38	42
2-yr steers	14	10
Bulls	3	3
Contract[2]	225	257
Total cattle	*439*	*484*
Deer, opening numbers (head)		
Total deer	*149*	*160*
Performance indicators, ewes		
Lamb/wean date	05 Sep, 28 Nov	15 Sep, 08 Dec
Preg/lamb/wean (%)	167/134/130	202/186/182
Ewe efficiency[3] (%)	62.5	83.2
Performance indicators, cows		
Calv/wean date	26 Sep, 16 Apr	17 Oct, 07 May
Preg/calv/wean (%)	92/88/87	95/92/91
Cow efficiency[4] (%)	38.5	40.5

[1]Annual pasture production, kg DM/ha. [2]Contract grazing, dairy heifers. [3]Total standardised lamb weaning weight (at 90 days, in kg) per kg ewe mated, expressed as a percentage. [4]Total standardised calf weaning weight (at 200 days, in kg) per kg cow mated, expressed as a percentage.

Total meat and fibre production was greater for the 2040 farming system; animal production was increased by 43%, from greater total intakes and greater feed conversion efficiencies (Table 4.6). In addition, the 2040 farming system showed a greater reliance on home grown feed (less than half the amount of conserved feed required) compared with the 1990 farming system. These changes resulted in a further increase in gross margin in 2040 (median of NZ$1385 ha^{-1}) as well as a decrease in the variability of these annual gross margins ('2040adapt' in Figure 4.11).

Table 4.6. Intake and animal performance of the Southland farm modelled for the current and 2040 (high scenario) time periods. Output from Farmax.

Parameter	***Time period***	
	1990	***2040***
Pasture consumed (t DM ha^{-1})	7.01	8.39
Conserved feed consumed (t DM ha^{-1})	0.24	0.13
Total feed consumed (t DM ha^{-1})	7.25	8.52
Conserved feed/feed consumed, (%)	3.3	1.5
Feed conversion efficiency (FCE)[1]	26.0	21.4
Animal production, net growth (kg/ha)		
Sheep	142.5	237.9
Beef	74.0	83.1
Wool	43.2	50.7
Total	264.5	377.2

[1]FCE = kg DM consumed per kg net animal production.

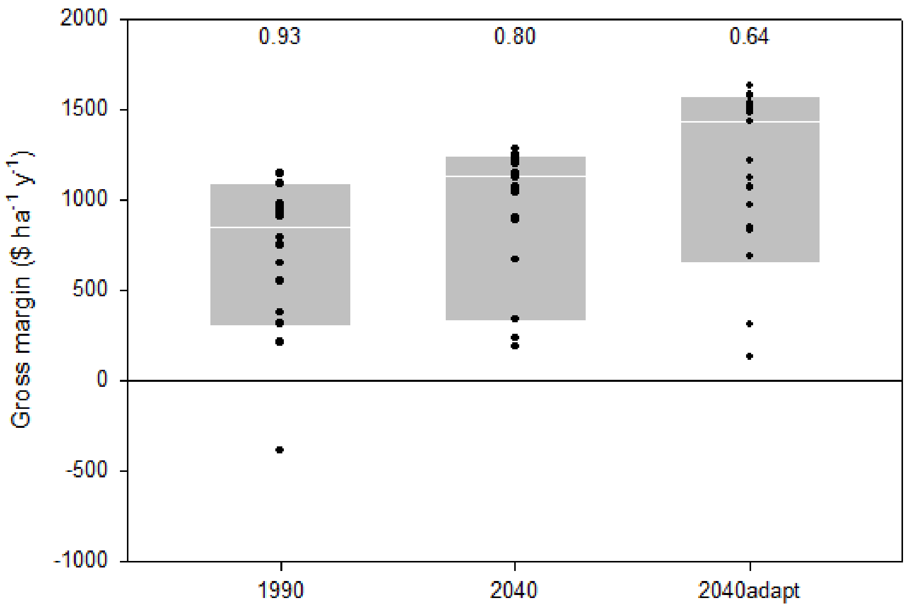


Figure 4.11. Boxplots of the gross margins for Southland using the high climate change projections for: the current farming system in the time period 1980–1999 (labelled '1990'), the current farming system with projected pasture growth for 2030–2049 ('2040') and an adapted farming system with projected pasture growth for 2030–2049 ('2040adapt'). The bottom boundary of the box indicates the 10th percentile, the line within the box marks the 50th percentile (median), and the upper boundary of the box indicates the 90th percentile. The individual annual gross margins are also shown and the variability indices for each period are shown above the boxplots (see text for details).

6.2 Hawke's Bay

6.2.1 Farm location and description

The Hawke's Bay MPI model represents approximately 2000 farms in the Hawke's Bay, Tararua and Wairarapa regions and is nominally located near Maraekakaho. Soils in this region are largely yellow-grey earths with inclusions of yellow-brown loams, and are generally high in natural fertility. Soil slip erosion events are frequent as a consequence of occasional heavy rain events, and can cause severe damage to the infrastructure of farms in the region. The model farm is 570 effective hectares in size and comprises sheep and cattle breeding and finishing (MPI 2012b). The terrain is a composite of easy to medium hill, with some steeper country with less intensive farming practices.

The sheep component is a breeding ewe flock breeding its own ewes with approximately two-thirds of the lamb progeny finished to slaughter weights and the remaining sold to store. Cattle policies include a range of practices from breeding cow herds to steer and heifer finishing. For the purpose of this modelling exercise, brought-in weaner bulls with a smaller proportion of older bulls to be finished was replaced with a dairy calve/heifer grazing enterprise. Class 4 farms (North Island, hill country) comprise mainly Romney sheep with a carrying capacity of ~10 SU ha^{-1} and a high proportion of stock sold to store, whereas Class 5 farms (North Island, intensive finishing) have greater carrying capacities, replacements ewes are often brought in and greater stock numbers are sold as finished (works). Opening stock numbers, stocking policies and efficiencies for Hawke's Bay are presented in Table 4.9.

6.2.1.1 Climate projections

Table 4.7 details some of the key changes in the climate of the Hawke's Bay hill country farm for the two climate change projections. For both scenarios annual incident radiation was slightly higher while mean annual temperature increased 0.7°C and 1.0°C for the low and high scenarios respectively. For the low scenario annual rainfall decreased from 883 to 857 mm while for the high scenario it decreased only 7 mm. Changes in climatic extremes in the high scenario are shown in Table 4.8. In terms of maximum temperatures, days with a temperature in excess of 28°C are projected to increase from about 6 days per year in 1990 to 12 days in 2040. In contrast, the number of days with a minimum temperature of less than 2°C is projected to decrease from about 50 in 1990 to 34 in 2040. There were only small changes in daily rainfall intensity.

Table 4.7. Projected changes in climate and atmospheric CO_2 concentration (averaged over 20 years) for Hawke's Bay.

Parameter	***IPCC scenarios***	***1990***	***2040***
CO_2 (ppmv)	High	353	491
	Low	353	463
Radiation (MJ m^{-2} y^{-1})	High	5298	5334
	Low	5308	5314
Mean annual temperature (°C)	High	12.9	13.9
	Low	12.8	13.5
Mean annual precipitation (mm)	High	887	880
	Low	883	857

Table 4.8. Extreme weather events in the high scenario for Hawke's Bay: average number of days per year with: daily maximum temperatures greater than specified; daily minimum temperatures less than specified; and days with total rainfall more than specified.

Parameter		***Time period (days)***	
		1990	***2040***
Daily maximum temperature greater than (°C)	>28	5.8	11.8
	>30	1	2.9
	>32	0.3	0.6
	>34	0.1	0.1
	>36	0	0.05
Daily minimum temperature less than (°C)	<2	49.2	33.7
	<0	23.1	13
	<-2	6.4	2.1
	<-4	2.1	0.1
	<-6	0	0
Days with rainfall of (mm)	>100	0.1	0.2
	>75	0.7	0.9
	>50	2.2	2.7
	>25	8.4	8.8
	>10	27.2	25.4

6.2.1.2 Pasture growth projections

Total annual pasture production for the low and high climate change projections are shown (Figure 4.12). For the low scenario pasture production decreased slightly from about 6500 kg DM ha^{-1} y^{-1} in 1990 to about 6300 kg DM ha^{-1} y^{-1} in 2040. For the high scenario in 2040, pasture production was about 100 kg DM ha^{-1} y^{-1} lower than in the low scenario (to about 6200 kg DM ha^{-1} y^{-1}). For the high scenario, inter-annual variation increased slightly in 2040.

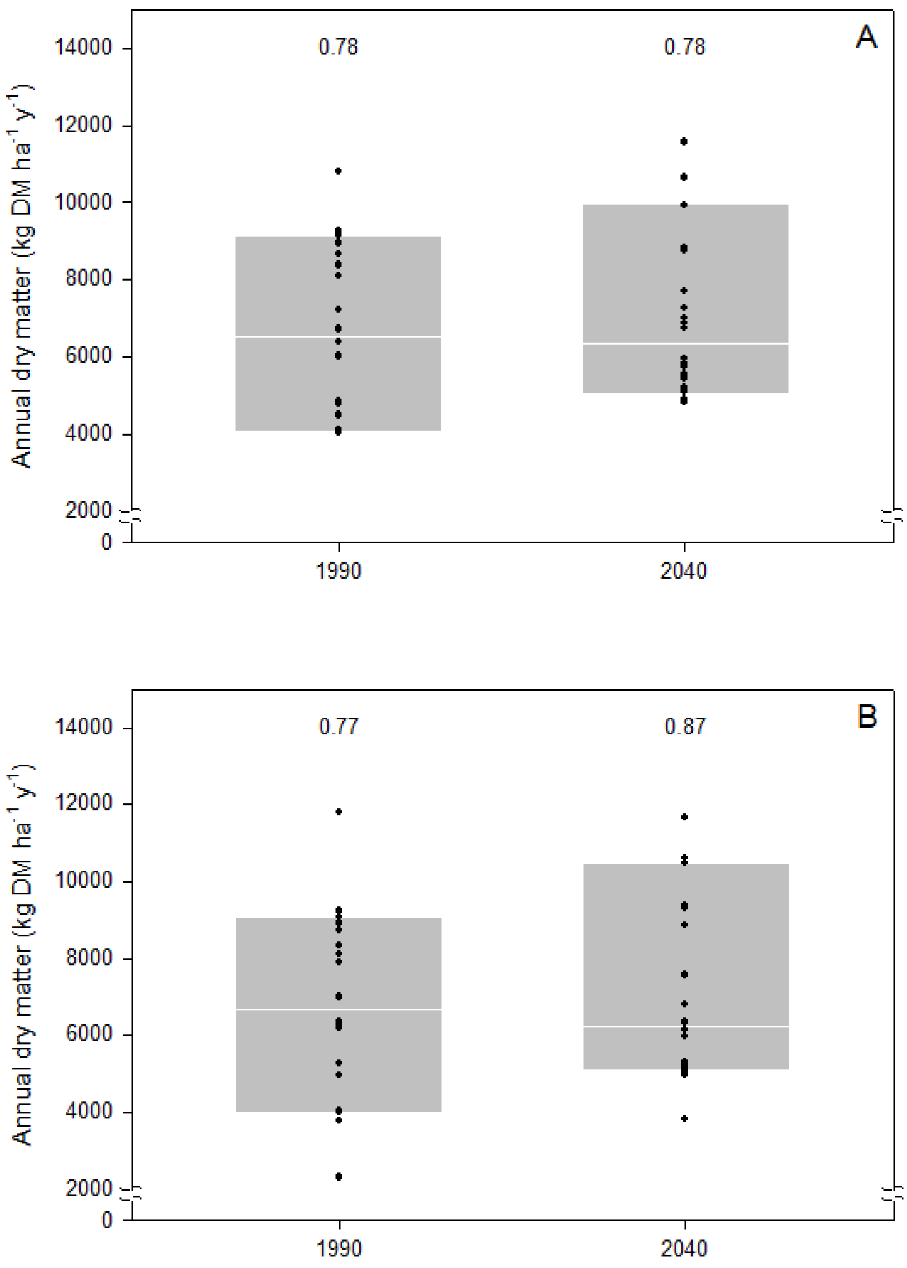


Figure 4.12. Boxplots of annual DM production in Hawke's Bay for the periods 1980–1999 (labelled '1990') and 2030–2049 ('2040'). (A) Low High climate change scenario. (B) High climate change scenario. The bottom boundary of the box indicates the 10th percentile, the line within the box marks the 50th percentile (median), and the upper boundary of the box indicates the 90th percentile. The individual annual DM production values are also shown and the variability indices for each period are shown above the boxplots (see text for details).

Though median annual pasture production decreased only slightly for both scenarios, there were changes in the monthly average daily growth rates (Figure 4.13A and C). For example, late winter-early spring pasture growth rates (August to October) were about 15% greater in 2040 compared to 1990. For the high scenario, of particular interest is the decrease by up to 30% in the November to January growth rates. Also of interest is the increase in the high scenario of the inter-annual variation in the summer monthly growth rates: the variability index in February for example increased from 2 to 8 (Figure 4.13D).

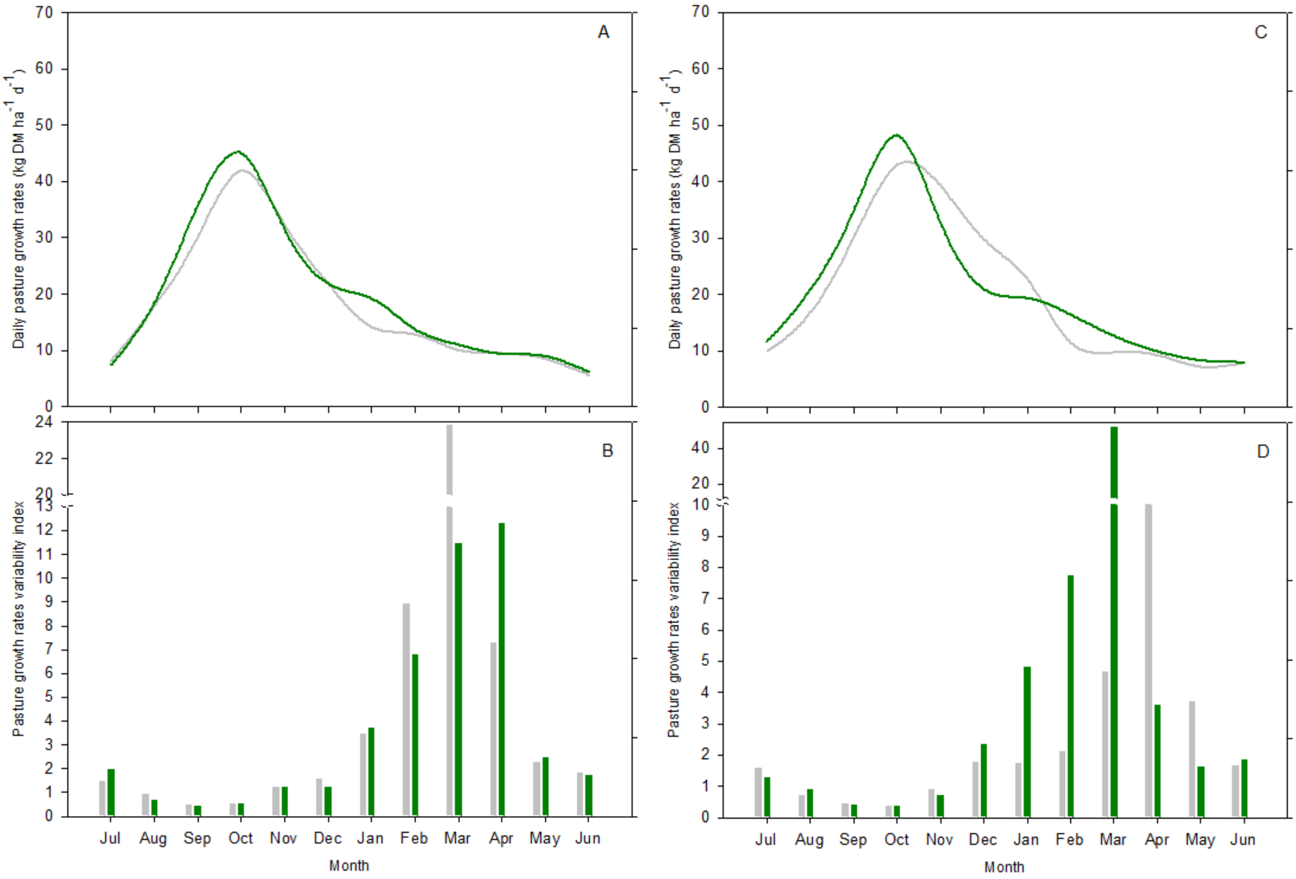


Figure 4.13. Average monthly pasture growth rates in Hawke's Bay for the low (A) and high (C) climate change scenarios for the 1990 (grey lines) and 2040 (green lines) time periods. Variation in the 20-year monthly growth rates are shown in B and D respectively (see text for calculation details).

6.2.1.3 Farm systems modelling

Table 4.9 details some of the physical indicators and measures of reproductive efficiency for the 1990 and 2040 Hawke's Bay farm systems optimised for the pasture growth curves under the high scenario (Figure 4.13) while Figure 4.14 shows the gross margins in 1990 and 2040 for both the un-adapted and adapted farming systems.

Table 4.9. Main physical indicators and measures of reproductive efficiency of the Hawke's Bay farm modelled for 1990 and 2040 (high scenario) time periods. Output from Farmax.

Parameter	***Time period***	
	1990	***2040***
Mean pasture production[1]	7123	7524
Effective area (ha)	570	570
Stocking (SU ha^{-1})	10.0	9.7
Sheep, opening numbers (head)		
Ewes	2600	2290
Ewe hoggets	766	674
Mixed hoggets	172	138
Rams	40	35
Total sheep	*3578*	*3137*
Cattle, opening numbers (head)		
Cows	102	90
1-yr heifers	42	40
2-yr heifers	25	24
1-yr steers	43	41
2-yr steers	18	8
Bulls	3	3
Contract[2]	52	46
Total cattle	*285*	*252*
Performance indicators, ewes		
Lamb/wean date	29 Aug, 07 Dec	25 Aug, 03 Dec
Preg/lamb/wean (%)	158/125/121	177/150/146
Ewe efficiency[3], (%)	53.2	60.5
Performance indicators, cows		
Calv/wean date	16 Sep, 06 Apr	28 Aug/24 Feb
Preg/calv/wean, (%)	95/86/83	97/90/89
Cow efficiency[4] (%)	36.7	39.9

[1]Annual pasture production, kg DM/ha. [2]Contract grazing, dairy heifers. [3]Total standardised lamb weaning weight (at 90 days, in kg) per kg ewe mated, expressed as a percentage. [4]Total standardised calf weaning weight (at 200 days, in kg) per kg cow mated, expressed as a percentage.

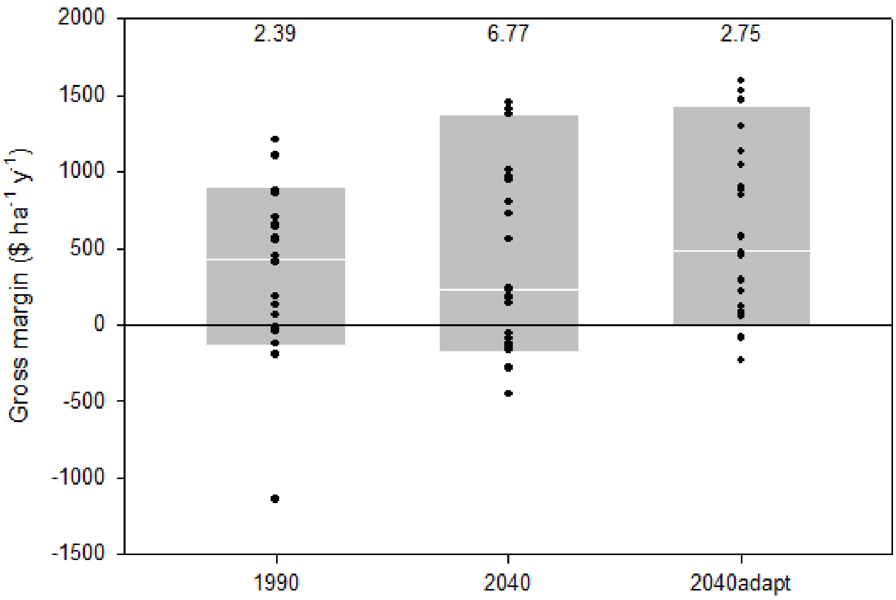


Figure 4.14. Boxplots of the gross margins for Hawke's Bay using the high climate change projections for the current farming system in the time period 1980 – 1999 (labelled '1990'), the current farming system with projected pasture growth for 2030 – 2049 ('2040') and an adapted farming system with projected pasture growth for 2030 – 2049 ('2040adapt'). The bottom boundary of the box indicates the 10th percentile, the line within the box marks the 50th percentile (median), and the upper boundary of the box indicates the 90th percentile. The individual annual gross margins are also shown and the variability indices for each period are shown above the boxplots (see text for details).

The current 1990 farming system had 10 SU ha^{-1} as a mixed sheep and beef system, with most lambs being finished. Based on DM intake, the current 1990 farm comprised an animal species ratio of 73:27 (sheep:cattle) including Romney ewes and Angus x Hereford cows. A similar species ratio (76:24) was assumed for the 2040 farming system.

Ewe pregnancy, lambing and weaning percentages were increased from 158%, 125% and 121% respectively, to 177%, 150% and 146% respectively, for the 1990 and 2040 farming systems (Table 4.9), increasing overall ewe reproductive efficiency by 14%; corresponding ewe mating weights increased from 61.9 to 63.1 kg LW. Cow efficiencies were also increased; corresponding pregnancy, calving and weaning percentages were increased from 95%, 86%, and 83% respectively, to 97%, 90% and 89% respectively, increasing overall cow reproductive efficiency by 9%.

Total meat and fibre production was slightly greater for the 2040 farming system; but animal production was only increased by 5% as a result of reduced stock numbers despite greater feed conversion efficiencies (Table 4.10). In addition, the 2040 farming system showed a much greater reliance on home-grown feed (imported conserved feed was only a small fraction relative to total feed consumed), compared with the 1990 farming system. Under 1990 pasture growth conditions, this system had a median gross margin of just under NZ$500 ha^{-1}, with six years in the 20 year period showing a negative gross margin ('1990' in Figure 4.14). It should be noted however, that four of the years had gross margins at or greater than the 90th percentile, with two of these years having gross margins greater than NZ$1000 ha^{-1}, indicating that even under current climatic conditions farming in the Hawke's Bay is very variable. This point is emphasised by contrasting the relative 20-year variability of gross margins the Hawke's Bay in 1990 (2.39; Fig 4.14) with that in Southland (0.93; Figure 4.11).

When the 1990 management system was applied to the pasture growth rates projected for the 2040 time period, the median gross margin decreased ('2040' in Figure 4.14). However, more importantly, the variability in gross margins increased markedly (to 6.77) with a decrease in the 10th percentile and an increase in the 90th percentile. The number of years with a negative gross margin increased only by one compared to 1990, while in three years the gross margins increased to nearly NZ$1500 ha^{-1}.

The most important changes in pasture growth in 2040 were slightly earlier spring growth and a decrease in pasture growth in the summer and early autumn. The measures to adapt the 1990 farming system to 2040 pasture growth patterns included earlier lambing and weaning and higher reproductive efficiencies (through higher lambing rates and lamb growth rates) (Table 4.9). These measures not only restored the gross margin to 1990 levels but also reduced the variability of the gross margins in this period and only two years had negative gross margins ('2040adapt' in Figure 4.14).

Table 4.10. Intake and animal performance of the Hawke's Bay farm modelled for the current and 2040 (high scenario) time periods. Output from Farmax.

Parameter	***Time period***	
	1990	***2040***
Pasture consumed (t DM ha^{-1})	5.57	5.70
Conserved feed consumed (t DM ha^{-1})	0.39	0.05
Total feed consumed (t DM ha^{-1})	5.95	5.75
Conserved feed/feed consumed, (%)	6.6	0.8
Feed conversion efficiency (FCE)[1]	26.8	24.4
Animal production, net growth (kg/ha)		
Sheep	115.4	134.9
Beef	52.2	46.2
Wool	38.8	36.3
Total	206.5	217.4

[1]FCE = kg DM consumed per kg net animal production.

6.3 Waikato

6.3.1 Farm location and description

The Waikato farm used in this modelling exercise represents a Class 3 enterprise (North Island, hard hill country) located in North West Waikato (Whatawhata). Soils in this region frequently comprise a clay component, developed from argillaceous greywacke, with some recent volcanic ash on the gentle slopes on site. The site was assumed to include a wide range of topography, slopes, and altitudes. With an effective area of 782 hectares, this farm represents an intensified operation relative to that of MPI's Central North Island hill country (MPI 2012a), which represents 1270 hill country farms located throughout the central area of the North Island. The land use capability in terms of annual pasture growth was defined by a fixed proportion of hill country with easy slopes (20% of the farm, 156 ha, 10.8 t DM/yr) relative to steeper country (80% of the farm, 626 ha, 8.3 t DM/ha). The farm carries 3200 breeding ewes and 120 breeding cows throughout the winter, a total stocking rate of 10.1 SU/ha, and a sheep to beef ratio of 67:33. There are four stock enterprises: breeding sheep, breeding cattle, trading sheep and trading cattle, which represent 61.0, 26.5, 5.8 and 6.7% of feed consumed, respectively. Note also that the pasture composition of this enterprise is a mixture of ryegrass, white clover and paspalum, a C4 species that is expected to increase in abundance with warmer temperatures (Sage & Kubien 2003).

6.3.1.1 Climate projections

Table 4.11 details some of the key changes in the projected climate of the Waikato hill country farm for the two climate change projections. For both scenarios annual incident radiation was slightly higher while mean annual temperature increased 0.9°C and 1.2°C for the low and high scenarios respectively. For the low scenario annual rainfall increased slightly (by 14 mm) while for the high scenario it decreased significantly from 1668 to 1548 mm. Changes in climatic extremes in the high scenario are highlighted in Table 4.12. In terms of maximum temperatures, days with temperatures in excess of 28°C are projected to increase from about 3 days per year in 1990 to 9 days in 2040. Conversely, the number of days with a minimum temperature of less than 2°C is projected to decrease from 31 in 1990 to 18 in 2040. Projected changes in daily rainfall intensity are less marked.

Table 4.11. Projected changes in climate and atmospheric CO2 concentration (averaged over 20 years) for Waikato.

Parameter	IPCC scenarios	1990	2040
CO_2 (ppmv)	High	353	491
	Low	353	463
Radiation (MJ m^{-2} y^{-1})	High	5045	5140
	Low	5079	5123
Mean annual temperature (°C)	High	13.5	14.7
	Low	13.3	14.2
Mean annual precipitation (mm)	High	1668	1548
	Low	1651	1665

Table 4.12. Extreme weather events in the high scenario for Waikato: average number of days per year with a) daily maximum temperatures greater than specified; b) daily minimum temperatures less than specified and c) days with total rainfall more than specified.

Parameter		Time period (days)	
		1990	2040
Daily maximum temperature greater than (°C)	>28	3.1	9.4
	>30	0.5	1.8
	>32	0.1	0.5
	>34	0.0	0.1
	>36	0	0.05
Daily minimum temperature less than (°C)	<2	30.9	18.0
	<0	12.5	5.9
	<-2	3.1	0.3
	<-4	0.0	0.0
	<-6	0	0
Days with rainfall of (mm)	>100	0.6	0.5
	>75	1.5	1.6
	>50	5.0	4.7
	>25	17.4	16.3
	>10	49.2	46.0

6.3.1.2 Pasture growth projections

Annual pasture production for the two climate change scenarios are shown in Figure 4.15. For the low scenario median annual pasture production increased only 4% to about 9400 kg DM ha^{-1} y^{-1} in 2040 but for the high scenario it increased about 13%. The inter-annual variability in pasture production was similar in the low scenario and decreased slightly in the high.

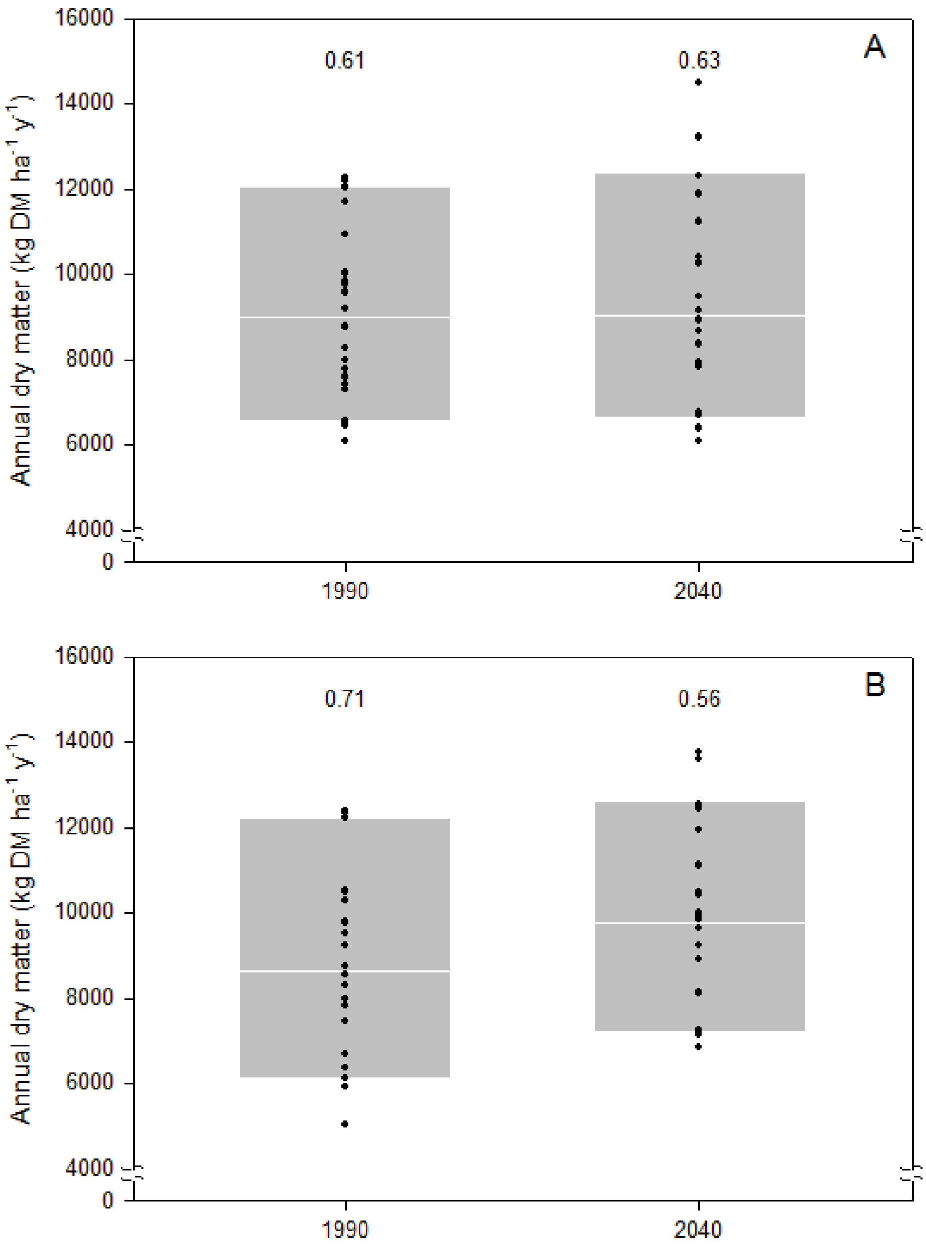


Figure 4.15. Boxplots of annual DM production in Waikato for the periods 1980–1999 (labelled '1990') and 2030–2049 ('2040') for the low (A) and high (B) climate change scenarios. The bottom boundary of the box indicates the 10th percentile, the line within the box marks the 50th percentile (median), and the upper boundary of the box indicates the 90th percentile. The individual annual DM values are also shown and the variability indices for each period are shown above the boxplots (see text for details).

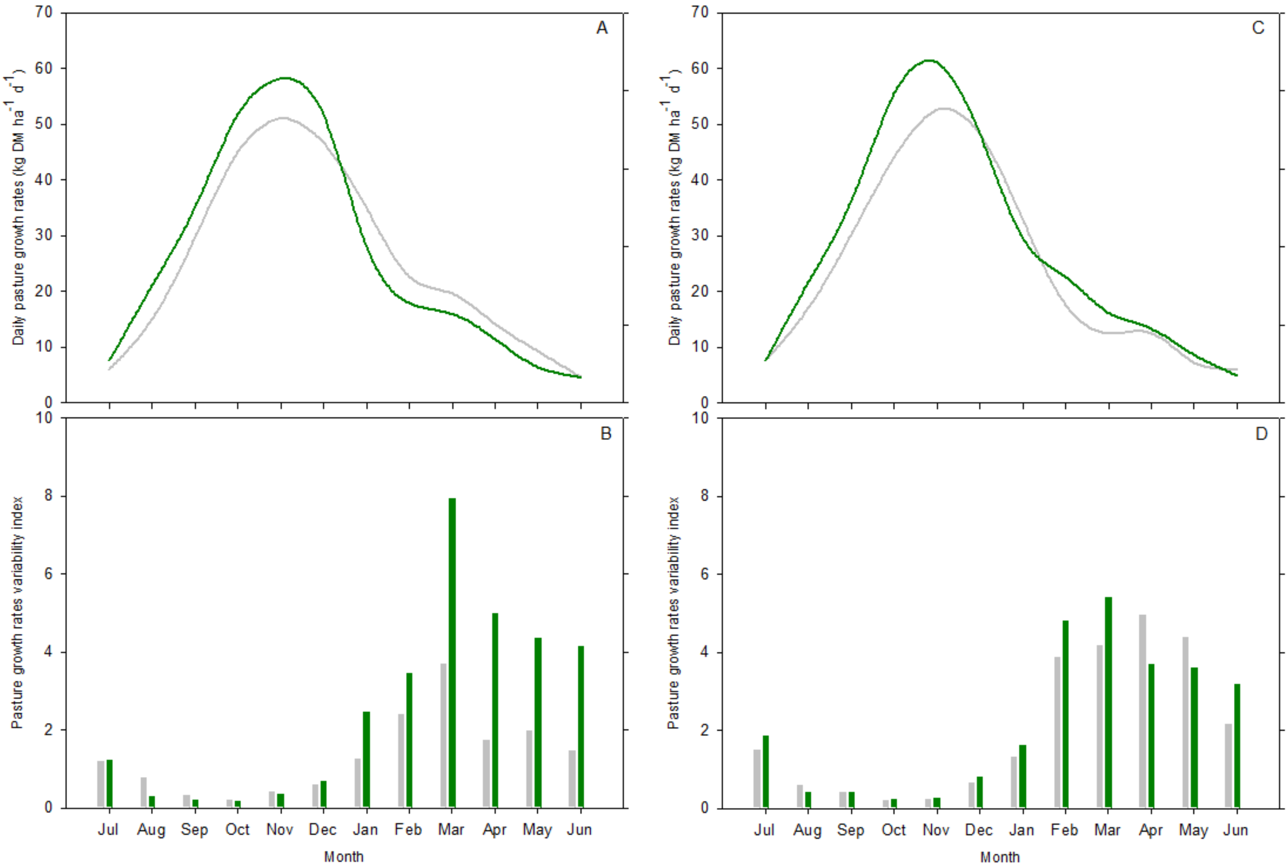


Figure 4.16. Average monthly pasture growth rates in Waikato for the low (A) and high (C) climate change scenarios for the 1990 (grey lines) and 2040 (green lines) time periods. Variation in the 20 year monthly growth rates are shown in B and D respectively (see text for calculation details).

The distribution of pasture growth rates throughout the year for the two scenarios and time periods are shown in Figure 4.16. In addition, the inter-annual variability of the monthly growth rates is shown. For both the low and high scenarios there was a marked shift in seasonality with earlier spring growth. Also, particularly for the low scenario there was a decrease in pasture production in the late summer-early autumn, with an increase in the monthly inter-annual variability. For the high scenario, there was a similar level of summer – autumn variability in 1990 and 2040. The difference between the low and high scenarios was mainly due to more variable rainfall in the low scenario.

Paspalum is a C_4 (sub-tropical) genus that is expected to show enhanced growth under warmer conditions (Sage & Kubien 2003). The enhancement in growth is likely to be greater than that of ryegrass – hence we could expect not only greater pasture growth but also a higher proportion of paspalum in the sward. Though this may be of some advantage in terms of overall DM production, paspalum generally has a lower feed value (quality) so the intake of metabolisable energy may stay the same or even decrease. Our pasture modelling in the Waikato showed an increase in paspalum proportion from late spring to autumn: from February to March paspalum percentages were twice as high in 2040 as in 1990 (approximately 12% vs. 6%). Because the pasture model and the farm model were not dynamically linked, based on a survey of the literature we accounted for this by decreasing pasture quality in 2040 for the relevant months from 10.5 to 9.5 MJ ME kg DM^{-1}.

6.3.1.3 Farm systems modelling

Farm system modelling results are shown in Figure 4.17. A major issue, even under current (1990) conditions is how to deal with excess feed. Our simple management rules assumed that excess feed would be converted into hay and used for contract grazing of dairy heifers. However, especially on hard hill country modelled here, it is unlikely that hay making or heifer grazing can be carried out to the extent modelled in this exercise, particularly in the three 1990 years with a gross margin of over NZ$300 ha^{-1} (Figure 4.17).

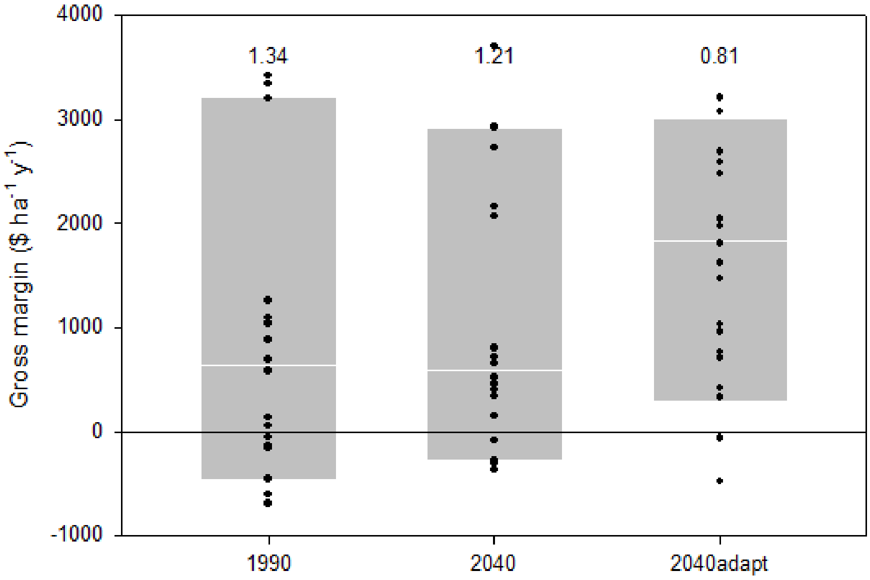


Figure 4.17. Boxplots of the gross margins for Waikato using the high climate change projections for the current farming system in the time period 1980–1999 (labelled '1990'), the current farming system with projected pasture growth for 2030–2049 ('2040') and an adapted farming system with projected pasture growth for 2030–2049 ('2040adapt'). The bottom boundary of the box indicates the 10th percentile, the line within the box marks the 50th percentile (median), and the upper boundary of the box indicates the 90th percentile. The individual annual gross margins are also shown and the variability indices for each period are shown above the boxplots (see text for details).

What is more likely, is that farmers will use tactical stock buying options to deal with the excess feed and it is probable that the gross margins resulting from this will not be as high as those modelled here; we again emphasise that the gross margins generated here are nominal ones that are based on the simple management rules used for the modelling. We discuss the issues of dealing with excess feed in Section 8.

Notwithstanding the issues raised above, applying the 1990 management system to the pasture growth curves projects for 2040 made little impact on the median gross margin of the enterprise. However, by using tactical adaptations for the average 2040 farm (outlined in Table 4.13), not only was the median gross margin increased substantially but the inter-annual variability in gross margin decreased as well.

Table 4.13. Main physical indicators and measures of reproductive efficiency of the Waikato farm modelled for 1990 and 2040 (high scenario) time periods. Output from Farmax.

Parameter	***Time period***	
	1990	***2040***
Mean pasture production[1]	8792	9849
Effective area, ha	782	782
Stocking, SU/ha	10.1	11.3
Sheep, opening numbers, head		
Ewes	3200	3025
Ewe hoggets	992	1015
Mixed hoggets	397	267
Rams	50	46
Total sheep	*4639*	*4353*
Cattle, opening numbers, head		
Cows	120	115
1-yr heifers	66	63
2-yr heifer	40	37
2-yr finishing heifers	26	26
1-yr steers	65	63
2-yr steers	54	51
Bulls	6	6
Total cattle	*377*	*361*
Performance indicators, ewes		
Lambing/weaning date	20 Sep, 19 Dec	05 Sep, 04 Dec
Pregnancy/lambing/weaning, %	159/134/126	174/152/147
Ewe efficiency[2], %	53.3	60.1
Performance indicators, cows		
Calving/weaning date	27 Sep, 25 Mar	27 Sep, 25 Feb
Pregnancy/calving/weaning, %	95/86/85	97/90/89
Cow efficiency[3], %	38.4	47.0

[1]Annual pasture production, kg DM/ha. [2]Total standardised lamb weaning weight (at 90 days, in kg) per kg ewe mated, expressed as a percentage. [3]Total standardised calf weaning weight (at 200 days, in kg) per kg cow mated, expressed as a percentage.

Based on DM intake, the current 1990 farm comprised an animal species ratio of 67:33 (sheep:cattle) including Perendale ewes and Angus x Hereford crossbred cows; the same species ratio was kept for the 2040 farming system. Ewe pregnancy, lambing and weaning percentages were increased from 159%, 134% and 126% respectively, to 174%, 152% and 147% respectively for the 1990 and 2040 farming systems, (Table 4.13); increasing overall ewe reproductive efficiency by 13%; corresponding ewe mating weights increased from 59.0 to 61.2 kg LW. Cow efficiencies were increased to an even greater extent: corresponding pregnancy, calving and weaning percentages were increased from 95%, 86%, and 85% respectively, to 97%, 90% and 89% respectively; increasing overall cow reproductive efficiency by 22%.

Table 4.14. Intake and animal performance of the Waikato farm modelled for the current and 2040 (high scenario) time periods. Output from Farmax.

Parameter	***Time period***	
	1990	***2040***
Pasture consumed (t DM ha^{-1})	5.63	6.45
Conserved feed consumed (t DM ha^{-1})	0.37	0.28
Total feed consumed (t DM ha^{-1})	6.00	6.72
Conserved feed/feed consumed, (%)	6.2	4.2
Feed conversion efficiency (FCE)[1]	27.3	23.9
Animal production, net growth (kg/ha)		
Sheep	103.6	142.6
Beef	68.3	85.0
Wool	31.7	32.4
Total	203.6	260.1

[1]FCE = kg DM consumed per kg net animal production.

Total meat and fibre production was greater for the 2040 farming system; animal production was increased by 28%, from greater total intakes and greater feed conversion efficiencies (Table 4.14). In addition, the 2040 farming system showed a greater reliance on home-grown feed but, unlike Southland and Hawke's Bay, the difference was only minor. As in Southland and Hawke's Bay the main changes to the farming system were to have an earlier lambing date as well as increased reproductive efficiency. In addition there was a change in the breeding to trading stock ratio: trading sheep and trading cattle consumed 6% and 7% of the feed in 1990 but this was doubled for both stock classes in 2040.

7 Analogue Results

7.1 Southland

The average pasture growth curve projection for Southland in 2040 under the high climate change scenario was compared against current growth rates at other sites in New Zealand (Figure 4.4). The best match in seasonality and total yield was for Masterton (Figure 4.18; other East Coast sites shown for comparison).

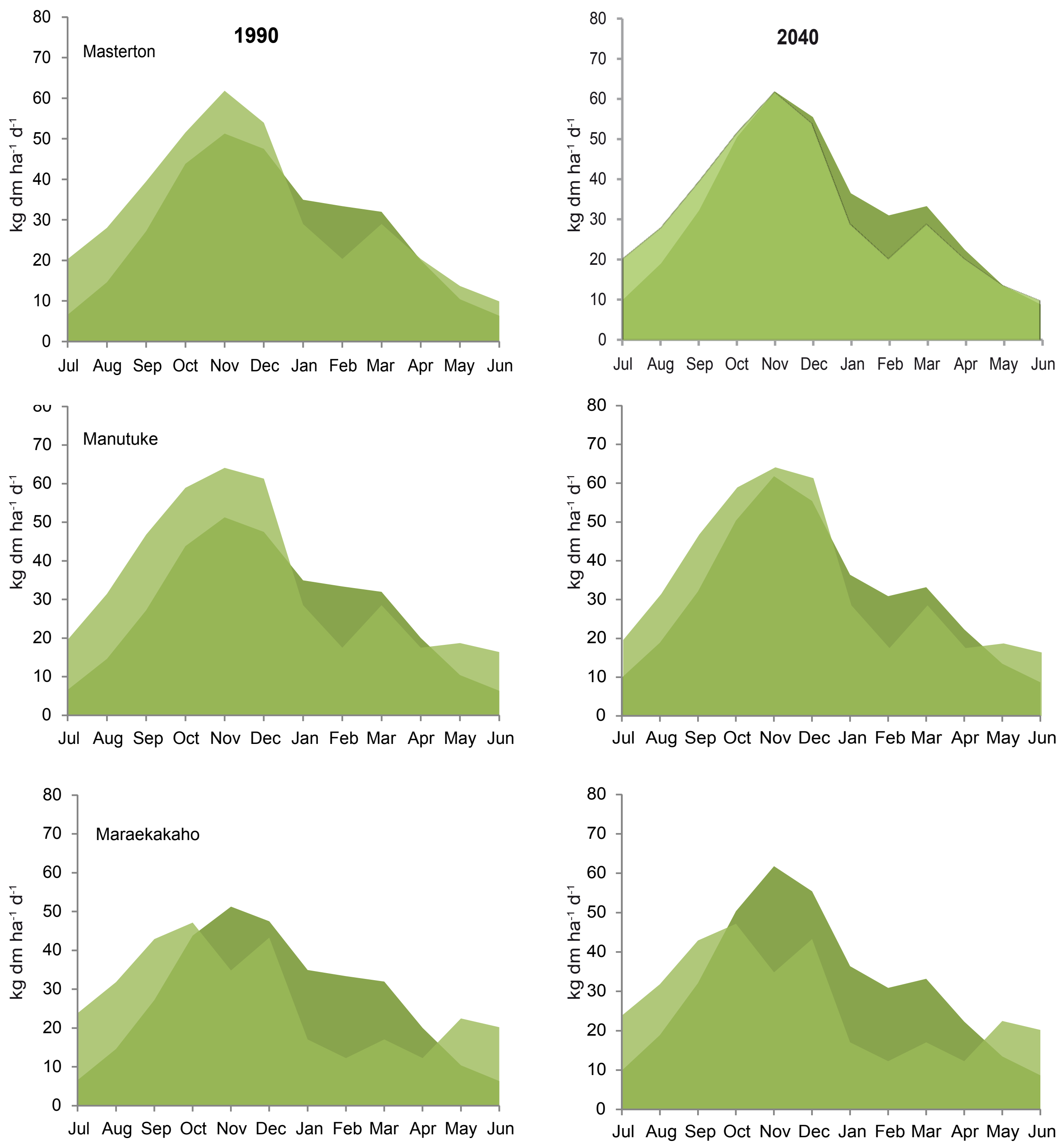


Figure 4.18. Pasture growth curves for a selection of potential analogue sites (shown as the lighter shade) compared to simulated growth curves for Southland in 1990 and 2040 (shown as the darker shade). The best match in seasonality and total yield was for Masterton; other sites shown for comparison.

7.2 Hawke's Bay

A comparison with other sites in New Zealand showed that the predicted pattern of pasture growth for Hawke's Bay in 2040 was unlike any other sites in the country. As there were no suitable analogues within New Zealand, we compared the projected growth curves with different sites in Australia using the database available at (http://www.makingmorefromsheep.com.au/turn-pasture-into-product/tool_8.2.htm) (accessed 20 April 2012). We tested 87 sites and found three sites that best fitted the projected 2040 Hawke's Bay curves. The pasture growth rates for the three Australian sites in New South Wales are shown by comparison with the Hawke's Bay predictions in Figure 4.19.

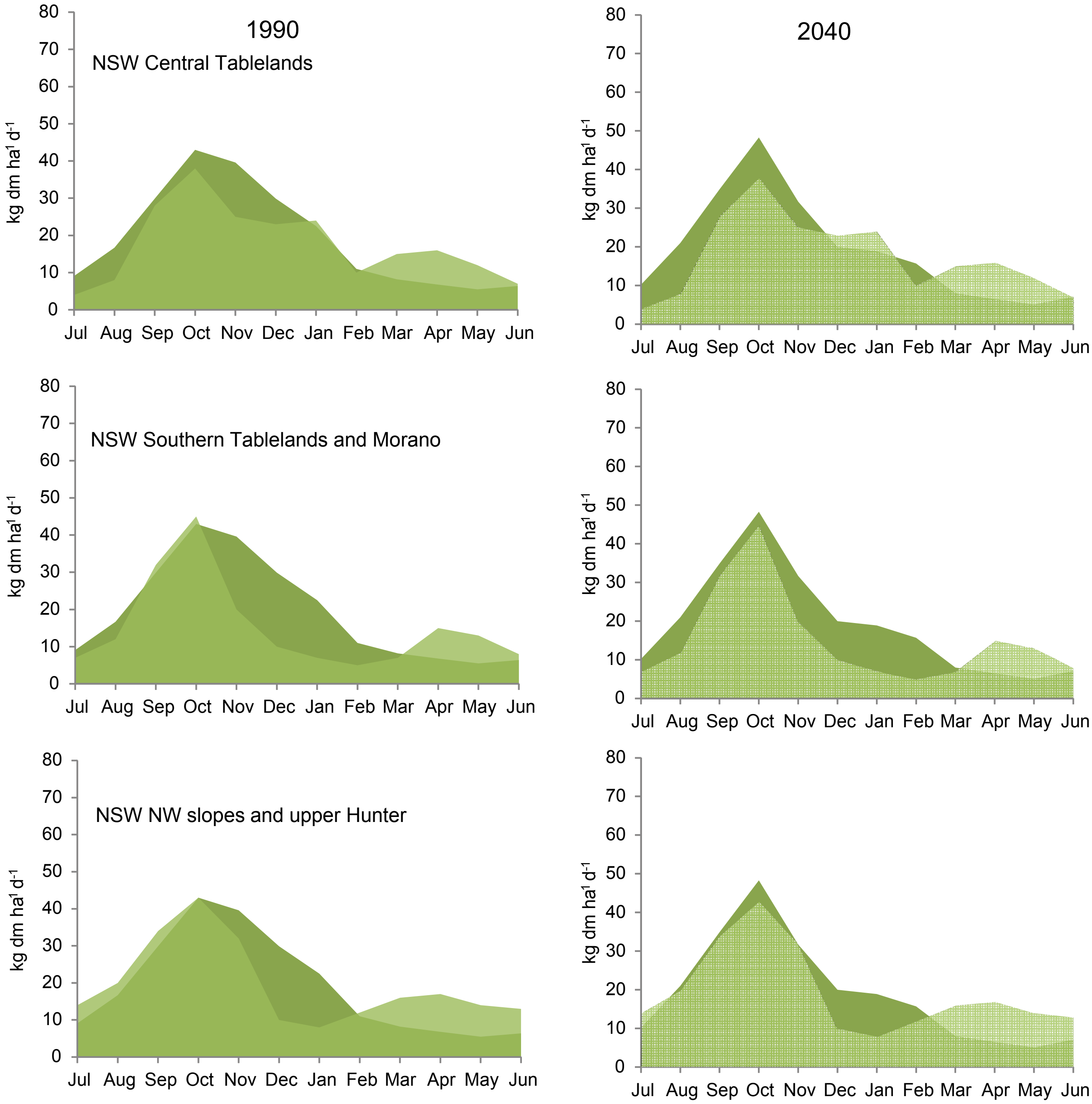


Figure 4.19. Pasture growth curves for three Australian New South Wales sites (shown as lighter shade) selected as analogues for Hawke's Bay simulations for 1990 and 2040 (shown as the darker shade).

7.3 Waikato

The only analogue for future pasture growth in Waikato was Masterton (Figure 4.20); interestingly this site was also the strongest analogue for Southland.

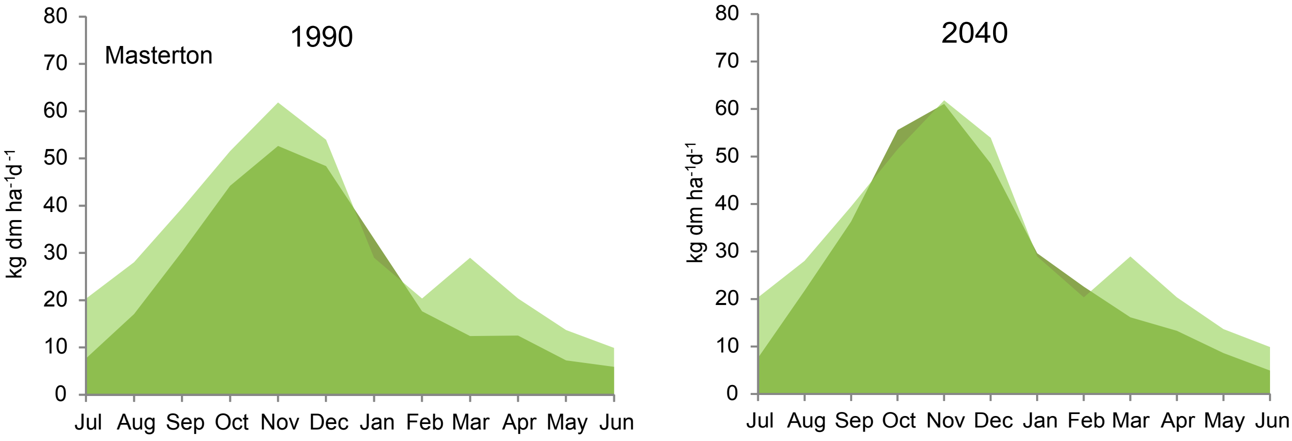


Figure 4.20. Pasture growth curves for Masterton (shown as the lighter shade), an analogue for projected growth in Waikato (darker shade).

7.4 The value of analogues – some caveats

It is important to stress that the analysis we conducted to identify analogues only considered the seasonal patterns of growth and the average annual yield. Variability in yield (annual or monthly) was not considered although this might prove to be an important difference between locations. We made an initial comparison of variability (Figure 4.21) between 2040 monthly average daily pasture growth rate values for Waikato and Southland and the current values for the Masterton site which had the highest similarity in total herbage production and seasonal pattern. Under the future climate there was little difference in variability between Masterton and Southland –strengthening the argument that Masterton is an appropriate analogue for Southland. However, the variability in Waikato, particularly during summer and autumn was much higher than in Masterton, raising some questions about the validity of this site as an analogue for Waikato. Introducing a variability metric would considerably strengthen the analogue analysis. Similar analyses could not be carried out for Hawke's Bay and its potential Australian analogues because we did not have data on the variability of monthly pasture growth rates for the analogues. In addition, the analogue comparison with Australia raises other caveats related to differences in the wider regional agricultural infrastructure that is in place (particularly how this affects the trading of stock and/or the importing of supplementary feed), factors that may heavily influence the choice of systems. A final caveat for the analogue methodology in general is that there is also the need to account for differences between the location under consideration and the analogue with regard to other environmental factors such as future levels of CO_2 and different soils types.

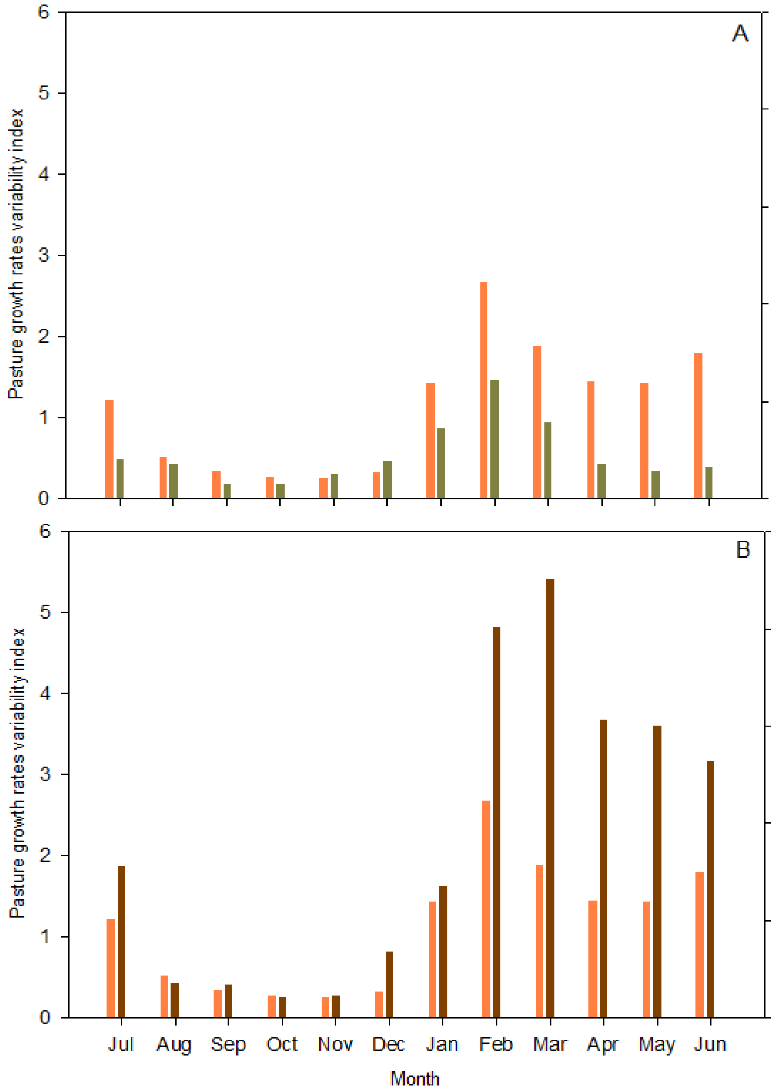


Figure 4.21. Comparisons of variability in monthly pasture production (variability index calculated for 20-year period). (A) At Masterton under current conditions (light bar) compared with Southland in 2040 under the high climate change scenario (darker bar). B) At Masterton under current conditions (lighter bar) compared with Waikato (darker bar) in 2040 under the high climate change scenario.

8 General discussion

The pasture growth projections in our report are consistent with previous work (Baars et al. 1990;Korte et al. 1990; Clark & Newton 2001) in that they show largely positive effects of climate change on pasture production. On average, annual pasture production increased by about 15% in Southland and Waikato and was unchanged in Hawke's Bay. Regional differences were also suggested by Wratt et al. (2008) but their projected changes in pasture production for 2030 (compared to a 1972–2002 average) in response to the Medium High scenario for the IPCC Third Assessment (see Wratt et al. 2008) for details) were +5% in Southland and Waikato and -50% in Hawke's Bay. Using a database (as opposed to a mechanistic) model (Baars et al. 1990) average changes in the Hawke's Bay of +36% and +67% were predicted by Korte et al. (1990). The values depended on the climate scenario used and for equivalent sites to our Waikato site were +12% and +19%, while for Southland they were +19% and +28%.

The most striking difference between current and future pasture growth in our simulations was the marked change in seasonality that was evident at all three sites. The shifts were primarily reduced summer-autumn growth and substantially increased spring growth. The seasonality projections in Korte et al (1990) were for reduced summer growth and increased spring growth but also suggested increased winter and autumn growth in contrast to our simulations which show a reduced autumn feed shoulder. Projected changes in Korte et al (1990) for Hawke's Bay were +59% (winter), +19% (spring), +6% (summer) and +67% (autumn); at a site equivalent to our Waikato, they were +72%, +16%, -14%, +49%; and for Southland they were +100%, +14%, -11%, +32%.

A second important result is the increased variability in inter-annual production that we identified in Hawke's Bay. This was also a general outcome of the simulations run by Korte et al. (1990). We are not aware of other studies that have explicitly calculated variability within and between years.

The translation of the pasture growth projections into financial returns showed that business-as-usual farm management would result in little change in gross margins in Waikato, a reduction in Hawke's Bay and an increase in Southland. Using a metric of percentage of national revenue generated compared to the 1972–2002 average, Wratt et al. (2008) projected values for 2030 of +6% in Southland, -1% in Waikato and -45% in Hawke's Bay. Korte et al. (1990) found little change in milk, meat and wool production if the same management was applied to future pasture growth predictions, which is in agreement with our conclusions.

When adaptations were put in place to tailor the system to the changed pasture growth, we found that gross margins could be achieved that exceeded those in the current system under current climate. The only reference point we have for this finding is Korte et al. (1990,) who showed increased animal production could be achieved if appropriate tactical adaptations were employed.

We now need to consider what appropriate adaptations might be and how readily these could be deployed. In Table 4.15 we have listed the adaptations we used in Farmax as well as some alternatives that were not used. We have also listed some of the groups involved in making decisions on the use of the adaptations.

Table 4.15. The impacts of projected climate change on hill country sheep and beef enterprises. The groups in bold type are those responsible for, or interested in, the adaptation. The adaptations in normal type are those used in our Farmax simulations. The underlined adaptations are potentially useful strategies that were not appraised in our study; and the italicised adaptations are those often cited as relevant but not considered as effective as those in normal script.

Impact	***Tactical***	***Strategic***	***Transformational***	***Comments on further work required***
Changed seasonality in pasture growth; in particular, increased spring growth and loss of autumn 'shoulder' in Southland and Hawke's Bay	Earlier lambing Faster lamb growth rates (through higher plane of nutrition) Increased flexibility in stock number **(land managers)** Increased feed conservation (hay) **(land managers)**	Faster lamb growth rates and increased reproductive efficiency (through selection and breeding) **(land managers and researchers)** Out of season lambing **(land managers, processors)** *Irrigation*		More regions need to be assessed
Increased variability in annual feed supply, particularly in Hawke's Bay	Increased flexibility in stock number **(land managers)** Purchase of supplementary feed and feed conservation **(land managers)**	Exchange of stock and feed between regions **(farming community, policy makers)** Increased unit size **(land managers, finance institutions)** Faster lamb growth rates and increased reproductive efficiency **(through selection and breeding)** (land managers and researchers) *Grow drought tolerant species*	Change location **(land managers; banks, regional councils, farming community)** Change whole farming system or land use type **(land managers)**	Need to assess whether climate change will alter the capacity to move stock and feed between regions

We will deal initially with some of the adaptations that we did not consider (i.e. the italicised adaptations in Table 4.15). The use of irrigation and drought tolerant species are often among the first adaptations mentioned for drought prone regions. There are of course some difficulties in introducing irrigation into hill country situations (even where some flat land is part of the farm) both for reasons of terrain and economics; consequently, irrigation is not a popular investment by farmers in dry-land areas (Gray et al. 2011). Drought tolerant species are also low on the priority list of farmers (Gray et al. 2011), as there is considerable uncertainty whether the costs of introduction and maintenance will be recovered in increased animal performance (Korte & Rhodes 1992; Korte & Rhodes 1993).

The strategies we did consider were driven by the need to manage substantial shifts in the seasonality of growth. Managing a magnified spring peak in feed supply required greater animal intake which was achieved by purchasing stock, increasing the reproductive efficiency of existing stock and increasing the amount fed, resulting in enhanced live weight gains. These are exaggerated responses of the way farmers currently deal with large seasonal imbalances driven by dry-land environments where farmers aim to have a high lambing percentage and high animal growth rates through the spring period (Gray et al. 2011). However, it is important to remember that our tactical adaptations were applied in an 'academic' exercise not in a real situation. While the individual changes we made in e.g. reproductive efficiency or live weight gain, do not fall outside those possible with current technology they do, for many of the adaptations, represent a high level of management. Consequently, the farm we have adapted for the future conditions really represents a farm managed to the highest level of achievement while the 1990 base farm was set up to represent an averagely managed farm. While it is important to note that while our analyses show that tactical adaptations may be sufficient to deal with climate change to 2040, it should be remembered that we are in a sense considering optimum adaptive capacity; there are many reasons why this might not be achieved on-farm. This is a particularly relevant issue for Hawke's Bay, where it required substantial manipulation of the adaptation options to bring the gross margin back to 1990 levels. We suggest this means that this region will become a more challenging place to farm. Fortunately, because farmers in this region are already faced with a highly variable climate, there is a high level of adaptive capacity. However, our finding that future pasture growth patterns in the Hawke's Bay moved outside anything similar in New Zealand does mean that this adaptive capacity will be thoroughly tested.

Some of our tactical adaptations involved buying and selling of supplementary feed as well as contract grazing to deal with feed surpluses and deficits. Movement of stock/feed between regions is a common solution to drought. Our simulations suggest more of these movements will be necessary in the future. However, we were not able to test the climate change effects across regions which would be necessary to determine if additional stock and feed were likely to be available under climate change. Any change in the synchronicity of regional droughts would be a severe constraint on inter-regional movements. We have included this adaptation in both tactical and strategic categories because while decisions about purchase will be made on-farm (tactical) the establishment of effective networks to move stock and feed requires strategic planning.

Increased unit size or alternative sites (see previous paragraph) are an obvious hedge against difficult local conditions. We did not explicitly explore this potential adaptation but our comments about possible interactions between slope and aspect and climate change (Section 5.2.5) are particularly relevant here as these different locations offer alternative environments that may provide useful flexibility in feed supply within the farm unit.

There are two limitations of the modelling that are important: (a) Farmax only runs on a single year basis; and (b) the biophysical pasture simulation model and the farm systems model were not linked dynamically. Because of (a), each year (July) started without stored hay and any feed shortages were covered by hay purchases. However, under real conditions, it may not be possible or economic to buy hay (because of increased demand in the region and higher prices) and farmers may choose to de-stock and, in extreme cases, sell capital or breeding stock. Not only would this have an impact on the current year's gross margin but it would also have one on the following year's one – because breeding stock would need to be bought when re-stocking the farm. The consequence of (b) was that changes in the amount of hay made did not feed through into changes in pasture growth. If excess feed is not kept under control, pasture quality suffers, resulting in reduced animal intake and performance.

We used pasture growth curve analogues to explore adaptation options. To do this, we used a catalogue of monthly pasture growth curves for a wide range of sites around New Zealand and compared them to the projected future growth curves for Southland, Hawke's Bay and the Waikato generated in this report. While analogues could be found for Southland and the Waikato, no current pasture growth curves could be found for Hawke's Bay. This means that under climate change, conditions for Hawke's Bay will be unlike any experienced in New Zealand at the moment. That led us to look further afield and the closest growth curve analogues that we found were located in Australia. Though the tactical adaptations used for Hawke's Bay were enough to cope with the projected pasture growth curves, it may be beneficial to examine farming systems in Australia in order to better adapt to future conditions (notwithstanding the caveats mentioned in Section 7.4).

There are a number of other potentially important issues that we did not examine that could impact pasture production and farm feasibility. These include the influence of climate change on weeds and the effects on pasture production. A recent review for MAF (Newton et al. 2011) showed that there is almost nothing known about the effects of climate change on most of the key weeds affecting New Zealand pastoral agriculture. In addition we know very little about the effects of climate change on N fixation – as the major source of N in hill country farms this could affect productivity. We also did not look at the effects of climate change on animal diseases, feed intake and heat stress. Some of these effects were described in Chapter 3 and may be relevant to sheep and beef cattle in hill country.

It must be stressed that the analyses we have carried out in this report in no way represent an assessment of the overall impacts of climate change on the sheep and beef sector. As a modelling exercise, it is extremely difficult to capture the huge variety and complexity of sheep and beef farming at farm, regional and national levels both in terms of the impacts of climate change as well as in the adaptations that could be used to minimise or take advantage of these effects. Rather, our analyses should be interpreted as snapshots of the impacts and potential adaptations of enterprises in three regions taken in isolation. In particular, no account has been made for changes in the supply and demand for feed and stock both within and between regions; and some of our adaptations depended on the assumption that there would be no physical or financial constraints on the buying and selling of feed and stock. Should these assumptions not be valid then our conclusions may be different.

We have shown that the generally positive outcome of climate change for pasture growth in New Zealand found in the literature (Korte et al. 1990; Clark & Newton 2001) is a reasonable conclusion from projected changes in average annual production. However, the likely changes in seasonality which we have shown, present substantial challenges to farm management in dealing with both excess feed and feed shortages. We have made an initial exploration of the extent of adaption that will be required to maintain or increase farm profitability; further progress will require feedback from land managers who will be faced with these new challenges.

9 Conclusions

Our biologically-based industries will inevitably be affected by a changing climate and increasing CO_2. The sheep and beef sector of New Zealand is diverse, and it is not possible to examine every farming approach at the level of detail required to understand adaptation fully. For the study presented here, three farm types were carefully selected: an extensive finishing-breeding operation in Southland, a hill country farm in Hawke's Bay and a 'hard' hill country farm in the Waikato. Together, these three farm types account for nearly a large proportion of New Zealand's sheep and beef stock units. The broad conclusions of our study are:

- Changes in average annual pasture production by 2040 were modest and largely positive.
- Changes in seasonality – primarily increased spring growth and reduced autumn and summer growth – were evident at all sites.
- Variability in annual and seasonal production increased in Hawke's Bay.
- 'Business-as-usual' management resulted in reduced (Hawke' Bay) unchanged (Waikato) or increased (Southland) gross margins in 2040.
- Adaptations to the 2040 conditions resulted in unchanged (Hawke's Bay) or increased (Waikato and Southland) gross margins.
- The adaptations used were not outside the biologically feasible options possible today – but did involve

changes in reproductive efficiency and animal growth rates that are only currently achieved on the highest performing farms.

- Hay making was an important tool for converting excess spring growth into dollars and for controlling pasture quality. The practicality of this adaptation on the scale required would need to be assessed further.
- There will probably be increased demand for stock and feed movement between farms and regions.
- Analogues can provide useful information on future opportunities and constraints.
- Feedback from land managers would be an important next step in evaluating the implications of our results.

10 References

Baars, J.; Radcliffe, J.; Rollo, M. (1990). Climatic change effects on seasonal patterns of pasture production in New Zealand. ***Proceedings of the New Zealand Grassland Association (New Zealand)*** 51**:**43–46.

Beef+LambNZ. (2011). Compendium of New Zealand Farm Facts. Wellington, 26 p.

Clark, H.; Newton, P.C.D. (2001). The sensitivity of pasture yields to climate change. ***In***: R.A., Warrick A.B.M.; G.J. Kenny; B.D. Campbell; H. Clark; P. Austin; C.G. Cloughley; T.L. Flux; A. Hall; J.J. Harman; P.D. Jamieson; N.D.Mitchell; P.C.D. Newton; A. Parshotam; A.S. Porteous; M.J. Salinger; C.S.Thompson; K. Tate; Wei Ye (ed.). The CLIMPACTS Synthesis Report: An Assessment of the Effects of Climate Change and Variation in New Zealand Using the CLIMPACTS System pp. 70-77. International Global Change Institute, University of Waikato.

Cornforth, I.S.; Sinclair, A.G. (1984). Fertiliser and lime recommendations for pastures and crops in New Zealand. 2nd revised edition. Ministry of Agriculture and Fisheries, Wellington, New Zealand, 76 p.

Denman, K.L.; Brasseur, G.; Chidthaisong, A.; Ciais, P.; Cox, P.M.; Dickinson, R.E.; Hauglustaine, D.; Heinze, C.; Holland, E.; Jacob, D. (2007). Couplings Between Changes in the Climate System and Biogeochemistry. ***In***: Solomon, S.; Qin, D.; Manning, M.; Chen, Z.; Marquis, M.; Averyt, K.B.; Tignor, M.; Miller, H.L. (eds). Climate Change 2007: The Physical Science Basis; pp. 499–587. Cambridge University Press, Cambridge, UK.

Dolman, A.; van der Werf, G.; van der Molen, M.; Ganssen, G.; Erisman, J.W.; Strengers, B. (2010). A Carbon Cycle Science Update Since IPCC AR-4. ***AMBIO: A Journal of the Human Environment*** 39: 402–412. <http://dx.doi.org/10.1007/s13280-010-0083-7>

Edwards, G.; Clark, H.; Newton, P.C.D. (2001). The effects of elevated CO_2 on seed production and seedling recruitment in a sheep-grazed pasture. ***Oecologia*** 127: 383–394. <http://dx.doi.org/10.1007/s004420000602>

Gentile, R.; Dodd, M.; Lieffering, M.; Brock, S.C.; Theobald, P.W.; Newton, P.C.D. (2012). Effects of long-term exposure to enriched CO_2 on the nutrient-supplying capacity of a grassland soil. ***Biology and Fertility of Soils*** 48: 357–362.

Ghannoum, O.; Searson, J.; Conroy, J.P. (2007). Nutrient and water demands of plants under global change. ***In***: Newton, P.C.D.; Carran, R.A.; Edwards, G.R.; Niklaus, P.A. (eds). Agroeosystems in a Changing Climate; pp. 53–83. CRC Press; New York.

Gray, D.I.; Reid, J.L.; Horne, D.J. (2011). The management of risk in a dryland environment. ***Proceedings New Zealand Grassland Association*** 73: 13–22.

Howden, S.M.; Stokes, C.J. (2010). Introduction. ***In***: Stokes, C.; Howden, S. (eds). Adapting Agriculture to Climate Change: Preparing Australian Agriculture; Forestry and Fisheries for the Future, pp. 1–11. CSIRO Publishing, Collingwood, Australia.

Johnson, I.R.; Chapman, D.F.; Snow, V.O.; Eckard, R.J.; Parsons, A.J.; Lambert, M.G.; Cullen, B.R. (2008). DairyMod and EcoMod: biophysical pasture-simulation models for Australia and New Zealand. ***Australian Journal of Experimental Agriculture*** 48: 621–631. <http://dx.doi.org/doi:10.1071/EA07133>

Johnson, I.R.; Lodge, M.; White, R.E. (2003). The sustainable grazing systems pasture model: description, philosophy and adaptation to the SGS national experiment. ***Australian Journal of Experimental Agriculture*** 43: 711–728.

Keating, B.A.; Carberry, P.S.; Hammer, G.L.; Probert, M.E.; Robertson, M.J.; Holzworth, D.; Huth, N.I.; Hargreaves, J.N.G.; Meinke, H.; Hochman, Z.; McLean, G.; Verburg, K.; Snow, V.; Dimes, J.P.; Silburn, M.; Wang, E.; Brown, S.; Bristow, K.L.; Asseng, S.; Chapman, S.; McCown, R.L.; Freebairn, D.M.; Smith, C.J. (2003). An overview of APSIM, a model designed for farming systems simulation. ***European Journal of Agronomy*** 18: 267–288.

Korte, C.J.; Newton, P.C.D.; Baars, J.A.; Rollo, M.D.; Foote, B.; Martin, R.B.; Baird, D.B. (1990). Predictions of the impacts of climate change on pasture and animal production in New Zealand, 61 p.

Korte, C.; Rhodes, A.P. (1992). Computer modelling of drought tolerant farm systems. ***Report to the New Zealand Meat Producers Board. Meat Research and Development Council project 91 MT 30/3.1***.

Korte, C.J.; Rhodes, A.P. (1993). Economics of drought-tolerant pastures for cattle finishing on Hawkes Bay and Wairarapa hill country farms. ***Proceedings of the New Zealand Grassland Association*** 55: 45–49.

Lemaire, G.; Salette, J. (1984). Relation entre dynamique de croissance et dynamique de prelevement d'azote pour un peuplement de graminees fourageres I. Edude de l'effet du milieu. ***Agronomie*** 4: 423–430.

Lewin, K.F.; Hendrey, G.R.; Nagy, J.; LaMorte, R.L. (1994). Design and application of a free-air carbon dioxide enrichment facility. *Agricultural and Forest Meteorology* 70: 15–29. <http://dx.doi.org/10.1016/0168-1923(94).90045-0>

Li, F.Y.; Snow, V.O.; Holzworth, D.P. (2011). Modelling the seasonal and geographical pattern of pasture production in New Zealand. ***New Zealand Journal of Agricultural Research*** 54: 331–352.

Lin, L.I. (1989). A concordance correlation coefficient to evaluate reproducibility. ***Biometrics*** 45: 255–268.

Lin, L.I. (2000). A note on the concordance correlation coefficient. ***Biometrics*** 56: 324–325.

Lobell, D.B.; Field, C.B. (2008). Estimation of the carbon dioxide (CO_2) fertilization effect using growth rate anomalies of CO_2 and crop yields since 1961. ***Global Change Biology*** 14: 39–45.

McBride, G.B. (2005). A proposal for strength-of -agreement criteria for Lin's concordance correlation coefficient. NIWA client report HAM2005-062 for the Ministry of Health; NIWA project MOH05201, 10 p.

McKeon, G.M.; Stone, G.S.; Syktus, J.I.; Carter, J.O.; Flood, N.R.; Ahrens, D.G., Bruget, D.N.; Chilcott, C.R.; Cobon, D.H.; Cowley, R.A.; Crimp, S.J.; Fraser, G.W.; Howden, S.M.; Johnston, P.W.; Ryan, J.G.; Stokes, C.J.; Day, K.A. (2009). Climate change impacts on northern Australian rangeland livestock carrying capacity: A review of issues. ***Rangeland Journal*** 31: 1–29.

Medlyn, B.E.; Duursma, R.A.; Zeppel, M.J.B. (2011). Forest productivity under climate change: A checklist for evaluating model studies. ***Wiley Interdisciplinary Reviews: Climate Change*** 2: 332–355. <http://dx.doi.org/10.1002/wcc.108>

MPI (2012a). Farm monitoring report 2011 – pastoral monitoring: Central North Island Hill Country sheep and beef. http://www.mpi.govt.nz/news-resources/publications.aspx?title=Central%20North%20Island%20hill%20country%20sheep%20and%20beef (accessed May 24th 2012).

MPI (2012b). Farm monitoring report 2011 – pastoral monitoring: Hawke's Bay/Wairarapa sheep and beef. http://www.mpi.govt.nz/news-resources/publications.aspx?title=Bay/Wairarapa (accessed May 24th 2012).

MPI (2012c). Farm monitoring report 2011 – pastoral monitoring: Southland/South Otago Hill Country sheep and beef . http://www.mpi.govt.nz/news-resources/publications.aspx?title=Southland/South%20Otago%20hill%20country%20sheep%20and%20beef (accessed May 24th 2012).

MPI (2012d). Pastoral monitoring reports: methodology and calculations used in the models' . http://www.mpi.govt.nz/news-resources/statistics-forecasting/statistical-publications/methodology-and-calculations-used-in-the-models.aspx (accessed May 24th 2012).

Muller, C. (2011). Agriculture: Harvesting from uncertainties. Nature Climate Change 1: 253–254.

Newton, P.C.D.; Allard, V.; Carran, R.A.; Lieffering, M. (2006). Impacts of elevated CO_2 on a grassland grazed by sheep: the New Zealand FACE experiment. ***In***: Nosberger, J., Long, S.P., Norby, R.J., Stitt, M., Hendrey, G.R., Blum, H. (eds). Managed Ecosystems and CO_2: Case Studies, Processes, and Perspectives, pp. 157–171. Springer-Verlag, Berlin.

Newton, P.C.D.; Carran, R.A.; Edwards, G.R.; Niklaus, P.A. (2007). Introduction. ***In***: Newton, P.C.D.; Carran, R.A.; Edwards, G.R.; Niklaus, P.A. (eds). Agroecosystems in a Changing Climate , pp. 1–8. CRC Press, New York.

Newton, P.C.D.; Lieffering, M.; Bowatte, W.M.S.D.; Brock, S.C.; Hunt, C.L.; Theobald, P.W.; Ross, D.J. (2010). The rate of progression and stability of progressive nitrogen limitation at elevated atmospheric CO_2 in a grazed grassland over 11 years of Free Air CO_2 enrichment. ***Plant and Soil*** 336: 433–441. <http://dx.doi.org/10.1007/s11104-010-0493-0>

Newton, P.C.D.; Lieffering, M.; Kirschbaum, M.U.F.; Brock, S.C. (2011). Impacts of elevated carbon dioxide on pasture, forestry and weeds: a review. Report to MAF on SLMACC contract C10X1007, 97 p.

NIWA (2011). Climate change scenarios for New Zealand. http://www.niwa.co.nz/our-science/climate/information-and-resources/clivar/scenarios (accessed 6 June 2012).

Pannell, D.J. (2010). Policy for climate change adaptation in agriculture. Presented at the Annual Conference of the Australian Agricultural and Resource Economics Society. Adelaide, Australia 2010. http://dpannell.fnas.uwa.edu.au/dp1003.htm

Payne, R.W.; Murray, D.A.; Harding, S.A.; Baird, D.B.; Soutar, D.M. (2010). An Introduction to GenStat for Windows (13th Edition). VSN International, Hemel Hempstead, UK.

Pinsonneault, A.J.; Matthews, H.D.; Kothavala, Z. (2011). Benchmarking climate-carbon model simulations against forest FACE data. ***Atmosphere-Ocean*** 49: 41–50.

Ramírez-Villegas, J.; Lau, C.; Köhler, A.-K.; Signer, J.; Jarvis, A.; Arnell, N.; Osborne, T.; Hooker, J. (2011). Climate analogues: finding tomorrow's agriculture today. ***Working Paper No. 12. Cali, Colombia: CGIAR Research Program on Climate Change, Agriculture and Food Security (CAFS).*** Available online at:www.ccafs.cgiar.org.

Ross, D.J.; Newton, P.C.D.; Tate, K.R. (2004). Elevated CO_2 effects on herbage production and soil carbon and nitrogen pools and mineralization in a species-rich, grazed pasture on a seasonally dry sand. ***Plant and Soil*** 260: 183–196.

Rotter, R.P.; Carter, T.R.; Olesen, J.E.; Porter, J.R. (2011). Crop-climate models need an overhaul. ***Nature Climate Change*** 1: 175–177.

Sage, R.F.; Kubien, D.S. (2003). Quo vadis C4? An ecophysiological perspective on global change and the future of C4 plants. ***Photosynthesis Research*** 77: 209–225.

Thornley, J.H.M.; Cannell, M.G.R. (1997). Temperate grassland responses to climate change: an analysis using the Hurley pasture model. ***Annals of Botany*** 80: 201–221.

Von Caemmerer, S.; Ghannoum, O.; Conroy, J.P.; Clark, H.; Newton, P.C.D. (2001). Photosynthetic responses of temperate species to free air CO_2 enrichment (FACE) in a grazed New Zealand pasture. ***Functional Plant Biology*** 28: 439–450.

Willows, R.I.; Connell, R.K.E. (2003). Climate adaptation: risk, uncertainty and decision-making. UKCIP Technical Report. UKCIP, Oxford, 154 p.

Wratt, D.; Mullan, A.B.; Tait, A.; Woods, R.; Baisden, T.; Giltrap, D.; Hendy, J.; Stroombergen, A. (2008). Costs and benefits of climate change and adaptation to climate change in New Zealand agriculture: what do we know so far? Contract report by the EcoClimate Consortium: Integrated Research on the Economics of Climate Change Impacts Adaptation and Mitigation. Wellington: Ministry of Agriculture and Forestry, 112 p.

Chapter 5. Broad acre Cropping

Adapting broad acre farming to climate change

Edmar I. Teixeira	Plant & Food Research
Hamish E. Brown	Plant & Food Research
Andrew L. Fletcher	Plant & Food Research
Guillermo Hernandez-Ramirez	Plant & Food Research
Afshin Soltani	Plant & Food Research
Suvi Viljanen-Rollinson	Plant & Food Research
Abie Horrocks	Plant & Food Research
Paul Johnstone	Plant & Food Research