The CLIMPACTS Synthesis Report

An Assessment of the Effects of Climate Change and Variation in New Zealand Using the CLIMPACTS System

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In the late 1980s, New Zealand undertook the first national assessment of climate change and its possible impacts on the country.[1] The landmark report, reflecting the judgement of scores of national experts, called for greater efforts in building the national research capacity in order to better quantify the range of impacts that could occur in New Zealand from climate change and variability. In response, the collaborative CLIMPACTS Programme was established to provide this capacity. Ten years on from the first national assessment, the present *synthesis* offers some results from, as well as a demonstration of, the capacity developed by the CLIMPACTS Programme[2].

CLIMPACTS – both a Programme and a Model for New Zealand

What is the effect of climate variability and change on the New Zealand environment?

This is the central question that the CLIMPACTS Programme set out to answer when it began in 1993 with funding from the New Zealand Foundation for Research Science and Technology. From the outset, the CLIMPACTS Programme was designed to be collaborative and interdisciplinary – *collaborative* because it involves a team comprised of Universities and Crown Research Institutes, and *interdisciplinary* because the team members work together and blend their scientific expertise (see Figure 1).

The central focus — the "glue" — that has brought the team together has been the development of the CLIMPACTS model, an integrated system of linked models spanning global, national and local scales (see Chapter 1[3]). The purpose of CLIMPACTS, the model, is to provide a tool that helps to answer questions about

[1] Ministry for the Environment, 1990: *Climatic Change: Impacts on New Zealand, Implications for the Environment, Economy, and Society,* Ministry for the Environment, Wellington; Another milestone report was the publication of the proceedings of *Greenhouse 94* conference (W.J. Bouma, G.I. Pearman and M.R. Manning [eds.], 1996: *Greenhouse: Coping with Climate Change*. CSIRO Publishing, Collingwood, VIC, Australia).

[2] The full CLIMPACTS Assessment Report, from which the present *synthesis* is derived is: Warrick, R.A., Kenny, G.J. and Harman, J.J. (eds) 2001: *The Effects of Climate Change and Variation in New Zealand: An Assessment Using the CLIMPACTS System.* International Global Change Institute (IGCI), University of Waikato.

[3] Chapter citations in this *synthesis* refer to chapters in the full CLIMPACTS Assessment Report.

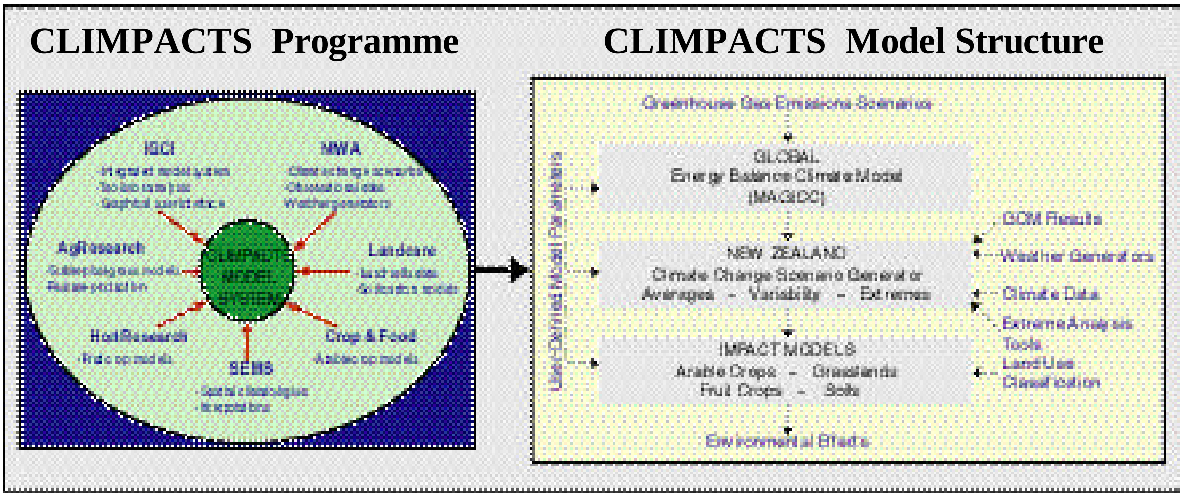

Figure 1: The CLIMPACTS collaborative team (left) and the structure of the CLIMPACTS model. The CLIMPACTS Programme is funded by the New Zealand Foundation for Research, Science and Technology.

present climate variability and future climate changes and their biophysical effects. In terms of impacts, the CLIMPACTS modelling has, thus far, concentrated on the land production sectors – pastoral agriculture, horticulture, arable crops and soils.

The purpose of the present document is to provide a summary report from the CLIMPACTS Programme on climate change and its effects on New Zealand. The chapters and their contents are not comprehensive. Rather, they are focussed on a specific set of questions, which conform to the particular expertise of the CLIMPACTS Programme members and which employ a limited set of the wide range of tools available within the CLIMPACTS Model (see Chapter 1 for an overview of the full model capabilities). Other important areas such as forests, indigenous ecosystems and pests and diseases are not yet covered.

Climate Change in the Global Context

Global climate change is the overall context in which this report is set. Since the late 1980s, there has been an enormous effort by the international scientific community, particularly through the Intergovernmental Panel on Climate Change (IPCC), to assess the extent to which increasing atmospheric concentrations of greenhouse gases (GHG) – especially carbon dioxide, methane, nitrous oxide and the halocarbons and related compounds – are changing the global climate. The major conclusions of the IPCC have remained relatively unchanged over the various assessments. In summary, there is **little doubt** that:

- *The atmospheric concentrations of carbon dioxide (CO_2) and other GHGs have increased.* In 2000, the concentration of CO_2 was 368 parts per million (ppm), about 31% higher than the pre-industrial concentration. Most of that increase has occurred since about 1970. Methane (CH_4) has more than doubled its pre-industrial concentration.

- *The increases in GHG concentrations are due primarily to human activities.* There is little doubt that the rise in CO_2 concentration is due largely to fossil fuel burning and changes in land cover. The annual emission rate of carbon into the atmosphere from fossil fuel burning averaged 6.3 billion tonnes of carbon during the 1990s, about three times the rate of the 1950s.

- *Carbon dioxide will continue to increase in concentration for many decades.* Due to its long "lifetime" in the atmosphere, CO_2 will continue to increase, even if international policies are successful in stabilising global CO_2 emissions.

- *The net effect of the increase in GHG concentrations is a "positive radiative forcing".* That is to say, GHG absorb some of the long-wave radiation emitted from the Earth and prevent its loss to space, thus causing the average surface temperature of the globe to rise.

- *Over the last century, the global-mean temperature has increased*. The world has, on average, warmed by about 0.6°C. It is, however, not precisely clear how much of this warming is due to changes in GHG concentrations and how much is due to solar variations and other sources of natural variability.

- *The world should warm in future as a consequence of greenhouse gases*. There is not a single global climate model that shows global cooling – all model results indicate warming.

There remain, however, **large uncertainties** that have major implications for both the world and for New Zealand, including:

- *The future emission rates of GHGs.* In this regard, the uncertainties are not primarily about the lack of scientific understanding, but about future changes in population, technologies, development pathways, international and national policies and so on. These are factors that involve human behaviour and can be guided by human decision-making.

- *The value of the "climate sensitivity".* The climate sensitivity refers to how sensitive the global climate is to increases in GHGs. Conventionally, it is indicated by the equilibrium change in global-mean temperature for an equivalent doubling of atmospheric CO_2. Currently, the value of the climate sensitivity is estimated to lie in the range of 1.5-4.5°C for a CO_2 doubling. The uncertainties in the value are due to the imprecise knowledge of the "feedbacks" in the climate system – for example, changes in cloudiness, snow and ice cover, ocean circulation, water vapour – that can enhance or reduce the rate of global warming.

- *The rates of global warming*. The two uncertainties noted above make the projected rate of global warming highly uncertain. Currently, IPCC estimates that the world could be 1.4 to 5.8 degrees celsius warmer than today by the year 2100.

- *The regional changes in climate.* Very complex General Circulation Models (GCMs) are used in GHG experiments to make projections of changes in temperature, precipitation and other climate variables at regional scales. However, as a general rule, the uncertainties increase as one moves from global average results to regional and local detail. Thus, the regional patterns of climate change, particularly for precipitation, may look very different between GCMs. This is especially true for small countries like New Zealand which get "lost" in the relatively coarse spatial resolution of the GCMs and which are difficult to "pinpoint" in the relatively broad regional patterns of change.

These four major uncertainties severely limit the ability of scientists to predict precisely how climate will change in a country like New Zealand in the future. In order to get some perspective on the future, we have to know something about the factors that affect climate in the past.

Has the climate of New Zealand changed?

One answer to this question is that the New Zealand climate continually changes — greenhouse gases or not. As described in Chapter 2, there are identifiable patterns in climate that occur, which are related to the atmospheric circulation around New Zealand and the consequent variations in the airflow direction. These circulation patterns are, in turn, associated with El Niño and La Niña years, which occur on a timescale of 1-3 years, and the Interdecadal Pacific Oscillation (IPO), which oscillates between "negative" and "positive" phases on a timescale of about two decades.

Table 1 summarises these sources of natural patterns of climate change in New Zealand. Very generally, a more westerly and southwesterly airflow over New Zealand, such as occurs during El Niño, brings overall cooler temperatures to New Zealand with increases in precipitation in the south and west and precipitation decreases in the north and east. With a more easterly and northeasterly airflow, the climate changes are approximately the reverse. For example, Figure 2 shows typical patterns of annual average changes in temperature and rainfall over the North Island during El Niño and La Niña years. One should bear in mind that these patterns are *very generalised* and that many "exceptions to the rule" can be found.

On a longer timescale, is New Zealand experiencing a warming trend? And, if so, is it due to global increases in greenhouse gas concentrations?

Table 1: Sources of natural variations in New Zealand's climate

Interdecadal Pacific Oscillation (IPO)		
Time Period	**Phase**	**Increased Circulation/Airflow From:**
1922-1945	Positive	[1]South to southwest
1946-1977	Negative	[2]East to northeast
1978-1998	Positive	[1]West to southwest
El Niño Southern Oscillation (ENSO)		
El Niño		[1]West to southwest
La Niña		[2]East to northeast
[1]Generally cooler with drier conditions especially in the north and east		
[2]Generally warmer with wetter conditions especially in the north and east		

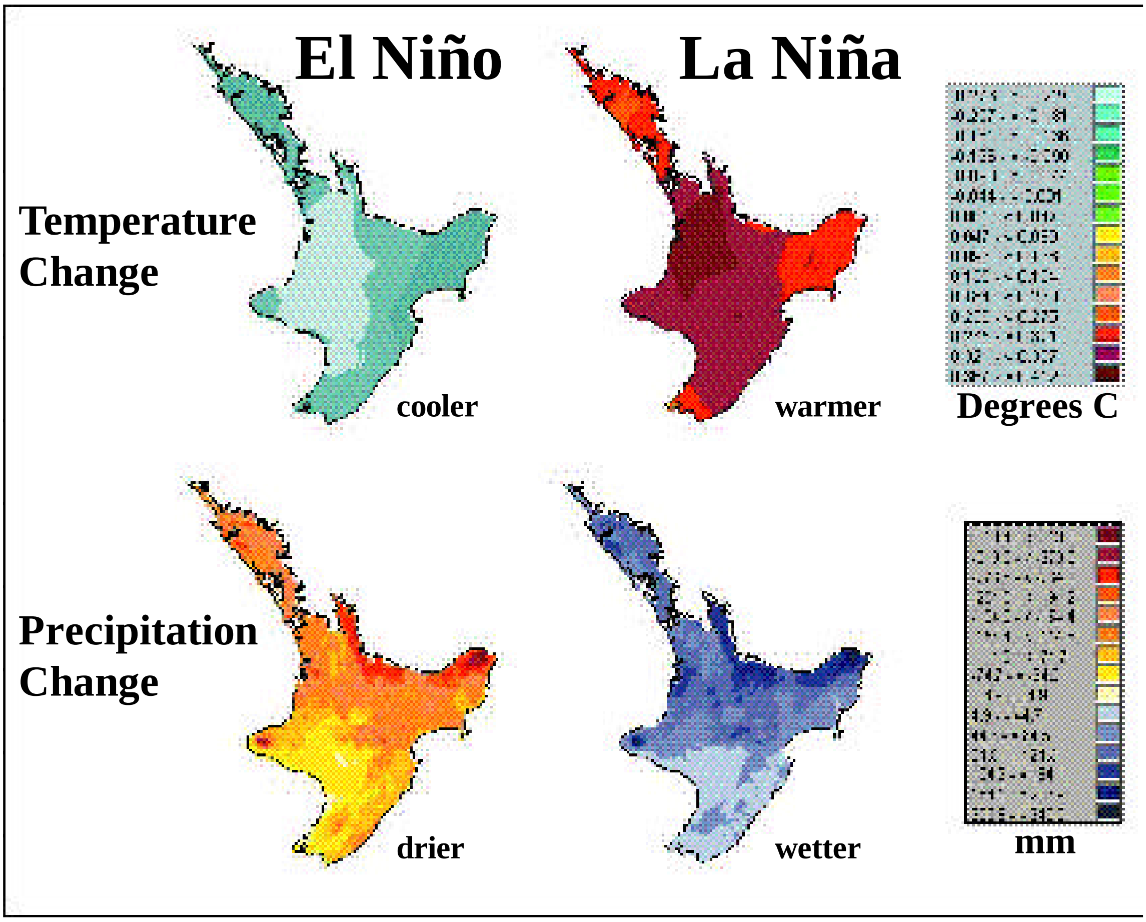

Figure 2: Typical patterns of North Island annual temperature and precipitation changes associated with El Niño and La Niña, as compared to average conditions.

Figure 3, as presented in Chapter 2, displays the annual mean surface temperature changes from 1855 to 1999 (shown as departures from the 1961-90 average). For comparison, the global temperature record over the same time period is also shown. The two records have some features in common, including a warming trend during the first half of the 20th century, followed by a period of no discernible trend until the mid-1970s. Thereafter, the global record shows a resumption of a

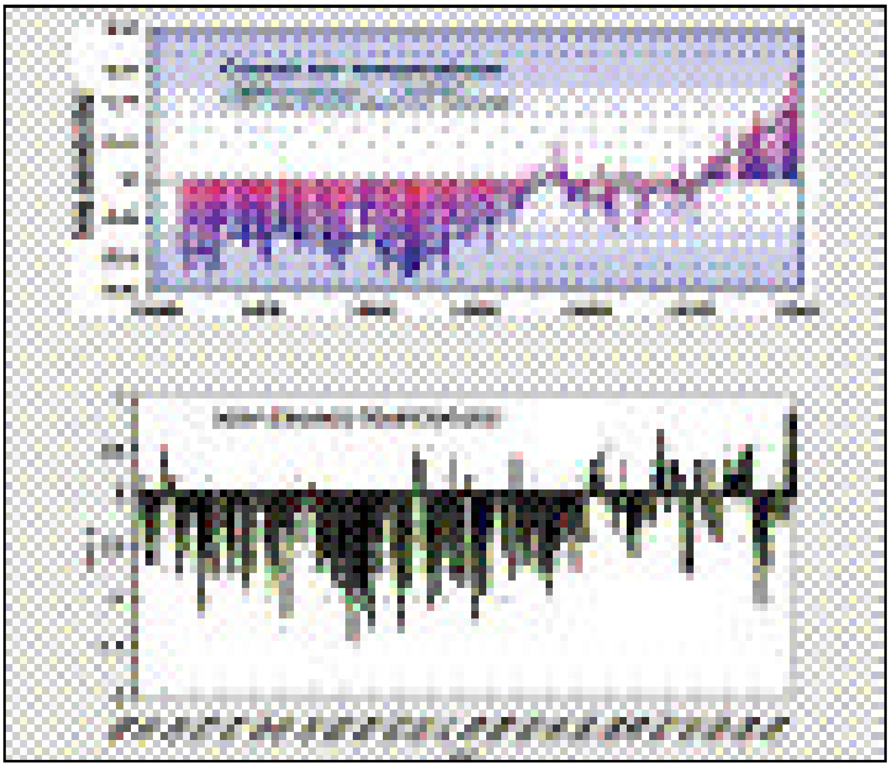

Figure 3: Global (top) and New Zealand (bottom) mean-annual temperature records, 1855-1999. The values are expressed as changes from the 1961-90 average.

strong warming trend, although New Zealand's record is punctuated by several cool departures in the early 1990s, owing to a prolonged El Niño episode and, in part, to the cooling effect of the Mt Pinatubo volcanic eruption of 1991. Both records share the warmest year (1998). Overall, Chapter 2 concludes that, since 1940, New Zealand has been experiencing a warming trend of between 0.1 and 0.2°C per decade.

It is difficult to say for certain whether the New Zealand warming trend is due to GHG increases. Certainly, the similarities between the global and national records suggest that there are some globally-coherent factors that are influencing New Zealand's climate. The increasing concentration of GHGs certainly must be a strong contender as one of these factors. However, at this stage, it is not possible to unravel the precise mix of local, regional and global causes. At best, we can be assured that as New Zealand experiences GHG-induced climate warming in the future, it will occur in concert with the natural inter-annual and inter-decadal variations that we have experienced in the past.

How might New Zealand's climate change in the future?

It is because of the major uncertainties in climate modelling, noted above, that scientists are unable to predict exactly how the climate of New Zealand *will* change in the future. Despite the uncertainties, however, there is still a need to anticipate the possible impacts of climate change on New Zealand. For this purpose, the approach of CLIMPACTS is to produce *scenarios* – or "what if" projections – of how, within the bounds of current scientific understanding, climate *could* change in New Zealand.

For the purposes of the present assessment, four scenarios were created using the CLIMPACTS model. These scenarios reflect the combined uncertainties in future global GHG emission rates, the value of the climate sensitivity, and differences between regional patterns of change from GCMs (refer to above discussion). An example of one such scenario, applied at the national scale to annual-mean temperature, is shown in Figure 4.

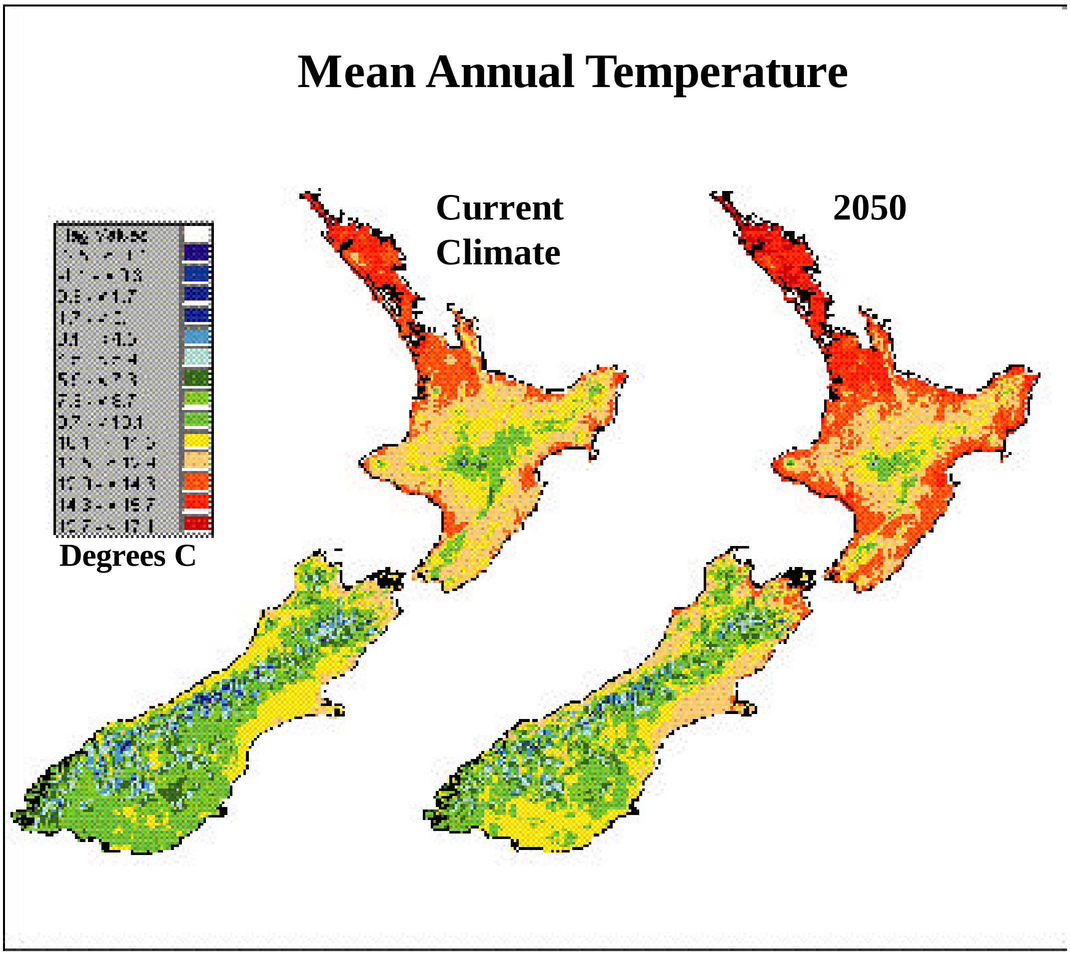

Figure 4: A scenario of change in mean annual temperature in New Zealand. This 2050 scenario assumes mid-range assumptions for future GHG emissions (SRES A1) and the climate sensitivity (2.5 deg C), and uses the downscaled pattern from the CSIRO9 general circulation model.

From developing a range of such future scenarios, the following conclusions can be reached with a reasonable degree of confidence:

- The ambient concentrations of carbon dioxide and other GHGs will be higher in New Zealand than today;
- As a consequence of increasing atmospheric concentrations of GHGs, the whole of New Zealand should become, on average, warmer. No model shows cooling for New Zealand;
- On average, the rate of warming throughout New Zealand will probably be slightly less than the rate of global warming, due to our geographic location with its moderating maritime influence and its proximity to the high latitude southern ocean where warming is very slow because of ocean overturning;
- Throughout New Zealand the number of frost days should decline and the number of extreme warm days should increase.

Unfortunately, nothing definite can be said about future changes in precipitation. Overall, GCMs disagree on the direction, amounts and spatial patterns of change as they pertain to our region (although both the two recent transient GCM results used as scenarios for the present CLIMPACTS assessment indicate wetter conditions in the west of the country and drier in the east). Similarly, little can be said about changes in storminess or windiness.

How might the growing environments of New Zealand be affected by climate change?

One of the important climatic issues faced at the regional scale in New Zealand is that of **drought**. In some regions of New Zealand extreme soil moisture deficits are a constant risk to agriculture. How might climate change affect regional droughts?

In this volume, regional analyses were carried out (Chapter 8) using CLIMPACTS tools to determine how future change in mean climate could alter soil moisture variations. One analysis focussed on the severe summer drought that occurred in Canterbury during 1997/98. In this case, if that particular Canterbury drought event were to recur in 2100, the climate change scenarios would intensify the severity of the soil moisture deficits and widen the area affected by drought (Figure 5). As discussed in Chapter 8, even without changes in precipitation, warmer conditions will increase evaporation of soil moisture and consequently the risk or severity of drought. In general, unless offset by increasing rainfall, future warming could be expected to worsen regional droughts.

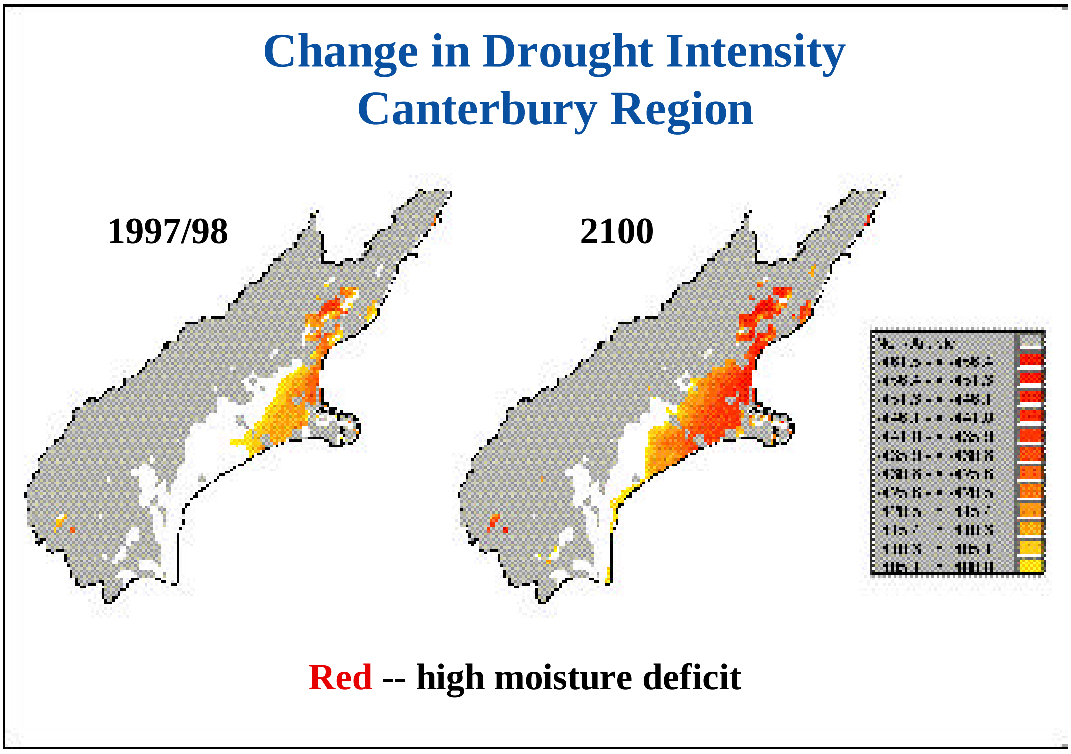

Figure 5: Change in severity of soil moisture deficits in Canterbury. The left panel shows the aerial extent and intensity (measured in millimetres of moisture deficit) that occurred during the 1997-98 drought in Canterbury. The right panel indicates the changes in drought severity of the same drought with a climate change scenario for 2100 superimposed.

Another issue of concern is soil quality. One important indicator of soil quality is the **soil carbon** content, which is a key to understanding changes in soil organic matter that is critical for maintaining sustainability of land-based production systems. The relationship of climate change to soil carbon is complex. For example, higher temperatures would be expected to increase respiration rates and deplete soil carbon, while higher CO_2 concentrations may stimulate plant biomass production and increase soil carbon. How do such processes balance?

As described in Chapter 7, a preliminary site-specific analysis was conducted using a soil carbon model contained within CLIMPACTS. The various scenarios of climate change were applied and the net effect on soil carbon content was examined. As shown in Figure 6, soil carbon decreased by about 2-5% at the site (in the Manawatu), the decline being sensitive to the rate of warming. However, this decline is considered relatively minor compared to the potential decline from intensive use and abuse of land, which should be considered in conjunction with climate changes. It should be noted that the potential offset from the possible positive effects of higher CO_2 concentrations (see below) and greater nutrient availability on soil carbon were not considered in these analyses.

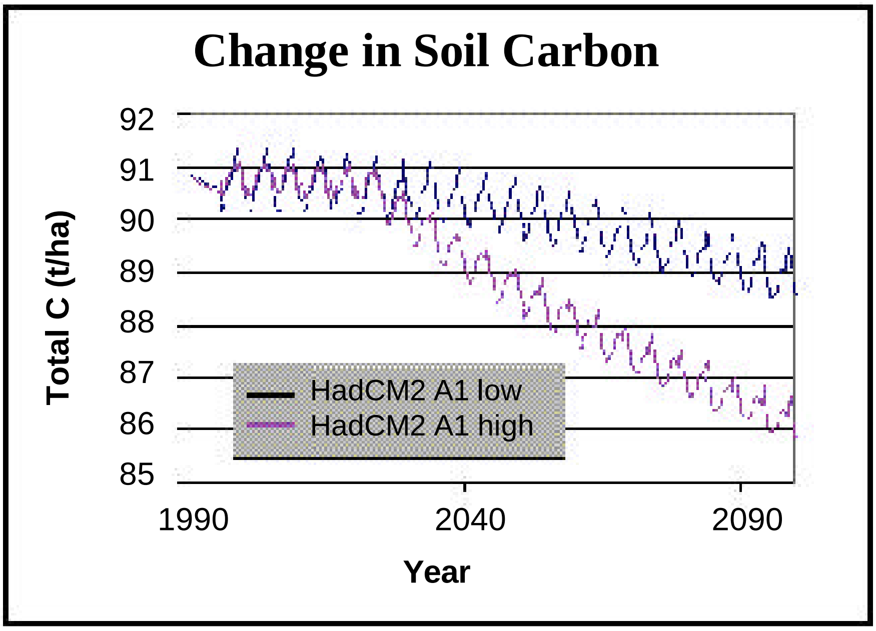

Figure 6: The change in soil carbon content (for Kairanga, in the Manawatu) under two scenarios of climate change, 1990-2100.

In what ways are plants affected by climate change?

Broadly speaking, there are two ways that GHG-induced climate change could affect vegetation and thus agricultural activities in New Zealand: the direct effect of increased atmospheric concentrations of CO_2 on plants; and the effects of changes in climate variables like temperature, rainfall or radiation.

The current ambient levels of carbon dioxide in the atmosphere are sub-optimal for most plants in terms of their growth and yield. The direct effect of increasing CO_2 is to enhance the rate of photosynthesis (by making more carbon available for assimilation into carbohydrates) and to increase the water use efficiency (by reducing the openings, or stomata, on the leaf surface through which water vapour is expired from the plant to the atmosphere). A CO_2–enriched environment is thus generally beneficial to plants, more so for the so-called C_3 plants (e.g. wheat, barley, many temperate grass species) than C_4 plants (e.g. maize, many sub-tropical grass species).

The effects of changing climate variables like temperature or precipitation can have both beneficial and detrimental effects on plants. The effects depend on a large range of factors including the direction and magnitude of the climate changes, geographical location, soils, the suitability of current climate, and so on. Throughout much of New Zealand, especially the South Island, temperature is a major limiting factor (through insufficient warmth for completing the plant's stages of development, low productivity or risk of frost), although there are areas of non-irrigated agriculture in which water is a constraint. Thus, climate warming can be expected to have beneficial, as well as detrimental, effects on plants.

However, whether these direct or indirect effects of climate change on plants are beneficial for farmers depends on whether the plant in question is a desirable species or an undesirable competitor. In general, there is less understanding about how enhanced CO_2 and climate changes will affect weeds, pests, diseases and their interactions than about individual plants themselves.

How might climate changes affect the geographical distribution of plants and agriculture?

Climate change in New Zealand is likely to change both the growing environments for plants and the botanical composition of plant communities, with implications for the geographical distribution of different agricultural activities. From a spatial view, CLIMPACTS is able to provide some examples about the possible changes.

On the potential “down-side”, analyses conducted on the likely effects of climate changes on two sub-tropical invasive grass species, **Paspalum** (*Paspalum dilatatum*) and **kikuyu** (*Pennisetum clandestinium*), show a likely southward spread as New Zealand’s climate becomes warmer (Chapter 6). The present, and future, occurrence of these invasive species (which are considered of poorer quality for animal production) is far more probable for areas of the North Island than South Island. Figure 7 shows the spread of the probability of presence of Paspalum in the North Island with one of the scenarios of climate change, and Figure 8 shows the total land area involved over time. This southward spread, at varying rates, of Paspalum is evident across all scenarios. For kikuyu, the total amount of land affected is far less, but the relative rate of increase of land area affected is higher.

For the horticultural sector, the climates suitable for growing “Hayward” **kiwifruit** are strongly related to temperature. The optimum climate is bracketed by a winter chilling requirement (winter temperature affects the number of flowers produced) and summer warmth sufficient to bring fruit production to maturity. At present, the Bay of Plenty, one of the principal kiwifruit-producing regions, meets both requirements. Analyses using CLIMPACTS suggest that the optimal land area for kiwifruit in the Bay of Plenty will decline with future climate change (Chapter 3). As shown in Figure 9, three of the four climate scenarios result in a decrease in optimal land area for kiwifruit beginning about the year 2020. The decrease is due to the loss of sufficient winter chilling, which implies an increased use of chemical intervention (dormancy-breaking agents) to artificially promote flowering if kiwifruit production in the region is to remain viable. Opportunities for kiwifruit production could open up elsewhere.

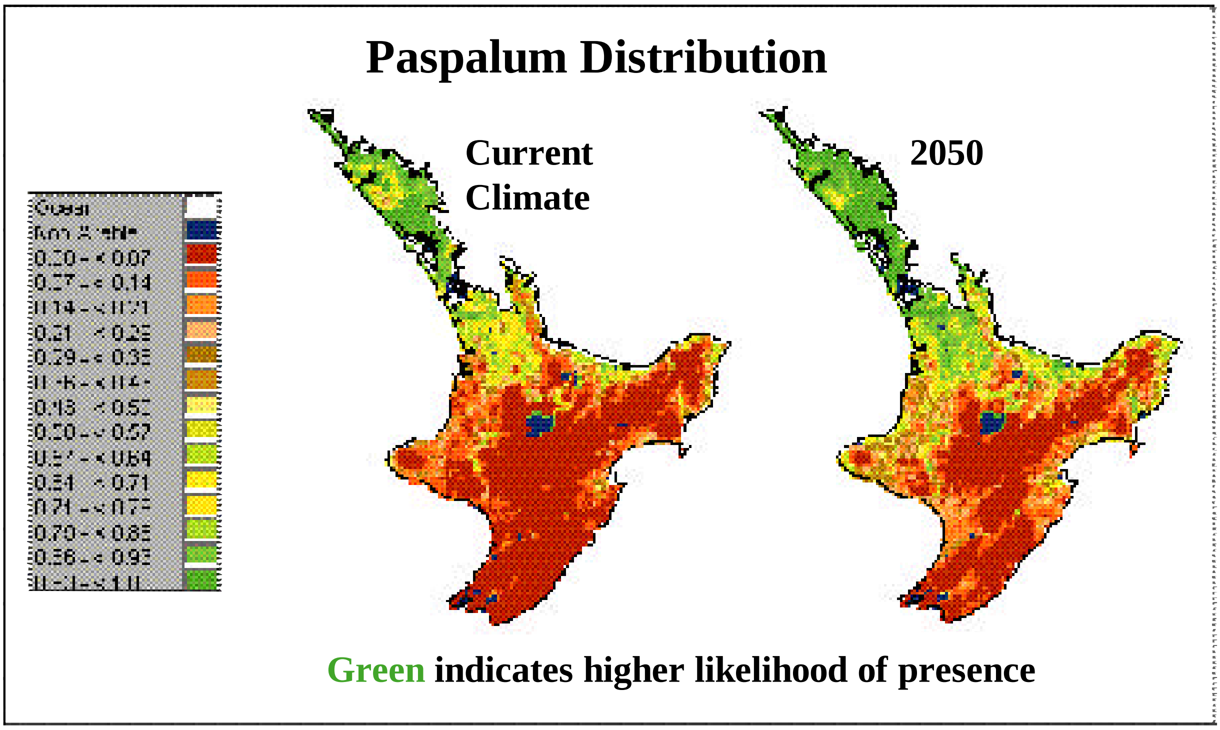

Figure 7: Change in the probability of Paspalum presence in the North Island - current climate versus 2050. Under the scenario of climate change, Paspalum spreads southward.

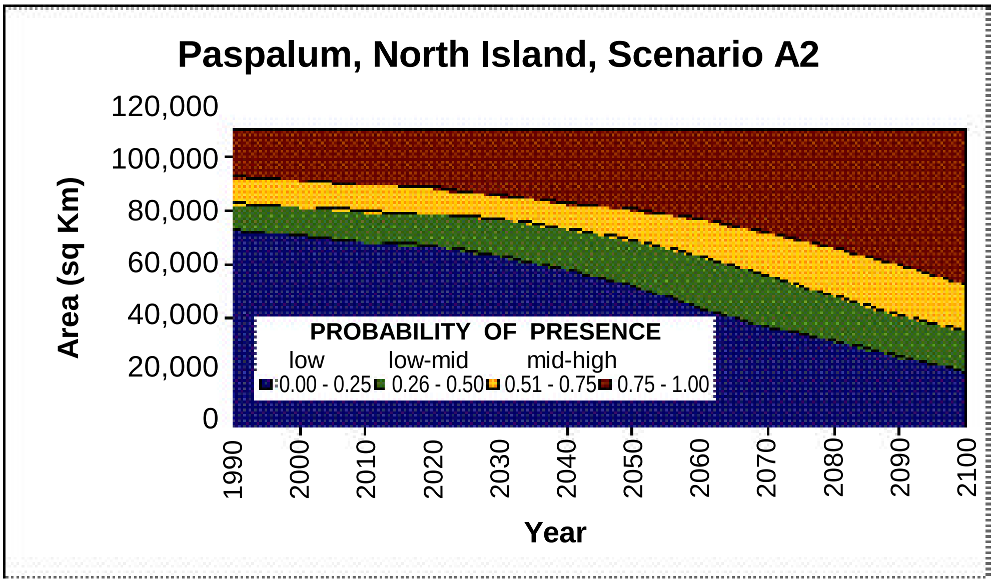

Figure 8: Change in land area subject to the presence of Paspalum in the North Island. A greater proportion of land is likely to have Paspalum present in a warmer climate.

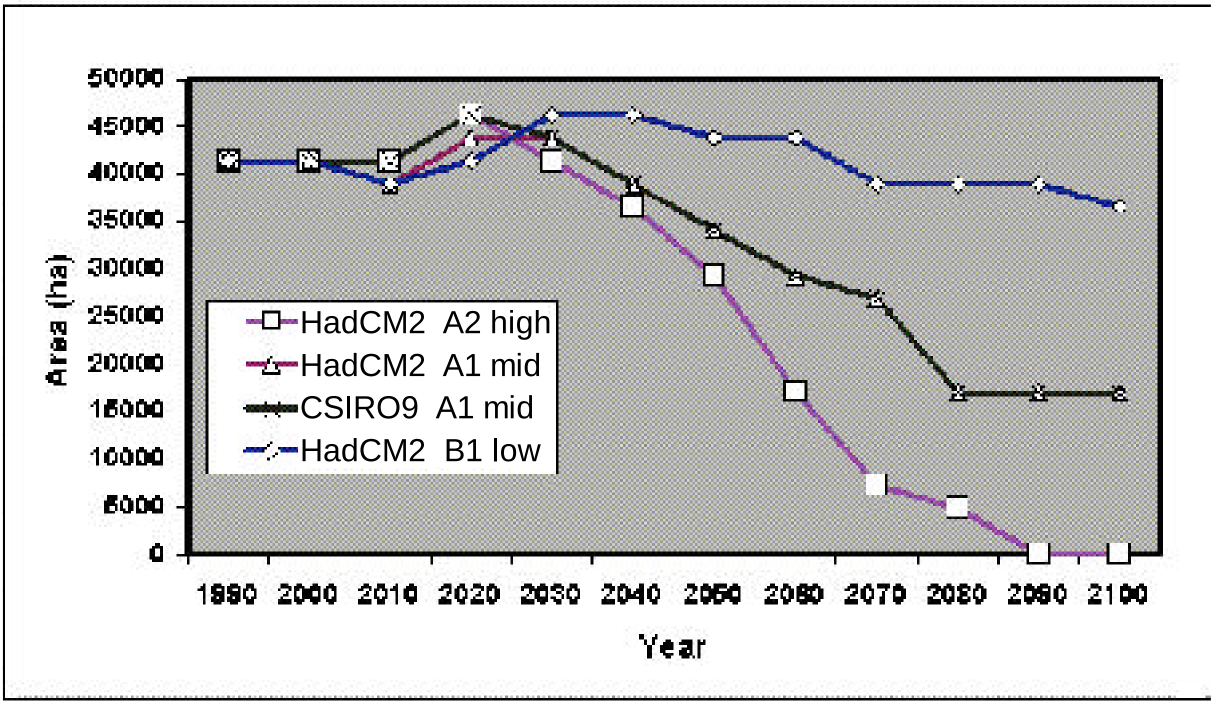

Figure 9: Change in land area that is optimal for 'Hayward' kiwifruit production in the Bay of Plenty.

With changes in geographical distribution of climatic suitability for crop production, a number of such opportunities for land use changes could occur. Particularly in the South Island where many agricultural crops reach the thermal limits of their production, climate change could push the margins of production southward. One such example is **grain maize**. In the South Island maize production under current climate is generally not viable due to the lack of warmth during the growing season to mature the crop. With climate warming, large areas of the Canterbury Plains could presumably be suitable for maize, as shown in Figure 10, although the suitability of soils and moisture availability could be limiting factors. With further warming, grain maize could conceivably extend into Southland given adequate water and soil conditions.

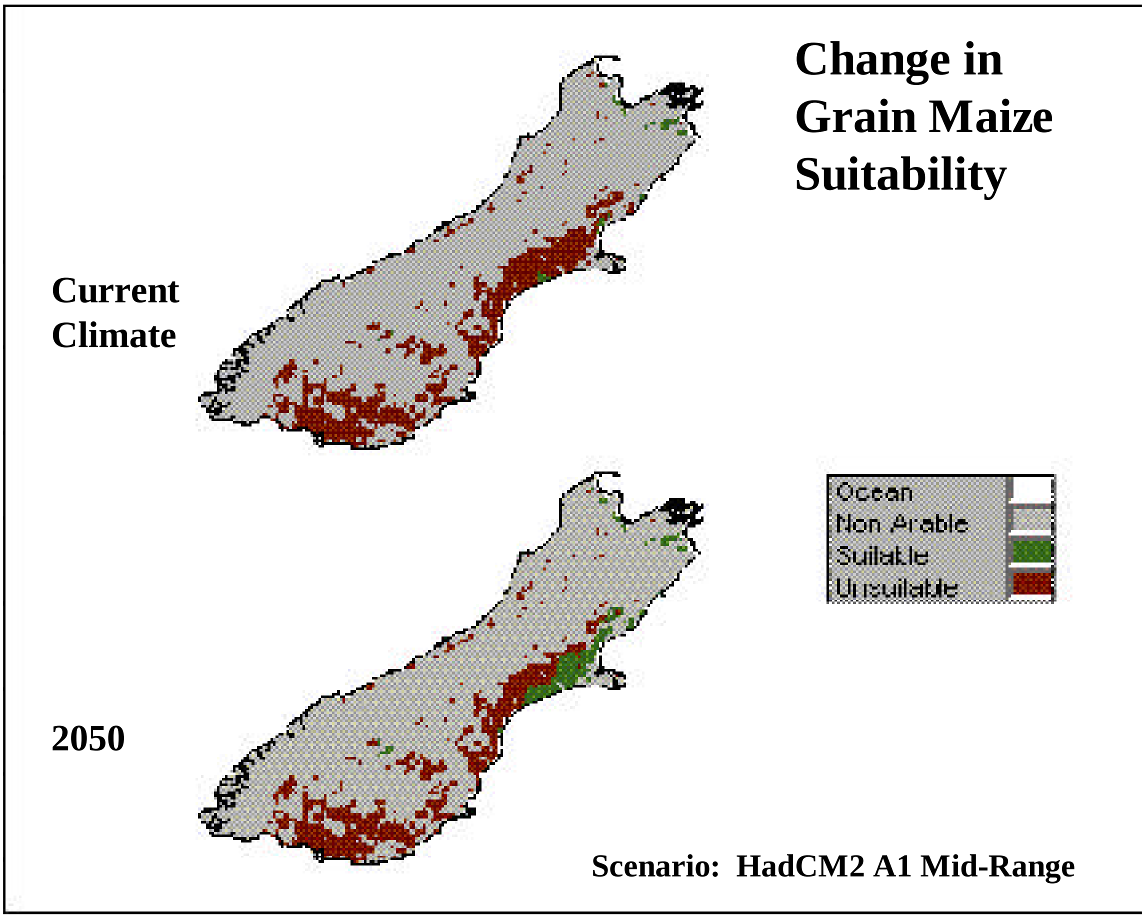

Figure 10: Change in areas of South Island that are suitable for growing grain maize.

How might plant processes and productivity be affected by climate change?

Within the CLIMPACTS system, insights into how climate changes could affect plant processes and responses can be gained by conducting analyses using plant models for specific sites. For sites, more complex models can be used, which often require detailed daily climate data.

For small grains like **wheat**, climate has a strong influence on the phenology (or developmental stages) of plant growth and thus on yield. As described in Chapter 5, in model simulations carried out within CLIMPACTS, the effect of higher temperature on wheat is to shorten the stage of grain filling so that the plant reaches maturity sooner, which *decreases* yield. However, the enriched CO_2 growing environment means that the rate of photosynthesis is higher during the shortened stages of development, which *increases* yield. In all the model simulations carried out for both winter and spring wheat at three sites (see Figure 11), the CO_2 "fertilisation" effect dominates, so that average yields increase over time. In short, for wheat production most of the implications of climate warming are positive, assuming adequate water supply and soil conditions.

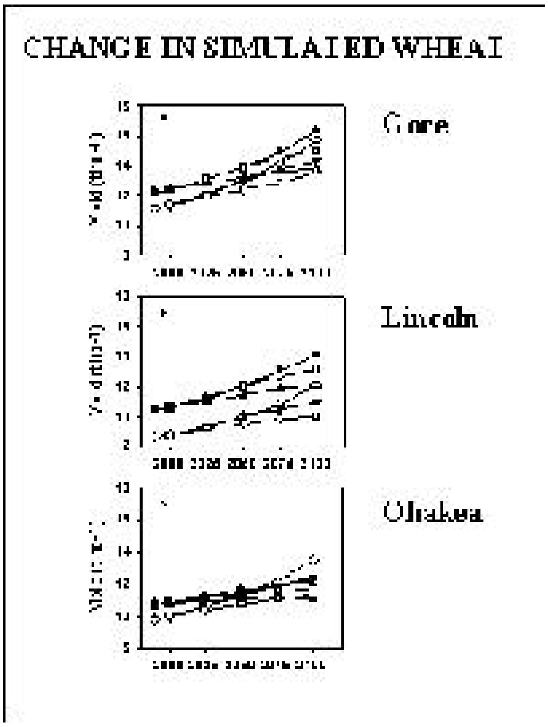

Figure 11: Changes is wheat yield with three scenarios of climate change for three sites. The top three curves in each graph are for winter wheat, the bottom three curves are spring wheat. In all cases the effect of climate change is to increase yields.

The relationship between temperature and phenology is also crucial for **kiwifruit** production in New Zealand (Chapter 3). The models used in CLIMPACTS enable the prediction of dates of bud break, flowering and maturity of 'Hayward' kiwifruit. These dates, in turn, prescribe the critical lengths of time over which weather has its influence on determining crop performance, of which two important indicators are: number of 'king' flowers per winter bud and the proportion of the fruit that is dry matter. Temperature is the driving variable.

As described in Chapter 3, analyses of the effects of temperature change were carried out for sites in four regions where kiwifruit is currently grown. The main conclusions are:

- Timing of phenological events may change significantly in warmer regions. Bud break is likely to occur later, while the effects on flowering and maturity dates are less clear;

- In warmer regions, the most important effect will be a drop in flower numbers. For this reason, kiwifruit production could become uneconomic in Northland, even when dormancy-breaking chemicals are applied, by around the year 2050 under a mid-range scenario of climate change. At the same time production in the Bay of Plenty will be uneconomic without the use of dormancy-breaking agents;

- In cooler regions, low dry matter due to cool summers will become less of a problem over the next 50 years.

The choice of warming scenario does not affect these main conclusions, only the timing of the effects. Rainfall and water supply were not factored into the analyses.

The CLIMPACTS **apple** fruit growth model is not dissimilar in concept to that of the kiwifruit model (Chapter 4). It describes the effects of temperature on the dates of bloom and fruit maturity, and the rate of fruit growth between these two dates. It builds on research that shows that early season temperature strongly influences potential fruit size. Fruit size is a quality characteristic that influences consumer choice. Overall, it was found that the effect of climate change is to bring forward the dates of bloom and, especially, maturity, and to increase apple fruit size (see Figure 12). However, these effects are only significant under the high warming scenarios, and then not until the middle of the century. Such effects are considered relatively minor compared to other forces of change, including market forces and inter-annual climate variability, and are within the scope of the industry's capacity to adapt.

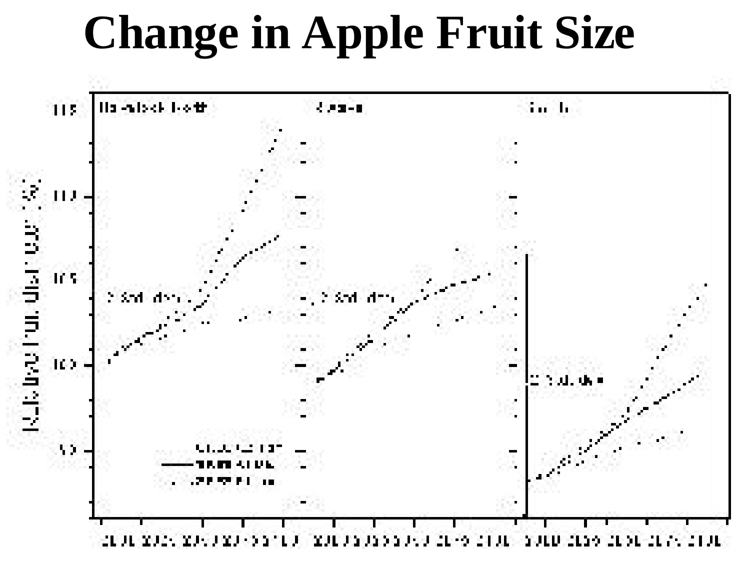

Figure 12: The relative change in apple fruit diameter with climate changes. In all cases, apple size increases, but the changes are small, particularly for the first half of the century.

The potential impacts of climate change on **pastures** is a critical issue for New Zealand, since dairy, wool and meat exports make up close to 40% of the country's export of goods. In general, higher CO_2 and temperatures would tend to increase pasture yields, while lower available moisture supply would decrease yields. As described in Chapter 6, the pasture model in CLIMPACTS was run for five sites.

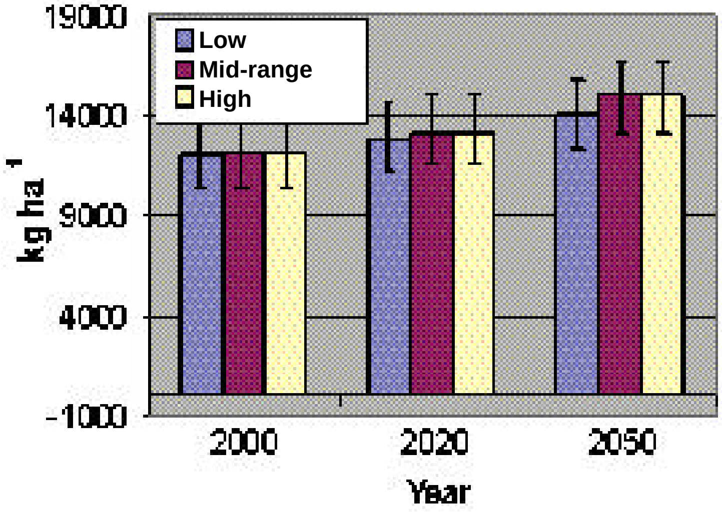

Figure 13: Annual dry matter yields (average of five sites) obtained under three scenarios of climate change. In all cases, yields increase.

Figure 13 shows the results averaged across the five sites. For all sites and all scenarios, the effect of climate change is to *increase* pasture yields, with the highest percentage increases occurring in the early part of this century. The analysis found little change in the seasonal distribution of yield. In short, the net effect of climate change appears positive for pasture yields.

Can New Zealand adapt to climate change?

Across the sectors examined and the limited production aspects investigated, climate change would appear to have a complex mix of beneficial and detrimental effects. The impacts vary widely depending on the nature of the climate scenario, the geographical location and the particular aspect of production under examination. Certainly, some would gain while others would lose.

One of the key unknowns has to do with changes in water availability. Water is a ingredient common to the success of all production sectors. As patterns of land use evolve with a warming climate, the competition for water could intensify. And climate models are, as yet, unable to provide reliable predictions of future changes in precipitation patterns for New Zealand.

Nonetheless, at the current time, it is the judgement of the CLIMPACTS members that climate change is not necessarily all "bad news" for New Zealand. Given the diversity of landscapes, climate regimes and production types, and the apparent capacity of the agricultural sector to adapt to current variations in market and climate forces, there is a cautious optimism that agriculture can evolve as climate changes.

Yet, in order to adapt, people in New Zealand must be able to perceive and anticipate the likely changes that could occur. That is the purpose of the CLIMPACTS Programme – to create the information and the awareness of the effects of climate change and variability that will foster adaptation. In this sense, CLIMPACTS and programmes like it become part of the adaptation process.

What are the next steps?

The set of CLIMPACTS methods and tools, and therefore the present assessment, is limited in scope. How might the capacity for such assessments be improved? The CLIMPACTS team has, in consultation with various end-users, identified several directions for improvement, some of which are currently underway, including:

- **Greater emphasis on shorter-term climate variations**, **including extremes**. The shorter-term climate variations between and within decades and years (like El Niño events), as well as climatic extremes (like droughts and hot spells), are currently very important for our production-based economy. Such variations will, of course, continue to occur even as climate changes and may become increasingly important to resource decision-making and management as their intensity, frequency or persistence change in the future. Blending longer-term change with shorter-term variations is thus a crucial step in making realistic assessments and is a priority with CLIMPACTS development.

- **A focus on water**. Water is a “common currency” of land use. The quality and quantity of available soil moisture, groundwater and surface water helps to shape patterns of land use in New Zealand. Too much or too little water, as influenced by climatic variations and change, is a fundamental concern of production sectors and territorial local authorities alike. CLIMPACTS is currently making efforts to better link land uses, climate and water through the introduction of hydrological model components.

- **Better integration of soils and plant models**. Like water, maintaining the quality and quantity of soils is crucial to ensuring sustainable land use systems. Linking soil and plant models provides the capacity to better understand the relationships between soil organic content, available moisture and nutrients, and plant growth and yield, as influenced by climate. Such understanding is a critical first step in defining areas and land classes at risk from climate change.

- **Expanded modelling of plant impacts**. What is the sensitivity of plants throughout their entire growth cycle to climate variations? How might climate change and variations affect agricultural and horticultural pests and diseases? What are the effects of climate change on the spread and distribution of pasture species? In some cases the answers require more sophisticated and new plant physiology models for CLIMPACTS. In other cases the inclusion of a broadened, related set of models, such as those pertaining to climate-pest relationships, the spread and distribution of species and species competition, is required.

- **Economic consequences of climate impacts**. Methods are required for aggregating model outputs to regional and national scales in order to estimate the production and economic effects of climate change and variations. Such information is crucial for considering adaptive measures that will ensure sustainable patterns of land use in the face of climate change and variability. Ultimately, it is these "human dimensions" of climate that are of major concern to New Zealand.

- **Broadening the sectors of concern**. The primary focus of CLIMPACTS to date has been agriculture. Other areas given high priority include: forestry; native ecosystems; coastal impacts; bio-security and bio-diversity.

In short, the efforts of the CLIMPACTS Programme are being directed toward achieving better *integration* of climate effects, through the explicit inclusion of a wider range of land use and environmental issues, water resource factors, and economic evaluation into the modelling framework.

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