Impacts of climate change on key primary industries on the Kāpiti Coast

A report for the Kāpiti Coast District Council

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1 Executive Summary

This report, prepared for the Kāpiti Coast District Council, provides additional insight into the climate change scenarios for the Kāpiti Coast District provided by Baldi et al (2007). It also surveys the available literature for the possible impacts of climate change on pastoral agriculture, horticulture and native forest in the region and explores the possibility of *Miscanthus x giganteus* being utilised as a biofuel to aid in climate change mitigation. However, it should be noted that this report does not address any issues surrounding sea level rise and related changes in groundwater, which the Kāpiti Coast District Council is researching separately.

Some explanation as to the uncertainties surrounding climate change projections, which are particularly noticeable at the regional scale, is made, reinforcing the need for caution when considering model results. Baldi et al (2007) suggest temperature increases of around 0.9°C of warming by 2040 and 2.1°C by 2090 on average, whilst frost risk declines and extreme temperatures increase. Rainfall is set to increase in winter but decline in summer. The 5th IPCC report, due out in 2014, will probably reinforce these predictions but may show that previous projections of significant increases in westerly wind flow have been overplayed (Renwick, pers.comm.). Sea level rise projections for the Kāpiti Coast have already been well-documented and are not considered in this report.

In terms of impacts on dairy and sheep/beef farming, climate change is unlikely to drive a trend towards increases or reductions in the industry, with factors like increased transport costs, reduced land availability and demand having a greater influence. Average pasture production will probably increase due to warmer and longer growing seasons and CO_2 fertilisation. However, pasture quality may be reduced by soil erosion, UV and invasion by subtropical species. The industry may also have to contend with an increase in extreme events, causing more frequent pest outbreaks and higher incidence of heat and water stress in cattle.

Climate change is unlikely to prevent horticulture becoming a keystone of the local economy; high land prices might. Overall, the industry will benefit from longer growing seasons, warmer weather and reduced frost damage. However, of concern is that reduced frosts may not provide the winter chilling berries require for spring growth. There will also be greater risk from extreme events such as heatwaves, storms and high winds, damaging fruit and encouraging pest and disease outbreaks. Kāpiti may benefit from northern growing regions experiencing increased drought, whilst southern areas' fewer frosts may reduce berry quality. Further, increasing transport costs may make its proximity to Wellington attractive. More research is needed to accurately assess the scope of any competitive advantage Kāpiti may develop in the coming century.

No study of the impacts of climate change on native forest has yet been undertaken, although it is possible that longer growing seasons and elevated CO_2 levels will encourage plant growth, whilst increased water stress, fire risks, wind damage and pest outbreaks will become problematic. However, as most native species are well within their natural climatic range in Kāpiti and are currently surviving in much warmer conditions further north, it appears likely most will tolerate all but the most extreme potential climatic changes.

Miscanthus as a biofuel would provide high yields of a high quality combustible material with relatively little pesticide and fertiliser inputs. Climate change will probably only bring the plant closer to its optimum growing conditions on the Kāpiti Coast. However, for it to be harvested efficiently using machinery, it must be grown on flat land which would be better and more economically used for horticulture.

Overall, climate change’s biggest impact will be through enhancing and increasing the frequency of extreme events. It is also these extremes which are hardest for scientists to predict. However, as long as this increased risk is properly considered and factored into management plans, there does not appear to be any reason why changes to average conditions should force alterations in land use in the Kāpiti Coast District. Again, it should be remembered that this conclusion has been reached without reference to sea level rise and related issues.

2 Introduction

That global warming is occurring is virtually unequivocal, with the Intergovernmental Panel on Climate Change (IPCC) anticipating 1.1-6.4°C of warming before the end of the century. Changes to patterns of rainfall and wind are expected, with alterations to climatic extremes of great concern. The question has thus shifted from whether the climate is changing, to how much it is likely to change by. The answer to this is of particular import to local authorities, upon whom much of the responsibility for adapting to future conditions is devolved by statute.

The Kāpiti Coast District occupies 730km^2 of the southwestern North Island, with a population of around 50,600 (Kaye-Blake & Allen, 2011). In addition to questions surrounding the impacts of sea level rise on coastal properties, there are concerns around the influence of changing temperatures and rainfall on the agriculture and horticulture which already generate a significant amount of the region's income, particularly in the less prosperous area of Greater Ōtaki, and may have an even greater role to play in future decades.

This report for the Kāpiti Coast District Council provides additional insight into the climate change scenarios provided by Baldi et al (2007), a full update being impossible until the IPCC's Fifth Assessment Report is released in 2014. It also endeavours to provide a comprehensive summary of what is known about climate change's impacts on pastoral agriculture, horticulture and native forest as a carbon sink and apply this to the particular circumstances of the Kāpiti Coast. It should be noted that, as yet, no survey of climate change's likely impacts on native forest in New Zealand has been published. Finally, this report considers the possibility of *Miscanthus* as a solid biofuel being utilised to reduce carbon emissions for the region.

3 Climate change predictions for the Kāpiti Coast District

3.1 *Background*

The IPCC's 4th Assessment report, published in 2007, declared global warming to be 'unequivocal' with a 90% probability of it being mostly anthropogenic (Meehl et al, 2007). Indeed, New Zealand has already seen average temperatures increase 0.9°C from 1908 to 2006 (Ministry for the Environment, 2008).

The scientific basis of climate change has increasingly become common knowledge. Natural greenhouse gases in the atmosphere raise Earth's average surface temperature from the minus 18°C it would otherwise be to a more habitable 13°C. These gases allow incoming short wave electromagnetic radiation from the Sun to pass through them, whilst trapping the long wave radiation the planet would otherwise emit back into space, thus acting like the glass of the aforementioned greenhouse. Of the principal greenhouse gases, water vapour, carbon dioxide (CO_2), ozone (O_3), methane (CH_4) and nitrous oxide (N_2O), it is water vapour which has the strongest effect but CO_2 which is most worrying. Natural concentrations of CO_2, as ice cores tell us, have not exceeded 280 parts per million (ppm) in the last 20 million years and yet currently stand at 392ppm, the excess being due primarily to burning of fossil fuels as humanity industrialised (Baldi et al, 2007). Since CO_2 increases have been strongly linked to rising temperatures throughout Earth's history, and with carbon dioxide levels set to rise dramatically this century if long-sought international action does not take place, significant global warming seems inevitable.

3.2 *Climate change projections*

An understanding of how climate projections are made is essential to comprehending their uncertainties, and consequently, the degree to which the figures cited in this report should be treated with caution.

Projections generally start with a Global Climate Model, with supercomputers using equations to represent complex interactions between the atmosphere, ocean, land surface and ice (Ministry for the Environment, 2008).Difficulties arise as it is highly uncertain what path humanity, and its emissions, will take. Thus, for the 4th Assessment Report, the IPCC ran simulations using 40 different emissions pathways or 'scenarios', grouped into four families. The A1 family represents scenarios involving rapid economic growth with global population peaking around 2050. A1F1 in particular, is the highest emission scenario and represents a world highly dependent on fossil fuels. The A2 group assumes continually growing populations, but fragmented economic growth and technological development, with regional groupings important and no unified global approach, each region instead following its own path. B1, as with A1, assumes a peak in global population mid century but imagines a transition to clean technology and a more service and information based economy. Finally, the B2 family represents slower population growth and technological change (MfE, 2008). Given the complexity of these models, it is not feasible to use them all to generate regional climatic projections. Instead, NIWA's 2007 report for the Kāpiti Coast, Baldi et al (2007), is based primarily on the IPCC's mid-range scenario, A1B, its lowest scenario, B1, and highest emissions scenario, A1F1. It is the findings of this report which are considered below. Other reports utilise different scenarios, with for example, the Ministry for the Environment's 2008 report preferring to concentrate on the A1B scenario, with A2 and B2 on either side.

It should be noted that for the IPCC's 5th Assessment Report, due out in 2014, these families of scenarios have been replaced by RCPs or Representative Concentration Pathways, which focus principally on CO_2 emissions. However, as these have not yet filtered through into the literature, they cannot be considered in this report.

Global Climate Models operate at too large a scale to give accurate projections for small areas of New Zealand. Many have grid squares 100-300km across and so are unable to take into account the subtleties of local terrain and must be downscaled to make regional-scale projections (Ministry of Agriculture and Forestry, 2011). This is often done statistically, through utilising historical data to develop regression equations, which attempt to relate local climatic variations to the larger scale fluctuations visible in models. The historical data may then be replaced by that from the GCM, generating projections at the kilometre rather than hundreds of kilometres scale (MfE, 2008).

Whilst the projections made using climate models are as accurate as possible, there are still uncertainties, and thus, results are not precise values, but rather are presented with an associated error, or a probability of the actual figure lying within a particular range. At a basic level, scientists do not know precisely what levels greenhouse gases will be reach this century, as this depends on complex political and economic factors (Baldi et al, 2007). There is also the issue that climate models of any kind are endeavouring to describe an atmosphere, which varies continuously in space and time, using a grid. The finer the grid, the more closely it will match reality as the closer it is to being continuous; however, the smaller the grid squares are the more complex the model is and the more time and computer processing power will be needed to run it. Climate models also require defined boundaries, with most limited to the lower 30-50km of the atmosphere (Räisänen, 2007). Specifying such boundary conditions is artificial and so generates further inaccuracies, but is necessary to allow the model to work within the confines of the computer processing power available. Thus, there must be a compromise and some of the model's potential accuracy must be sacrificed. Further, climate models are attempting to describe vast numbers of variables. Each variable will have an error bar associated with it, the size of which depends on how easily it may be described by a mathematical equation; thus again, the potential errors mount up. Some elements of the climate system are simply not well-enough understood for them to be accurately represented in a climate model (Räisänen, 2007).

At the regional level, uncertainties are even greater owing to the downscaling process and the complex interactions of local scale processes. However, these errors are being reduced as scientific understanding improves so that there is now greater certainty over the direction of changes in climatic variables (for example, greater precipitation being expected in the west of New Zealand), although there are still conflicting estimates as to the magnitude of this change (MfE, 2008). The difficulty involved in producing anything other than broad qualitative statements about possible change is underscored by recent concerns that NIWA's climate model might be overly sensitive to small changes in sea surface temperature as these might alter the predicted position of the westerly wind belt which has such a large impact on New Zealand's climate (Renwick, pers.comm.)

It is thus prudent to treat climate projections, particularly at the regional scale, with caution, considering them likely climate futures, but acknowledging that other paths are possible (Fowler et al, 2008). This is not to say they should be ignored as they give a valuable insight into what might, and indeed probably will, happen in future. Additionally, models should improve over time through greater understanding of the climate system and further inclusion of observational data, which has already seen a movement away from the IPCC's B1 scenario, as it is now widely considered likely to be exceeded (Baldi et al, 2007).

3.3 *Temperature projections*

3.3.1 **Average temperatures**

The Kāpiti Coast experiences a generally mild climate, with an annual mean temperature, as recorded at Paraparaumu Airport from 1971-2000, of 13°C (Baldi et al, 2007). Summers are mild with typical daily maximums of 21°C and minimums of 13°C, whilst cool winters produce maximums of 13°C and minimums of 5°C (Baldi et al, 2007).

New Zealand is warming at around 70% of the rate the rest of the world is experiencing, a fact expected to be confirmed by the next IPCC report (Renwick, pers.comm.). Between 0.5 and 5.5°C of warming are expected before 2100, with the greatest warming experienced in summer (Baldi et al, 2007). For the Kāpiti Coast in particular, NIWA projects around 0.9°C of warming by 2040 and 2.1°C by 2090; however as the table below indicates, this warming is not spread evenly between the seasons (Baldi et al, 2007).

Period	Summer	Autumn	Winter	Spring	Annual
2040	1.0 [0.2, 2.2]	1.0 [0.2, 2.5]	1.0 [0.2, 2.1]	0.8 [0, 1.9]	0.9 [0.2, 2.2]
2090	2.2 [0.8, 5.6]	2.1 [0.6, 5.1]	2.1 [0.6, 5.0]	1.8 [0.3, 4.8]	2.1 [0.6, 5.1]

Table 1: Seasonal and annual mean temperature projected changes (in °C). The first number given is the best estimate, whilst those in brackets are the upper and lower limits. Source: Baldi et al (2007).

Whilst these temperature changes may appear small, it should be remembered that a 2 degree temperature change is equivalent to a 600km shift in latitude or 330m in elevation (Gerard et al, 2010). Indeed, the best estimate is that by 2090, Kāpiti will have a climate similar to Taranaki's and Waikato's at present (Baldi et al, 2007).

3.3.2 **Extreme temperatures**

As average temperatures increase, so will extreme temperatures, although these are somewhat harder to predict, with the biggest increases expected in areas which are already hot. Wellington currently experiences an average of three days a year with temperatures above 25°C, and the Kāpiti Coast has about the same (MfE, 2008). By 2100, the Wellington region is expected to experience between 15 and 45 more days a year with maximum temperatures above 25°C, suggesting a significant increase in extreme temperatures for Kāpiti (MfE, 2012a).

3.3.3 **Frost risk**

Whilst the 2007 NIWA report gives no indication as to the prevalence of frosts on the Kāpiti Coast currently, the Ministry for the Environment suggests the Wellington region will be experiencing 10-20 fewer frosts each year by the end of the century (2012). However, some regions such as Hawke's Bay are seeing increased examples of spring frosts damaging crops, even as frost numbers reduce overall (Kenny, 2011). There is some suggestion that increasing numbers of spring and autumn anticyclones may bring more extreme early and late season frosts, especially following a cold southerly, although it is not clear whether this is applicable to the Kāpiti Coast (Cherry, 2001).

3.4 Rainfall

3.4.1 Average Rainfall

Annual rainfall on the Kāpiti Coast is around 1000-1100mm, with an additional 330mm for every 100m altitude. Heavy rainfall events may happen at any time, although there is a tendency towards long dry spells in late summer and early autumn (Baldi et al, 2007).

Since 1950, New Zealand has in general seen increasing rainfall in the southwest and less in the northeast (Hennessey et al, 2007). This is expected to continue although the trend is principally observed in projections for winter and spring, with no strong pattern evident for summer and autumn (Renwick, pers.comm.) In line with expected changes in wind patterns (see below), slightly drier summers and wetter winters are expected on the Kāpiti Coast (Baldi et al, 2007) (see table 2). However, the authors note the significant differences between models mean that only increased rainfall in winter can be viewed with any confidence (Baldi et al, 2007).

Period	Summer	Autumn	Winter	Spring	Annual
2040	0 [-21, +13]	+4 [-3, +14]	+4 [-1, +13]	+2 [-5, +14]	+2 [-3, +10]
2090	-1 [-38, +16]	+2 [-12, +14]	+9 [0, +26]	+2 [-15, +26]	+3 [-7, +14]

Table 2: Seasonal and annual mean rainfall projected changes (in %). The first number given is the best estimate, whilst those in brackets are the upper and lower limits. Source: Baldi et al (2007).

3.4.2 Extreme rainfall

As the atmosphere warms, its capacity to hold water vapour increases, with 1°C equating to an extra 8% more water held (Baldi et al, 2007) or an extra 6.2% added to the total rainfall expected in a 1-in-10 year event (Gray et al, 2005). The result is an increase in the number of extreme rainfall events expected. The volumes of extreme rainfall events are very hard to project and there is considerable variation in estimates for New Zealand. However, the worst case scenario appears to be rainfall events with a return period of 50 years becoming a 1-in-7 year event by 2100 (MfE, 2008).

For the Kāpiti Coast specifically, extreme rainfall events are expected to increase in intensity by 1.6-13.6% (with 5.9% as a best estimate) by 2030 and by 4.8-40.8% (with a best estimate of 16.4%) by 2090 (KCDC, 2010d). To put this in perspective, a 10% increase in heavy rain volume would be sufficient to change a 1-in-20 year event to a 1-in-10 (Gray et al, 2005).

In terms of the storms which often bring these heavy rainfall events, cyclones between 40 and 60°S (the Kāpiti Coast lies around 41°S) have generally reduced in number over the last 40 years, but increased in intensity (Mullan et al, 2011). In future, the intensity of storms is expected to continue increasing, as mid-latitude cyclones are partly fuelled by north-south temperature gradients, which will rise for the mid-latitudes as the Hadley Cell (the circulation which sees warm, moist air rise at the equator, generating heavy rainfall, before moving north and south to sink at around 30° latitude where this high pressure generates desert regions) moves increasingly polewards and latent heat, which will increase with additional water vapour in the atmosphere (Revell, 2003). What remains uncertain is how climate change will affect factors like the frequency and path of storms (Baldi et al, 2007), although the number of mid-latitude cyclones over the North Island may well decrease as cyclone tracks shift polewards (Mullan et al, 2011). An increase in intensity may allow more ex-tropical cyclones to reach as far south as New Zealand, especially during La Niiña years, as Cyclone Bola did in 1988 (MfE, 2008). Small but intense convectional storms are set to increase in number and intensity as temperatures rise (Mullan et al, 2011).

3.4.3 Drought

Although rainfall on the Kāpiti Coast is expected to increase on average, this may occur mostly at the extremes i.e. more rainfall could fall during storms and not at other times, leading to increased time spent in drought conditions. Under more extreme scenarios, the whole of New Zealand, with the exception of the South Island's West Coast, may be spending over 10% more time in drought conditions by 2050 (Clark et al, 2011). Other models appear to show a 1-in-20 year drought for the Kāpiti Coast region becoming between a 1-in-15 and 1-in-10 year event by the 2080s under a low-medium climate scenario, or as frequently as a 1-in-5 year event under a medium-high scenario (Mullan et al, 2005). However, Kāpiti is at a much lower risk of drought than many other areas of the country.

3.5 Winds

3.5.1 General Circulation

One of the most noticeable features of New Zealand's climate is the strong east-west divide, with the east generally being considerably drier than the west. The primary reason for this is New Zealand's position in the mid-latitude westerly belt. The predominantly westerly air flow off the ocean brings rain to the west of both islands, but once it runs up against the axial ranges, the moisture is rained out, leaving little to make it to the east.

This difference is projected to be enhanced over the coming century with increases in the mean westerly component of winds. The amount of the increase is uncertain, with the IPCC suggesting a 60% increase by the 2080s (Hennessey et al, 2007), whilst the more recent Ministry for the Environment report suggests increases of only 10% by 2040 and 20% by 2090 (MfE, 2080).

Additionally, these changes are highly seasonal with significantly greater increases in the westerly component in winter (over 50% by 2090) than any other season (MfE, 2008). Spring too in most models (but not all; indeed, only for winter do models consistently show changes in a particular direction) shows an increased westerly component (20% according to MfE (2008)). However, in summer and autumn, westerlies are projected to decrease around 20%, as the descending branch of the Hadley cell, and the associated anticyclone belt moves down towards New Zealand (MfE, 2008). The result is an increase in the rainfall disparity between west and east during winter and spring, but a lessening of it for the rest of the year. For Kāpiti in particular, models suggest a 70% chance of more easterlies during summer, with an 80% probability of increased westerlies in winter (Mullan et al, 2011).

However, it should be noted that the 5th Assessment Report is likely to find that the increases in the westerly component have been overplayed, particularly for winter and spring, so the results above may be subject to review when this report becomes available (Renwick, pers.comm.)

3.5.2 Strong winds

The exposed nature of the Kāpiti Coast ensures that it often gets extreme winds courtesy of weather systems moving in off the Tasman Sea (Baldi et al, 2007). Climate change is expected to bring an increase in the frequency of extreme winds during winter, but a decrease over the summer months for all of New Zealand, but especially the Wellington region and South Island, in line with changes in the number of troughs reaching the country (Mullan et al, 2011). Overall, a maximum of a 10% increase in strong winds (being those above 10m/s) is expected by 2090, although there remain significant uncertainties involved in this projection (MfE, 2008).

3.5.3 Natural climate variability

When examining climate change projections, it should be remembered that the current variability which gives us things like temperature extremes will continue, just superimposed on a long term warming trend (MfE, 2008). Natural cycles like the El Niño Southern Oscillation (ENSO) will continue, if potentially modified, and affect whether a particular year is warmer or colder than usual etc.

3.5.4 El Niño Southern Oscillation

El Niño Southern Oscillation describes one of Earth's largest natural climate forcings, involving a close coupling between ocean and atmosphere. El Niño represents a warming of the central Pacific Ocean off South America, accompanied by a decrease in atmospheric pressure known as the Southern Oscillation. The Southern Oscillation Index (SOI) is the most commonly used way of measuring ENSO, taking the difference in pressure between Tahiti in the east and Darwin in the west. When the index is positive, a La Niña event is in progress. A negative SOI indicates an El Niño and these recur around 3 to 7 years apart.

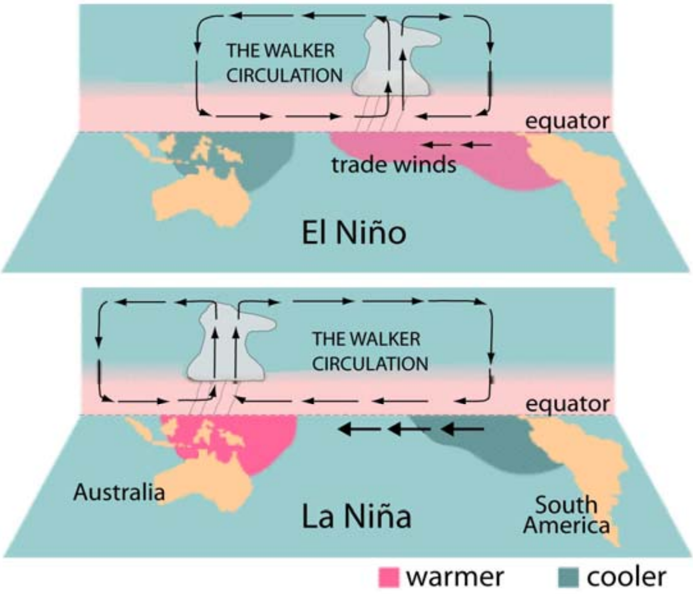

Fig. 1.El Niño Southern Oscillation (DiMaggio, n.d.)

Generally, the trade winds blowing across the Pacific towards Australia in the west move surface waters with them, allowing cold water to upwell behind them off South America. The result is warmer water in the west encouraging evaporation, low atmospheric pressures as air rises and thus rainfall on Australia's western coast. However, in an El Niño year, the trade winds weaken and warmer water exists off South America, causing increased rainfall there, whilst the comparatively cooler water off Australia results in drought. In contrast, during La Niña, the trade winds get stronger, causing unusually low pressure off Australia and abnormally high pressure off South America.

New Zealand, whilst not as affected by ENSO as many areas of the Pacific, still experiences noticeable changes in El Niño and La Niña years. Generally, El Niño conditions mean more frequent westerly and southwesterly winds and thus more rain for western regions like Kāpiti, whilst the east is drier. In contrast, in La Niña years, a more northeasterly flow is observed, meaning a drier west and wetter east than usual.

Kāpiti Coast climate records show no clear pattern which might be attributed to ENSO, although Baldi et al report some data organisation, with drier conditions more likely during La Nińa years whilst it is generally wetter during El Nińo (2007).In terms of climate change, there is some suggestion that warming of the Pacific may lead to more El Nińo events than would be expected over the next 50 years, which may equate to wetter conditions for Kāpiti (MAF, 2010a).

3.5.5 Interdecadal Pacific Oscillation

The Interdecadal Pacific Oscillation refers to another source of natural climatic variability, which causes circulation patterns in the Pacific to change for decades at a time, affecting New Zealand’s temperature and rainfall average as it does so (Baldi et al, 2007).

The IPO changes between its positive and negative phases about once every 20-30 years. The most recent change appears to have been in 1999/2000. The current negative phase of the IPO is likely to herald more northeasterly winds over New Zealand and a tendency towards La Niña in the Pacific, whilst in its positive phase,westerlies are more prevalent leading to an increase in the rainfall disparity between east and west (Baldi et al, 2007).

3.6 Conclusion

It thus appears that even with the next IPCC report due out in 2014,little alteration will be made to climate projections for Kāpiti, with the possible exception of more conservative expectations regarding changes in the westerly wind flow. Baldi et al’s projection of around 0.9°C of warming by 2040 and 2.1°C by 2090 on average will probably stand, as will increases in winter rainfall, whilst summers become increasingly dry. However, the biggest changes may come at the extremes, with increased drought, extreme temperatures and rainfall events. It should also be remembered that current sources of natural climatic variability, like ENSO, will continue despite alterations to average conditions.

4 Climate Change, dairy and sheep/beef farming

4.1 Introduction

Both dairy and sheep/beef farming have declined in the Kāpiti Coast District over recent years, with the number of dairy cattle dropping by 2200 over a ten year period, whilst sheep numbers fell from 46,000 to 23,000 between 1996 and 2007 (Andrew et al, 2010). However, the dairy industry still brings $11 million to the local economy, with its 6961 cows occupying 2956.5ha of land (Mackay et al, 2005). Sheep and beef is somewhat less lucrative, contributing around $2 million (Mackay et al, 2005), and perhaps is more vulnerable to competition worldwide (Kenny, 2001). Further, an increasing population with a taste for meat and dairy products (meat consumption is already very high in developed countries, but developing nations have also seen an increase in consumption of 18.9kg per capita since the 1960s) means demand is only likely to increase in the coming decades (MAF, 2011).

The following section canvasses the issues surrounding climate change and pastoral agriculture, in terms of effects on pasture and animal health. However, once again, it should be remembered that there are inherent uncertainties in the model projections described. For example, only about half the variation in a growing season is seen as predictable, and only 30% of the seasonal rainfall (Kenny, 2010).

4.2 Climate change effects on pasture

4.2.1 More favourable pasture growing conditions

The warmer, and to some extent, wetter conditions forecast for the coming decades are expected to be beneficial for pasture growth, ensuring a longer growing season (Kenny, 2001). For example, growing degree days are a measure of heat accumulation in plants, being the sum total for a year of the extent to which a day's temperature is above 5°C (representing the temperature at which pasture crops are seen as commencing growth) (Hutchinson et al, 2000). The Kāpiti Coast District currently accumulates between 2500-3000 GDDs a year, but this is modelled to increase by up to 150 by 2020 and 500 by 2070 under a low-medium emissions scenario, with further increases possible with higher emissions (MAF, 2007)[1]. Warmer conditions should also see pasture plants spend more time in optimum temperature ranges, with C3 species (the terms C3 and C4 refer to different photosynthetic pathways used by plants; C3 species tend to be found in more temperate climates, whilst the C4 pathway is more commonly used by subtropical species) growing best at between 20-25°C, with minimal growth below 8°C (Lee et al, 2012).

Climate change may also change the pasture growing season. Warmer weather may allow pasture to dry earlier in spring and thus start growing earlier (as much as two to four weeks earlier), affecting when farmers must have stock ready and bringing calving forward ten days by 2030 and five more by 2090 (Dynes et al, 2010). However, the complexity of factors at work here is underscored by concerns that warmer winters will prevent the build up of microbial nitrogen which may retard onset of the new year's growth (Baars et al, 1990). Should this not occur, however, hay making will become increasingly important to make use

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[1] Please note that the models referred to in these reports were not specifically run to consider the Kapiti Coast and no information is given as to the size of grid squares used, so these figures should be treated with due caution.

of spring growth (Lieffering et al, 2012). Warmer temperatures will also encourage pasture, and indeed crops in general, to develop quicker, allowing for earlier harvests (up to three weeks earlier by 2090 under a high emission scenario) (Dynes et al, 2010). However, there is a danger of pasture productivity declining at the end of such a long growing season, forcing cows to be dried off earlier (Kalaugher et al, 2012).

4.2.2 Extreme weather damage to pasture and soils

Whilst rainfall is expected to increase on the Kāpiti Coast in general, it may very well decrease during summer months. This combined with higher temperatures may lead to increased drought, especially for lighter coastal soils, reducing plant growth and increasing mortality (MAF, 2010b). Once soils have dried, they quite often crack and will be difficult to re-wet (MAF, 2012a). Drought also reduces the digestibility and quality of grasses in particular (Baars et al, 1990). However, the extent of the problem depends greatly on the severity and duration of the water deficit, with studies showing no discernible impact for the first 35 days, but a 31% reduction in growth over 107 days (Baars et al, 1990). There is also likely to be an increased risk of fire with warmer weather and increasingly strong wind (MAF, 2012b).

Conversely, heavy rainfall may also become an issue, with waterlogging causing a 15% reduction in ryegrass (a common pasture plant) growth after only 24 hours (Campbell, 1996). Flooding may also be a risk, particularly with the increased winter rainfall expected in the Kāpiti Coast District, as the coastal plain is crossed by a number of fast-flowing streams and rivers with steep catchments (Kāpiti Coast District Council, 2010). Increased rainfall and wind may result in soil erosion, in addition to reducing the quality of waterways through increased sediment load (Lundquist et al, 2011). Topsoil, nutrients and organic matter may be stripped away, exposing subsoils which are less conducive to plant growth and are even more susceptible to further erosion (MAF, 2012a). Strong winds are also a risk in and of themselves, increasing the chance of pastures drying out and sand blasting vulnerable plants (MAF, 2012b).

4.2.3 Increased rates of photosynthesis

Whilst increased CO_2 in the atmosphere is having a detrimental effect in causing climate change, it may act to increase rates of photosynthesis in plants and thus growth. At temperatures between 5 and 25°C, C3 grasses (which most of Kāpiti's pastures are) experience increased photosynthesis and photorespiration as CO_2 concentrations increase, an effect known as 'CO_2 fertilisation' (Baars et al, 1990). Further, increases in CO_2 concentration means more can be taken in with the same unit volume of air. Plant stomata may thus be partially closed without any negative effect, reducing transpiration and consequently water stress in dry conditions (Lee et al, 2012).

There are, however, factors which may reduce the fertilising effect of CO_2. Firstly there is some evidence that after a number of years plants acclimatise and the impact of increased CO_2 concentration is reduced (Baars et al, 1990). Such an effect may perhaps be more likely given the gradual change in CO_2 over time. Further, there is a point above which the negative impact of temperature begins to offset the fertilisation effect of CO_2, which Casella et al (1996, cited Lee et al, 2012) suggest may be as low as 18.5°C. Additionally, in order to take advantage of the increased photosynthesis the added CO_2 makes possible, plants may require more of other nutrients, particularly nitrogen (Lee et al, 2012). If these are not available in soils, fertiliser may need to be added. Similarly, whilst increased CO_2 may reduce water stress somewhat, there is a point where irrigation will be needed to increase yields, although this will probably not be nearly the issue in Kāpitiit will be in New Zealand's east (Dynes et al, 2010).

There is also debate as to the extent of the CO_2 fertilisation effect, with studies yielding varying results. Increasing CO_2 to 500pppm, with a 1.5°C temperature rise, was found to increase ryegrass and white clover (the principal component of most New Zealand pastures) 10 to 15% (Dynes et al, 2010), whilst an increase to 700ppm yielded a 33% increase in production (Baars et al, 1990). Other authors suggest an increase of 7-26% over the next 50yrs, with the largest gains in winter and autumn, although where nitrogen is limited, gains of only 4% may be expected (Lee et al, 2012). However, the model results presented by Baisden et al (2010, cited Lee et al, 2012) suggest only a 0-5% increase in summer and autumn, 5-10% in spring and 10-15% in winter for the Kāpiti area. Further, there are limits as to what might be said as to effects on photosynthesis in the long term, it being especially hard to predict given interactions with factors other than CO_2, such as humidity, temperature and nutrient availability (Lundquist et al, 2011). Some US university studies are even beginning to question traditional thinking that increased CO_2 will benefit plants at all (Mason et al, 2011).

4.2.4 Decreased pasture quality

Modelling suggests that, for the Manawatu at least but probably elsewhere also, the milk solids produced per cow and per hectare are likely to decline over the coming century as lower pasture quality results in a lower energy intake for the same amount of grass (Dynes et al, 2010). The additional pasture growth described above may allow this to be remedied by having greater numbers of cows, but this will not solve the underlying issue (Dynes et al, 2010).

Part of the problem is that increased pasture growth means more of it going to waste, with pasture utilisation expected to decline up to 13% this century, causing increased accumulation of dead and decaying matter for cows to ingest (Dynes et al, 2010). Further, studies have linked increased UV doses, expected to rise 10% per decade until 2050, with depressed pasture yields (Campbell, 1996).

Poorer quality pastures are most likely to harm those cows most in need of nutrition, as it will be the youngest and least dominant cows who reach paddocks last after milking and are thus left with the grass nearest ground level which has decreased nitrogen content and a disproportionate amount of dead matter (Waghorn& Clark, 2004). Further, increased CO_2 concentrations are expected to increase the carbohydrate content of pasture plants, whilst the protein and nitrogen content decreases. However, as New Zealand plants generally have more crude protein than cows require, this is not in itself expected to reduce dairy production (Lee et al, 2012).

A change in quality may also occur as a result of alteration in pasture composition. Most pasture is currently perennial ryegrass, which is high quality and easily digestible by cows. However, weed species are likely to respond quicker to the advantage of increased CO_2 concentration and thus help deteriorate pasture quality (Kenny, 2001). Legumes, like white clover, also a significant component of pasture, should do likewise and counteract some of this reduction in quality (Kenny, 2001). Legumes are generally better quality as feed than grass as they contain less fibre but more carbohydrates and protein (Waghorn& Clark, 2004). Further, they require no additional nitrogen fertiliser and so may become increasingly useful as consumers demand the use of fewer chemicals in production (Waghorn& Clark, 2004). However, there is some suggestion of legumes being in general vulnerable to UV damage (Campbell, 1996).

There is also the potential for increased invasion of pastures by the subtropical grasses, like paspalum, which has already made it as far south as Waikato and the Bay of Plenty as well as limited parts of the Manawatu and Nelson (Campbell, 1996). Indeed, it managed a 1.5°southerly shift in latitude between 1976 and 1988 and will undoubtedly achieve further advances with climate change (Kenny, 2001). It is projected to reach coastal Taranaki by 2050 and the Manawatu properly by 2060 under a high emissions scenario (Kenny, 2000) and thus, there does seem a possibility of it reaching the Kāpiti Coast at some point in the future. It appears likely that subtropical grasses already present in the area, such as kikuyu will become increasingly dominant. The damage done to pastures by pugging and waterlogging as a result of the increased rainfall expected in the region may open up space for invasive subtropical species (Campbell, 1996). However, their advance southwards may be slow as such subtropical grasses are favoured by rainfall when temperatures are above 25°C, which is not as yet a frequent occurrence on the Kāpiti Coast, and may never become so should projections of lower summer rainfall hold true (Campbell, 1996). There is also some suggestion that increases in CO_2 concentration may make these C4 grasses less competitive compared to the currently established C3 ryegrass (Campbell, 1996) and additionally, they are often slow to establish themselves (Dodd et al, 2011).

There would be some advantages to a greater proportion of subtropical grasses in pastures. They grow better in the hotter conditions anticipated with global warming and will provide more feed during times when soil moisture is low (Kenny, 2001). Subtropical species are also better able to survive attacks by pests (Campbell, 1996).

However, invasion of pastures by subtropical grasses also presents problems. They tend to be less easily digested by ruminants, due to their higher fibre content, and thus encourage greater methane emissions from cows and sheep (Kenny, 2001). They are also less nutritionally beneficial. For example, 23% of temperate ryegrass dry matter is crude protein, whilst levels in common subtropical species range from only 8 to 17% (Campbell, 1996). The cost of providing additional feed for dairy cows to make up for the lack of nutrition in subtropical species could be as much as $250 per hectare, although the likely effect of CO_2 retarding C4 plant growth should keep this down to $75 (Dodd et al, 2011). Further, they have a less even pattern of annual growth and would struggle in any unusually cold season (Kenny et al, 2000). As temperatures in winter and spring are likely to be less favourable to subtropical grass growth than those in summer, there will be less energy available from pasture at crucial times of year for animals (Dodd et al, 2011).

4.2.5 Soil nutrients

Whilst this issue has not received the attention other aspects of climate change’s interaction with agriculture have, various authors have raised concerns about the impacts of global warming on soil nutrients. The Ministry of Agriculture and Forestry (2012) suggests that warmer temperatures may cause nutrients such as nitrogen, phosphorus and sulphur to become more mobile, meaning less is stored in soil organic matter, which may impede plant growth. This effect is expected to be most noticeable in winter, causing a deficiency in soil nitrogen come spring (Campbell, 1996). There are also suggestions that climate change may alter the flow of carbon in and out of soil, as warmer soils mean changes to current decomposition patterns and soil microbial communities (Frazer, 2009). The activity of some microorganisms is expected to increase with temperature so more carbohydrates are broken down, with increased fungal decomposition of lignin also ensuring less carbon remains in the soil (Frazer, 2009). However, some molecules will remain resistant to microbes and this unusable form of carbon will build up in soils (Frazer, 2009).

Further issues may arise with increased rain and storms eroding sediment and taking phosphorous, which binds to sediment, with it; unlike nitrogen, which dissolves in water instead (Kenny, 2001).

4.2.6 Pasture pests and disease

The extremes of weather which climate change is likely to bring may increase pest outbreaks as ecosystems destabilised by unfavourable conditions are made vulnerable and predator numbers are reduced (Lee et al, 2012). Insect pests like the clover root weevil and clover flea are expected to benefit from warmer conditions (MAF, 2010b), which will also allow plant pests currently prevalent only in northern New Zealand to spread further south (MAF, 2010c). Increased temperatures are also likely to reduce the time taken for insect eggs to hatch and larvae develop, although this may be counteracted by greater mortality in adults (Baars et al, 1990). Further, new and 'sleeper pests', those already in New Zealand but currently limited in number due to factors like temperature or host unavailability but which might become active under climate change scenarios e.g. the migratory locust, may become problematic (Gerard et al, 2010). Common plants like sorrel and acacia may make the transition to become pests in some regions (Gerard et al, 2010).

A further issue is that biocontrol techniques currently in use may cease to be effective. Biocontrol (the use of organisms to control pests) is currently employed to control the Argentine stem weevil, clover root weevil, blowflies and more and may suffer from climate change in multiple ways (Gerard et al, 2010). There may be discrepancies between effects on pests and theirbiocontrol e.g. with 2°C warming, aphids are anticipated to increase in number, but the parasitoid (a parasite which spends part of its lifecycle attached to the host and generally kills it) and ladybirds which control them are less likely to survive (Gerard et al, 2010). Similarly, the ragwort flea beetle may cease to effectively control ragwort in some areas of the Kāpiti Coast if rainfall increases significantly (Gerard et al, 2010). Increased temperatures may also give hosts a greater chance of surviving parasitoid attack (Gerard et al, 2010). There is also some risk of biocontrolparasitoids, upon losing their natural prey in the ways described above, starting to attack non-pest or native species instead (Gerard et al, 2010). However, predicting the likely effects of climate change on biocontrol is inherently uncertain, given the complexities of interactions between species at different trophic levels (Gerard et al, 2010).

Diseases are also likely to become more prevalent amongst pasture crops with climate change as their susceptibility increases. Fungal diseases in particular are set to benefit from warmer and wetter conditions, as well as rising winds, which will better distribute their spores (Baars et al, 1990). Higher CO_2 concentrations were also found by Baars et al (1990) to increase the number of fungal pathogens found on C3 grasses, although this is perhaps due only to increased leaf longevity.

4.2.7 Conclusion on climate change effects on pasture

As with many issues involving climate change, the factors affecting future pasture growth will be many and varied. It is thus no surprise that projections as to potential pasture yield vary significantly between reports. Campbell (1996) suggests an increase of 10-15% nationwide by the second half of this century, whilst Zhang et al (2007) suggests an 11-59% gain for the North Island's southwest. For the Kāpiti Coast region in particular, the models used by Baisden et al (2010) anticipate an overall increase in pasture production by 2050 of 2.5 to 15% for sheep/beef farms and 7.5 to 12.5% for dairy for a mid-range climate change scenario. However, these changes are highly seasonal with decreases of up to 10% and 5% in summer for sheep/beef and dairy respectively, whilst winter yields rise up to 20% and 25%. Whilst overall changes are not much different under a high climate change scenario, the disparities between winter and summer are more marked with sheep/beef pasture declining by up to 15% in summer but increasing 20% in winter, whilst for dairy these figures become minus 20% and +30% (Baisden et al, 2010).

There is thus much to be hopeful about in terms of future pasture production for the Kāpiti Coast. However, it should be remembered that the weather in a particular year will have perhaps the largest effect on pasture growth, and that all described here are general trends. Rainfall is perhaps the most important factor with 60% of variation in pasture growth reliant on spring and summer rainfall (Zhang et al, 2007). Temperature in winter and early spring may also have a significant influence (Zhang et al, 2007).

4.3 Animal Health

4.3.1 Heat and cold stress

Increasing temperatures in general and more days at the extremes are likely to increase the incidence of heat stress in dairy cattle, although Kāpiti will not experience the problems with this that the North Island's north and eastern regions will.

Dairy cows tend to start experiencing heat stress above 25°C, although modelling suggests that feed intake and consequently milk production begins to decline at 17.8°C, with decreases of up to 40% not uncommon above 25°C (Lee et al, 2012). Calves are even more susceptible to heat stress, and for best results should not be kept above 15°C (Lee et al, 2012). High yielding cows are also sensitive to heat stress as their basal-metabolic heat production is greater along with their milk yield (Lee et al, 2012). Such heat stress may cause rumen problems, as well as reducing conception rates and the health of newborn cows, who receive less protein and immunoglobulin from milk (Lee et al, 2012). Water requirements are also two to three times higher in heat stressed cows, which is likely to be a problem as hot weather is generally accompanied by water shortages (Lee et al, 2012). However, it should be remembered that cows will be able to acclimatise to long term increases in temperature which should reduce some of these effects, although this will not address the problem of extreme weather events (Lee et al, 2012).

However, cold stress in cattle, which occurs below -5°C, should reduce with warmer winters (MAF, 2010b). Calves are even less tolerant to cold, becoming stressed and experiencing increased mortality risk up to six months of age at below 13°C (Lee et al, 2012). As well as improving animal health, warmer conditions are expected to increase reproduction rates (MAF, 2010b). However, increased rainfall and high winds during winter months may generate some cold stress, particularly in young stock, even with warmer average temperatures

4.3.2 Animal Diseases

The increasingly warm and humid conditions expected with climate change may also affect the spread of diseases to stock. Fungi-related diseases in particular are expected to increase, and may cause damage to the liver and bile ducts of dairy cattle, as well as reducing overall immunity (Lee et al, 2012). Conversely, after heavy rainfall, standing in wet and muddy ground can increase the chance of mastitis and lameness amongst cattle, as well as encouraging the spread of parasites (Lee et al, 2012).

4.3.3 Other factors influencing dairy and sheep/beef farming

Factors other than climatic change may influence the development of the dairy and sheep/beef industries on the Kāpiti Coast.

One consideration for future dairy farms will be the potential addition of agriculture into the Emissions Trading Scheme, although this has been postponed indefinitely for the present (MfE, 2012b). Altogether, agriculture accounts for around half New Zealand's emissions, mostly as methane (Lundquist et al, 2011). However, the ETS is anticipated to have little impact on the dairy industry, as it is highly profitable with declining emissions per unit output, although increased fertiliser use may counter this somewhat (Baisen et al, 2010). Transport may also increase the cost of dairy farming in future with energy prices expected to become increasingly volatile over the coming decades. This is a particular issue for Kāpiti, as milk produced here must be taken 225km away to Hawera for processing, a cost which may become prohibitive in future, given the size of Kāpiti's industry does not warrant its own processing plant (Andrew et al, 2010).

Perhaps the biggest handicap to Kāpiti's dairy and sheep/beef industries is that the limited amount of land availableprevents expansion to utilise economies of scale. The problem is compounded by an increasing urban population occupying more land, with 200ha more expected to be required in the next 25 years (KCDC, 2010b). Climate change might make Kāpiti appear a more attractive prospect long term, as the already hot and dry agricultural regions of the country, like Hawke's Bay, the Wairarapa and the eastern South Island become increasingly more so. The droughts which already devastate these regions will be exacerbated, with a current 1 in 20 year drought under a medium-high scenario returning to Canterbury every 3.5 years, and the Hawke's Bay every 2.5 years on average (Mullan et al, 2005).However, it will be a long time, if it happens at all, before areas like the Kāpiti Coast become a more attractive location than the current agricultural centres in the east of New Zealand.

4.4 Conclusion: Climate change, dairy and sheep/beef farming

The following table summarises the effect climate change is expected to have on pastoral agriculture.

Expected benefits with climate change	**Expected costs of climate change**
• Longer and warmer growing seasons	• Drought decreasing the quality of

for pasture • Warmer conditions should increase the speed of pasture development • CO_2 fertilisation might increase the growth of pasture plants and increase tolerance to water stress • An increased proportion of legumes in pastures is expected to increase nutritional value and decrease fertiliser use • Decreased instances of cold stress in cattle	pasture • Flooding and waterlogging may decrease the growth of pasture • Increased soil erosion as a result of increased rainfall and wind • Faster growth may decrease the nutritional value of pasture plants, whilst increased UV may depress yields • Invasion of pastures by subtropical species may decrease their nutritional value • Climate change may also negatively impact flows of soil nutrients • Increasingly warm temperatures may result in pest outbreaks, whilst hindering biocontrol efforts • Diseases amongst cattle and pasture plants are likely to increase with warming • Warmer temperatures are likely to increase cases of heat stress in cattle

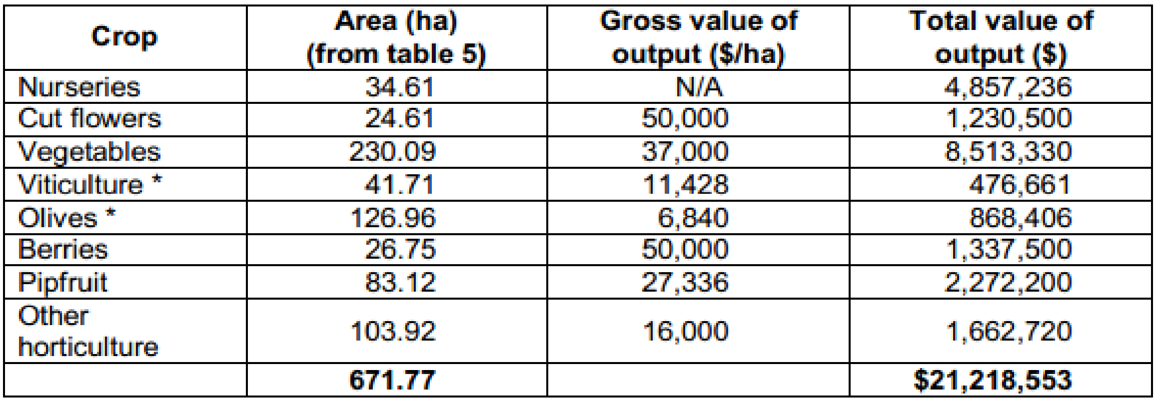
Overall, the impact of climate change through the interactions of the above factors on dairy, sheep/beef farming is uncertain. The Ministry of Agriculture and Forestry projects national dairy production will remain at 96-101% of current levels, whilst sheep/beef farming is expected to decline less than 9% as a result of climate change over the coming century (2007). However, during very dry years, this is expected to be reduced to 52 and 50% of present production levels (MAF, 2007). The models presented in that report appear to indicate a somewhat more favourable picture for the Kāpiti Coast District than for New Zealand as a whole, suggesting that even under a medium-high climate change scenario average production will remain around 90-100% of present by the 2080s, with production in abnormally dry years reduced to around 60-80% (MAF, 2007). However, these figures must be treated with caution.

It thus appears unlikely that climatic change alone will cause a decline or otherwise in the dairy and sheep/beef industries in the Kāpiti Coast District.

5 Climate Change and Horticulture

5.1 *Introduction*

It is Kāpiti's soils, such as the alluvial plains around the Ōtaki River, which make it so suitable a location for horticulture, with class 1 soils ideal for vegetable production, whilst berries, olives and grapes might be grown on class 3 (KCDC, 2010b). Horticulture currently contributes 58% of the $36 million Ōtaki receives from agriculture, whilst utilising 60% of the labour force but only 6% of productive land (dairy by contrast generates only 31% of Ōtaki's agricultural income using 60% of the land), hence the desire to expand the horticultural industry in the area (Mackay et al, 2005). The table below shows the current division of horticultural land in Ōtaki.



Crop	Area (ha) (from table 5)	Gross value of output ($/ha)	Total value of output ($)
Nurseries	34.61	N/A	4,857,236
Cut flowers	24.61	50,000	1,230,500
Vegetables	230.09	37,000	8,513,330
Viticulture *	41.71	11,428	476,661
Olives *	126.96	6,840	868,406
Berries	26.75	50,000	1,337,500
Pipfruit	83.12	27,336	2,272,200
Other horticulture	103.92	16,000	1,662,720
	671.77		**$21,218,553**

Table 3: Current size and value of horticulture in the northern region of the Kāpiti Coast. Source: Andrew et al, 2010.

Expanding horticulture has been repeatedly suggested as a strategy to enhance the Kāpiti Coast District's economy, especially in the area around Ōtaki, with a 50% increase in horticultural land (from 672ha to 1010ha) potentially adding 135 jobs and $9.3 million to the economy (KCDC, 2010b). Stretching this to 3000ha, which Sanderson &Dustow (2011) suggests is possible, would add $72 million to Gross Domestic Product and 1087 jobs. Further, there is potential to link into Wellington's supply chain (KCDC, 2011) as well as meeting local and regional food needs (Kāpiti Action Group, 2011). Additionally, horticulture may contribute to reducing greenhouse gas emissions, particularly if it is replacing dairy farming and is not fertiliser-intensive (Andrew et al, 2010). Horticulture has yet to reach its full potential in Ōtaki, with viticulture in particular able to increase production (Mackay et al, 2005). Olives also have significant potential to employ far more people in the district (Kaye-Blake & Allen, 2011).

This is not to say that there are not barriers to increased horticultural production in Ōtaki and the Kāpiti Coast, without even considering climate change. In terms of pipfruit production, Greater Ōtaki is not an ideal location, meaning fruit may need increased disease management and may not grow to their full potential (Andrew et al, 2010). In particular, the region is not as suited to apple growing as New Zealand's main production areas, but would still be competitive in the Australian market, recently opened up by a World Trade Organisation decision, although investment would be needed in coolstores and packhouses (Andrew et al, 2010). Areas of Ōtaki are particularly suited to wine production, although without strong branding, it is unlikely to break into such a competitive market (Andrew et al, 2010). Berry production may be an option for the Kāpiti Coast, although strawberries with their strong demand and longer shelf life are already monopolised by big commercial growers in Auckland and Waikato (Andrew et al, 2010). A few small growers already produce blackberries and raspberries in Greater Ōtaki, but have difficulty persuading supermarkets to stock them, as there is less demand and they perish quickly, so research would probably be needed into longer lasting varieties and the potential to supply local jam makers (Andrew et al, 2010).

In terms of this report, where information is available, the impacts of climate change on apples, grapes, olives, raspberries (as these are what Andrew et al (2010) recommend as the crops of choice for improving Ōtaki's economy) and vegetables specifically will be examined, being representative of most types of horticulture which could reasonably be anticipated in the region.

5.2 Higher annual temperatures

As for pasture production, increasing average temperatures should ensure a greater number of growing degree days (GDDs), so fruit should mature earlier and reach greater sizes, although it has been suggested that impacts in this area may be minimal for the next 50 years (Kenny, 2001). Olives, for example, should reach the 400 GDDs they require above 9.1°C before flowering at an earlier point in the year (Gutierrez et al, 2009), being positively affected by warmer spring temperatures (Avolio et al, 2012). Earlier planting and a later end to the growing season may allow more crop cycles and harvests throughout the year, although shorter development periods may reduce quality of produce as carbohydrates are not allowed to accumulate (MAF, 2010d). Fewer frosts, as a result of warmer temperatures but also increased moisture in the air in winter, will also be a significant advantage for wine production and other crops (Clothier et al, 2012). Similarly, frost damage two to three weeks before harvest has previously rendered 20% of oil made from the olives unusable, a situation unlikely to occur under extensive climate change (Clothier et al, 2012). Also, as frosts reduce and temperatures increase, there may be greater scope for planting subtropical horticultural crops like citrus and avocado commercially, although increased winds may keep down effective temperatures to prevent this (MAF, 2010b).

However, sufficient water is needed to make the most of potential gains from temperature (Kenny, 2001), whilst pollination during summer may be hindered by the heat, causing a reduction in yield (MAF, 2010d). There is also a risk of damage to fruit in hot weather, with apples getting sunburn or water core damage and grapes shrivelling, whilst premature development of seed heads may also be problematic (Clothier et al, 2012). Further, vine crops like grapes may not see the increase in size vegetables do, as increased temperatures tend to favour growth of leaves and roots, hindering development of the plants' reproductive elements (Clothier et al, 2012). Olives too may suffer in hot climates, with disruptions to the flowering process, fruit softening, a brown discolouration called pit burn disorder and reduced oil quality (Clothier et al, 2012); however, as olives are generally considered to grow best at between 15 and 34°C, even with climatic change they are unlikely to be damaged by high temperatures (Taylor & Burt, 2007). Berries may suffer from erratic bud break and uneven ripening under higher temperatures also (Anon., 2008).

One further difficulty with warmer temperatures is that they may prevent vernalisation, the 'accumulated chilling' some fruits, particularly berries, require to end their winter dormancy

(Clothier et al, 2012). Without this chilling, plants may be ‘overly dormant’, resulting in lower yields and quality, although there may also be a reduction in costs as growers need not hand thin the excessive flowering they might experience otherwise (Clothier et al, 2012). However, for some fruit such as grapes, hydrogen cyanide may be used to artificially end winter dormancy, although this will of course increase the number of chemicals used on products, something consumers are becoming increasingly concerned about (Clothier et al, 2012). Fewer cool nights may also reduce fruit colour, which is all important at market (MAF, 2010e).

Overall, in terms of temperature change, the picture does not appear too bleak for the Kāpiti Coast. As discussed above, olives should continue to grow well under most climate change scenarios, and indeed may do better for the increased heat. Apples and grapes are currently grown in the Hawke’s Bay in warmer conditions than Kāpiti might expect for many decades, even with significant climatic change. The raspberries suggested for Kāpiti by Andrew et al (2010) might fare worst under climate change with their ideal growing temperature of 20°C likely to be exceeded in summer under most climate change scenarios (Pritts, n.d.). However, as some raspberry varieties may be grown in summer temperatures not averaging more than 30°C, as long as they get at least 250 hours at below 7°C over winter, growers should still have some success, even with significant climate change (Menzies& Brien, 2002).

5.3 Changing rainfall patterns

The wetter winters/springs and drier summers expected as the climate changes may also be problematic. Should soils become waterlogged in spring, planting may be delayed and fewer plants are likely to survive (Clothier et al, 2012). Waterlogged soils also increase the chances of fruit and roots rotting, whilst a lack of oxygen reaching the roots will ultimately kill the tree (Clothier et al, 2012). Some growers in the U.S. are already struggling with root rot in raspberries due to warmer, wetter winters (Bainas, 2007). Additionally, wet weather may cause difficulties during harvest (MAF, 2010d).

Too little rainfall during summer may cause water stress to plants and consequently reduce yield and the size of fruit (Clothier et al, 2012), whilst drought may cause watercore (areas of fruit flesh becoming water-soaked and consequently hard and glassy) in various pipfruit (MAF, 2010e). Hot, dry winds may also reduce fruit set (the changing of a flower into fruit) (Clothier et al, 2012). However, some crops, such as olives, already grown in the Kāpiti District, are fairly resilient to drought. Additionally, Kāpiti has the advantage of currently, and for the foreseeable future even with climatic change, experiencing far fewer droughts than many of the country’s preferred fruit growing regions, and of not having fully allotted its water resources, unlike Nelson and the Hawke’s Bay (MAF, 2010e).

5.4 Damage from storms and high winds

With increasing storm severity, and possibly increased frequency, there is also a greater risk of damage to fruit, especially if a storm were to hit during a sensitive stage of development (Rutledge et al, 2011). However, no work appears to have been done on potential changes in the pattern of hail storms, which have previously cost the industry up to $10 million in a single event (Clothier et al, 2012).

High winds also may be very costly in terms of damage to horticulture (Mullan et al, 2011) and young trees in particular are at risk (MAF, 2010e). Further, wind can cause blemishes, wind-rub and other cosmetic damage, whilst reducing harvestable crop by encouraging fruit drops (MAF, 2012b). Pollination may also be impacted, whilst spraying may be rendered ineffective (MAF, 2012b).

5.5 Increased photosynthesis

As for pasture plants, increased CO_2 may act like a fertiliser, encouraging photosynthesis and consequently increasing biomass (Clothier et al, 2012). For those crops for which experiments have been undertaken, which include cucumber, squash and tomatoes, CO_2 has also been shown to increase flowering and fruit and vegetable production up to 30% (Clothier et al, 2012). Raspberry growth rates are also improved under elevated CO_2 conditions (Martin & Johnson, 2011). However, as with higher temperatures, this effect is likely to concentrate higher growth rates in vegetative parts of the plant, rather than fruit (Clothier et al, 2012).

5.6 Increased diseases and pests

Disease imposes significant limitations on horticulture (Clothier et al, 2012). Fungal-based diseases in particular are likely to benefit from a more humid climate (Baars et al, 1990). Beresford and McKay (2012) examined the likely effects of climate change on particular diseases affecting apples, grapes and onions. Apple black spot, they found, would likely increase with higher temperatures and rainfall, although currently projected changes will probably not have a significant impact as long as the fungicides, which must be applied 16 times a season, remain readily available (by no means guaranteed given most are petroleum-based) (Beresford & McKay, 2012). There is also concern that the fungus is beginning to develop resistance to sprays, a significant problem as a single black spot lesion renders an apple unfit for sale (Clothier et al, 2012). Grapevine downy mildew would again be little influenced by climate change, with more southern regions expected to attain similar levels as the Hawke’s Bay is already experiencing (Beresford & McKay, 2012). Onion downy mildew, which damages foliage causing a reduction in size and quality of onions, will again probably increase with climate change, requiring a continuation of the high levels of fungicide already applied (Beresford & McKay, 2012). Fruit rot is also likely to increase in moist weather (Clothier et al, 2012).

However, it should be noted that rather than just increasing the average risk of disease, climate change is likely to bring increased yearly fluctuation, with greater impacts further south (Clothier et al, 2012). There are also concerns that not only might fungicide become more expensive in the long term as oil supplies reduce, but that as consumers become more concerned by the chemicals applied to products, limits on fungicide and bactericide residue will remove the most effective way of keeping diseases at bay (Clothier et al, 2012).

As for pasture, horticultural production is likely to be limited by increased pest outbreaks as a result of climate change. Warmer weather will allow pests previously kept at bay by New Zealand’s temperate climate to expand their range, with the oriental fruit fly expected to reach much of New Zealand by the 2080s (Hennessey et al, 2007). Increased CO_2 levels are likely to increase the likelihood of crops succumbing to pest attack, whilst encouraging invasive weeds and bolstering their resistance to herbicides (Gutierrez et al, 2009). In the UK, even genetically pest-resistant raspberries are expected to come under increased attack from aphids under elevated CO_2 conditions (Martin & Johnson, 2011). Particular examples of pests which might benefit under climate change include the olive lace bug, which, in hot and humid weather, reduces foliage and thus fruit development, as well as exposing more fruit to sun damage; and the green vegetable bug, which in Australia in 2009 reduced saleable olives from 22 tonnes to only 3.5 (Sergeeva, 2011). Warmer weather may encourage fruit flies, which leave maggots in fruit, whilst the more favourable conditions may see more generations of coddling moth, woolly apple aphid and others in a year (MAF, 2010e). Warmer winters are also likely to kill off pests in much smaller numbers (McEwan, 2009).

5.7 Other factors influencing the horticulture industry

Even without considering climate change, there are a significant number of barriers to expanding horticulture in the Kāpiti Coast District. Firstly, there is the issue of finding markets for produce, as well as the knowledge, skills and labour to set up growing operations (Mackay et al, 2005). Competition from other regions will also be problematic as the Kāpiti Coast is too small to allow economies of scale. Even if this were possible, monocultures of a particular fruit or vegetable crop would not go anywhere towards encouraging self-sufficiency (KCDC, 2010b) and would make the region's economy particularly vulnerable to pest outbreaks or extreme weather. High land prices, due to competition with lifestyle blocks, despite Council's minimum limit on subdivision size for land with high quality soils to prevent just such an event, and a lack of infrastructure like packhouses forcing growers to incur significant transport fees, are further barriers (Kaye-Blake & Allen, 2011).

However, if such barriers might be overcome, Kāpiti's location may offer some advantages to the horticultural industry. Northern centres of production like the Hawke's Bay are likely to see much higher temperatures, with an extra 30-45 days above 25°C this century, whilst more regular drought conditions will also damage fruit. Meanwhile, southern regions like Canterbury and Otago are expected to see numbers of frosts, crucial to stimulate berry growth, reduce by up to 40 and 60 a year respectively (MfE, 2012c). Additionally, as transport becomes increasingly expensive, Kāpiti's location close to Wellington may become attractive. Further research is needed to determine the extent of the competitive advantage Kāpiti may develop.

5.8 Conclusion

The table below summarises the expected effects of climate change on horticulture.

Expected benefits with climate change	**Expected costs of climate change**
• Longer and warmer growing seasons • Reduced frost damage • Elevated CO_2 concentrations may encourage plant growth	• Increased damage to fruit through sunburn and watercore • Increased risk of water stress • Lack of winter chilling may inhibit berry growth • Waterlogged soils may damage plants • Possible increase in damage from storms and high winds • Increased risk from disease in hotter

	and wetter conditions - Increased risk from pests

Overall, a similar conclusion to that for pastoral agriculture may be drawn: that climate change in and of itself is unlikely to force any shift towards or away from horticulture in Greater Ōtaki or the Kāpiti Coast in general. Perhaps the biggest concern climatically would be higher winter temperatures potentially not chilling berry plants sufficiently, but given Kāpiti's current climate, a significant warming would be needed before this became an issue. Other horticultural centres are likely to suffer from this far more. In terms of storms, pests and diseases, these are likely to be accentuated in individual years, rather than being a continuous issue, and hopefully, with careful management, not present too much of a problem. High land prices, lack of a local skills base and competition from other regions will probably be more significant barriers to Kāpiti becoming a horticultural centre than climate change.

6 Climate change and native forests

6.1 Introduction

The Kāpiti Coast retains significant areas of native forest in scenic reserves such as Hemi Matenga, which contains 330ha of kohekohe forest, and in the Tararua Forest Park (Wellington Regional Strategy, n.d.). As well as being attractions for tourists and locals alike, they are important legacies for future generations. Further, native forest has the potential to sequester 324 tonnes of CO_2 per hectare over 50 years, offsetting some of the district's emissions (Climate Change (Forestry Sector) Regulations 2008). This option has been considered by the Kāpiti Coast District Council to offset some of its approximately 2,000 tonnes CO_2 equivalent emissions which cannot be eliminated by other means (Roos, 2012b), with large areas of public land viewed as potential locations (Roos, 2012a). Such carbon farming has the potential to make use of land otherwise too steep, liable to erode or lacking in fertility to be profitable for agriculture or forestry, whilst also protecting soils and intercepting water to prevent flooding (Rowson, 2007). Despite the enhanced carbon sequestering which might be achieved planting exotic pine forest, native forest is preferred given its additional benefits in maintaining biodiversity and helping protect remaining forest fragments (Roos, 2012a). Also native forest is overwhelmingly the ratepayers' preferred option over exotic, evidenced by the 20 environmental restoration groups in existence by 2009 (KCDC, 2010c).

Despite its cultural significance, carbon sequestering potential (which will only be of value if forests are able to survive well beyond the present century) and the 6.4 million hectares of indigenous forest remaining in New Zealand (Watt et al, 2012), no report appears to have been done on the likely effects of climate change on native forest species. However, multiple studies have been done on the more lucrative exotic pine forests, and some of this research may be applied to indigenous species also. In addition, this section endeavours to provide some useful, if general, information regarding native trees likely to make up a significant part of any carbon sinks. These include manuka (*Leptospermum scoparium*), kohekohe (*Dysoxylumspectabile*), tawa (*Beilschmediatawa*), nikau (*Rhophalostyissapida*), rimu (*Dacrydiumcupressinum*), northern rata (*Metrosiderosrobusta*) and kamahi (*Weinmanniaracemosa*) (KCDC, n.d.).

6.2 Increasing average temperatures and rainfall

In general, increasing average temperatures are expected to alter the composition as well as the distribution of native forests, with northern species expanding their ranges southwards as well as to higher altitudes, causing amongst other things, upland forests to be displaced by broad leaf species (Lundquist et al, 2011). However, native forest may struggle to adjust to new conditions as forest clearance reduces availability of seeds, whilst the birds which would have dispersed seed to more favourable locations have often been lost along with their habitat or to predation. The problem is also compounded by invasion of exotic weed species from nearby developed land (MfE, 2001). Higher temperatures may encourage growth of some plants, and perhaps increase wood density of trees, enabling them to store more carbon (Watt et al, 2012). A longer growing season would certainly be expected for deciduous trees (Watt et al, 2012).

However, lower summer rainfall increases the chance of water stress and drought. This may increase mortality of plants in its own right, as well as having indirect effects like increasing susceptibility to fire and pest attack (Dunningham et al, 2012). This may be a particular issue for native species preferring shaded, moist environments such as kamahi, tawa and kohekohe. Conversely, high winter rainfall on steep slopes may encourage soil erosion.

In reality, without a very dramatic change in climate, most native species which currently survive in northern areas of the North Island such as manuka, nikau, tawa, rata and rimuare likely to tolerate the warming climate projected for the next century(Northland Regional Council, 1999). However, kohekohe are not found in the hot, dry conditions of the Hawke’s Bay, with stands in Gisborne close to their tolerance limit, whilst kamahi is a southern species and may struggle to meet its soil-moisture needs during summer (Savage, 2006). Indeed, unpublished data from Landcare Research cited in a 2001 Ministry for the Environment report suggests that up to 7.5% of native species might be lost from the Kāpiti Coast area with 1.6°C warming.

6.3 Increased fire risk

Fire risk may be increased both directly and indirectly by a number of factors relating to climate change. Fire is a significant issue for many areas of native forest around New Zealand, with the potential to drain an entire carbon sink in one go. Higher temperatures, particularly in summer, will inevitably increase the risk of fire, as will reduced rain at this time of year ensuring potential fuel is drier (Dunningham et al, 2012). In addition, increased wind speeds may help fan any flames (Watt et al, 2012), whilst more thunderstorms (either from increased cyclones or convective storms caused by hot weather) increase the chance of lightning igniting native forest (Dunningham et al, 2012).

Changes within the forest community may also enhance the fire risk. The spread and greater growth of weeds may provide increased fuel (Dunningham et al, 2012). Processes on the forest floor may be altered with climatic change, as increased CO_2 levels may increase rates of decomposition, reducing the amount of material to burn, whilst an increased level of carbohydrate in organic material may have the reverse effect (Dunningham et al, 2012). Fire damaged areas are expected to be more easily colonised by pests (Dunningham et al, 2012).

Longer fire seasons seem almost inevitable for many areas under climate change, with the greatest increases expected in the west of the North Island (Watt et al, 2012). The Kāpiti Coast appears to be more fortunate than much of the Wellington area, which is projected to add a further 17.3 days to its fire season (the period for which an area experiences a high fire danger level) by the 2090s, effectively doubling its present length (Watt et al, 2012). The area around Paraparaumu is anticipated to add on only 4.7 days, although other areas of the district may see increases of up to 12 days (Watt et al, 2012).

6.4 Increased risk of wind damage

The increased winds (both in strength and frequency) anticipated with climate change means an increased risk of wind damage to native and plantation forest. At lower strengths, wind may simply prevent trees from reaching their potential width or height, whilst also encouraging erosion of particularly shallow or saturated soils (Dunningham et al, 2012). Winds above 50km/hr may do significant damage with young trees especially vulnerable (Watt et al, 2012). Of our indigenous trees, tawa in particular are at risk of wind damage, even when mature (KCDC, n.d.) Most wind damage is done by extra-tropical cyclones; cyclone Bola damaged over 26,000ha of planted forest in 1988 (Watt et al, 2012).

Despite all this, Watt et al (2012) suggests that it will be through other factors causing a reduction in growth rates and thus increasing the vulnerability of trees, rather than through increased winds, that climate change will most affect wind damage.

6.5 Increased photosynthesis

No specific research has been done on the impact of increased CO_2 concentrations on native forests, although from studies done on exotic species, the prevailing view appears to be that rising CO_2 levels will in general be beneficial, encouraging photosynthesis and therefore growth (Dunningham et al, 2012). In *Pinus radiata,* increasing CO_2 levels to those expected in the coming century caused a 179% increase in growth (other studies have found more conservative 30-50% increases in growth), although this reduced to 70% over the years as trees acclimatised (Dunningham et al, 2012). This acclimatisation is thought to occur within around two years as trees reduce their intake through their stomata, which in turn allows greater water use efficiency as less water vapour is allowed to escape through the open stomata (Mason et al, 2011). CO_2 has also been widely found to encourage fruit yields (Clothier et al, 2012). It has also been suggested that sensitivity to CO_2 increases with temperature, so even greater benefits might be expected as the climate warms, although there is as yet little experimental evidence of this (Dunningham et al, 2012).

However, Mason et al (2011) also report that studies undertaken at high profile American universities are beginning to suggest that higher CO_2 levels are only beneficial to forest species when temperature is kept at current levels and plenty of nitrogen and water is provided. Increased CO_2 may also decrease wood density, and thus the amount of carbon stored (Mason et al, 2011). There is, as always, a significant amount of uncertainty as to these results. The difficulty with predictions as to the impact CO_2 will have on ecosystems is that, unlike with temperature, researchers cannot simply go somewhere else to see what might happen under a different set of conditions (Watt et al, 2012). To discover what Kāpiti might look like with higher annual temperatures, we might examine conditions in Taranaki, Waikato or further north; this is simply not possible for CO_2.

6.6 Increased risk from pests and diseases

As for pasture and horticultural plants, climate change is likely to increase the vulnerability of native forest to attack by pests and disease. A warming climate may encourage invasion by subtropical, and even some temperate, exotic weed species better suited to the new conditions, which would outcompete native trees for soil and water resources (MfE, 2001). Native Australian species like eucalyptus and acacia perhaps pose the biggest threats, being better suited for warmer, drier conditions, although currently ornamental species like kudzu and broad-leaved paperback have the potential to become invasive also (MAF, 2010f). More frequent water stress may also make forest species less resilient to insect pests, like the native pinhole borer, which itself prefers dry conditions (Allen et al, 2002). Presumably, this would extend also to mammalian pests, including the possums already causing significant damage to native species like kamahi and rata (Allen et al, 2002). Increased temperatures, and possibly also CO_2 levels, encourage growth and reproductive rates amongst insect pests, creating further problems (Dunningham et al, 2012). Additionally, should pests' natural predators or pathogens be more severely impacted by a changing climate than the pest itself, outbreaks may occur (Dunningham et al, 2012).

Similarly, with disease, climate change is likely to increase the susceptibility of native forests. Increasing temperature and drought may encourage fungal diseases, increasing their reproductive capabilities and aggressiveness, e.g. *Sporotbrix*sp. which frequently kills otherwise healthy kamahi trees (Allen et al, 2002). Further, as pathogens reproduce so much faster than native trees, they will be able to quickly adapt to and take advantage of changing conditions (Dunningham et al, 2012).

6.7 Changing nutrient conditions

Climate change may disrupt the nutrient cycling processes so essential to a healthy forest community. A key part of this is decomposition, where organic material in soil is broken down to release CO_2, whilst nitrogen and phosphorus are mineralised into a form usable by plants (Watt et al, 2012). Increased CO_2 in the atmosphere means more will be taken in by plants, which along with higher temperatures may generate more growth, and consequently more leaf litter and soil organic material (Dunningham et al, 2012). This will tie up the nutrients, nitrogen and phosphorus, in soil organics meaning less is available for future plant growth (Watt et al, 2012). However, increased temperature may speed up decomposition and thus mineralisation of nitrogen to make it usable by plants, whilst at the same time, increased carbon to nitrogen ratios in organic material is slowing decomposition down (Dunningham et al, 2012). It is thus clear that there are many complexities in nutrient cycles and that the effects of climate change are far from obvious.

6.8 Conclusion

The table below summarises the possible impacts of climate change on native forests:

Expected benefits with climate change	Expected costs of climate change
• Longer and warmer growing seasons • Reduced frost damage • Elevated CO_2 concentrations may encourage plant growth	• Risk of native forests not being able to adjust to conditions due to loss of seed dispersers • Increased risk of water stress in summer • Increased fire risk • Increased risk of wind damage • Increased risk of pest outbreaks, as trees become more susceptible and insects thrive under new conditions • Increased risk of disease outbreaks • Possible disruption to soil nutrient cycling

Overall, the Ministry for the Environment's comment in its 2001 report still probably holds true: climate change on its own is unlikely to push native species to extinction or cause the deterioration of native forest; however, it probably will have a compounding effect when combined with other factors, like a sudden storm or fire. Temperature and CO_2 changes are likely to be too small to do significant damage in their own right, especially as plants will have time to acclimatise (Dunningham et al, 2012). Most danger comes at the extremes, with the droughts and wind events which are a natural part of climate variability made worse by changes in average conditions. However, individual extreme events are inherently unpredictable.

The other thing to remember is that few native species are at the end of their range in Kāpiti; most survive and indeed flourish further north, suggesting they will tolerate any changes brought on by climate change. The other advantage of this is that monitoring of any problems faced by more northern districts with their native forest may give Kāpiti advanced warning of issues to come. Ultimately, however, there is a conspicuous lack of research in the field of native forest and climate change which must be addressed before any firm conclusions can be drawn.

7 Climate Change Mitigation: *Miscanthus x giganteus* as a biofuel

7.1 Introduction

The previous sections of this report have focused on climate change adaptation: how the climate is likely to change and what that is likely to mean for different sectors. In contrast, the following section examines a mitigation option, something to contribute to reducing the impacts of climatic change in the first place by limiting the amount of CO_2 being emitted.

The focus here is on *Miscanthus* as a biofuel. Biofuels operate to reduce CO_2 emissions through replacing fossil fuels for energy generation (which can in some cases represents an 80-90% reduction in emissions (Chum et al, 2011)) and, in the case of plant-based biofuels, through sequestering carbon in the soil during growth (Clifton-Brown et al, 2007). They also form part of the US$2.1-6.3 trillion commercial opportunities surrounding environmental sustainability expected before 2050 (OECD, 2011). Further, by 2100, it is likely that New Zealand will have to meet a much greater proportion of its energy needs domestically as world resources decline whilst population and consumption increase (Rutledge et al, 2011). Indeed, the country could meet all its energy needs from woody biomass grown on 2 million hectares of currently marginal land (Rutledge et al, 2011). Biofuels also provide an area like the Kāpiti Coast with the ability to generate its own power, encouraging self-sufficiency as well as reducing its 323 kiloton CO_2e per year carbon footprint (Kāpiti Action Group, 2011). Woody biofuels in particular may be beneficial for the Kāpiti Coast, providing fuel for the wood fired sewage drier at the Paraparaumu treatment plant (Roos, 2012).

Miscanthus x giganteus(referred to here as *Miscanthus) is* a tall rhizomatous grass originating from tropical and subtropical Southeast Asia, which utilises the same C4 photosynthetic pathway as the invasive tropical pasture species examined in chapter 3 (Richter et al, 2008). It originated as a hybrid between two pre-existing *Miscanthus*species, *M. sacchariflorus* which is fast growing and produces considerable biomass in warm and wet conditions, and *M. sinensis*, which prefers colder conditions. The resultant hybrid is a highly productive grass which grows well in temperate climates (Heaton et al, 2012). *Miscanthus*has the potential to sequester 0.6-1.12 tons of CO_2 into the soil per hectare per year, whilst mitigating 4-5.3 tons per hectare per year when burnt in place of coal, according to European trials (Clifton-Brown et al, 2007).

*Miscanthus*is not new to New Zealand, although as yet is not widely utilised. Fonterra has around 30,000 plants at Darfield, where it is trialling burning *Miscanthus* in its processing plant in an attempt to cut coal use by 20% (Nelson Mail, 2011). Otago University has also been trialling *Miscanthus* at a former sewage treatment site (Otago Daily Times, 2012), whilst company Miscanthus NZ has 150,000 plants growing at 9 different sites for co-firing with coal (Miscanthus NZ, 2012).

The following sections explore the viability of *Miscanthus*as a source of energy for the Kāpiti Coast District.

7.2 High output to input ratio and low long term costs

One of the advantages of *Miscanthus* over other potential biofuel crops currently used worldwide, such as corn ethanol and switchgrass, is its high yield and energy content, despite low maintenance requirements (Brosse et al, 2012). Its energy output to input ratio is also particularly high at 15 to 20:1 (Christian et al, 2008). Unlike most biofuel crops which can only convert 0.1% of sunlight they receive to biomass, Miscanthus can manage up to 2% (Heaton et al, 2008).

Miscanthus also generates particularly high yields, although estimates vary significantly on what might be expected. Harvestable dry matter yields of around 20 tons per hectare have been recorded across Europe (Heaton, 2010), whilst smaller trials near Montreal yielded around 10 tons (Brosse et al, 2012). Some locations in Europe and the US have achieved up to 44 tons per hectare under favourable conditions (Brosse et al, 2012). There is as yet no estimate for potential yields under New Zealand conditions. However, high temperatures and rainfall tend to induce greater yields (Brosse et al, 2012), with reduced soil moisture causing yields to decline up to 23% (Richter et al, 2008).

Miscanthus does not require reseeding, with each stand remaining productive for 15 to 20 years even on otherwise marginal land (Heaton, 2010). Further, it has very few significant pests and consequently does not need regular pesticide application (Christian et al, 2008), reducing costs further. Whilst potassium and phosphorus fertiliser may be necessary, C4 crops in general require less nitrogen input than their C3 counterparts (Beale et al, 1996). *Miscanthus* in particular grows from a rhizome (an underground part of the stem), so when an autumn or winter frost halts growth, its nitrogen moves gradually into the rhizome to be reused by the plant the following year (Heaton, 2010). Thus, *Miscanthus's*long term upkeep costs are minimal.

7.3 Impacts on biodiversity

As mentioned previously, *Miscanthus x giganteus* is a hybrid of two pre-existing *Miscanthus* species. It is a triploid hybrid, meaning it has three of every chromosome, whereas most species like humans are diploid (have only two sets), and is thus infertile and unable to produce seeds (Heaton, 2010). Consequently, it is unlikely to be invasive as its parent species have been as it cannot spread nearly as quickly (Heaton, 2010). A further positive aspect of *Miscanthus*in terms of biodiversity is that it is usually harvested late, allowing any animals living in its fields to complete their lifecycles without being too disrupted (Heaton et al, 2008).

7.4 High start-up costs

The advantage of *Miscanthus* not being invasive due to its sterility comes at a cost. As *Miscanthus* has no seed, it must be planted using pieces of rhizome or live plants, which is far more expensive, given that the 4000 needed per acre cost over US$1000 (Heaton et al, 2012). Further, rhizome pieces are hard to plant as traditional machinery must be specially modified, adding to the cost (harvesting however, may be done using conventional hay equipment), and the young plants are particularly vulnerable to weeds for the first few months (Heaton et al, 2012).

7.5 High quality material for combustion

Miscanthus burns well and cleanly, yielding 17 to 20 megajoules of energy per kilogram (Brosse et al, 2012). Delaying harvest until late winter or early spring improves the quality of material for combustion as nitrogen, along with potassium, chlorine and sulphur, moves out of the stem and into the rhizome for re-use the following year (Brosse et al, 2012). Failing to wait for this to occur can lead to reduced efficiency as slag is created, as well as emissions of gases like nitrogen oxides and sulphur dioxide which are harmful to the environment (Brosse et al, 2012). A delayed harvest also gives the crop chance to dry out, which makes the resulting wood chips lighter and easier to transport (Brosse et al, 2012). However, the downside is that in delaying harvest until after winter, 30-50% of biomass may be lost through stem breakage (Heaton et al, 2012).

7.6 Potential uses of Miscanthus

In addition to being burnt as a fuel, there are a number of other potential uses for *Miscanthus* which might be explored, particularly if other regions decide to invest in it too. *Miscanthus* wood chips are already used for bedding, heating and electricity production in Europe (Heaton et al, 2012). Further, thermochemical conversion may be used to generate liquid biofuel which has potential for transport, although considerable expense would be involved in setting up a facility to do this (Brosse et al, 2012).

Whilst unlikely to be feasible in the near future given prohibitive start-up costs, *Miscanthus* may be utilised for bio-based products such as plastics and solvents. This may become increasingly important as fossil fuels run short, since 73% of products made from oil are plastic, and bio-based plastics are set to increase from less than 0.4 megatons in 2007 to 3.45 in 2020 (Chum et al, 2011). In the UK, research is already underway into utilising *Miscanthus* in biodegradable plastic car parts, in addition to the structural filler in parts like wheel trims it can already be used as. These parts will not degrade during the life of the car, but can be composted later (ScienceDaily, 2001). Research appears to be still ongoing.

7.7 Miscanthus production and climate

For *Miscanthus* to be considered for the Kāpiti Coast, it must be able to survive the changes expected with global warming. This it should be able to do. *Miscanthus* comes from tropical and subtropical regions of Southeast Asia, so will not experience declines as average temperatures increase (Beale et al, 1996). Increased spring rain and hotter, drier summers, as are expected under climate change scenarios for Kāpiti, tend to increase production (Maughan et al, 2012). Indeed, optimal conditions for *Miscanthus* growth are in the range of 30-35˚C (Maughan et al, 2012). One possible issue may be that a period of frost appears to be required to commence dormancy and the removal of nutrients like nitrogen to the rhizome (Maughan et al, 2012). Long periods of drought, should they occur, may also be problematic (Maughan et al, 2012).

Miscanthus is also unlikely to suffer from cold temperatures, despite its tropical origins, yielding over 20 tons per hectare in some parts of Northern Europe (Beale et al, 1996). This said, young plants may be vulnerable to temperatures below -3˚C, despite mature stands being able to withstand down to -26˚C (Maughan et al, 2012). Low temperatures do not affect rates of photosynthesis, allowing *Miscanthus*to grow in both warm and cool conditions (Naidu et al, 2003).

In terms of other consequences of climate change, most plants are expected to suffer from increased pest outbreaks as insects benefit from warmer temperatures. However, even intensive studies have failed to find any major pests to *Miscanthus* in the US at least (Bradshaw et al, 2010). Indeed, frequent pests, like aphids, are unable to survive on *Miscanthus* as it provides insufficient nutrients to sustain them (Bradshaw et al, 2010).

7.8 Conclusion

The table below suggests some of the costs and benefits of *Miscanthus* growth for Kāpiti:

Expected enablers of *Miscanthus* growth	**Expected barriers of *Miscanthus* growth**
• High energy output to input ratio • High yields • No need to reseed • Low requirements for pesticides and fertiliser • As a sterile hybrid it is unlikely to become invasive • Delayed harvest can result in high quality combustion material • Further opportunities through liquid fuel and bioplastics • Production is likely to increase with increased temperatures due to climate change • Few pests affect *Miscanthus*	• High start-up costs • Possible problems with reduced frosts not commencing winter dormancy

Whilst *Miscanthus* provides many opportunities, it is not simply the high start-up costs listed here which are likely to prevent it becoming a workable climate change mitigation technique on the Kāpiti Coast. *Miscanthus*is able to grow well on marginal land, a property which should be taken advantage of so that more fertile land might be utilised for agriculture and horticulture, which would generate higher returns. However, to harvest Miscanthus effectively by machine, said land would also need to be flat. The Kāpiti Coast District is severely lacking in such flat marginal land, as the majority of its soils are highly fertile and would be better used for the more profitable horticulture.

8 Conclusion

That New Zealand's climate is changing, along with that of the rest of the world, is no longer in doubt. Projections made using climate models provide the greatest insight into what the coming decades are likely to bring, although these are not without their uncertainties. Particularly when downscaled to the regional level, errors can occur and so model results should be treated with caution.

Projections for the Kāpiti Coast District suggest around 0.9°C of warming by 2040 and 2.1°C by 2090 on average (Baldi et al, 2007). Greatest warming is anticipated in summer, whilst the frost risk in winter declines and extreme temperatures are expected to increase, with the Wellington region anticipating between 15 and 45 more days a year with maximum temperatures above 25°C (MfE, 2012a). Average rainfall is set to increase in winter, but may decline in summer, whilst the greater capability of the atmosphere to hold water makes extreme rainfall events more likely (Baldi et al, 2007). More westerlies and strong winds are also expected (Baldi et al, 2007). However, it should be remembered that current sources of natural climate variability, such as the El Nino Southern Oscillation and Interdecadal Pacific Oscillation, will continue to act as the climate changes, sometimes enhancing, sometimes detracting from the effects of global warming.

Climate change will inevitably affect the primary industries operating on the Kāpiti Coast. Dairy farming currently brings $11 million annually to the local economy, whilst sheep and beef farming earn $2 million (Mackay et al, 2005). Changes anticipated include longer and warmer growing seasons and CO_2 increasing pasture production, whilst pasture quality may suffer through increased drought, flooding, soil erosion, UV and invasion of pastures by less nutritious subtropical species. Pest outbreaks may become more frequent also. Increasing temperatures will increase the incidence of heat stress and disease in cattle, whilst cold stress during winter decreases. However, climate change is only likely to be a compounding factor in either increasing or decreasing pastoral agriculture on the Kāpiti Coast, with issues like increasing transport costs, reduced land availability and greater demand for dairy products worldwide having an important part to play.

It has been suggested that horticulture is a sensible sector of the economy to grow in Kāpiti, with the potential to add millions to the local economy and increase employment, whilst making use of the region's high quality soils. The industry is likely to benefit from climate change through longer, warmer growing seasons, a reduction in frost damage and fertilisation of plants through increased CO_2 concentrations. Of concern, however, is the increased risk of sunburn damaging fruit, water stress and damage from storms and high winds. A lack of winter chilling may prevent berry growth, whilst disease and pest are likely to become a bigger problem. However, of greater issue for Kāpiti will probably be the high land prices, lack of skills and competition with other regions (although climate change's effects on other regions may make Kāpiti appear more attractive in the long term) which are the main barriers to increasing the region's horticultural production.

Despite its significance both culturally and as a means to sequester carbon, no research has been published on the effects of climate change on native forest in New Zealand. Once again, longer and warmer growing seasons, elevated CO_2 and reduced frost damage will likely aid plant growth, whilst forests suffer from increased water stress, fire risk, wind damage as well as a greater risk of disease and pest outbreaks. Further, the lack of seed dispersers due to reduced numbers of native birds may reduce native species' ability to adapt to changing conditions by changing location. This said, few native species are at the edge of their natural range in Kāpiti and many survive much further north so they are likely to tolerate all but the most extreme of possible climatic changes.

In terms of mitigation of climate change, *Miscanthus* as a solid biofuel appears to be a good option for the Kāpiti Coast, growing on marginal land to produce high yields of a high quality combustible material from low inputs in terms of pesticide and fertiliser. There is also potential for development of liquid fuel and bioplastics with investment. However, high start-up costs and, more importantly, a lack of flat land which would not be better suited to more lucrative agriculture or horticulture are significant barriers to *Miscanthus* being produced in large quantities in the district. However, should the factors discussed above prevent horticulture becoming successfully established in the area, *Miscanthus* may be a suitable second choice.

Thus, overall, climate change will undoubtedly cause changes over the coming decades, but it should not be viewed in isolation. In many cases, it will simply be a compounding factor, enhancing alterations in land use which are already taking place. As noted previously, no attempt has been made in this report to consider issues relating to sea level rise which may turn out to have significant impacts. However, the research above suggests that other climate change impacts will have only a weak influence on Kāpiti's development in future, although individual extreme events will have a significant impact in particular years.

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