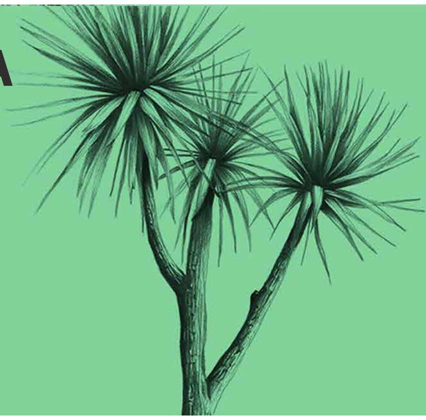
CLIMATE AND LAND-USE CHANGE: A SYNTHESIS OF LURNZ MODELLING



Motu Note #35 - May 2019

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SUMMARY HAIKU

Climate matters but
all climate models lead to
like outcomes for land.

INTRODUCTION AND KEY FINDINGS

Climate Changes, Impacts and Implications (CCII) was a four-year project (ending in September 2016) designed to tackle a broad research question:

> *What are the predicted climatic conditions and assessed/potential impacts and implications of climate variability and trends on New Zealand and its regional biophysical environment, the economy and society, at projected critical temporal steps up to 2100?*

The CCII project brought together an interdisciplinary research team with experience and modelling capabilities in climate, ecosystems, land and water use, economics and sociocultural research (Ausseil et al. 2017, Rutledge et al. 2017a, Rutledge et al. 2017b).

This note summarises Motu's contributions to the land-use modelling effort within the project. We completed simulations of land-use change using a version of the Land Use in Rural New Zealand (LURNZ) model that had been adapted to consider climate change scenarios. LURNZ results informed the analysis of impacts and implications at the national scale under Research Aim 3 (Identifying feedbacks, understanding cumulative impacts, and recognising limits) of the project, and at the catchment scale under the Lowland and Upland case studies of Research Aim 2 (Identifying pressure points, critical steps and potential responses). Our results complemented parallel simulations in the New Zealand Forest and Agriculture Regional Model (NZ-FARM), a model of land use run by Landcare Research.

Our key findings with respect to land-use change are that

- Future climate and future socio-economic outcomes could both significantly affect rural land use in New Zealand
- The amount and type of land use change is projected to vary significantly within the country
- Existing land use along with local geophysical and other features determine opportunities for land-use change. Accordingly, in some catchments land use is more sensitive to economic changes, and in other catchments it is more sensitive to climate change
- Uncertainty associated with climate modelling has relatively little bearing on land-use-economic outcomes

MODELLING STRATEGY

CCII scenarios were combinations of possible climate, socioeconomic and policy futures developed from the international literature. The project considered six scenarios, and one of these was selected for in-depth integrated analysis, including land-use modelling in LURNZ. Corresponding to a worst-case outcome, the selected scenario is characterised by high levels of radiative forcing and an economic future with high population growth, inequality and barriers to trade. The effects of assumptions embedded in this scenario were modelled for future biological productivity and future commodity prices. As explained below, changes in these two variables ultimately drove land-use change in LURNZ simulations.

Scenario Specification

CCII scenarios were New-Zealand-focused adaptations of six selected global scenarios developed under a global framework to support the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). The global scenarios are represented by pathways of possible future socioeconomic development (Shared Socioeconomic Pathway or SSP), radiative forcing (Representative Concentration Pathway or RCP) and policies for climate mitigation (Shared Policy Assumptions or SPA). The CCII scenarios augmented these global scenarios by specifying Shared Policy Assumptions for New Zealand (SPANZ) organised along considerations of mitigation and adaptation strategies and policies (Rutledge et al. 2017a).

Climate, population and macroeconomic modelling was carried out for six CCII scenarios, but a complete integrated assessment of impacts and implications including land-use modelling was only implemented in the Unspecific Pacific scenario (SSP3-RCP8.5-SPA0-SPANZ_A). It is a scenario characterised by high levels of challenges to both adaptation and mitigation.

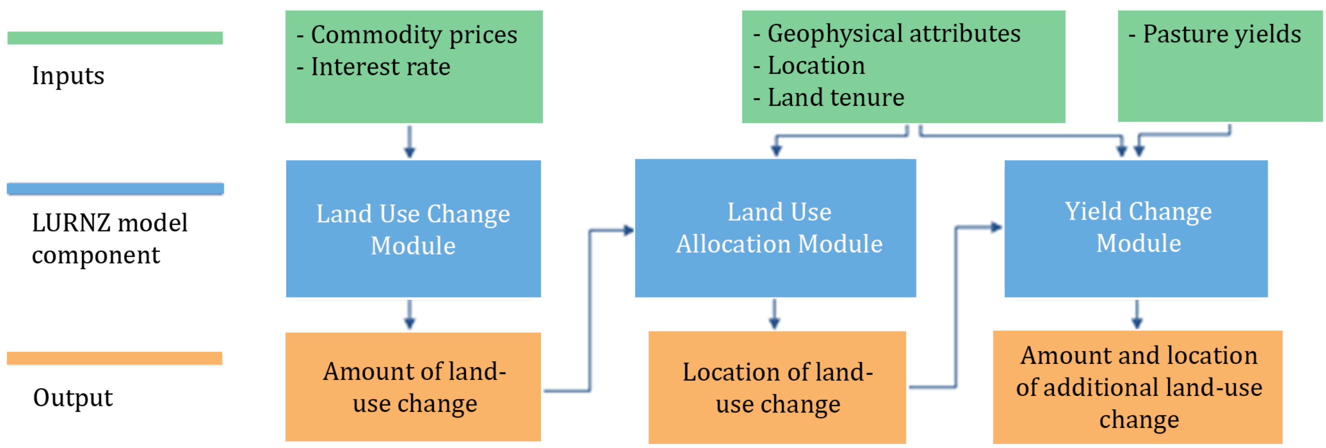
The Unspecific Pacific scenario is based on climate change under RCP8.5, the climate future with the highest greenhouse gas emissions – under this pathway, there is very little effort to curtail climate change on a global scale. The National Institute of Water and Atmospheric Research (NIWA) produced statistically downscaled climate projections from six Global Climate Models (GCMs) for New Zealand under different levels of radiative forcing, including RCP8.5. Simulated climate variables from NIWA's modelling were used as inputs into biophysical models of primary production, which in turn constituted the inputs for land-use modelling. This is described in more detail in the next section.

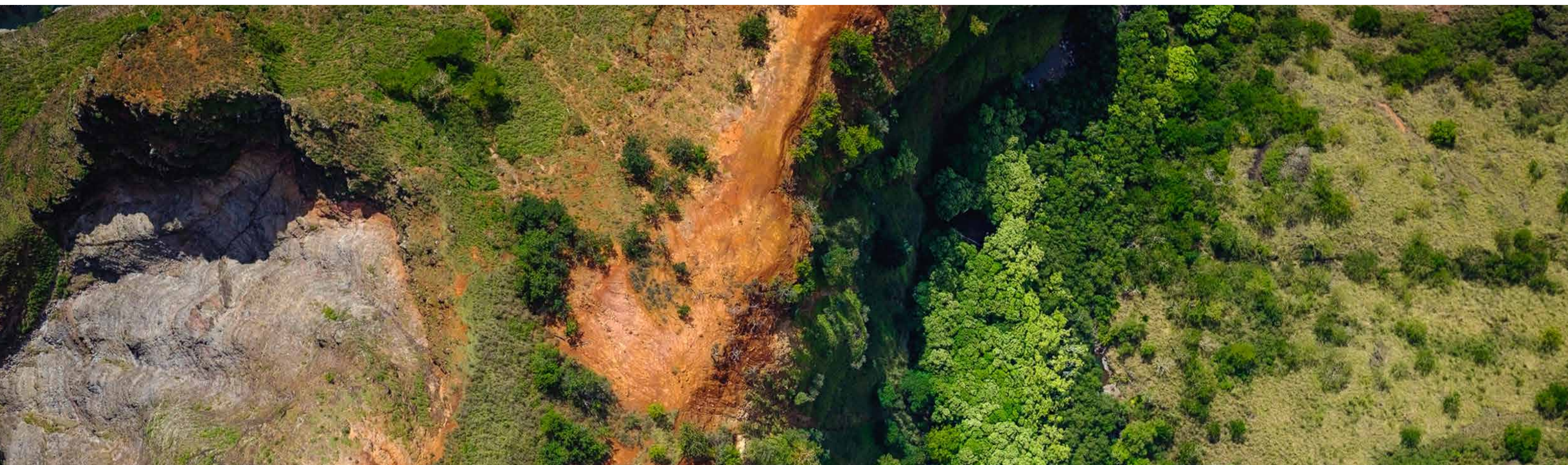
Describing a fragmented world with barriers to trade, high population growth and high inequality, SSP3 is a socioeconomic future thought to be consistent with RCP8.5. The economic parameters described in the next section are largely determined by assumptions embedded in SSP3.

The LURNZ Model

Land Use in Rural New Zealand (LURNZ) is a spatially explicit simulation model of national land use (Kerr et al. 2012; Anastasiadis et al. 2014). The foundation of LURNZ is provided by econometrically estimated models that establish the relationship between observed drivers of land use and land-use outcomes. A diagram of the model's main components used in the CCII project is shown below.

Figure 1. A schematic diagram of modelling land use in LURNZ





The Land Use Change Module is built around a system of regression equations that estimate dynamic land-use responses to changes in economic drivers, such as commodity prices, at the national level (Kerr and Olssen 2012, Kerr et al. 2012). These national land-use responses are allocated spatially across New Zealand in the Land Use Allocation Module. This module is parameterised using estimates from a multinomial logit discrete choice model relating observed land-use choices to various characteristics of the land and its location (Timar 2011). The Yield Change Module, developed for CCII to consider climate drivers of land-use change, also utilises a multinomial logistic regression. In LURNZ, climate drivers affect land use through their effect on pasture productivity (Timar 2016).

The revealed preference nature of LURNZ's underlying components enables us to make relatively few assumptions about farmers' objectives and decision processes: LURNZ results are largely driven by how land use has responded to its main drivers in the past. For instance, LURNZ does not require profit maximisation to be the main objective of farmers. Consequently, the model's data needs are modest, and it is generally robust and transparent. At the same time, this empirical foundation can lead to limitations associated with data quality. In particular, LURNZ simulations become less likely to accurately represent behavioural responses when future values of the explanatory variables lie outside their historical range or when these variables change in ways not reflected in their past behaviour. This feature of the model will have implications for the interpretation of results where projections of future commodity prices are beyond their sample range.

Climate parameters

In LURNZ, climate can affect land use indirectly through its effect on pasture productivity. Maps of net primary productivity, measured as mean annual total production in tonnes of dry matter per hectare, for sheep-beef and dairy pastures were produced in the Biome-BGC model by GNS Science (Keller et al. 2014). Biome-BGC incorporates biological and physical processes controlling carbon, water and nitrogen dynamics in terrestrial ecosystems. The most significant inputs to the model are daily temperature, precipitation, solar radiation, vapour pressure deficit (corrected for wind strength), day length, elevation and latitude.

Increasing degrees of climate change are projected to increase pastoral yields across most of New Zealand, primarily due to a carbon fertilisation effect that compensates for negative yield impacts of climate per se. Managed dairy pastures tend to experience slightly higher yield growth than managed sheep-beef pastures (increasing the relative attractiveness of dairying under climate change). Overall, pasture production is projected to increase by around 5-10% in most regions of the country under RCP8.5.

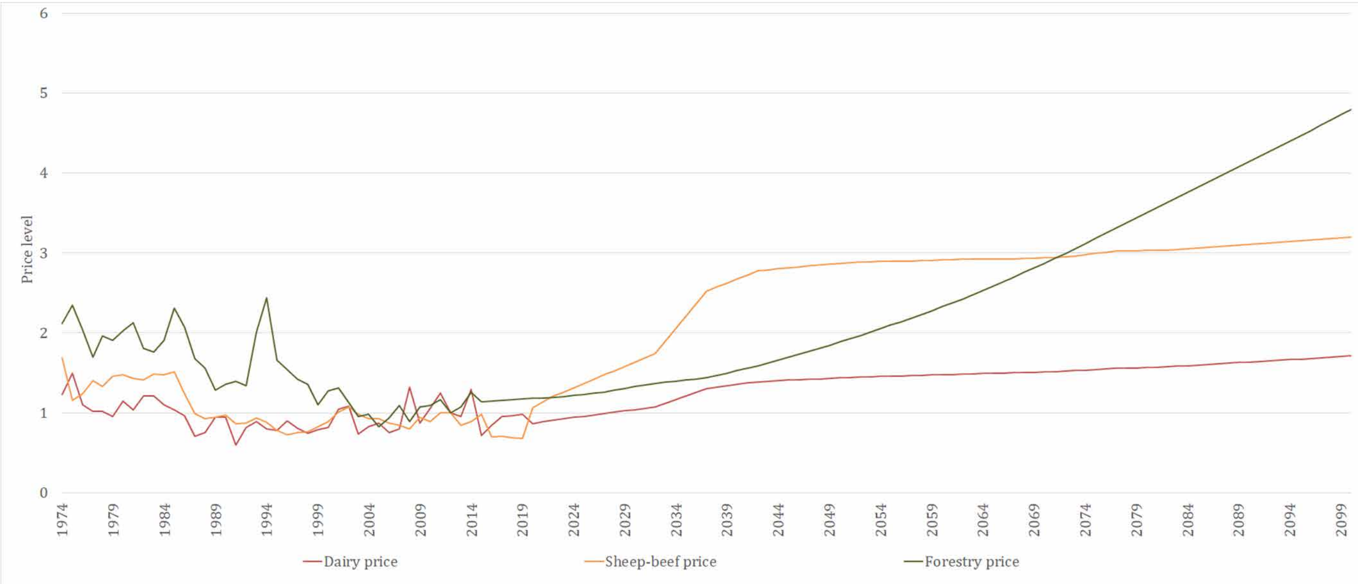
As reported by Timar (2016), LURNZ applies the estimated relationship between current pasture production and land use to projections of future pasture production under RCP8.5 – this drives climate-induced land-use change in the model.

Economic parameters

For short-term projections of commodity prices we consulted the Situation and Outlook for Primary Industries (SOPI) prepared by the Ministry for Primary Industries (2015). Beyond the SOPI projection years, The Climate Mitigation, Adaptation and Trade in Dynamic General Equilibrium (CliMAT-DGE) model was used to simulate global and New Zealand socioeconomic variables, including commodity prices, for all CCII scenarios. CliMAT-DGE is a multi-sectoral and multiregional, forward-looking dynamic general equilibrium model (Fernandez & Daigneault 2015). Commodity prices simulated to 2100 in CliMAT-DGE became inputs for the Land Use Change Module of LURNZ.

As the Unspecific Pacific scenario is associated with a socio-economic future (SSP3) characterised by high barriers to trade, population growth and inequality, simulated global commodity prices in this scenario tend to be high. In particular, CliMAT-DGE projects that prices for sheep-beef and forestry products increase far above their historical range by the end of the century. This is illustrated in Figure 1 showing historical and projected commodity prices scaled to the 2012 price level.

Figure 2. Historical and SSP3 commodity price projections (indices with 2012 base year)



All three prices are projected to exceed their historical maxima by the end of the century under SSP3 with sheep-beef and forestry experiencing nearly three and five-fold increases, respectively, from 2012. As such, the relationships between prices and land-use areas simulated in LURNZ, which are estimated by observing historical changes, may not hold for the high price projections.

LURNZ Simulations for Climate Change Impacts and Implications

The land-use simulations were designed to disentangle the effects of climate and economic drivers. Accordingly, four simulations were completed using a national version of LURNZ with a 25-hectare resolution. The simulations are:

1. Baseline runs apply Situation and Outlook for Primary Industries (SOPI) commodity price projections through 2019 and constant prices thereafter with current climate. The baseline serves as a reference against which other simulations can be evaluated.
2. Climate only runs hold prices at their baseline values, but allow climate to change under RCP8.5. Spatially explicit impacts on pasture yields were simulated in the Biome-BGC model.
3. Price only runs hold climate parameters at current values and allow only commodity prices to change. These runs are based on CliMAT-DGE price projections under SSP3 assumptions.
4. Combined runs accommodate changes in both commodity prices and climate. The two effects are additive at the national level (but not necessarily at other spatial scales).

All model runs start in 2012 and were evaluated at mid-century (2065) and end-of-century (2100) time frames. In addition to the national analysis, we also summarised simulations at the catchment level for two case study areas under Research Aim 2 of the project. The lowland case study area, lower Kaituna, is a relatively intensively managed catchment in the Bay of Plenty with a wide mix of land uses including dairy, sheep-beef, forestry, cropping, horticulture, viticulture, native forest, urban and conservation (Ausseil et al. 2017). The upland case study area, upper Waitaki, encompasses areas of high country of the Mackenzie Basin and surrounding watersheds, with extensive sheep-beef pasture and conservation land dominating the catchment's current land-use profile (Rutledge et al. 2017b).

SIMULATION RESULTS

Table 1 summarises land-use outcomes at the national level. Both price and climate effects are modelled for privately owned dairy, sheep-beef, forestry and scrub land in LURNZ. In addition, horticulture area can respond to climate-induced changes in yields. Other land uses are exogenous and are fixed at their 2012 levels.

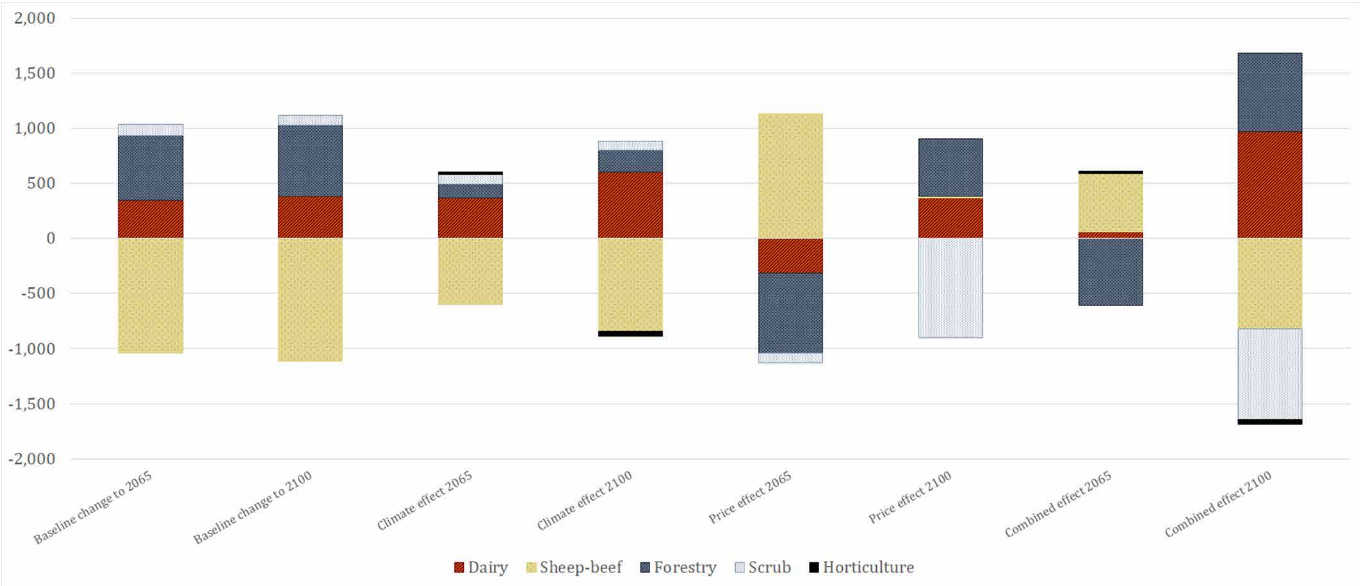
Table 1. Land-use areas by scenario nationally (1000 hectares)

	Baseline			Climate Only		Price Only		Combined	
Land use	2012	2065	2100	2065	2100	2065	2100	2065	2100
Dairy	1,694	2,042	2,073	2,414	2,679	1,730	2,440	2,101	3,045
Sheep-beef	6,366	5,328	5,253	4,727	4,411	6,459	5,271	5,858	4,429
Forestry	1,540	2,125	2,188	2,244	2,385	1,398	2,704	1,516	2,901
Scrub	1,338	1,443	1,424	1,537	1,508	1,351	523	1,445	607
Horticulture	394	394	394	412	351	394	394	412	351

Land-use change is projected to continue even in the absence of future climate and price shocks: under the baseline, dairy and forestry expand into current sheep-beef areas. These projections are driven by continual gradual adjustment to historical price changes and to SOPI commodity prices at the beginning of the simulation period. The projections suggest that, all else equal, land-use trends of the recent past will persist. Fixed climate and fixed prices under the baseline lead to land use approaching an equilibrium by 2065. Land use changes after 2065 are relatively small.

In order to better isolate the effect of various drivers of land-use change, the other scenarios are evaluated relative to the baseline. For instance, taking the difference between the 'Climate only – 2065' and 'Baseline – 2065' columns of table 1 suggests that favourable productivity shifts due to climate change under RCP8.5 cause dairy area to expand by an additional 372 thousand hectares by 2065. In figure 2, this difference is shown visually by the bar labelled as 'Climate effect 2065'. Similarly, the price effect shown in the figure is the difference between the 'Price only' run and its corresponding baseline. For reference, figure 2 also displays baseline change: land-use change that takes place from 2012 under the baseline scenario.

Figure 3. Land-use impact by LURNZ scenario nationally (1000 hectares)



The dominant impact of climate change is projected to be an increase in dairying and, to a lesser extent, forestry at the expense of sheep-beef farming. Scrub area also grows, likely because despite the overall increase in pasture productivity, some areas of the country experience negative yield impacts leading to the abandonment of marginal land. The magnitude of climate change grows over time, so end-of-century changes are larger than mid-century changes. These LURNZ results suggest that climate change will tend to reinforce land-use change that is already projected to occur under the baseline.

The estimated price effects are subject to the caveats on out-of-sample predictions previously noted. Nonetheless, they are plausible and intuitively consistent with commodity price movements in SSP3. Rapidly increasing sheep-beef prices early in the simulation period boost sheep-beef area by over a million hectares by 2065, and this more than offsets the decline the sector experiences under the baseline. All other land uses decrease (but this decrease is relative to baseline levels, not to 2012 areas). With the continued steady rise in commodity prices, productive land uses expand beyond baseline levels by the end of the century. Driven by a large increase in the price of forest commodities, forestry experiences the largest growth in area relative to other productive uses. Dairy also increases significantly, while sheep-beef, declining from its mid-century peak, falls back to close to baseline levels. A large decrease in scrub area is required to accommodate these changes.

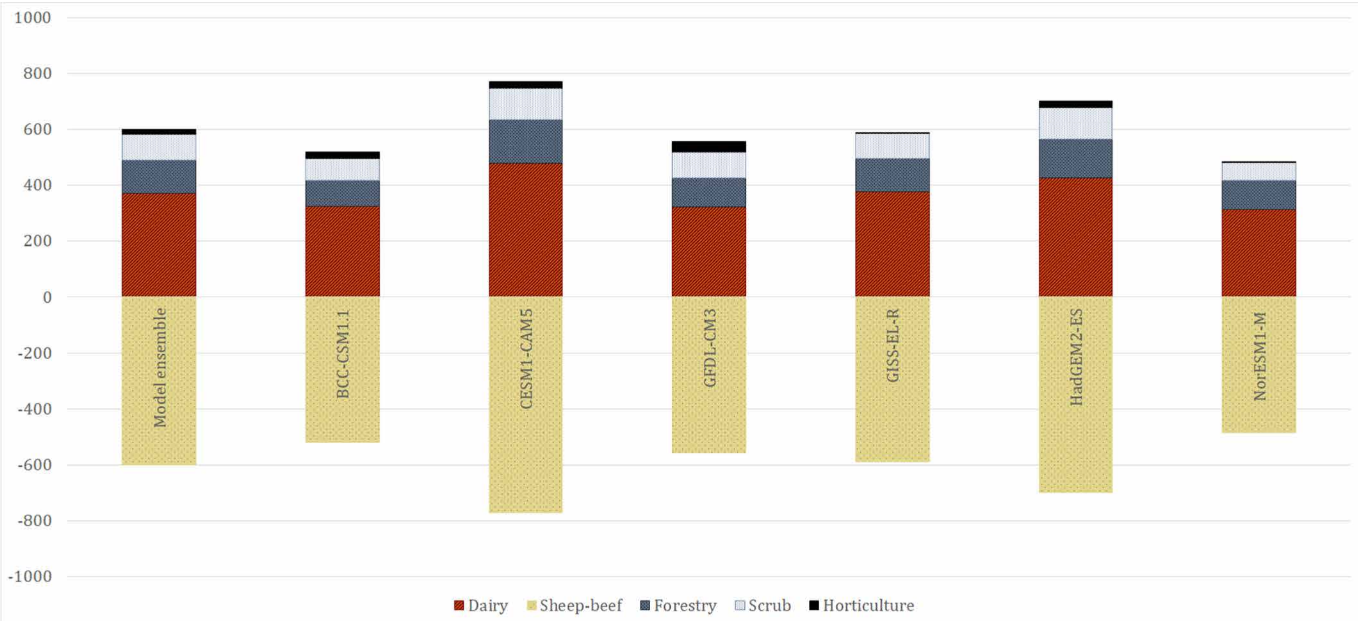
Nationally the price and yield effects are additive, so the combined effect is the sum of the two individual effects. At mid-century, economic and climate drivers work in opposing directions for the modelled land uses, but they become more aligned in the long term. In view of baseline land-use shifts, these results strongly suggest that in a world portrayed in the Unspecific Pacific scenario, dairy and forestry will replace a significant portion of today's sheep-beef (and scrub) land nationally by the end of the century. Land-use changes of the projected magnitudes are not unprecedented or even unusual at these time scales. For example, the area of dairy farming in New Zealand doubled in the four decades prior to 2012.

Climate modelling uncertainty

Projected climate impacts in the previous section are based on a model ensemble: modelled pasture production was averaged across Biome-BGC runs with future climates from each of the six individual GCMs under RCP8.5. The mean of pasture production from this ensemble was simulated in LURNZ in the results above.

The effect of climate modelling uncertainty was tested by repeating the integrated analysis of yields and land use on the climate output from the individual climate models. These simulations revealed that the choice of a climate model has relatively little bearing on land-use outcomes: the projected land-use change under all six GCMs is consistent with the model ensemble results. This can be clearly seen in figure 2, where the first bar replicates the mid-century model ensemble climate effect from figure 1, and the remaining bars correspond to projected climate effects under a particular GCM. End-of-century outcomes, though not reported here, are likewise similar across all climate models (Rutledge et al. 2017a).

Figure 4. Projected mid-century (2065) climate effect by climate model (1000 hectares)



Catchment Scale Analysis

The national level results presented above were based on aggregations of results at the 25 ha resolution. We also investigated more local impacts and implications by performing the aggregation at the catchment scale. In each catchment, results depend on existing land use in that catchment, its geophysical endowments and other characteristics. In some parts of New Zealand land use is more responsive to changes in commodity prices and other economic variables, while in other parts, it is more responsive to changes in climate.

Our catchment-scale analysis focused on case studies for the lower Kaituna and upper Waitaki catchments as these catchments are thought to represent key features of typical lowland and upland ecosystems in New Zealand. Detailed integrated analyses of lower Kaituna and upper Waitaki are included in Ausseil et al. (2017) and Rutledge et al. (2017b), respectively. A summary of key findings with respect to land-use change is reported here.

Conforming to national trends, both catchments are projected to experience a loss of sheep-beef pasture under the baseline scenario. In the lower Kaituna, most of the lost area is afforested, but some marginal sheep-beef land is also abandoned to scrub, and patches of high-quality pasture are projected to be converted to dairy farming. In the uplands of upper Waitaki, nearly all of the lost sheep-beef area is left to scrub reflecting the abundance of low-quality extensive pastures in that catchment.

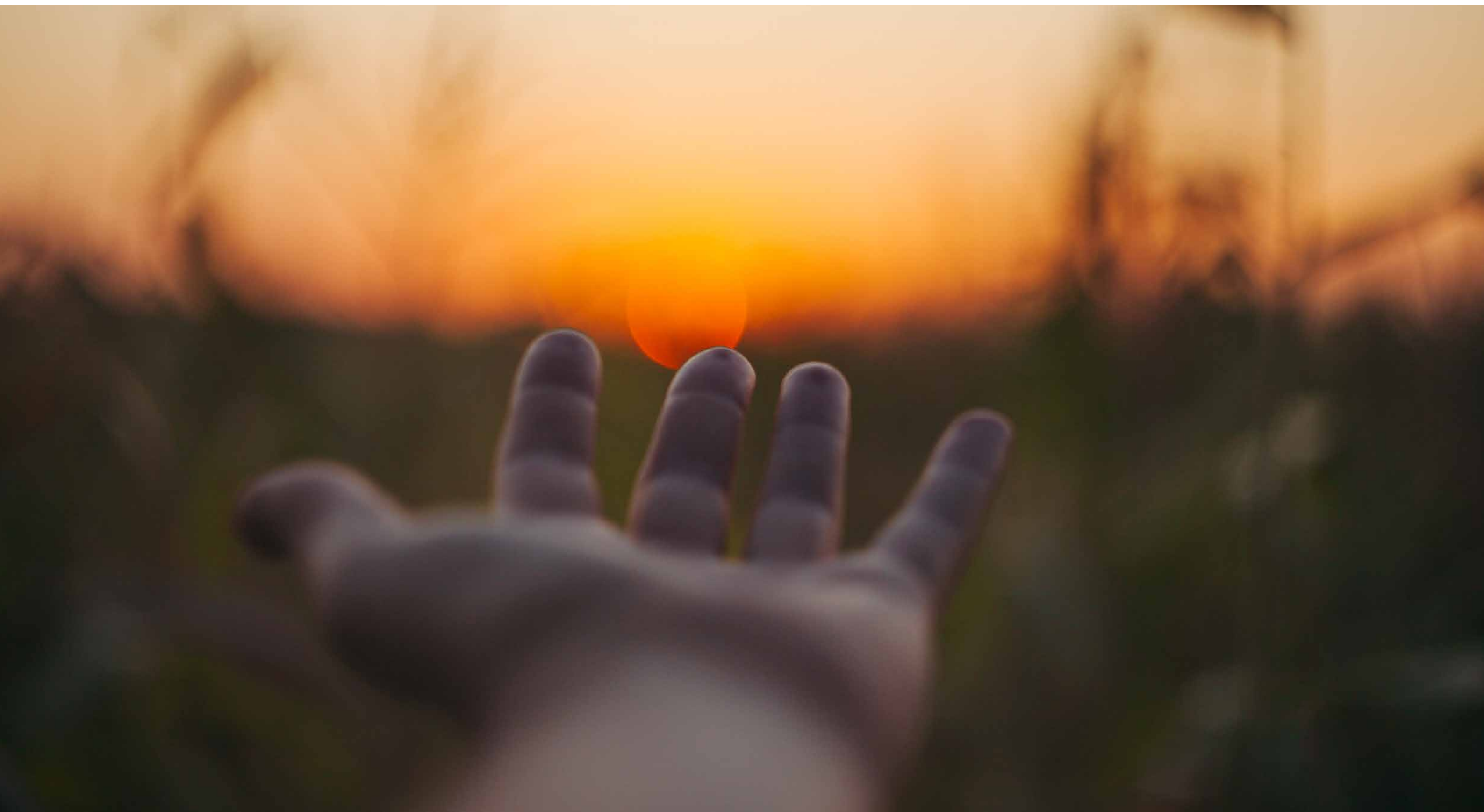
Similar to the national scale findings, high SSP3 meat prices at mid-century effectively reverse these baseline changes in both catchments. By the end of the century, the price effect causes both dairy and forestry to rise above baseline levels in the lowlands catchment, while sheep-beef and scrub fall. At the same time, afforestation becomes the dominant type of land-use change in the upland catchment.

The land use and land quality profile of the catchments also influences the way in which climate change affects land use. In the lowland catchment, reflecting increasing pasture yields, the climate effect is projected to lead to significant additional dairy conversions from sheep-beef farms. On the other hand, climate change has almost no impact on simulated land use in the upland catchment as dairy farming is not a feasible land-use alternative in most of the catchment. As a result, the price effect drives land-use change in upper Waitaki. However, in lower Kaituna climate change is projected to have a larger impact on land use than changes in commodity prices.

DISCUSSION AND CONCLUSION

While both the price and the climate effects are projections based on econometrically estimated relationships, the features of the underlying datasets and models lead to some important caveats for directly comparing the two effects. Land-use responses to price changes are modelled dynamically via time series techniques. In LURNZ, it may consequently take several years or even decades for simulated land use to fully adjust to a commodity price shock. In contrast, responses to yields are estimated from cross-sectional data. These represent steady-state relationships that cannot capture the process and speed of adjustment to shocks. A direct comparison of the projected price and climate effects at any point in time may therefore give too much weight to the climate effect (because, unlike the land-use response to climate signals, the full response to price signals does not unfold immediately).

It is also important to bear in mind that projected changes in pasture productivity are determined solely by changes in mean climate variables. The effect of climate variability and of extreme events such as droughts and floods on primary productivity was not accounted for in Biome-BGC. Neither was the potential increase in risks associated with biotic agents causing crop damage – for example, insects, pathogens and weeds. These factors would be expected to negate some of the yield growth attributed to changes in mean climate, so modelled yields are likely to be overly optimistic. In other words, New Zealand's future climate may be less suitable for pastoral agriculture than the results based on mean climate suggest: climate change may lead to fewer dairy conversions and more abandonment of marginal sheep-beef land.



The interplay of the two factors highlighted above (delayed price responses and climate variability) means that the modelled climate effect is likely amplified relative to the price effect. In addition, the uncertainty associated with future commodity prices and policies is large – it is likely larger than the uncertainty associated with future climate. While formal sensitivity testing to commodity prices was not part of the CCII project, other research has shown that changes in economic incentives can have a large effect on land use change (New Zealand Productivity Commission, 2018).

Finally, radiative forcing is high under the Unspecific Pacific scenario in part because the scenario assumes that no mitigation policies against climate change are in place. Such policies could significantly affect the incentives for land-use change. However, even in the absence of climate mitigation, there may be other constraints on future land use in New Zealand. For example, environmental regulations for freshwater quality are expected to limit the extent of intensive pastoral agriculture in the future (New Zealand Productivity Commission, 2018). Such environmental policies could affect the feasibility of the modelled land use changes, further restricting the projected pastoral intensification under climate change.

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