Land Use and Farming Intensity:
For 1996, 2008 and 2020

Simon Anastasiadis and Suzi Kerr

Motu Economic and Public Policy Research

Report for the Parliamentary Commissioner for the Environment

November 2013

Author contact details

Simon Anastasiadis
Motu Economic and Public Policy Research
Type email

Suzi Kerr
Motu Economic and Public Policy Research
suzi.kerr@motu.org.nz

Acknowledgements

We thank Alex Olssen, Levente Timar, Wei Zhang and Hugh McDonald (all of Motu Economic and Public Policy Research) for their input into the design of the LURNZ allocation algorithm. We also thank Alex Olssen for the summary note he provided on the forecasting of future changes in land use and Corey Allan for the most recent runs of LURNZ.

Motu Economic and Public Policy Research

PO Box 24390
Wellington
New Zealand

Email	info@motu.org.nz
Telephone	+64 4 9394250
Website	www.motu.org.nz

Contents

Table of Figures

Table of Tables

1. Introduction

This paper documents the production of land-use maps and measures of farming intensity for 1996, 2008 and 2020. These maps and measures of farming intensity are produced to be compatible with the Catchment Land Use for Environmental Sustainability model (CLUES) developed by NIWA.

This paper is set out as follows: In the remainder of this section we give an overview of our work. The production of land-use maps is discussed in section 2, and the production of measures of farming intensity is discussed in section 3. Section 4 concludes.

1.1. Producing land-use maps

We produce the 1996 and 2008 land-use maps by combining existing maps of land cover with data on land-use areas. The production of the 2020 map involves the simulation of anticipated changes in land use. The LURNZ allocation algorithm is used in the production of each of the maps.

We observe land cover in 1996 and 2008. It follows that producing land-use maps for these years only requires us to distinguish between different land uses that have the same land cover: in particular, to separate pasture land cover into dairy and sheep/beef farming. For each of these maps, we start from observed land use in 2002 and calculate changes in dairy and sheep/beef land according to industry statistics. These changes are spatially allocated by the LURNZ allocation algorithm.

Land use in 2020 can be simulated from the 2008 land-use map using the LURNZ model. Changes in land use are estimated from projected commodity prices and spatially allocated using the LURNZ allocation algorithm.

As New Zealand has implemented an emissions trading scheme for greenhouse gas (GHG) emissions, we replace commodity prices with effective commodity prices that account for the value of carbon. Due to the uncertainty associated with the value of carbon, we produce two 2020 maps: one assuming a price of \$25 per tonne of CO_2-equivalent, and the other assuming a price of \$5.

1.2. Trends in farming intensity

To complement our maps of land use, we produce indicators of farming intensity for 1996, 2008 and 2020 by regional council area. We define farming intensity as production per hectare (kg milk solids per hectare for dairy farms, kg meat and/or fibre per hectare for sheep/beef farms). It follows that, changes in farming intensity can be decomposed into changes in stocking rates and changes in production per animal.

For dairy farms: we consider trends in production per hectare directly from the Dairy Statistics Reports (LIC and DairyNZ, dataset, 2010). For sheep/beef farms: we use data from Meat and Wool Economic Service (now Beef and Lamb New Zealand) to consider trends in stocking rates (Meat and Wool Economic Service, dataset, 2009). We proxy production per animal using methane emissions from the Greenhouse Gas Inventory (Ministry for the Environment, 2010).

2. Land-Use Maps

We produce four maps of land-use: one for each of the years 1996 and 2008, and two for the year 2020 under different carbon price assumptions. The LURNZ allocation algorithm is used in the production of each of the maps. We first describe the construction of the 2008 and 1996 land-use maps. The LURNZ allocation algorithm is described second, followed by the construction of the maps for 2020.

2.1. Map of land use in 2008

We construct the map of land use in 2008 by combining together four maps. Changes in pastoral land uses are simulated according to the LURNZ allocation algorithm.

Agricultural land cover in 2008 is identified according to the Land Cover Database, version 3 (LCDB3) (Landcare Research, dataset, 2012). This enable us to classify the entire country into pasture, plantation forestry, scrub, horticulture, non-productive, urban, or indigenous forest land (see

Table 12 in the appendix). Public land is identified and classified separately according to an ownership map (Landcare Research, dataset, 2008). We differentiate between pasture on public land and all other public land. Where necessary, the Average Carrying Capacity (CCAV) map (Landcare Research New Zealand, dataset, 2002) is used to identify public land that is not suitable for animals.

As LCDB3 is a land cover map, it does not enable us to distinguish between different pastoral land uses (such as dairy and sheep/beef farming). In order to consider the spatial distribution of pastoral land uses within each TA, we use the LURNZ 2002 land-use map to provide an initial decomposition of the pastoral land into its different land uses.[1] Pastoral land in 2008 that was classified as dairy or other animal and lifestyle in 2002 is assigned to its respective land use. All other pastoral land is assumed to be sheep/beef farming.

This gives us a 2008 land-use map with 2002 pastoral land uses. We estimate pastoral land use in 2008 by spatially allocating changes in dairy and sheep/beef land from 2002 to 2008 using the LURNZ allocation algorithm. Due to data limitations, land used for other animals and lifestyle properties is assumed to remain constant between 2002 and 2008.

The amount of land used for dairy farming in each TA in 2008 is given by the Dairy Statistics reports (LIC and DairyNZ, dataset, 2010). In this data, TAs that contain fewer than five dairy herds have been merged with neighbouring TAs to preserve anonymity. For our work we consider TAs separately or in pairs, as necessary, to be consistent with the data. Annual changes in dairy land are calculated using simple linear smoothing between the areas given from the 2002 map and the areas from the dairy reports. Changes in sheep/beef land are assumed to be equal and opposite.

Simple linear smoothing is used as it reduces the year-to-year fluctuations in reported land-use areas. This minimizes the 'churning' or reshuffling of land uses while still resulting in the correct final quantity of each land uses.[2] We minimize churning as rural land-use change is a slow process (Kerr and Olssen, 2012) and churning increases the amount of land-use change that takes place.

The TA level changes in pastoral land are spatially allocated within each TA using the LURNZ allocation algorithm. For the construction of the 2008 map we constraint the algorithm

[1] The LURNZ 2002 land-use map is a baseline map in LURNZ. It is constructed by combining the same data sources as are used in the construction of the 2008 map, with an additional data source that enables it to distinguish between different pastoral land uses: the Agribase Enhanced LCDB2 map (AsureQuality, dataset, 2008).

[2] The 'churning' of land uses occurs in LURNZ where the location but not the quantity of land uses changes. Churning of land can occur across years (for example: a decrease in dairy land one year, followed by an increase in dairy land the following year) and within a single year (for example: where forestry is converted to dairy land, and then sheep/beef land is converted to forestry).

to allow only changes in dairy and sheep/beef land, and to simulate at the TA level (by default LURNZ simulates changes in dairy, sheep/beef, forestry and scrub land at a national level).

It follows that our final map of 2008 land use should be consistent with observed 2008 land cover, and historic counts of land use areas. The final 2008 map is given by Figure 8, and land use by regional council is given by Table 7, in the appendix.

2.2. Map of land use in 1996

We construct the map of land use in 1996 following a very similar process to the construction of the 2008 map: Agricultural land cover is identified according to LCDB3, and public land is identified according to an ownership map, using the CCAV map where necessary.

As with the 2008 map, we use the LURNZ 2002 land-use map to provide an initial decomposition of the pastoral land cover into its different land uses for the 1996 map. From this initial decomposition we would like to spatially allocate changes in dairy and sheep/beef land to construct our final 1996 map. However, the Dairy Statistics reports (LIC and DairyNZ, dataset, 2010) only provide dairy areas back to 1998.

In order to estimate the area used for dairy farming in each TA in 1996 we extrapolate the local time trend (between 1998 and 2001) back in time using linear regression. Our resulting national trend in dairy areas is consistent with the national trend in dairy areas given by Kerr and Olssen (2012) using Meat and Wool Economic Service data.

Given estimates of dairy areas in 1996, annual changes in dairy land are calculated using simple linear smoothing. Changes in sheep/beef land are assumed to be equal and opposite. The resulting TA level changes in pastoral land are spatially allocated within each TA using the LURNZ allocation algorithm, constrained as per the construction of the 2008 map.

It follows that our final map of 1996 land use should be consistent with observed 1996 land cover, and largely consistent with historic counts of land use areas. The final 1996 map is given by Figure 7, and land use by regional council is given by Table 6, in the appendix.

The use of the same data sources for the construction of both the 1996 and 2008 maps does not imply that the maps are almost identical. While LCDB3 is a single data source, it contains separate maps for the years 1996, 2002 and 2008 based on satellite photography taken in the summers of 1996/97, 2000/01 and 2008/09 respectively. The correct LCDB3 map is used during the construction of each land-use map. The only data that does not vary between the 1996 and 2008 (and 2002) maps are the maps used to identify public land. This means that there is no change in public land between our 1996 and 2008 maps. As we expect that changes in public land are slow, this seems to be a reasonable assumption.[3] Land-use changes between the 1996 and 2008 map are given by Figure 11 and Figure 12 in the appendix.

2.3. The LURNZ model

The Land Use in Rural New Zealand model is a dynamic, partial equilibrium model developed by Motu Economic and Public Policy Research.[4] Maps in LURNZ are constructed from a grid of pixels with each pixel possessing a single land use. The resolution of the map determines the size of each pixel. Typically LURNZ uses a 25 hectare resolution (each pixel represents a 500m x 500m block of land). To match the detail in CLUES, for this paper we use a 1 hectare resolution (each pixel represents a 100m x 100m block of land).

For producing maps of land use, we use the LURNZ allocation algorithm: the module in LURNZ that allocates changes in land use across space. Only dairy, sheep/beef, plantation forestry and scrub land are endogenous in the allocation algorithm; these are historically New Zealand's major rural land uses. All other land uses (horticulture, non-productive, urban, pasture for other animals, lifestyle blocks, indigenous forest, and public land[5]) are treated as exogenous. A summary of the land uses included in our maps is given in Table 10 in the appendix.

2.3.1. Conceptual model

In this section, we describe the conceptual model that informs the design of the LURNZ allocation algorithm. We limit our conceptual model to New Zealand's four major rural land uses; the land uses that are endogenous in LURNZ.

Consider the use of land for dairy, sheep/beef, plantation forestry and scrub; in general the more intensive land uses have higher costs but also higher payoffs from production. Given that the quality of the land determines its potential productivity and profitability, then profit maximizing landowners will select their land use according to its relative profitability, and the more intensive land uses will be more likely to occur on higher quality land.

It follows that, if we arrange land along a continuum by land quality, then the best quality land will be used for the most intensive land use: dairy farming. The worst quality land will be

[3] The land tenure review process is the key exception to this. High country leases have been converted into a mix of private land (initially pasture but can be changed) and DOC land. Land cover could gradually change on this land.

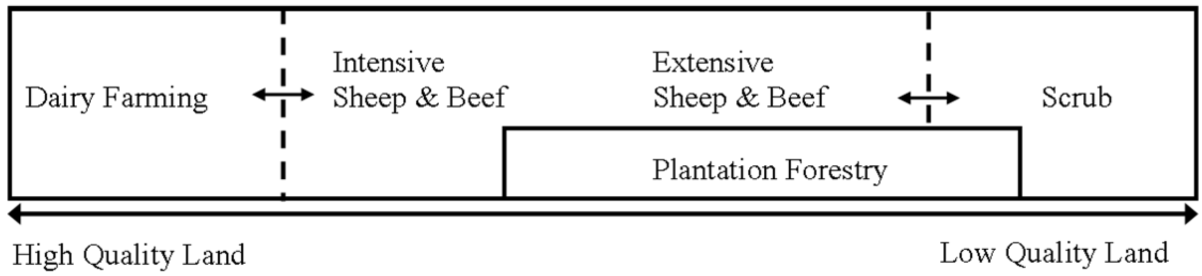
[4] For details, documentation and examples of uses see www.motu.org.nz/research/group/land_use_in_rural_new_zealand_model

[5] All public land is exogenous regardless of its land use. Public land is typically non-productive conservation land. However, where pasture is found on public land this is assumed to be sheep/beef farming. This assumption is consistent with TA rural land areas in 2002 reported by Statistics New Zealand (2008) and LIC and DairyNZ (2010). The South Island High Country leases are an example of pasture on public land.

left as unproductive scrub. The remaining land will be split between sheep/beef farming and plantation forestry. How much of the best land is used for dairy will depend on the returns from dairy farming relative to the returns from intensive sheep/beef farming. How much of the worst land is left as scrub will depend on the returns to scrub relative to the returns from extensive sheep/beef farming and plantation forestry.

Furthermore, we can consider thresholds with regard to land quality, where land over a certain threshold is all dairy land, land below a certain threshold is all scrub land, and land between the two thresholds is sheep/beef or forestry land. Figure 1 gives this pictorially. The locations of these thresholds will be determined by the relative returns to the different land uses.

Figure 1: Conceptual model of dairy, sheep/beef, forestry and scrub land by land quality



Plantation forestry occurs on similar quality land to extensive sheep/beef farming. However, unlike sheep/beef farming, there are high costs associated with land-use change for forestry. Converting land into forestry involves the giving up of potentially significant option value of the land; converting land out of forestry before the plantation has reached maturity reduces the return from harvest.

In contrast, there may be low costs for converting land between extensive sheep/beef farming and scrub land. When returns to sheep/beef farming are low, a farmer could close off less productive paddocks, allowing them to revert to scrub. When returns to sheep/beef farming are high the farmer would open up these closed off paddocks and clear scrub, enabling them to graze more animals over the increased area.

The conversion of land into and out of dairy farming is characterized by high costs and low costs respectively. Establishing a new dairy farm entails significant costs associated for example with the construction of milking sheds. These costs occur irrespective of the previous land use. Converting from dairy to sheep/beef farming has much lower costs, as the new sheep/beef farm will make use of the established pasture.

For LURNZ, this implies that conversions involving forestry land should occur less frequently than other land-use changes; it should be easy for conversions between sheep/beef farming and scrub land to occur; and if land is converted from dairy farming then it is most likely to convert to sheep/beef farming.

2.3.2. The LURNZ allocation algorithm

The LURNZ allocation algorithm used for this paper builds on the algorithm by Hendy et al. (2007). Given year-to-year changes in land-use area the algorithm spatially allocates changes in land use across pixels.

Note that, for each year only *changes* in land use are allocated, minimising the number of pixels that change land use. There are two reasons why we do not reallocate all land use each year. First, there are costs associated with transitions between land uses. Second, many unobservable factors drive land use and our models are unable to perfectly explain current land use.

Indicators of the suitability of a pixel for dairy farming, sheep/beef farming, plantation forestry and scrub, based on observable characteristics, are given by probabilities of the pixel being in each land use. These probabilities are estimated for each pixel by a multinomial logit model of land-use choice, according to the methodology by (Timar, 2011) (estimated coefficients are given by Table 11 in the appendix). For any given land use, those pixels with the greatest probability are considered most suitable, while those pixels with the smallest probability are considered the least suitable.

For each year, given the total change in each land use, the allocation algorithm assigns changes in land use in three steps. In order, these steps consider changes in dairy land, changes in sheep/beef land and changes in forestry land. The allocation algorithm is as follows:

Step 1) If dairy land increases: the sheep/beef, plantation forestry and scrub land that have the highest dairy probabilities change to dairy land, subject to an additional control on plantation forestry (given below). If dairy land decreases: the dairy land with the lowest dairy probabilities changes to sheep/beef land (and is possibly subject to further change in step 2).

Step 2) If sheep/beef land increases: the plantation forestry and scrub land that has the highest sheep/beef probabilities changes to sheep/beef land, subject to an additional control on plantation forestry (given below). If sheep/beef land decreases: the sheep/beef land (including any land released from dairy during step 1) with the lowest sheep/beef probabilities changes to scrub land (and is possibly subject to further change in step 3).

Step 3) If plantation forestry land increases: the scrub land (including any land released from sheep/beef during step 2) with the highest forestry probabilities changes to plantation forestry. If plantation forestry land decreases, beyond any conversion of land in steps 1 and 2, the forestry land with the lowest forestry probabilities changes to scrub land.

The conversion of plantation forestry to dairy or sheep/beef is subject to two additional controls as follows: First, LURNZ tracks the age of forestry on each pixel in each year.[6] Only those pixels that are identified as being of harvestable forest age (aged 26 to 32 years) or as awaiting replanting (age zero) may change land use.[7]

Second, if forestry land is increasing, no forestry land may change to dairy or sheep/beef. If forestry land is decreasing then the amount of forestry land that changes to dairy and sheep/beef must not exceed the total decrease in forestry land (for example: if sheep/beef land is increasing, forestry is decreasing by 150 ha overall and 50 ha of forest was converted to dairy land during step 1, then at most 100 ha of forestry land can change to sheep/beef land during step 2).

2.4. Maps of land use in 2020

We construct maps of land use in 2020 by simulating changes in land use from the 2008 map. Due to the uncertain value of carbon under the New Zealand Emissions Trading Scheme (NZETS), we produce two maps: one assuming a price of \$25 per tonne of CO_2-equivalent, and the other assuming a price of \$5.

Unlike the construction of the 2008 and 1996 maps, changes in land use from 2008 to 2020 are not already known. The production of 2020 maps therefore involves two stages: estimating ongoing changes in land use, and spatially allocating these estimated changes.

2.4.1. Estimating ongoing changes in land use

A dynamic econometric model of the four major land uses in New Zealand was developed by Kerr and Olssen (2012). In their model, the share of national rural land in each land use is determined as a function of export prices. Rural land areas used for pasture or plantation forestry between 1972 and 2005 were drawn from Statistics New Zealand data; these pasture areas were separated into dairy and sheep/beef areas according to data by Meat and

[6] The approach to doing this is discussed in Zhang and Kerr (2012).

[7] A proportion of forest pixels of harvestable age are harvested each year. Pixels that have been harvested but not yet replanted are classified as 'awaiting replanting'. A fixed proportion of pixels that are awaiting replanting are replanted each year.

Wool Economic Service (now Beef and Lamb New Zealand). Commodity prices for beef, lamb, wool and logs were drawn from Statistics New Zealand overseas merchandise trade data and prices for milk solids were drawn from Livestock Improvement Corporation data. Their final model allows for both short run and long run changes in land use in response to changes in commodity prices (Kerr and Olssen, 2012).

Estimates of future commodity prices are given by the Situational Outlook for New Zealand Agriculture and Forestry (SONZAF) produced by the Ministry for Primary Industries. These can be used with the model by Kerr and Olssen (2012) to estimate ongoing changes in land use. However, as New Zealand has implemented an emissions trading scheme to help manage greenhouse gas (GHG) emissions, we must account for the implied effect of a carbon price on projected commodity prices.

We transform the SONZAF projected commodity prices into effective commodity prices according to the methodology described by Kerr et al. (2012). In accordance with the Government policy at the time of this calculation, we assume that forestry enters the NZETS in 2008 and agriculture enters the NZETS in 2015. In addition, agriculture receives a free allocation that starts at 90 percent in 2015, and this free admission decreases annually by 1.3 percent of the previous year's free allocation. We assume that the 'one for two' policy (where farms surrender one emissions unit for every two tonnes of emissions) does not apply to agriculture. A summary note describing this process in included at the end of this paper.

Figure 2: Rural land-use shares projection out to 2020, $25 carbon price

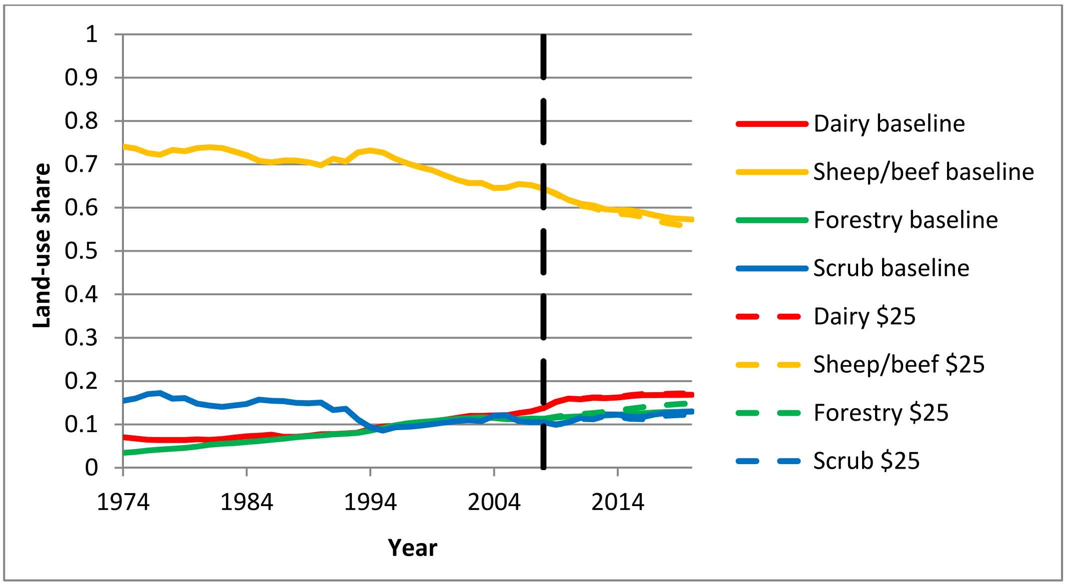


Figure 2 gives the projections of rural land-use shares according to the dynamic econometric model under both the baseline scenario (when there is no carbon price) and when the carbon price is $25. Under the baseline scenario, the share of sheep/beef land continues to decline while dairy and forestry shares increase. Under the $25 carbon price scenario the share of sheep/beef land and scrub land decrease and the share of forestry land and dairy increase relative to the baseline. Under the $5 carbon price scenario the effects are the same but are of a smaller magnitude for dairy, sheep/beef and forestry, and there is a small increase in scrub land.

2.4.2. Spatially allocating land-use changes

Given national changes in land use under $5 and $25 carbon prices we spatially allocate these changes across the private land in the country using the LURNZ allocation algorithm given in section 2.3. Land cover and use change on public land is not modelled because public land use is driven by different actors and mechanisms than land-use decisions on private land.

The spatial allocation of land-use change for the 2020 maps differs from the approach taken for the 2008 map in two ways: First, land-use changes are allocated spatially across the entire country rather than within each TA. Second, we introduce an additional restriction on land-use change from forestry as follows:

First, plantation forestry is treated differently under the NZETS based on when it is established (we can identify this from the LUCAS map). Pre-1990 forest receives no carbon credits for replanting, while Post-1989 forest does, but Pre-1990 forest has full carbon liabilities on deforestation. This means that while harvesting Pre-1990 forest is unaffected, replanting is more likely than for post 1989 land, particularly when carbon prices are high. This is incorporated in LURNZ by adding a restriction that Pre-1990 forest, as identified by LUCAS, may not change land use.[8]

Figure 9 and Figure 10 in the appendix give the final 2020 maps. Tables of land use by regional council are given in Table 8 and Table 9 for the $5 and $25 carbon prices respectively.

3. Trends in Farming Intensity

To complement our maps of land use, we also produce indicators of farming intensity for 1996, 2008 and 2020 by regional council area. We define farming intensity by production per hectare. It follows that changes in farming intensity can be broken down into changes in stocking rates and changes in production per animal. In this section we first consider measures

[8] We also add a restriction on pasture land that has a carrying capacity of zero – mostly tussock. We reclassify it as non-productive land and do not allow it to revert to scrub or be used for plantation forestry after 2008. This reflects a judgement that this land is mostly unused and only appears as pasture because it will not naturally revert to scrub.

of farming intensity for dairy and sheep/beef farms in turn, before discussing the inclusion of our intensity measures in CLUES.

For this analysis, we consider two models for the trends in productivity: a linear model and a logarithmic model. We prefer the logarithmic model in this paper as it allows for the rate of increase in production per hectare to be decreasing over time. This choice of model is more likely to provide a conservative estimate of farming intensity. We include the linear model as an indicator of sensitivity.

Table 1: Regression models for farming intensity

Linear Model	Logarithmic Model
$Y = a\,X + b$	$Y = a\log(X - b)$

Table 1 gives the two regression models for farm intensity, where Y = the measure of intensity, X = year, and a and b are coefficients fitted to minimise the sum of squared residuals. The logarithmic model we have specified differs from the more commonly used logarithmic model: $Y = a \, log(x) + b$. However, this more common model is not intended for time series analysis and is approximately linear between x = 1996 and x = 2020 (the timeframe of interest). We therefore use the logarithmic model given in

Table 1 as a superior alternative for this context.

One possible disadvantage of the logarithmic model is that it only fits a non-decreasing trend line. We may observe situations for which the data suggests decreases in production per hectare. However, such behaviour would seem to run counter to the intentions of farmers (for whom profit is generally increasing with production per hectare). Where this occurs, we assume that the underlying trend is constant over time and that the observed trend has been driven by short term variations: The logarithmic model is replaced by a horizontal trend equal to the average production per hectare between 1999 and 2008.

3.1. Dairy farm intensity

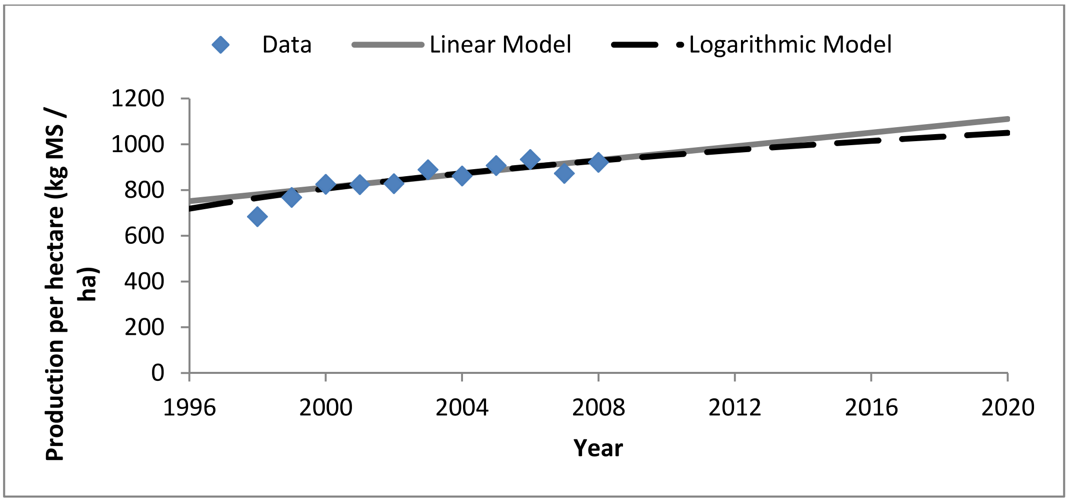
For dairy farms we use data from the Dairy Statistics Reports, 1998 to 2008 (LIC and DairyNZ, dataset, 2010). For each year, the data gives stock numbers, milk solids production and the number of effective hectares of farm land.

This data is available by TA and by LIC region. LIC regions are constructed from combinations of adjacent TAs. Comparisons between the TA and LIC region-level data suggests that there are minimal differences in trends between the two. Our analysis is conducted using LIC regions.

Inspection of the national trend in production per hectare suggests that milk solid production per hectare in 1998 was below the long-run trend. This is likely due to a drought occurring in 1998. We exclude this observation from the rest of our analysis.

Figure 3 gives the data (including the observation for 1998) and fitted trend lines for dairy farm intensity at the national-level.

Figure 3: National level trend in dairy farm intensity



3.1.1. Fitted trends

We fit the logarithmic model to production per hectare from 1999 to 2008 for each of the 17 LIC regions. Figures of these trends and tables of their regression coefficients can be found in Figure 25 and Table 17, respectively, in the appendix.

Of all the LIC regions, only the East Coast reports a negative trend in production per hectare over time. Further investigation of this region does not suggest anything counter to the assumption that the performance of farms on the East Coast is approximately constant over time with variation about the long term mean.

Table 2: Milk solid production: comparison of regional and national trends

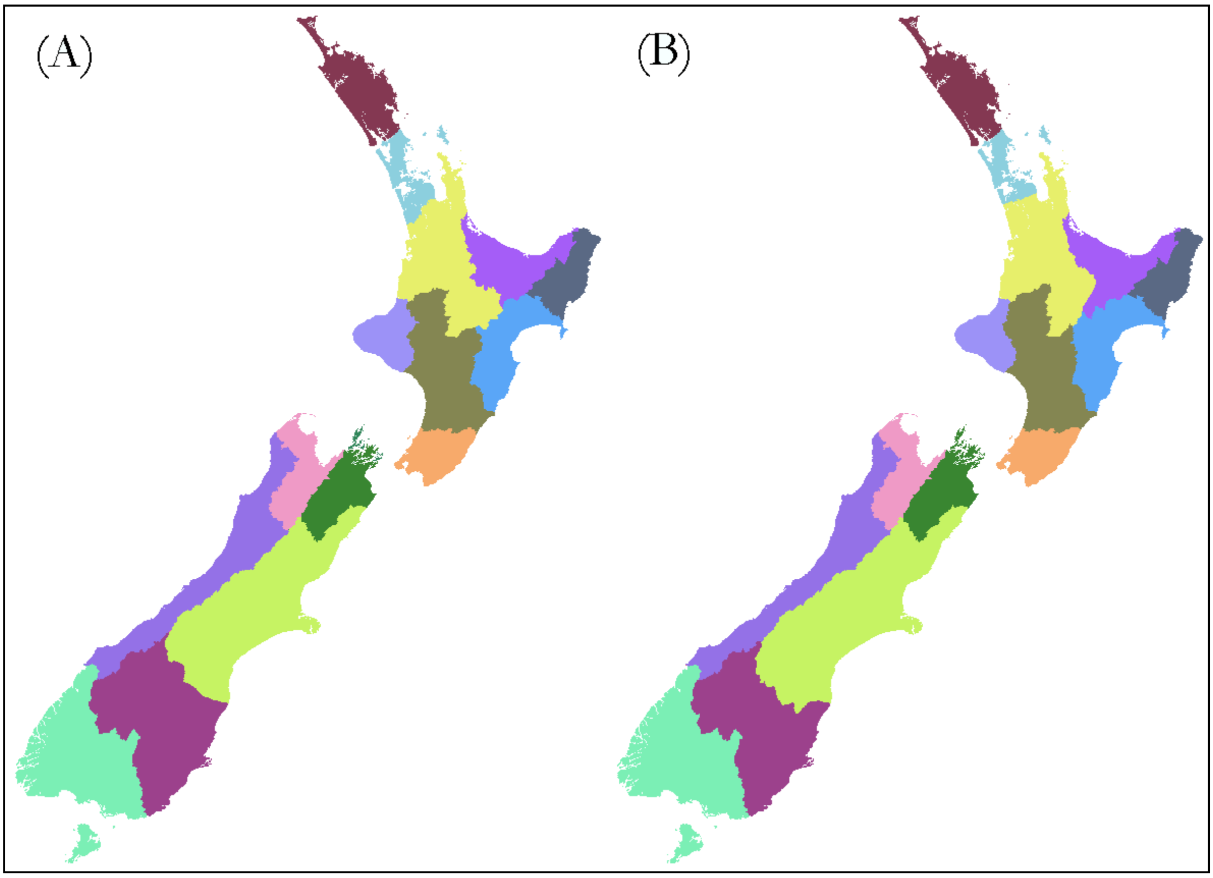
Total Production (tonnes MS)	1996	2008	2020
Calculated from regional trends	956,200	1,441,100	1,617,300
Calculated from national trends	936,200	1,410,100	1,594,400
Percentage difference	2.1%	2.2%	1.4%

Following the fitting of these models we compare the results from estimating total national milk solid production using regional trends in production per hectare against the results from using national trends in production per hectare. Table 2 gives estimates for national production in 1996, 2008 and 2020 calculated from regional trends and from the national trend. As the national totals from our regional level estimates are very similar to the national level trend we are confident that our regional trends are consistent with the national level trend.

3.1.2. Production per hectare by regional council area

To ensure our results are compatible with CLUES we transform our results from LIC region boundaries to regional council boundaries. Each TA was assumed to have the same production per hectare as the LIC region it belonged to. The production per hectare for each regional council area was calculated as the mean of their constituent TAs, weighted by dairy area. As TA boundaries do not always coincide with regional council boundaries this may introduce error into our results. Figure 4 compares the approximate regional council boundaries constructed from TAs (labelled A) against the true regional council boundaries (labelled B). Table 18, in the appendix, gives our concordance between LIC regions, TAs and regional council boundaries.

Figure 4: Pseudo regional council boundaries (A) vs. true regional council boundaries (B)



From Figure 4 it can be seen that approximating regional council boundaries using TAs produces a good match for Northland, Auckland, Gisborne, Wellington, Tasman, Nelson, Marlborough, West Coast and Southland, but a poor match for the central North Island.

Table 3 gives the production per hectare for dairy farms in 1996, 2008 and 2020 by regional council area.

Table 3: Dairy production by regional council area

	Production per hectare (kg MS / ha)		
Regional Council	1996	2008	2020
Auckland	646	698	764
Bay of Plenty	753	888	1014
Canterbury	743	1169	1449
Gisborne	804	821	806
Hawkes Bay	827	879	905
Manawatu-Wanganui	759	917	997
Marlborough	622	896	1083
Nelson-Tasman	622	896	1083
Northland	552	620	670
Otago	796	1053	1223
Southland	830	1017	1151
Taranaki	799	962	1012
Waikato	772	946	1083
Wellington	796	893	953
West Coast	541	691	835

3.2. Sheep/beef farm intensity

For sheep/beef farms we are unable to consider production per hectare directly due to data limitations. We instead separate the trend in production per hectare into changes in stocking rates (stock units per hectare) and changes in production per stock unit, and consider each of these separately.

3.2.1. Stocking rates

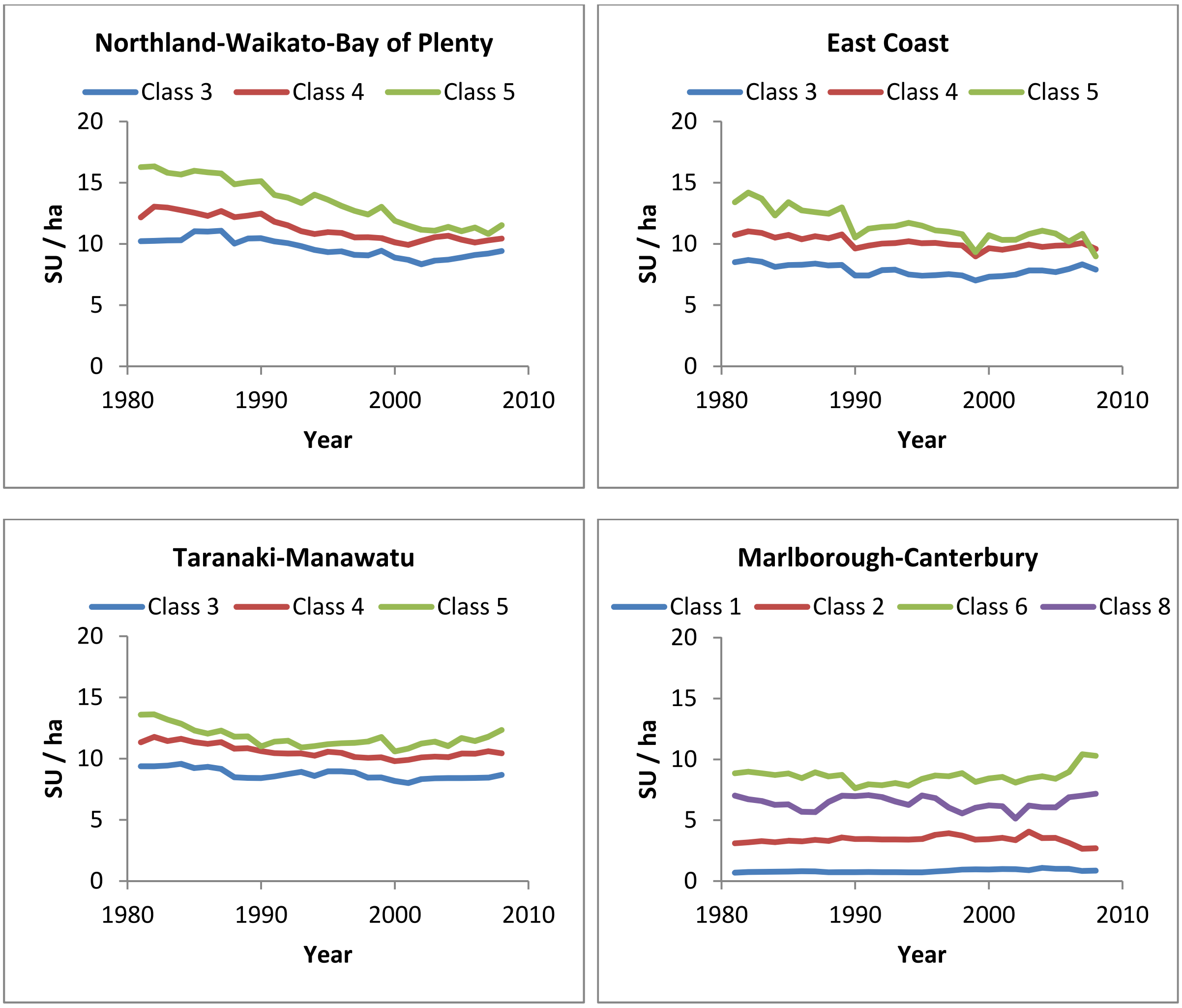
We use data from Meat and Wool Economic Service (now Beef and Lamb New Zealand) to consider trends in sheep/beef farm stocking rates from 1981 to 2008 (Meat and Wool Economic Service, dataset, 2009). This gives stocking rates across five farming regions and by the eight farm classes as given in

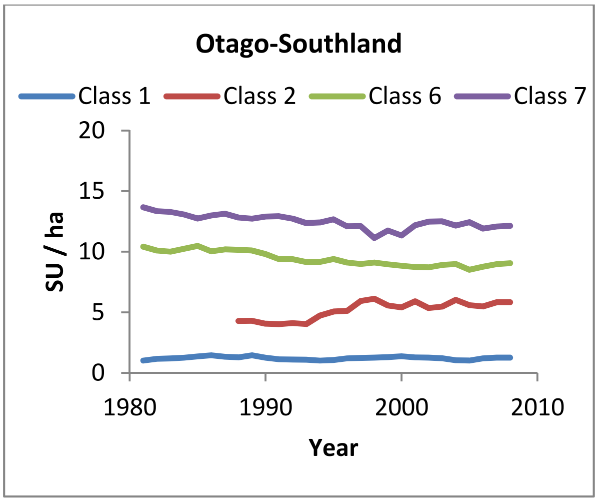
Table 4. Figure 5 gives the average number of opening stock units per hectare for each farm class by region.

Table 4: Meat and Wool Economic Service sheep/beef farm classes

Farm class	Name	Production activity
1	South Island High Country	Breeding and selling stock
2	South Island Hill Country	
3	North Island Hard Hill Country	
4	North Island Hill Country	
5	North Island Intensive Finishing Farms	Stock finishing and selling to works
6	South Island Finishing-Breeding Farms	
7	South Island Intensive Finishing Farms	
8	South Island Mixed Finishing Farms	

Figure 5: Trends in stocking rates for sheep/beef farms by region and farm class





For all regions other than Marlborough-Canterbury we observe a decreasing trend over the first 20 years (from 1981 to 2000) and no trend for the last eight years (from 2001 to 2008). For Marlborough-Canterbury we observe no trend across the entire time period. We attribute the decreasing trend in stocking rates during the first two-thirds of the data to the adjustment of farm management practices to the removal of agricultural subsidies in New Zealand in 1984. Considering stocking rates over the most recent years suggests that there is currently no trend in the number of stock units per hectare for a given region and given type of farm. Hence we will assume that there is zero change in farm intensity due to changes in stocking rate.

3.2.2. Production per stock unit

Due to data limitations, we use a proxy for production per stock unit. Enteric methane emissions from 1990 to 2009 are available from New Zealand's Greenhouse Gas Inventory report (Ministry for the Environment, 2010) at a national level. We convert sheep and (non-dairy) cattle numbers to stock units and consider enteric methane emissions per stock unit as a proxy for production per stock unit.[9] Our choice of proxy ensures that our results are consistent with official trends.

[9] Sheep are 0.92 stock units and (non-dairy) cattle are 4.8 stock units.

Figure 6: National sheep/beef enteric methane emissions intensity

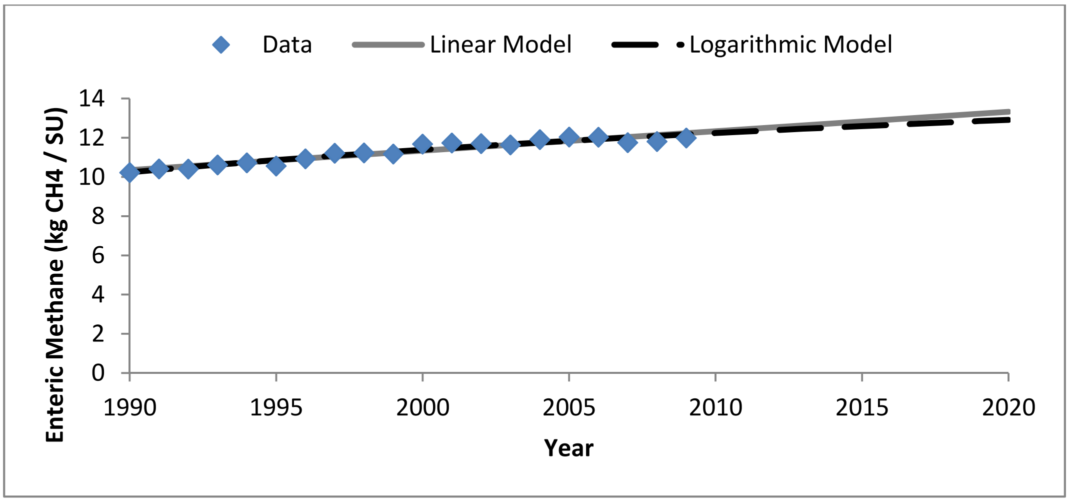


Figure 6 gives the data and fitted models for enteric methane production per stock unit. Regression coefficients can be found in Table 20 in the appendix. We use the logarithmic model to estimate emissions per stock unit in 2020 and historic data for 1996 and 2008. These results are given in Table 5.

Table 5: Sheep/beef enteric methane production per stock unit

Kg enteric CH4 / SU	1996	2008	2020
National	10.93	11.81	12.91

3.3. Providing input for CLUES

While we have constructed measures of intensity for dairy and sheep/beef farms, these measures must be expressed in a form that is compatible with CLUES. For each land area CLUES calculates nutrient loss using OVERSEER Lite. This takes the form of a dynamic linked library (DDL) to which CLUES provides certain inputs, including soil type, land use and stocking rate (Woods et al., 2006). The DDL is a 'black box' to NIWA. It is provided by AgResearch under contract and NIWA are not involved in its construction or the equations that inform its calculations (Sandy Elliot, NIWA, pers. comm. June 2011).

CLUES can consider percentage changes in stocking rates at a regional council level. However, it does not consider changes in production per animal. In order to incorporate changes in production per hectare in CLUES we propose an 'effective stocking rate': the stocking rate that would be required to achieve the estimated production per hectare if production per animal remained constant at 2001 levels – the year to which the OVERSEER defaults in CLUES were calibrated (Woods et al., 2006) (Sandy Elliot, NIWA, pers. comm. June 2011).

While not strictly correct, the use of effective stocking rates is a reasonable approach when considering nitrogen leaching as "the highest proportion of N leaching from grazing animals comes from urine and the amount of urine excreted per hectare is directly associated with the amount of protein ingested per hectare. If it takes twice the number of cows to ingest the same amount of protein than half that number, then the levels of nitrate leaching per hectare will be roughly similar, ceteris paribus. Thus, if you hold milk production per hectare constant and vary stocking rate then the nitrate leaching estimate should not vary greatly" (Graeme Doole, AgResearch, pers. comm. July 2011), see also de Klein et al. (2010).

The Overseer DLL was prepared for NIWA by David Wheeler of AgResearch. Although Wheeler was not completely satisfied with our approximation to use stocking rates to reflect stock intake in CLUES he acknowledged that this would be satisfactory given his knowledge of Overseer and how it is simplified in CLUES. Wheeler informed us that, while Nitrogen leaching is driven by stock consumption of protein, Phosphorus leaching is largely driven by fertiliser, soil Olssen P, slope and water run off. Hence changes in stocking rates should affect Nitrogen loss but not affect Phosphorus loss calculated by the DLL file (David Wheeler, AgResearch, pers. comm. July 2011).

For dairy farms, the percentage changes in effective stocking rates (for use with CLUES) can be found in Table 19 in the appendix. For sheep/beef farms, these can be found in Table 21 in the appendix. As the results for sheep/beef farms are calculated at the national level, we apply them to all regional council areas.

4. Conclusion

This paper has documented the production of land-use maps for 1996, 2008 and 2020, using the LURNZ model. Due to uncertainty about future carbon prices we have constructed two maps for 2020: assuming carbon prices of $5 and $25.

To complement these maps we have produced measures of farming intensity for dairy and sheep/beef farms for 1996, 2008 and 2020. These measures of intensity have be constructed using industry and government statistics.

These maps and intensity measures may be combined in several ways to produce water quality scenarios using CLUES: Historic water quality in 1996 and 2008 can be modelled using the land-use maps and corresponding intensity measures for the respective years. Future water quality in 2020 can be modelled using a combination of the 2020 maps (to capture differences in possible land-use change) and the 2008 and 2020 intensities (to capture differences in nutrient loss due to farming intensity).

Appendix

Land use and land use change

Figure 7: LURNZ 1996 land-use map

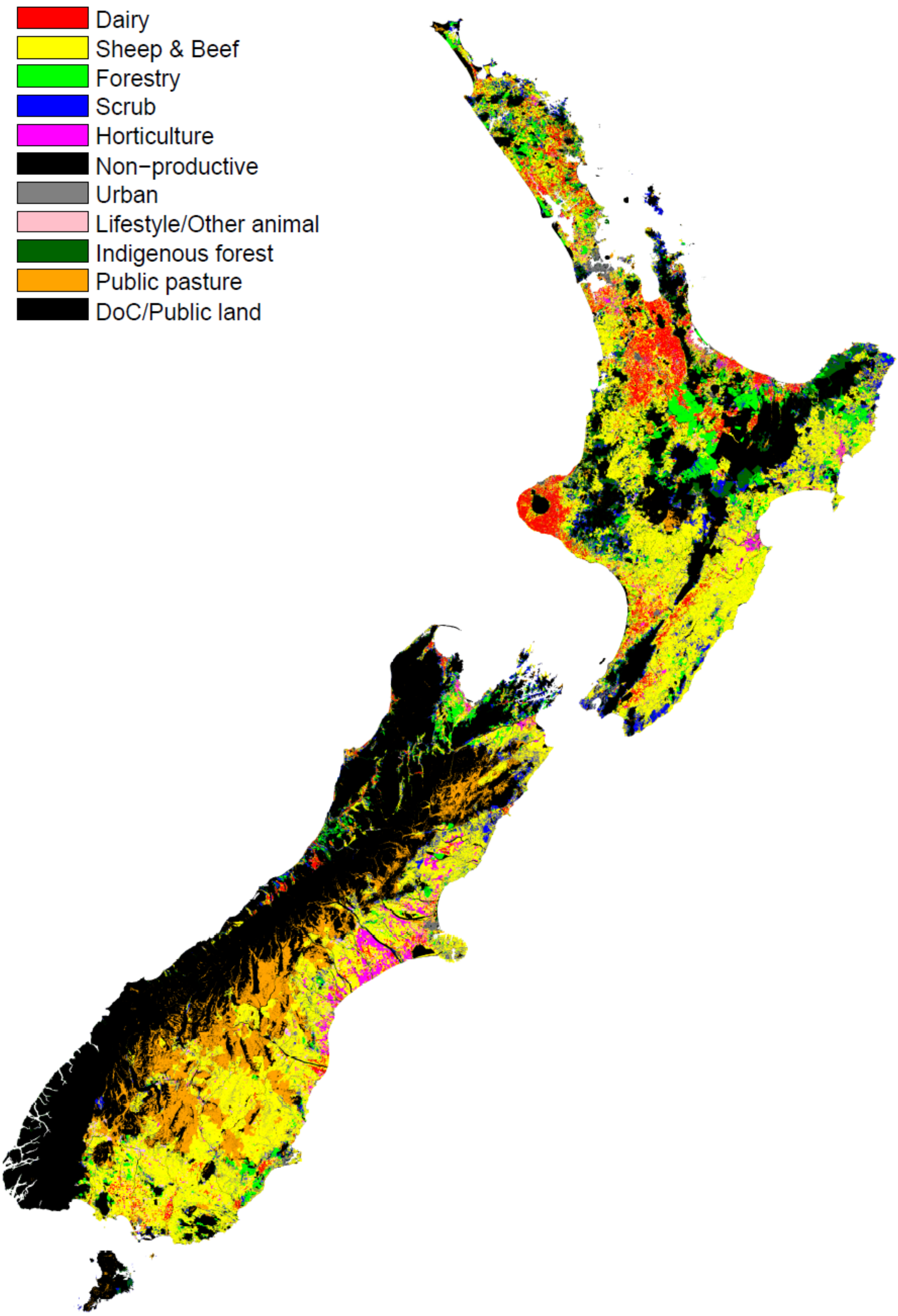


Figure 8: LURNZ 2008 land-use map

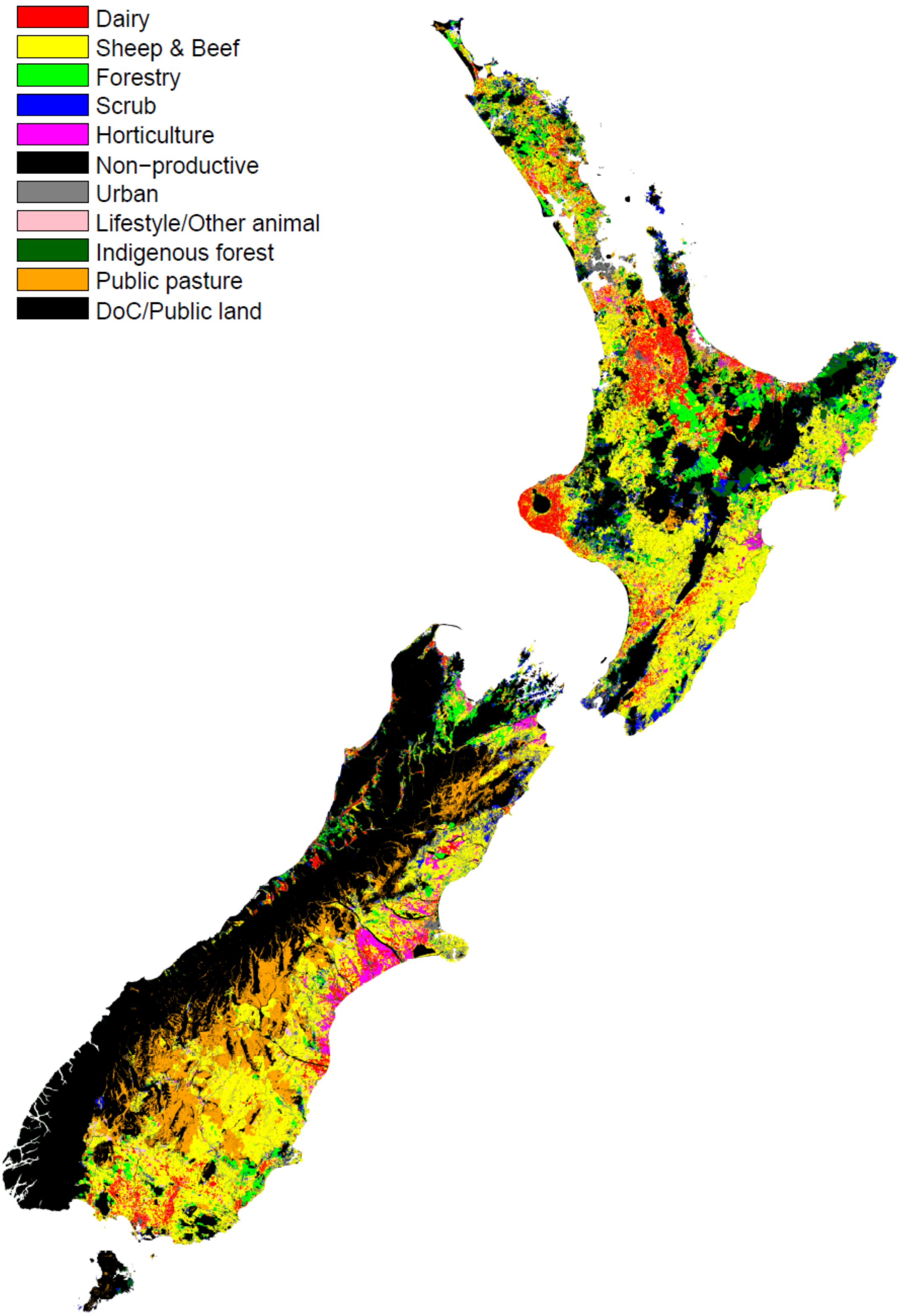


Figure 9: LURNZ 2020 land-use map, $5 carbon price

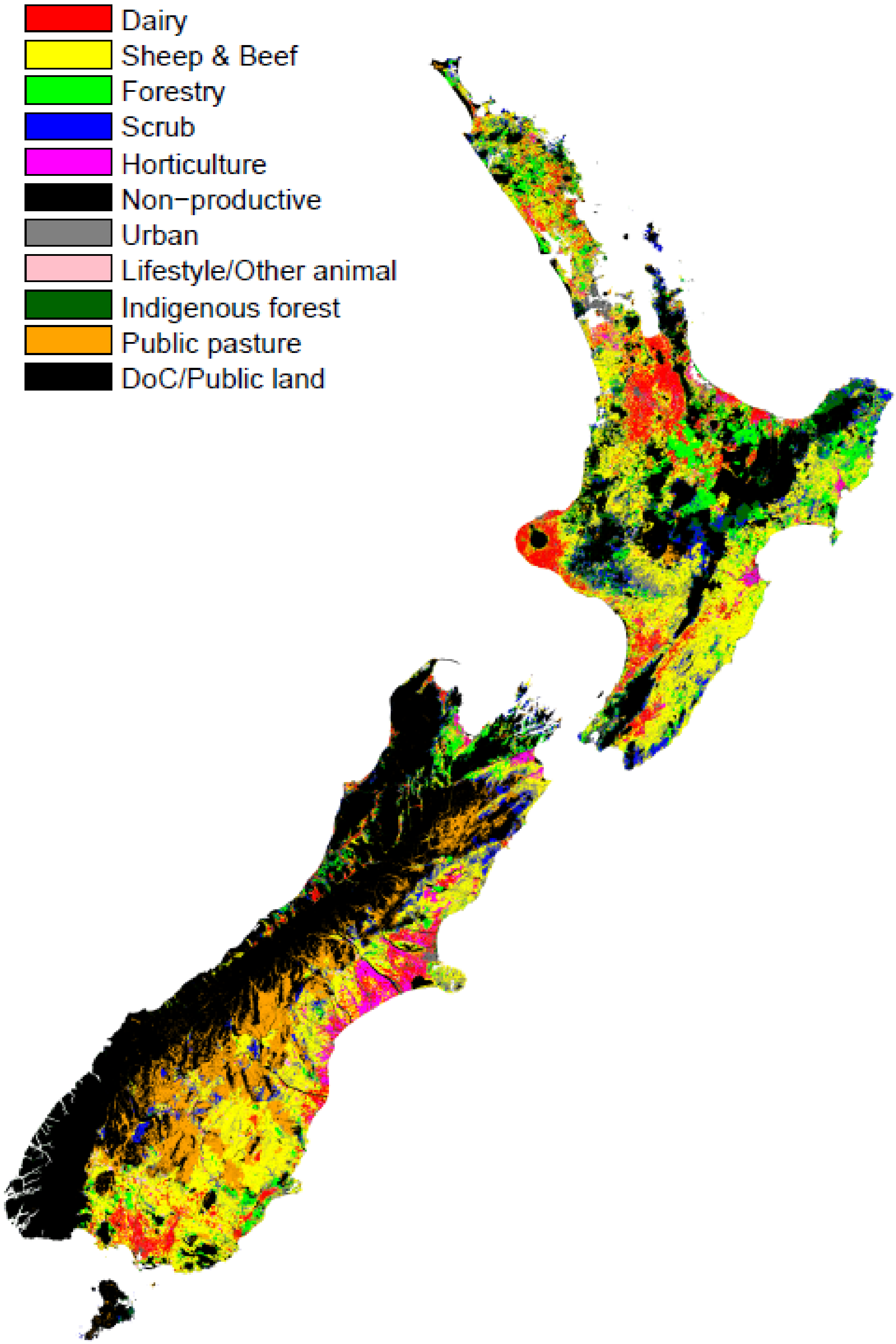


Figure 10: LURNZ 2020 land-use map, $25 carbon price

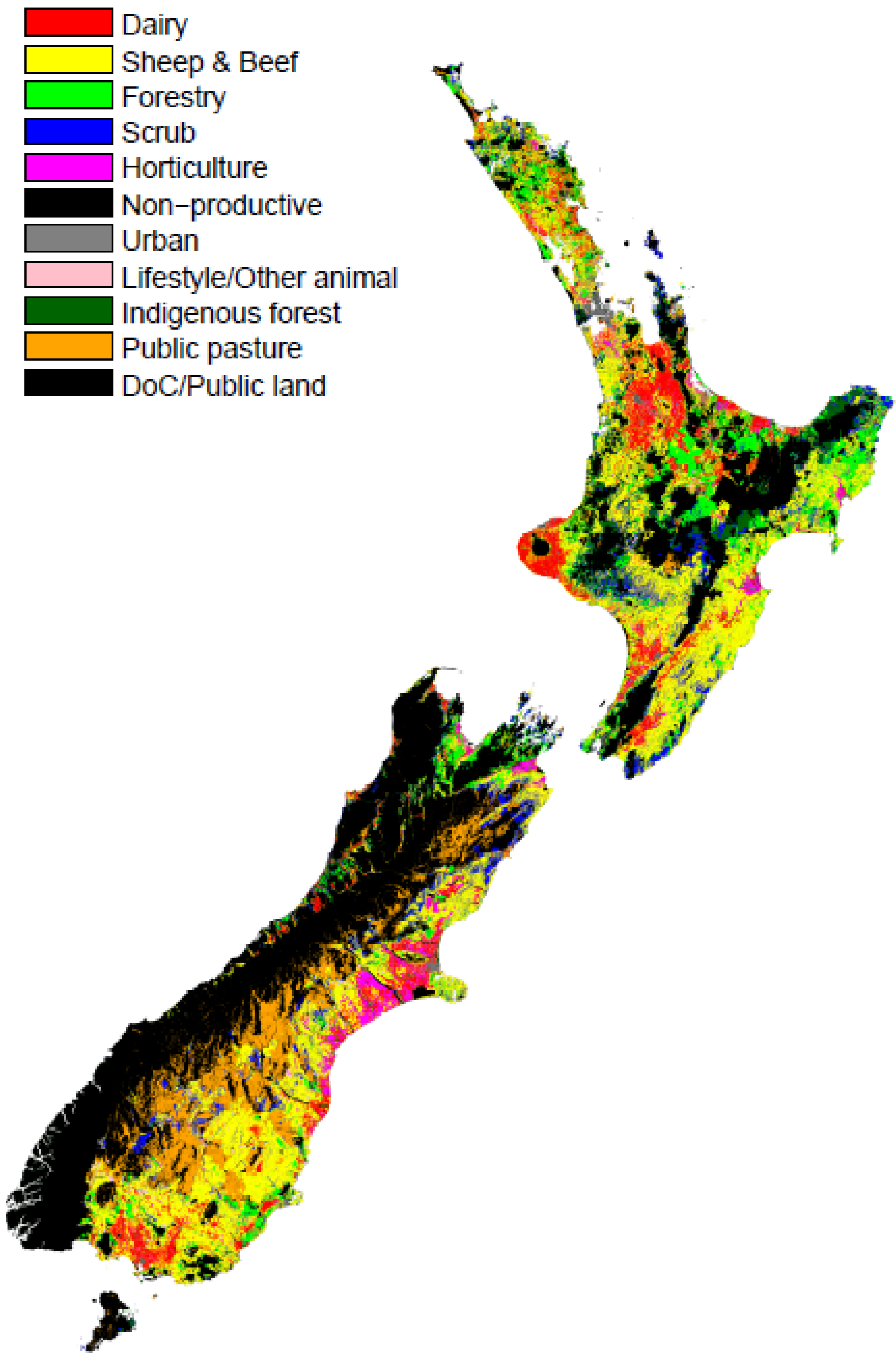


Figure 11 to Figure 18 give only those areas that have changed land use between maps. For ease of viewing, the size of pixels that have changed land use have been increased. Consequently these maps should only be used to judge the location of land-use changes, and not the magnitude.

Figure 11: LURNZ land-use change map 1996 to 2008 – original land use

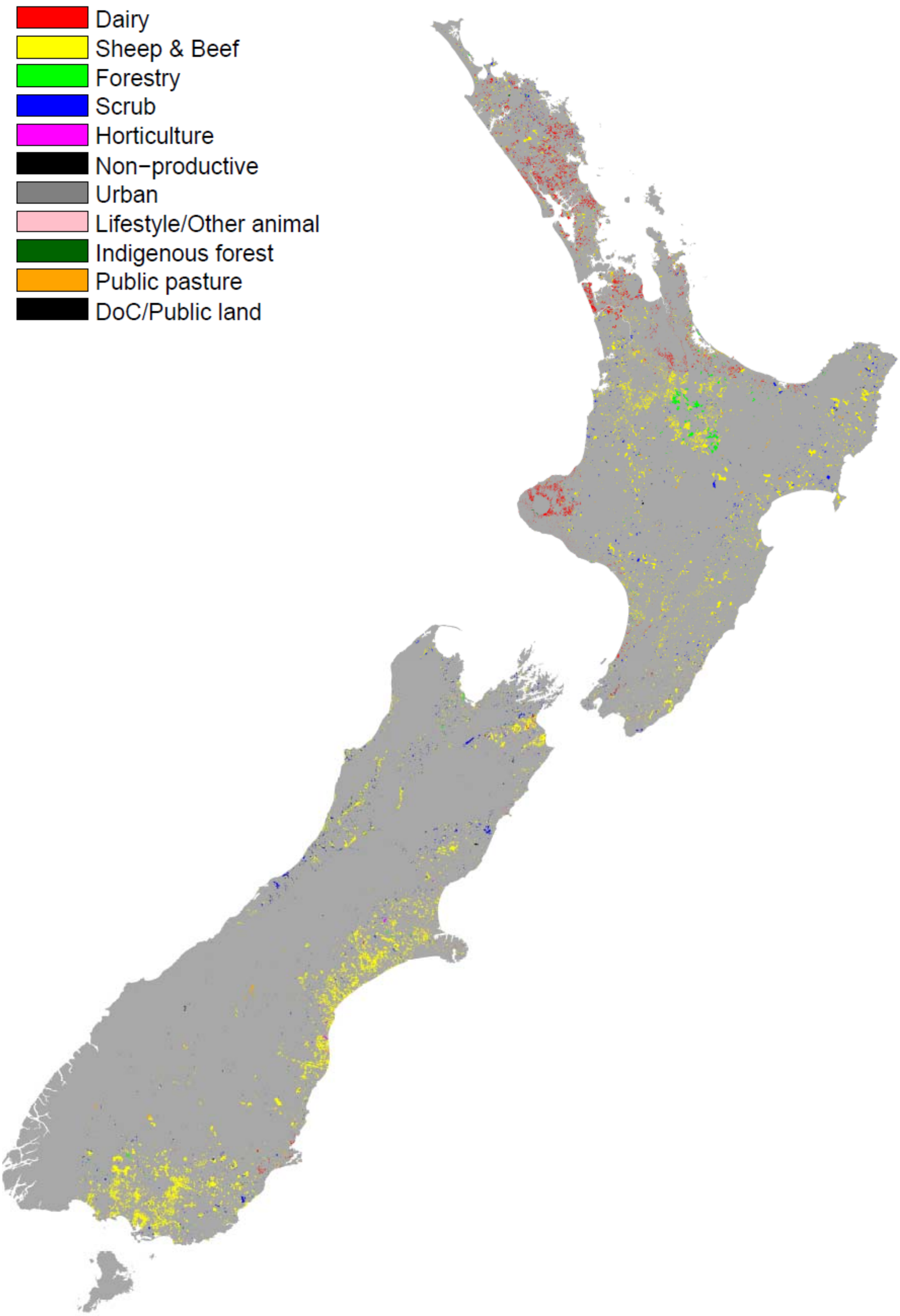


Figure 12: LURNZ land-use change map 1996 to 2008 – final land use

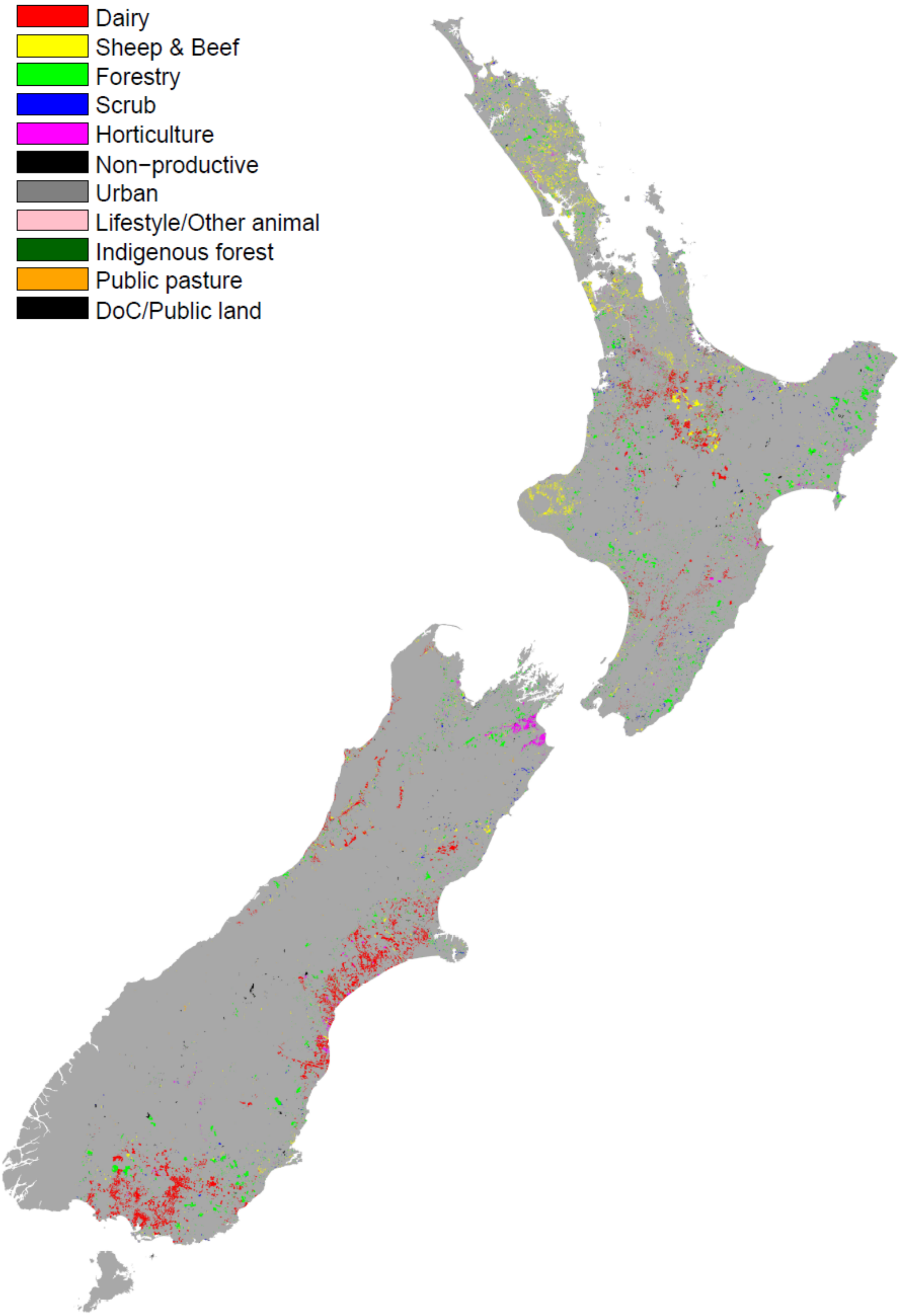


Figure 13: LURNZ land-use change map 2008 to 2020, $5 carbon price – original land use

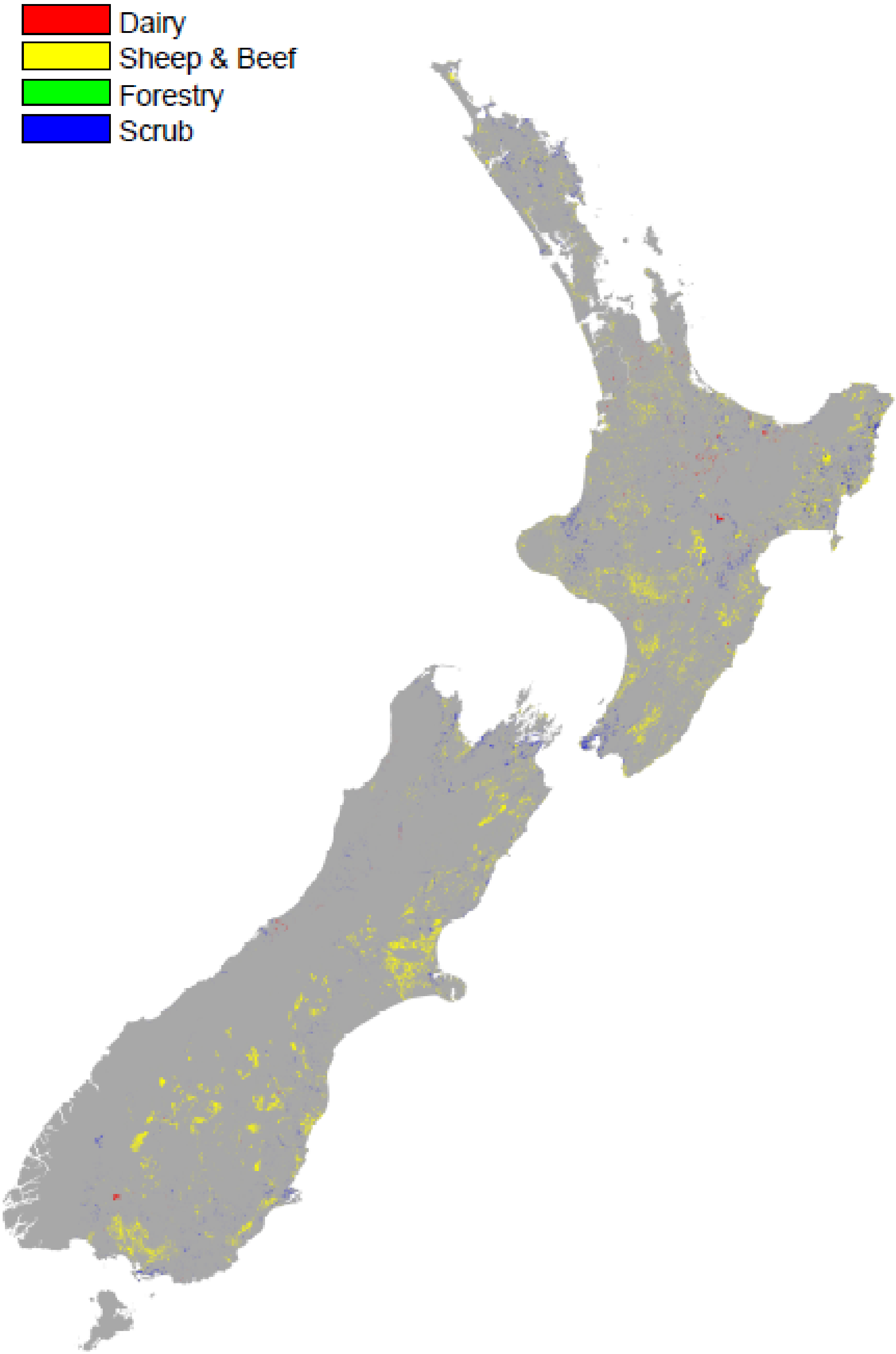


Figure 14: LURNZ land-use change map 2008 to 2020, $5 carbon price – final land use

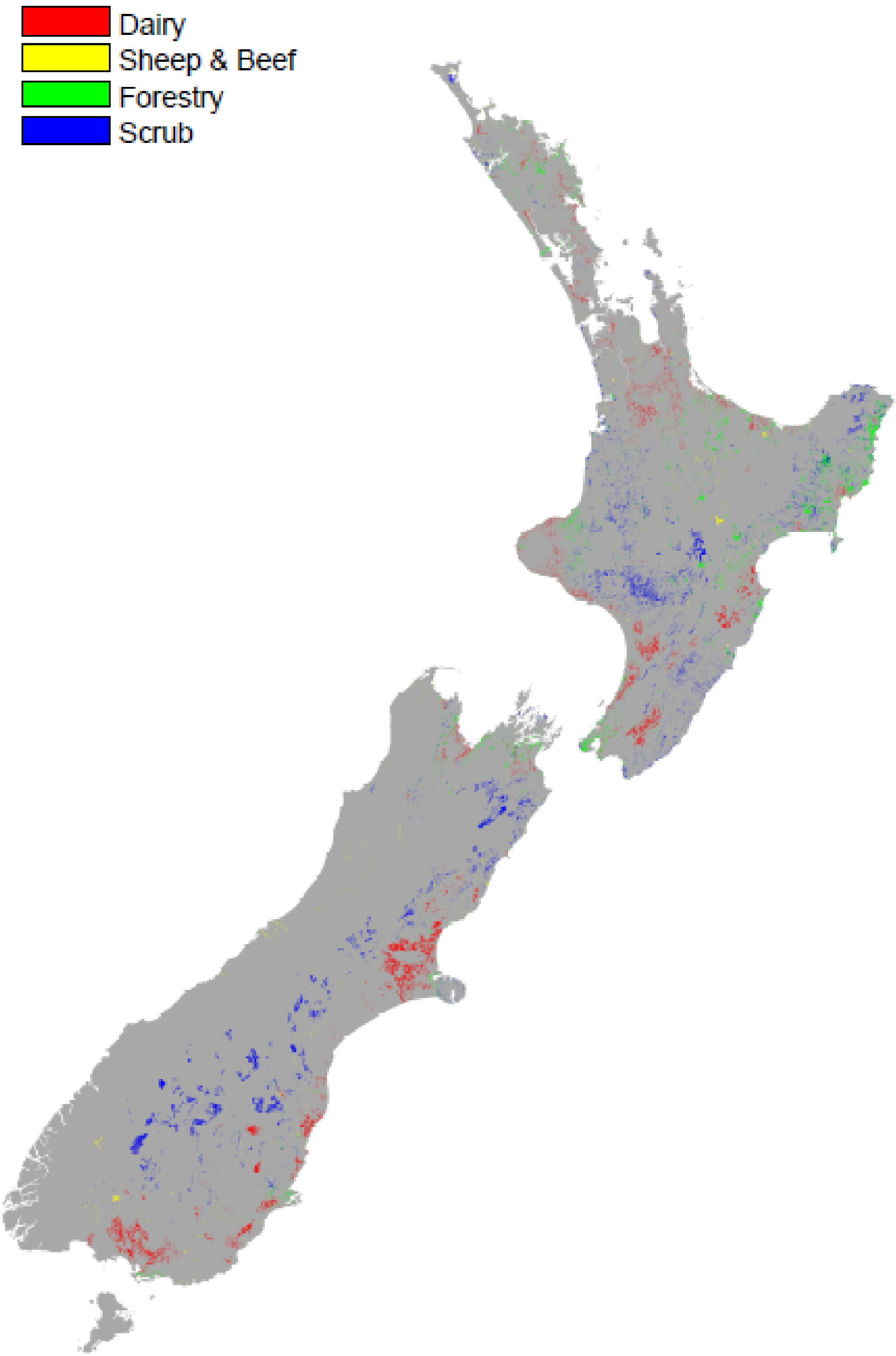


Figure 15: LURNZ land-use change map 2008 to 2020, $25 carbon price – original land use

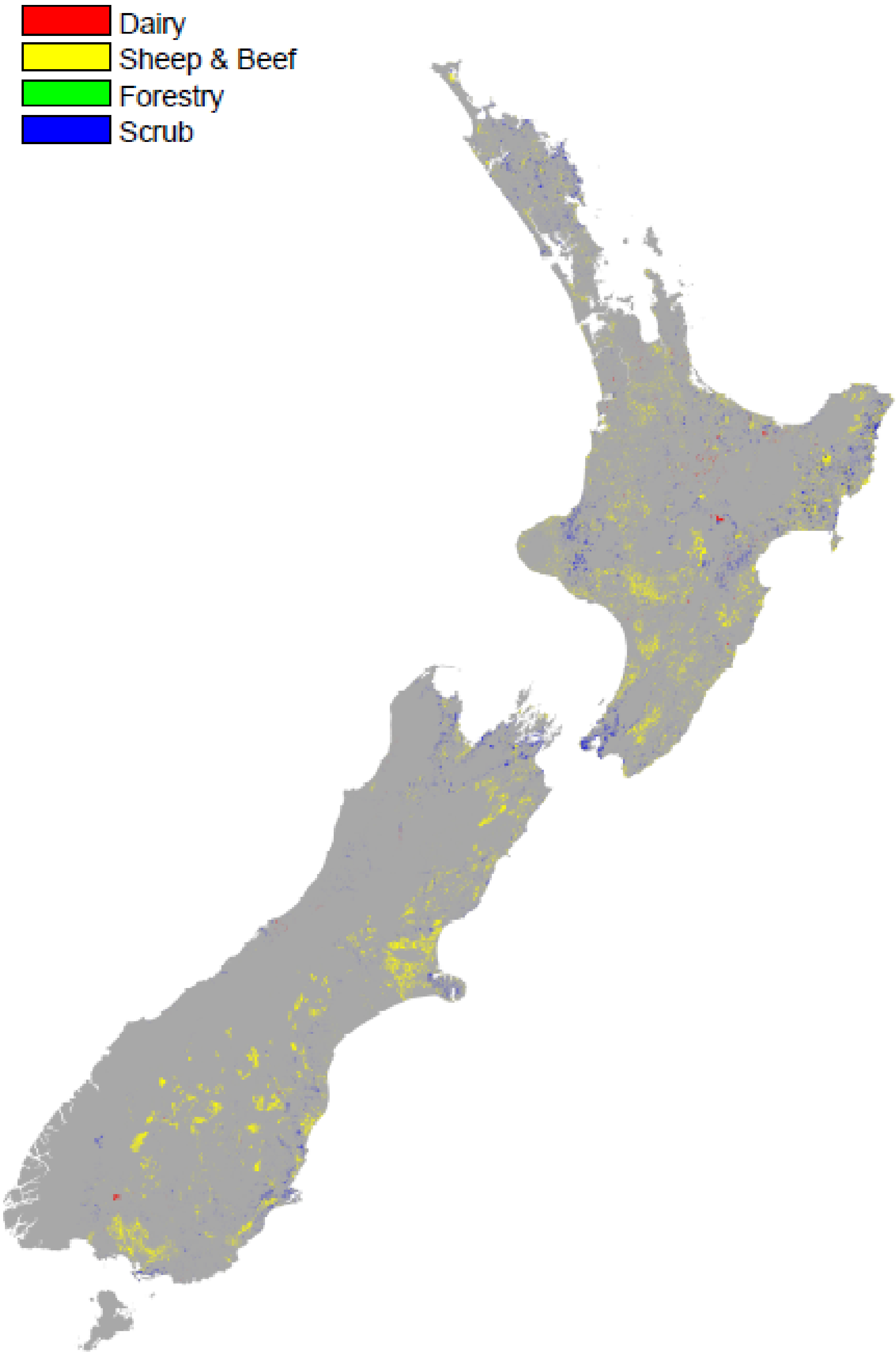


Figure 16: LURNZ land-use change map 2008 to 2020, $25 carbon price – final land use

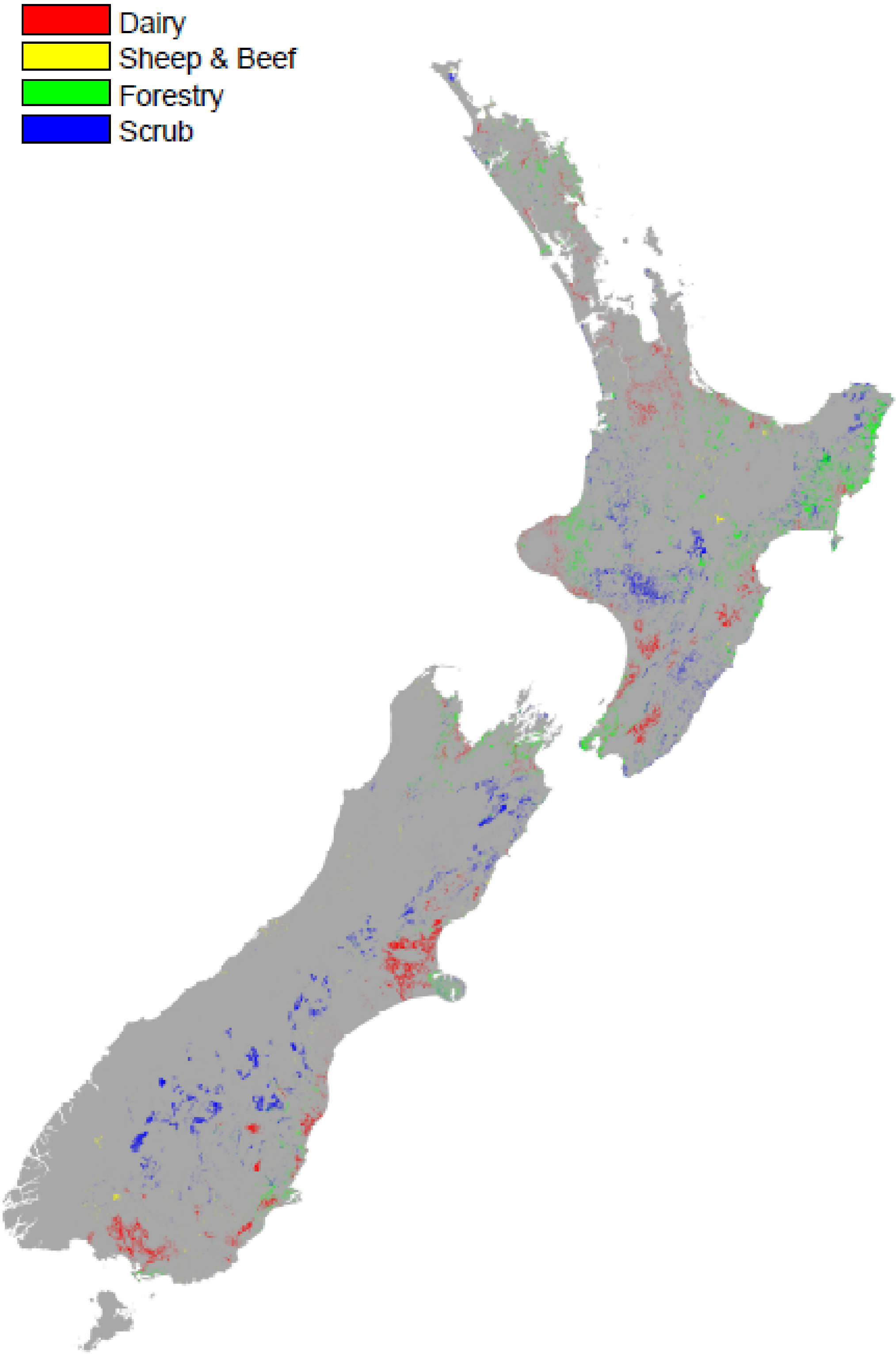


Figure 17: LURNZ land-use change map 2020 $5 to $25 carbon price – original land use

Figure 18: LURNZ land-use change map 2020 $5 to $25 carbon price – final land use

Table 6 to Table 9 gives the land-use areas for dairy, sheep/beef plantation forestry and scrub by regional council. Equivalent summary tables by TA were also constructed, but have not been given here due to size. These can be requested from the authors.

Table 6: Land-use areas by regional council in 1996

Regional council	Dairy (ha)	Sheep/Beef (ha)	Forestry (ha)	Scrub (ha)	Horticulture (ha)	Non-productive (ha)	Urban (ha)	Other animal & lifestyle (ha)	Indigenous forest (ha)	Pasture on public land (ha)	DoC and other public land (ha)
Northland	148,790	430,701	132,108	107,921	8,263	21,224	6,887	8,660	133,853	27,522	219,108
Auckland	51,714	160,708	33,195	38,554	10,994	7,415	41,627	17,601	35,788	13,497	88,216
Waikato	419,396	779,299	247,200	112,812	16,703	82,392	20,519	41,871	157,016	50,034	514,654
Bay of Plenty	82,556	147,765	140,818	38,059	25,284	6,571	11,826	12,837	133,576	20,030	603,430
Gisborne	319	385,335	104,667	114,801	14,562	13,575	2,296	4,004	58,461	10,012	127,401
Hawkes Bay	9,752	702,995	93,475	108,968	29,026	13,135	6,488	12,630	91,599	17,745	330,566
Taranaki	179,713	191,563	18,585	53,509	1,707	3,213	5,627	7,153	90,186	14,234	161,303
Manawatu-Wanganui	98,279	1,144,198	97,055	136,445	15,651	14,988	11,838	25,357	140,723	52,199	483,625
Wellington	27,274	346,058	39,778	105,878	7,132	6,071	16,804	7,631	23,207	11,029	221,144
West Coast	41,231	77,854	31,852	46,073	48	25,689	2,486	5,965	73,535	29,744	2,000,239
Canterbury	71,305	1,436,684	97,556	193,411	241,472	65,261	25,051	75,773	22,230	818,162	1,473,494
Otago	35,135	1,334,050	94,170	96,258	18,812	79,523	10,352	26,158	15,500	763,592	713,778
Southland	43,463	789,408	59,455	48,372	6,428	20,528	6,027	57,604	48,771	222,193	1,880,774
Tasman	19,120	94,702	71,086	44,974	10,312	6,065	2,037	7,242	45,245	6,127	657,583
Nelson	260	4,118	7,080	4,425	45	247	1,885	149	1,161	1,009	21,402
Marlborough	7,637	234,675	44,747	87,999	9,282	16,682	2,146	5,519	20,552	140,821	481,149

Table 7: Land-use areas by regional council in 2008

Regional council	Dairy (ha)	Sheep/Beef (ha)	Forestry (ha)	Scrub (ha)	Horticulture (ha)	Non-productive (ha)	Urban (ha)	Other animal & lifestyle (ha)	Indigenous forest (ha)	Pasture on public land (ha)	DoC and other public land (ha)
Northland	119,279	446,737	146,837	105,607	10,142	21,155	7,816	8,512	132,322	26,631	219,999
Auckland	35,521	169,534	37,521	38,651	11,517	7,450	44,221	17,517	35,664	12,441	89,272
Waikato	454,862	736,464	250,098	112,990	18,438	82,873	23,322	41,644	156,517	47,314	517,374
Bay of Plenty	86,657	136,893	143,016	39,906	27,308	6,741	12,863	12,604	133,304	18,758	604,702
Gisborne	610	358,119	132,803	113,381	15,218	13,128	2,379	3,988	58,394	8,853	128,560
Hawkes Bay	18,071	675,318	112,604	105,513	32,895	13,169	6,709	12,307	91,482	16,101	332,210
Taranaki	167,931	199,194	23,317	52,990	1,763	3,246	5,792	7,128	89,895	14,142	161,395
Manawatu-Wanganui	110,252	1,105,541	123,552	135,289	17,277	15,013	12,208	25,132	140,270	51,403	484,421
Wellington	26,264	332,649	54,362	104,859	7,532	6,145	17,405	7,544	23,073	10,430	221,743
West Coast	63,321	59,411	36,944	39,786	68	25,167	2,639	5,959	71,438	30,148	1,999,835
Canterbury	193,774	1,296,615	113,234	189,212	246,565	66,010	26,383	74,826	22,124	815,287	1,476,369
Otago	61,394	1,280,980	122,323	93,179	19,606	79,957	11,167	26,084	15,268	762,142	715,228
Southland	155,411	661,025	76,829	46,728	7,295	20,643	6,133	57,510	48,482	220,632	1,882,335
Tasman	20,132	90,573	76,362	42,436	10,869	6,008	2,433	7,187	44,783	5,797	657,913
Nelson	263	3,664	7,392	4,327	18	267	2,140	142	1,157	716	21,695
Marlborough	5,895	207,523	59,714	81,242	31,588	16,648	2,340	3,808	20,481	140,062	481,908

Table 8: Land-use areas by regional council in 2020, $5 carbon price

Regional council	Dairy (ha)	Sheep/Beef (ha)	Forestry (ha)	Scrub (ha)	Horticulture (ha)	Non-productive (ha)	Urban (ha)	Other animal & lifestyle (ha)	Indigenous forest (ha)	Pasture on public land (ha)	DoC and other public land (ha)
Northland	136,188	420,590	171,692	89,990	10,142	21,155	7,816	8,512	132,322	26,631	219,999
Auckland	43,266	161,285	37,866	38,810	11,517	7,450	44,221	17,517	35,664	12,441	89,272
Waikato	480,957	679,768	267,765	125,924	18,438	82,873	23,322	41,644	156,517	47,314	517,374
Bay of Plenty	91,337	118,827	161,225	35,054	27,308	6,770	12,863	12,604	133,304	18,758	604,702
Gisborne	4,853	284,547	195,169	120,309	15,218	13,163	2,379	3,988	58,394	8,853	128,560
Hawkes Bay	38,924	603,399	153,496	115,687	32,895	13,169	6,709	12,307	91,482	16,101	332,210
Taranaki	185,581	167,232	38,219	52,400	1,763	3,246	5,792	7,128	89,895	14,142	161,395
Manawatu-Wanganui	142,458	968,678	133,633	229,864	17,277	15,014	12,208	25,132	140,270	51,403	484,421
Wellington	51,830	290,268	70,549	105,487	7,532	6,145	17,405	7,544	23,073	10,430	221,743
West Coast	61,012	65,121	36,989	36,340	68	25,167	2,639	5,959	71,438	30,076	1,999,907
Canterbury	293,394	1,093,864	118,810	282,601	246,565	70,176	26,383	74,826	22,124	810,820	1,480,836
Otago	110,709	1,159,770	129,188	157,192	19,606	80,974	11,167	26,084	15,268	755,373	721,997
Southland	208,238	606,701	79,712	45,329	7,295	20,656	6,133	57,510	48,482	220,337	1,882,630
Tasman	29,845	77,392	84,936	37,328	10,869	6,010	2,433	7,187	44,783	5,797	657,913
Nelson	558	3,344	9,944	1,800	18	267	2,140	142	1,157	716	21,695
Marlborough	10,795	167,833	72,916	101,804	31,588	17,674	2,340	3,808	20,481	138,583	483,387

Table 9: Land-use areas by regional council in 2020, $25 carbon price

Regional council	Dairy (ha)	Sheep/Beef (ha)	Forestry (ha)	Scrub (ha)	Horticulture (ha)	Non-productive (ha)	Urban (ha)	Other animal & lifestyle (ha)	Indigenous forest (ha)	Pasture on public land (ha)	DoC and other public land (ha)
Northland	137,266	417,220	188,150	75,824	10,142	21,155	7,816	8,512	132,322	26,631	219,999
Auckland	43,866	160,000	38,759	38,602	11,517	7,450	44,221	17,517	35,664	12,441	89,272
Waikato	484,952	672,465	280,071	116,926	18,438	82,873	23,322	41,644	156,517	47,314	517,374
Bay of Plenty	92,560	116,660	167,080	30,143	27,308	6,770	12,863	12,604	133,304	18,758	604,702
Gisborne	4,975	278,526	229,627	91,750	15,218	13,163	2,379	3,988	58,394	8,853	128,560
Hawkes Bay	40,055	598,034	175,613	97,804	32,895	13,169	6,709	12,307	91,482	16,101	332,210
Taranaki	186,006	164,416	55,407	37,603	1,763	3,246	5,792	7,128	89,895	14,142	161,395
Manawatu-Wanganui	145,054	952,084	145,637	231,858	17,277	15,014	12,208	25,132	140,270	51,403	484,421
Wellington	52,969	285,795	85,524	93,846	7,532	6,145	17,405	7,544	23,073	10,430	221,743
West Coast	61,871	63,475	37,078	37,038	68	25,167	2,639	5,959	71,438	30,076	1,999,907
Canterbury	297,169	1,079,783	131,336	280,381	246,565	70,176	26,383	74,826	22,124	810,820	1,480,836
Otago	113,206	1,149,634	143,140	150,879	19,606	80,974	11,167	26,084	15,268	755,373	721,997
Southland	212,286	600,743	80,009	46,942	7,295	20,656	6,133	57,510	48,482	220,337	1,882,630
Tasman	30,155	75,919	93,957	29,470	10,869	6,010	2,433	7,187	44,783	5,797	657,913
Nelson	569	3,301	11,092	684	18	267	2,140	142	1,157	716	21,695
Marlborough	10,926	164,368	81,307	96,747	31,588	17,674	2,340	3,808	20,481	138,583	483,387

Figure 19 to Figure 22 give changes in land use areas for dairy, sheep/beef, forestry and scrub land. For ease of comparison the scale of Figure 19 to

Figure 21 are the same.

Figure 19: Change in endogenous land use areas 1996 to 2008

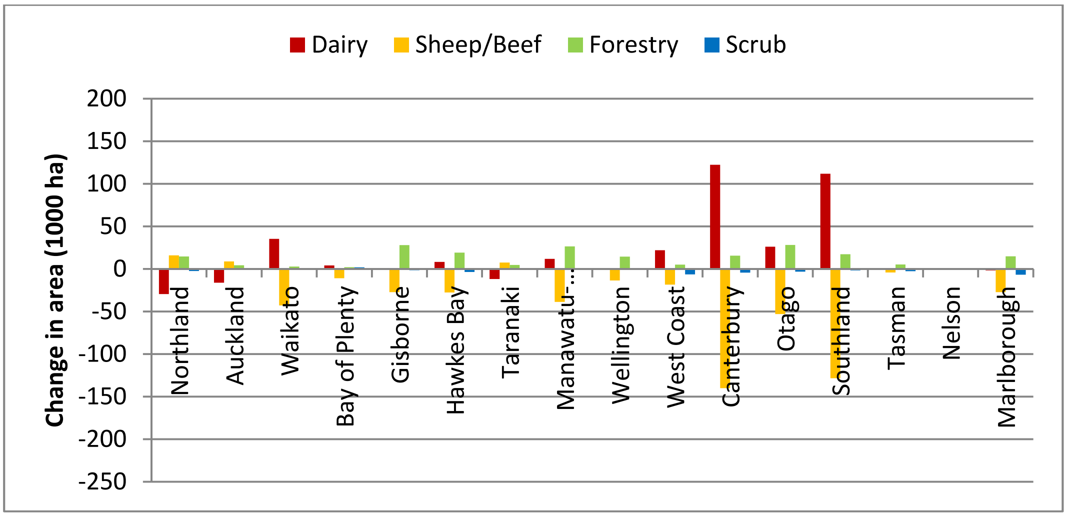


Figure 20: Change in endogenous land use areas 2008 to 2020, $5 carbon price

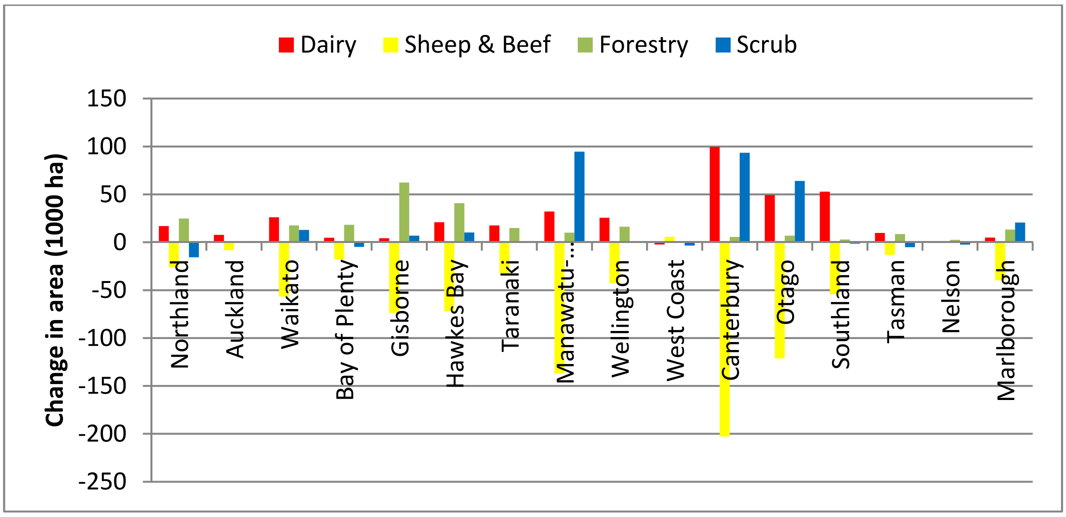


Figure 21: Change in endogenous land use areas 2008 to 2020, $25 carbon price

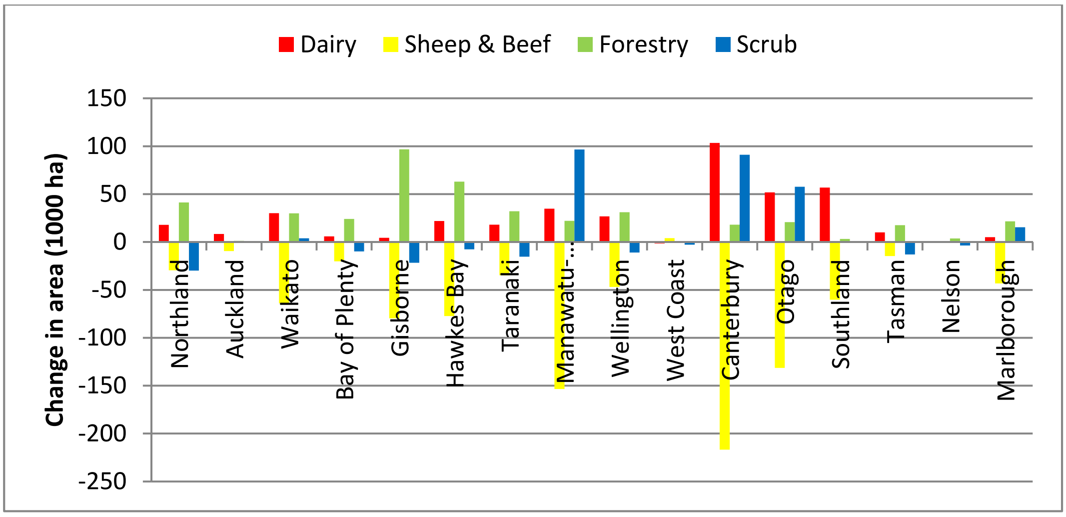


Figure 22: Difference in endogenous land use areas in 2020, $5 to $25 carbon price

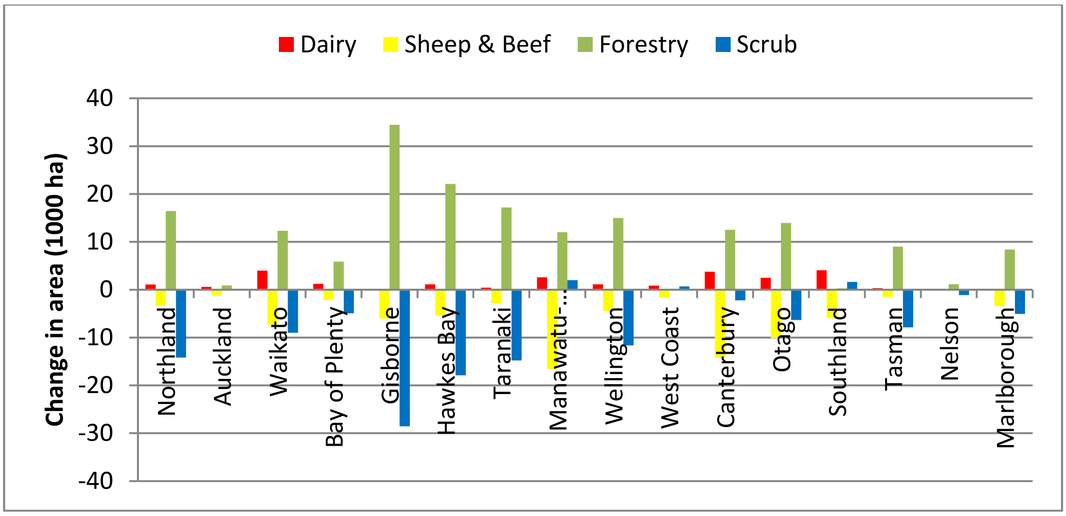


Figure 23 and Figure 24 give changes in all other land uses between 1996 and 2008. In our maps, these land uses do not change post 2008.

Figure 23: Change in other land use areas 1996 to 2008

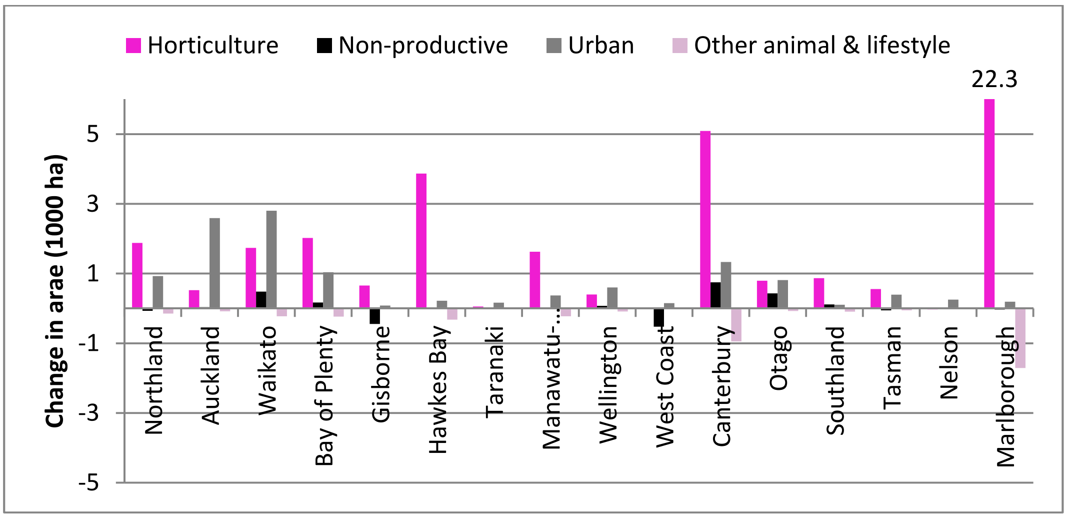
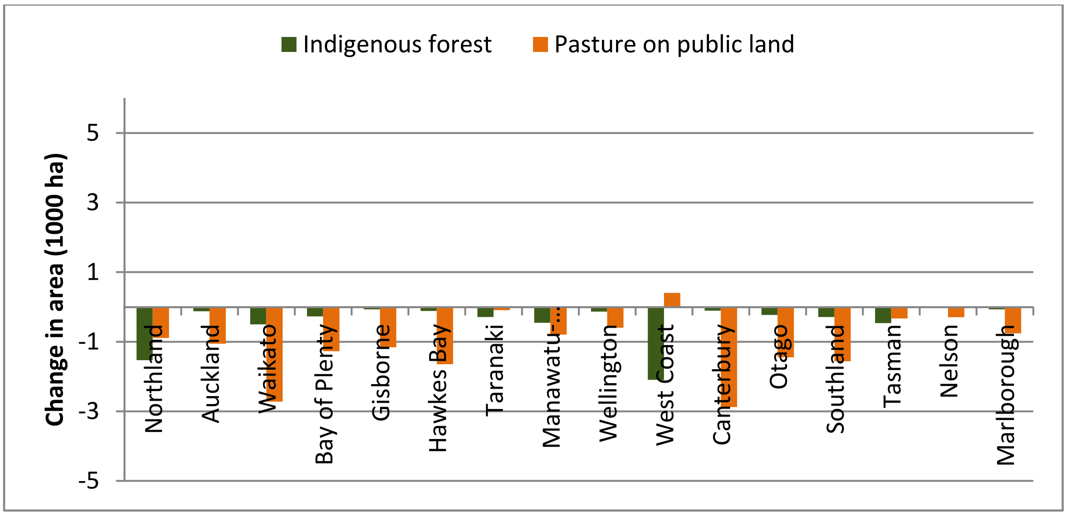


Figure 24: Change in native and public pasture land areas 1996 to 2008 (total public land is held constant)



Producing land-use maps

Table 10: Land uses in LURNZ

Land-use code	Land-use description	Variable type
1	Dairy	Endogenous
2	Sheep/Beef	
3	Plantation Forestry	
4	Scrub	
5	Horticulture	Exogenous
6	Non-productive	
7	Urban	
8	Other animal and lifestyle	
9	Indigenous forest	
10	Pasture on public land	
11	DoC and public land (excluding pasture)	

Land-use codes are used in the GIS compatible map files produced by LURNZ, as these files take numeric codes only. Endogenous variables are those that may change land use according to the LURNZ allocation algorithm.

Table 11: Multinomial logit model coefficients

Variable	Dairy	Sheep/Beef	Forestry
Slope	-0.1808	-0.0598	-0.0529
LUC class	-0.6985	-0.5292	-0.1186
Distance from nearest town	-0.2752	-0.0354	-0.0301
Distance from nearest port	-0.0181	-0.0292	-0.0186
Land is Maori owned	-1.9402	-1.6505	-0.5561
Constant	5.4909	5.3199	1.4540

Under the multinomial logit model, the probability of a pixel taking land use i is given by $p_i = e^{u_i}/\sum_i e^{u_i}$. Where u_i is the utility of choice i calculated according to the coefficients in Table 11. The utility of scrub land is zero by definition. Distance from nearest town and from nearest port are expressed as thousands of kilometres. All coefficients are significant at the

0.001% level, except for distance from port for sheep/beef land which is significant at the 5% level.

Table 12: Classification of LCDB3 classes to LURNZ consistent land uses

LURNZ consistent land uses	LCDB3 land-use class
Pasture	Depleted Grassland, High Producing Exotic Grassland, Low Producing Grassland, Tall Tussock Grassland, Alpine Grass/Herbfield
Plantation Forestry	Exotic Forest, Deciduous Hardwoods, Forest Harvested
Scrub	Broadleaved Indigenous Hardwoods, Flaxland, Gorse and Broom, Manuka and/or Kanuka, Matagouri or Grey Scrub, Mixed Exotic Shrubland, Sub Alpine Shrubland, Fernland
Urban	Built-up Area, Urban Parkland/ Open Space, Transport Infrastructure
Horticulture	Short-rotation Cropland, Orchard, Vineyard and Other Perennial Crops
Other / Non-productive	Gravel and Rock, Sand and Gravel, Estuarine Open Water, Herbaceous Freshwater Vegetation, Herbaceous Saline Vegetation, Lake and Pond, Landslide, Mangrove, Permanent Snow and Ice, River, Surface Mines and Dumps
Indigenous Forest	Indigenous Forest

This classification of land uses is consistent with the classification used for the 2002 land-use map. Land classified as pasture may be used for dairy farming, sheep/beef farming, or for other animals and lifestyle properties.

Table 13 gives the time series data for historical interest rates and commodity prices for dairy, sheep/beef (composite) and forestry. The forecasted commodity prices used for estimating future changes in land use are given in

Table 14. These are sourced from the Situational Outlook for New Zealand Agriculture and Forestry (SONZAF) produced by the Ministry for Primary Industries.

Table 13: Historic time series of prices and interest rates

Year	Interest rate (%)	Dairy price (cents)	Sheep/beef price (cents)	Forestry price (cents)
1974	5.41	713	1095	19295
1975	5.66	870	750	21399
1976	7.46	642	806	18522
1977	9.01	590	914	15494
1978	9.78	593	865	17900
1979	12.20	554	946	17399
1980	13.02	667	958	18464
1981	12.68	601	929	19395
1982	12.54	702	920	16827
1983	11.87	706	964	16489
1984	12.28	641	960	18026
1985	18.47	602	1000	22180
1986	17.14	730	808	20144
1987	16.68	410	644	17574
1988	13.45	437	605	16390
1989	12.78	549	616	13166
1990	12.46	548	634	14089
1991	10.00	349	560	14813
1992	7.87	477	569	14196
1993	6.69	516	607	20911
1994	7.48	449	574	25152
1995	7.94	453	509	17638
1996	8.04	521	472	16562
1997	7.21	469	489	15333
1998	6.47	435	496	14830
1999	6.13	457	539	11963
2000	6.85	472	580	13630
2001	6.12	607	656	13655
2002	6.28	627	698	11775
2003	5.51	422	638	10127
2004	5.98	478	604	10518
2005	5.98	502	605	8867
2006	6.01	432	569	10002
2007	6.81	465	552	11552
2008	6.17	725	520	9259

Table 14: Forecasted time series of prices and interest rates

Year	Interest rate (%)	Dairy price (cents)	Sheep/beef price (cents)	Forestry price (cents)
2009	3.7	458	620	10873
2010	2.7	581	572	10946
2011	3.0	683	653	11659
2012	3.0	607	596	12722
2013	3.9	627	581	13114
2014	4.7	661	646	13972
2015+	5.0	709	729	14029

The forecasted national land-use areas are given in Table 15 and

Table 16. Historical land-use areas are available from the Agricultural Production surveys and censuses (Statistics New Zealand, 2008), and from the Dairy Statistics reports (LIC and DairyNZ, dataset, 2010). However, we cannot be confident that the areas reported by Statistics New Zealand are a true representation of the actual areas in New Zealand (Danny Oberhaus, Statistics New Zealand, pers. comm. March 2013). It follows that the trends reported by Statistics New Zealand should not be expected to be consistent with our land-use maps. This data limitation has minimal impact on any of our results.

Table 15: Forecasted rural land-use areas, $25 carbon price

Year	Dairy area (ha)	Sheep/beef area (ha)	Forestry area (ha)	Scrub area (ha)
2009	1,836,324	7,647,154	1,419,352	1,193,763
2010	1,929,791	7,461,170	1,465,075	1,240,555
2011	1,918,062	7,340,576	1,488,720	1,349,235
2012	1,960,074	7,286,727	1,522,938	1,326,854
2013	1,952,540	7,172,740	1,552,925	1,418,388
2014	1,970,840	7,137,061	1,590,172	1,398,519
2015	2,015,747	7,118,957	1,636,748	1,325,139
2016	2,045,439	7,063,910	1,679,651	1,307,592
2017	2,046,532	6,967,044	1,713,191	1,369,826
2018	2,051,309	6,904,674	1,742,741	1,397,868
2019	2,056,839	6,860,697	1,769,862	1,409,194
2020	2,063,109	6,820,019	1,792,824	1,420,640

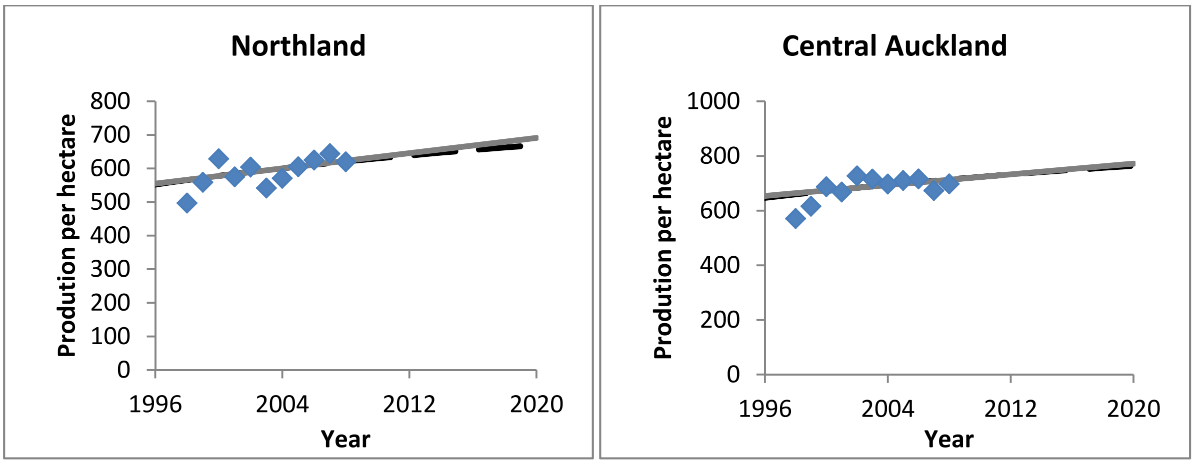
Table 16: Forecasted rural land-use areas, $5 carbon price

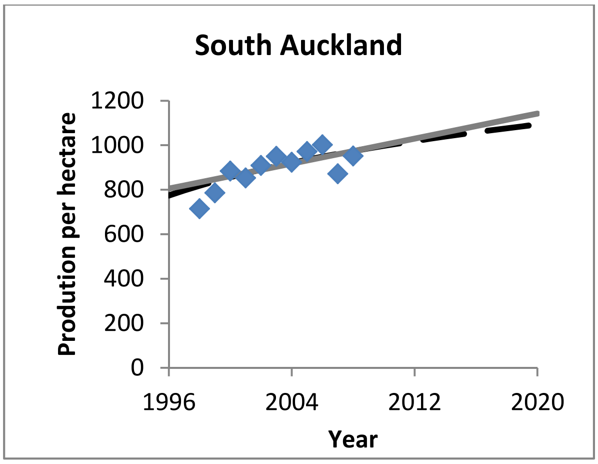
Year	Dairy area (ha)	Sheep/beef area (ha)	Forestry area (ha)	Scrub area (ha)
2009	1,834,389	7,653,834	1,404,049	1,204,320
2010	1,925,922	7,474,530	1,434,469	1,261,671
2011	1,912,258	7,360,615	1,442,811	1,380,907
2012	1,952,335	7,313,446	1,461,726	1,369,085
2013	1,942,867	7,206,139	1,476,410	1,471,176
2014	1,959,233	7,177,140	1,498,355	1,461,865
2015	2,002,205	7,165,716	1,529,628	1,399,042
2016	2,029,962	7,117,349	1,557,228	1,392,053
2017	2,029,120	7,027,163	1,575,465	1,464,844
2018	2,031,963	6,971,473	1,589,712	1,503,444
2019	2,035,558	6,934,176	1,601,530	1,525,328
2020	2,039,171	6,906,215	1,611,147	1,540,059

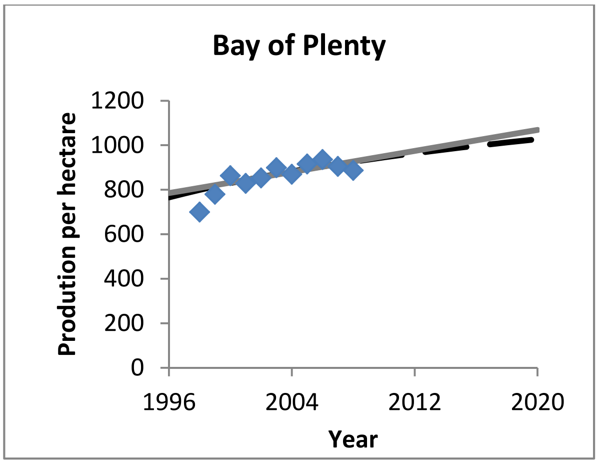
Measures of farming intensity

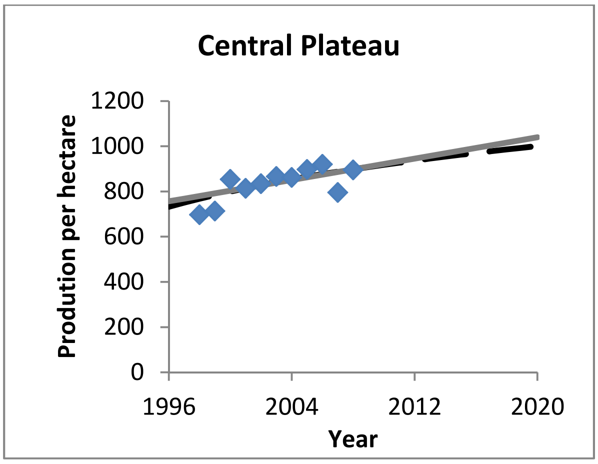
Figure 25 gives the trends in dairy farming intensity. For each panel, the dark blue points give the observed data, the dashed black line gives the logarithmic model, and the grey line gives the linear model. We show the observed production per hectare for 1998 even though it is excluded from the data when estimating trend lines.

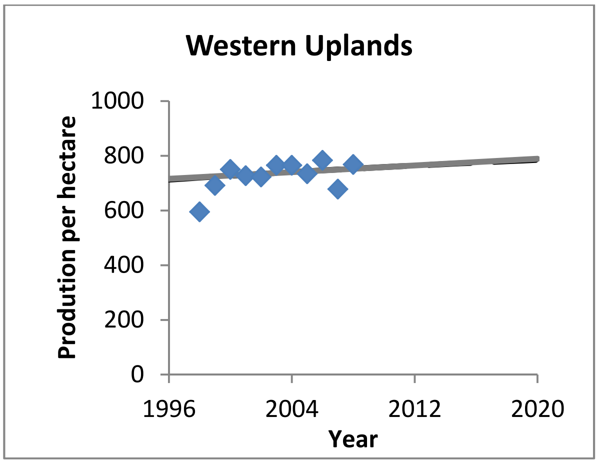
Figure 25: Trends in production per hectare for dairy by LIC region

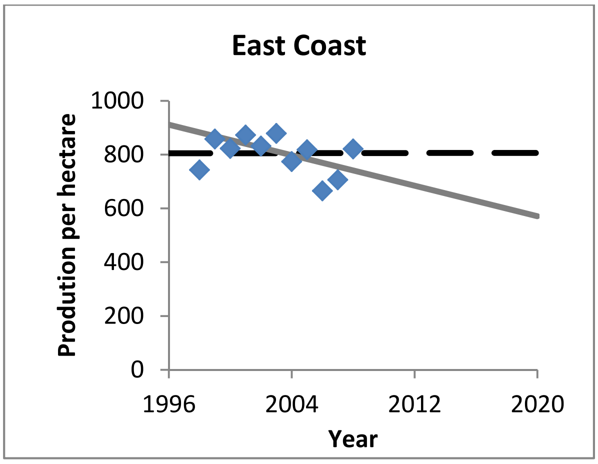


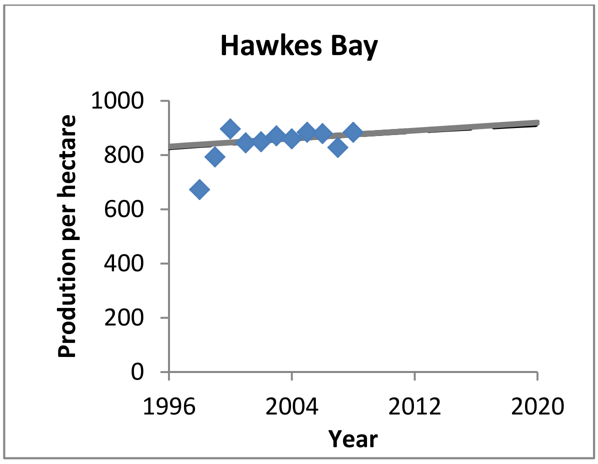

South Auckland
Prodution per hectare
1200
1000
800
600
400
200
0
1996
2004
2012
2020
Year

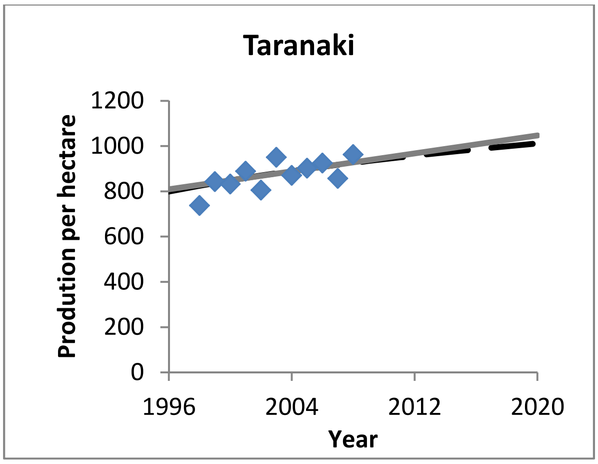

Bay of Plenty
Prodution per hectare
1200
1000
800
600
400
200
0
1996
2004
2012
2020
Year

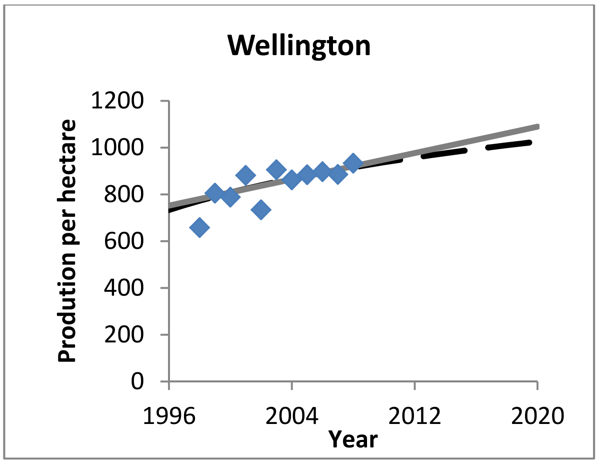

Central Plateau
Prodution per hectare
1200
1000
800
600
400
200
0
1996
2004
2012
2020
Year

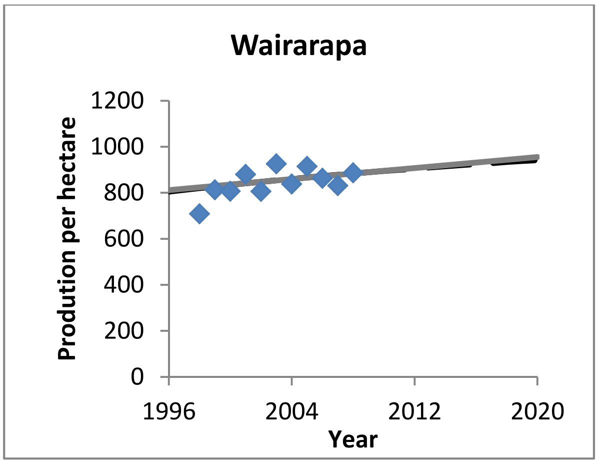

Western Uplands
Prodution per hectare
1000
800
600
400
200
0
1996
2004
2012
2020
Year

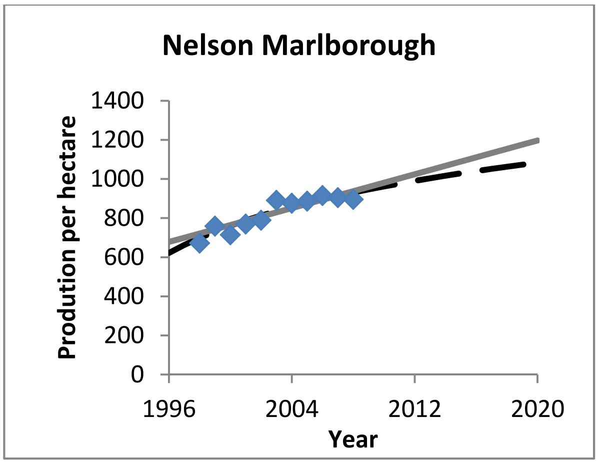

East Coast
Prodution per hectare
1000
800
600
400
200
0
1996
2004
2012
2020
Year

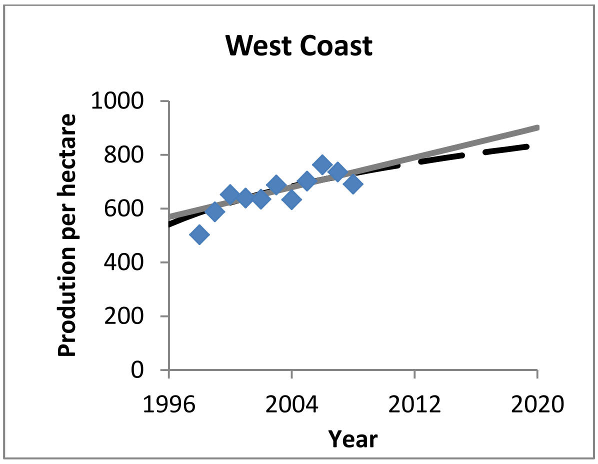

Hawkes Bay
Prodution per hectare
1000
800
600
400
200
0
1996
2004
2012
2020
Year

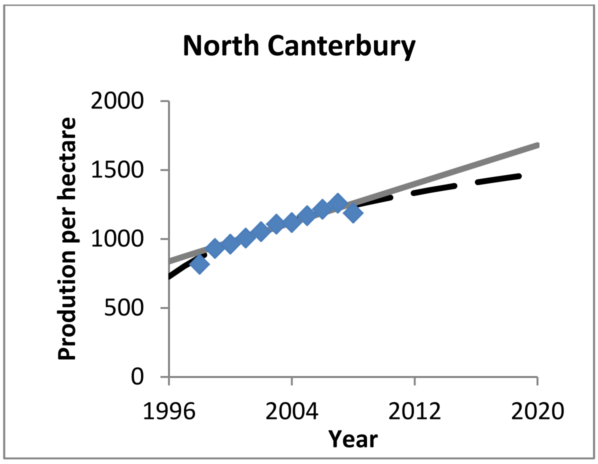

Taranaki
Prodution per hectare
1200
1000
800
600
400
200
0
1996
2004
2012
2020
Year

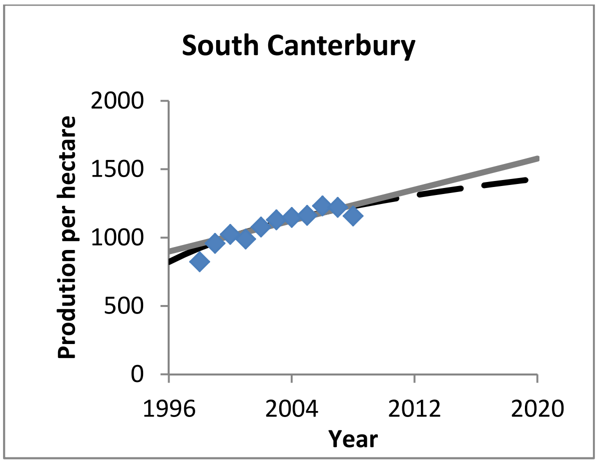

Wellington
Prodution per hectare
1200
1000
800
600
400
200
0
1996
2004
2012
2020
Year

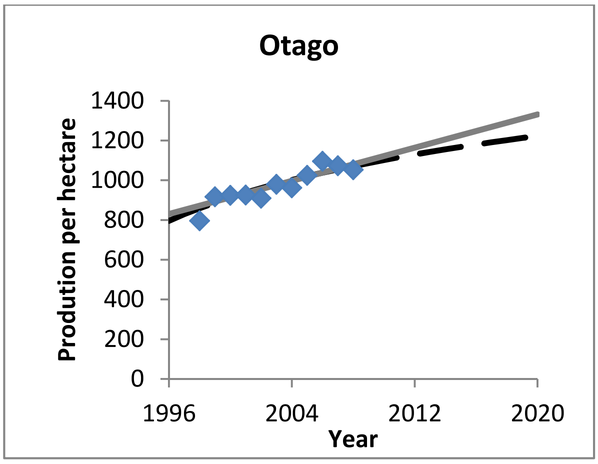

Wairarapa
Prodution per hectare
0
200
400
600
800
1000
1200
1996
2004
2012
2020
Year


Nelson Marlborough
Prodution per hectare
0
200
400
600
800
1000
1200
1400
1996
2004
2012
2020
Year


West Coast
Prodution per hectare
0
200
400
600
800
1000
1996
2004
2012
2020
Year


North Canterbury
Prodution per hectare
0
500
1000
1500
2000
1996
2004
2012
2020
Year


South Canterbury
Prodution per hectare
0
500
1000
1500
2000
1996
2004
2012
2020
Year


Otago
Prodution per hectare
0
200
400
600
800
1000
1200
1400
1996
2004
2012
2020
Year

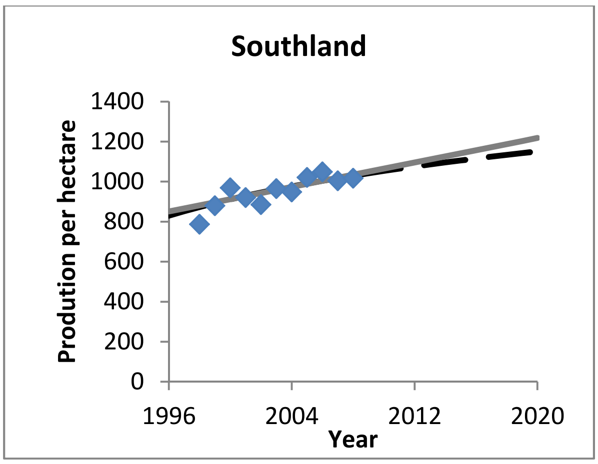

Southland
Prodution per hectare
0
200
400
600
800
1000
1200
1400
1996
2004
2012
2020
Year

Table 17 gives the regression coefficients for the trends in dairy farming intensity under the logarithmic and linear models.

Table 17: Regression coefficients for dairy production per hectare

Production per hectare (kg MS / ha)	Logarithmic model: Y = a log(X – b)		Linear model: Y = a X + b	
LIC region	a	b	a	b
Northland	173	1972	5.67	-10,768
Central Auckland	193	1967	4.92	-9,157
South Auckland	303	1983	14.05	-27,236
Bay of Plenty	279	1981	11.83	-22,828
Central Plateau	274	1982	11.80	-22,796
Western Uplands	183	1947	3.06	-5,394
East Coast	110	500	-14.18	29,206
Hawkes Bay	213	1947	3.68	-6,512
Taranaki	268	1976	9.92	-18,994
Wellington	283	1983	14.05	-27,289
Wairarapa	236	1966	5.99	-11,140
Nelson/Marlborough	315	1989	21.62	-42,472
West Coast	237	1986	13.82	-27,024
North Canterbury	436	1991	35.06	-69,143
South Canterbury	416	1989	28.30	-55,595
Otago	347	1986	20.87	-40,832
Southland	317	1982	15.29	-29,670

Table 18: Concordance between LIC region, TAs and regional council boundaries

LIC region	Territorial authority	Regional council area
Bay of Plenty	Opotiki	Bay of Plenty
Bay of Plenty	Tauranga	Bay of Plenty
Bay of Plenty	Western Bay of Plenty	Bay of Plenty
Bay of Plenty	Whakatane	Bay of Plenty
Central Auckland	Franklin	Auckland
Central Auckland	Manukau	Auckland
Central Auckland	Papakura	Auckland
Central Auckland	Rodney	Auckland
Central Plateau	Rotorua	Bay of Plenty
Central Plateau	Taupo	Waikato
East Coast	Gisborne	Gisborne
East Coast	Wairoa	Hawkes Bay
Hawkes Bay	Central Hawkes Bay	Hawkes Bay
Hawkes Bay	Napier/Hastings	Hawkes Bay
Nelson/Marlborough	Kaikoura	Canterbury
Nelson/Marlborough	Marlborough	Marlborough
Nelson/Marlborough	Tasman/Nelson City	Nelson-Tasman
North Canterbury	Ashburton	Canterbury
North Canterbury	Banks Peninsula	Canterbury
North Canterbury	Christchurch	Canterbury
North Canterbury	Hurunui	Canterbury
North Canterbury	Selwyn	Canterbury
North Canterbury	Waimakariri	Canterbury
Northland	Far North	Northland
Northland	Kaipara	Northland
Northland	Whangarei	Northland
Otago	Clutha	Otago

Otago	Dunedin	Otago
Otago	Waitaki/Central Otago	Otago
South Auckland	Hamilton	Waikato
South Auckland	Hauraki	Waikato
South Auckland	Matamata-Piako	Waikato
South Auckland	Otorohanga	Waikato
South Auckland	South Waikato	Waikato
South Auckland	Thames-Coromandel	Waikato
South Auckland	Waikato	Waikato
South Auckland	Waipa	Waikato
South Canterbury	Timaru	Canterbury
South Canterbury	Waimate	Canterbury
Southland	Gore	Southland
Southland	Invercargill	Southland
Southland	Southland	Southland
Taranaki	New Plymouth	Taranaki
Taranaki	South Taranaki	Taranaki
Taranaki	Stratford	Taranaki
Wairarapa	Carterton	Wellington
Wairarapa	Masterton	Wellington
Wairarapa	South Wairarapa	Wellington
Wairarapa	Tararua	Manawatu-Wanganui
Wellington	Horowhenua	Manawatu-Wanganui
Wellington	Kapiti Coast	Wellington
Wellington	Manawatu	Manawatu-Wanganui
Wellington	Palmerston North	Manawatu-Wanganui
Wellington	Rangitikei	Manawatu-Wanganui
Wellington	Upper Hutt	Wellington
Wellington	Wanganui	Manawatu-Wanganui
West Coast	Buller	West Coast
West Coast	Grey	West Coast
West Coast	Westland	West Coast
Western Uplands	Ruapehu	Manawatu-Wanganui
Western Uplands	Waitomo	Waikato

Table 19 gives the CLUES-compatible percentage changes in effective stocking rates, from 2001 levels, for dairy farming.

Table 19: Dairy percentage changes in effective stocking rates

Percentage changes in effective stocking rate from 2001 levels	1996	2008	2020
Auckland	-3.07	4.66	14.54
Bay of Plenty	-8.21	8.28	23.60
Canterbury	-25.15	17.80	45.97
Gisborne	-9.66	-7.79	-9.46
Hawkes Bay	-3.42	2.68	5.77
Manawatu-Wanganui	-13.78	4.22	13.27
Marlborough	-18.56	17.39	41.94
Nelson-Tasman	-18.56	17.39	41.94
Northland	-4.20	7.60	16.26
Otago	-13.96	13.86	32.24
Southland	-10.47	9.68	24.16
Taranaki	-10.05	8.30	13.87
Waikato	-8.76	11.89	28.11
Wellington	-9.71	1.24	8.07
West Coast	-16.13	7.07	29.36

Table 20 gives the regression coefficients for the trend in sheep/beef farming intensity under the logarithmic and linear models.

Table 20: Regression coefficients for sheep/beef production intensity

Production/Stock Unit Kg enteric CH4 / SU	Logarithmic model: $Y = a \log(X - b)$		Linear model: $Y = a X + b$	
	a	b	a	b
National	3.2460	1966.6	0.099131	-186.92

Table 21 gives the CLUES-compatible percentage change in effective stocking rates, from 2001 levels, for sheep/beef farming.

Table 21: Sheep/beef percentage changes in effective stocking rates

Percentage changes in effective stocking rate from 2001 levels	1996	2008	2020
For all regions	-6.84	0.67	10.04

Land-Use Scenarios in LURNZ

New Zealand's rural land has historically been divided between four major uses – dairy farming, sheep and beef farming, plantation forestry, and unproductive scrub land. Kerr and Olssen (2011) estimated the relationships between the share of land in each of these uses and the economic returns to rural production as proxied by the export prices for milk solids, a sheep and beef meat and wool composite, and log prices. A future land use projection was made assuming no pricing of carbon dioxide emissions. This projection also implicitly assumes that future land use responses to changing economic returns are similar to historic responses to similar changing economic returns.

In this note we document our methodology for estimating land use scenarios in the presence of an emissions trading scheme. Because we initially modelled land use in terms of commodity prices we essentially convert assumed carbon prices under an emission trading scheme into deductions on the price that land owners would receive for rural production.

The rest of this note is structured as follows: Section 2 explains how we converted assumed carbon prices into deductions in commodity prices given the emissions trading scheme framework most recently proposed. The coefficient that measures the response of the share of dairy land to forestry prices in our econometric model is positive and reasonably large. In section 3 we discuss how we have adjusted our projections in light of this. Section 4 presents some graphs showing our baseline and ETS scenario. Section 5 provides some final comments.

Modelling the impact of carbon prices

We convert an assumed carbon price, the current emissions trading environment, and MAF emissions factors into cost deductions on the commodity prices which we use to model land-use change. In particular we assume forestry enters the ETS in 2008; agriculture enters in 2015; agriculture receives a free allocation that starts at 90 per cent in 2015 and decreases annually by 1.3 per cent of the previous year's free allocation. We assume that the two-for-one policy does not apply to agriculture.

Dairy

We use MAF's emission factors to find the number of NZUs that must be surrendered per tonne of milk solids produced. We convert this to the number of NZU's per kilogram of milk solid production. We then multiply this by the assumed carbon price to get the estimated cost of carbon per kilogram of milk solid production. We take the proportion of this cost that is covered by free allocation (this varies annually from 2015) and subtract it from our projected milk solids price for all years after agriculture enters the ETS.

Sheep/Beef

We again calculate the number of NZUs that must be surrendered for the production of a kilogram of our sheep/beef composite. We calculate the carbon liability cost per kilogram of each of the separate meat components. We then take a weighted average of these costs, where we use slaughter weights as our weighting factors. This is adjusted for free allocation and subtracted from our projected composite sheep/beef price.

Plantation forestry

Afforestation decisions have historically depended on anticipated timber returns at harvest time. Under the ETS forests can also make a carbon return. In order to model the impact of the ETS on the amount of land used in forestry it is necessary to model what the return to carbon forestry is.

However capitalising on this carbon return can expose land owners to risk. Two major risks are due to price uncertainty and political uncertainty. On the price uncertainty side, forest owners who have opted into the ETS are liable for a large number of carbon credits at harvest time. If a land owner sold their carbon credits as they were received and the carbon price increased the land owner could face a large loss. This risk is potentially less relevant to large forest owners who can stagger harvest times or develop forests with equal age distributions so that sequestration in each year offsets harvest liabilities. Political uncertainty is a risk for the returns to forest owners who have opted into the ETS as changes to the sequestration rewards affect their carbon returns. In the extreme case that sequestration was no longer rewarded carbon returns to forestry would be zero.

In this note, we model the carbon return to plantation forestry by valuing the carbon credits from the first 10 years of forest growth. Valuing carbon returns for the first 10 years at a constant real carbon price may overestimate actual land owners' valuation of carbon returns if they are very sceptical about the political longevity of the ETS. However using the first 10 years is more conservative than using longer periods of time. The carbon stock at 10 years also coincides with the minimum carbon stock on land that is always replanted – and hence this return can be realised without exposing the land owner to any carbon liabilities at harvest time.

We calculate the net present value to the first 10 years of carbon credits using the unweighted regional average carbon stock from MAF look-up tables (Ministry of Agriculture and

Forestry, 2011), a constant carbon price, and a real discount rate of 8 per cent. Suppose that a forest owner could find somebody who valued the future stream of carbon credits this much. They could sell the future rights to the credits, get the present value and store it in the bank to receive the risk free return, which we assume to be 5 per cent. Because timber returns are realised at harvest time, we convert the net present value of the carbon return to a future return using the risk free rate. This is the value we add to our projected forest prices.

Modelling the effect of scrub returns

Since 2008 scrub land has been able to earn a return by entering the ETS. We have no data on historical responses to scrub returns – scrub has never had a return before. We model scrub returns as changing the value of the outside option in other land uses. Thus, while the carbon return from sequestration increases incentives for land to be used as plantation forestry, the fact that carbon returns can be earned from regenerative scrub reduces this incentive. The potential for carbon returns on scrub compounds the disincentive of agricultural carbon costs. Thus while we discussed above the direct impact of a carbon trading system on each of our projected price series, we further adjust these series to reflect that the outside option has changed. In particular we subtract off the potential carbon reward to scrub from the already adjusted price projections.

We calculate the scrub return in a similar manner to the forestry return. We use only the first 10 years of credits. Some scrub land may be of such a low quality of production that it is highly unlikely to ever be converted to productive uses. If conversion would never occur with certainty then the land owner would do best to sell all credits earned from the land (the timing of sales would optimally depend on the price path of carbon). (Uncertainty about the whether the return will be obtained at all – hence using a certain return of the whole lifecycle of carbon will be too large). However, plantation forestry sequesters carbon at a higher rate than regenerative scrub. Thus, putting establishment costs to the side, plantation forest can always earn higher carbon returns than scrub. In light of this, it would not make sense to value the carbon return to scrub using credits over its whole lifetime. We calculate the net present value from selling the first 10 years of credits (as given in MAF's look-up tables) as they are received, using our assumed carbon price, and an 8 per cent real discount rate. Suppose that a scrub owner sold the 10 years of future carbon credits, to somebody who valued them at the carbon price and used an 8 per cent discount rate, and put the money in the bank. They would earn the risk free return. Thus we annualise the net present value of the first 10 years of carbon credits from scrub in this way. This is what we subtract from the agricultural price projections.

Forestry conversion depends on anticipated returns at harvest. Thus we find the future value of the carbon return on scrub at harvest time using the money interest rate – once again think of selling the future rights to carbon credits and banking the money. This is what we subtract from the forestry price projections.

Dairy adjustment

Kerr and Olssen (2011) estimated the responses of rural land use shares to economic returns as proxied by relevant commodity prices. The econometric model was estimated on national level time series data, primarily for the reason that no consistent disaggregated data set exists to examine the influence of the economic determinants of land use choices. However, as a result the analysis has little data to work with. One uncomfortable result is that historically the share of land in dairy farming is correlated with forestry export prices (as measured by export log unit values). We do not think that this represents a causal relationship. However it has implications for any ETS scenario. In particular, the dairy share in our scenario increases as the forestry return increases. And because of the level of the dairy milk solids emissions factor, and the free allocation, the effect of the ETS on effective forestry prices is much larger than the corresponding effect on dairy prices.

We calibrate our projections because of this. In particular we run an auxiliary scenario in which we do not let forestry prices change in response to the ETS. This means that the change in dairy share in this scenario is not being driven by changing forestry prices. We use this as our dairy share for our final scenario. For the other series we use their shares with the full ETS model on plus a third of difference from dairy calibration to each land use (this is necessary to ensure adding up). Finally we linearise the dynamics in the first 10 years. This gives us our ETS land use scenario.

Discussion

This note has discussed how we generate ETS land use scenarios to 2020. The policy environment we have modelled matches closely the environment proposed for the NZ ETS as of early August 2011. Modelling the impact of the ETS on anticipated forestry and scrub returns is tricky and sensitive to assumptions. This is because anticipated returns depend on carbon price expectations as well as policy expectations. Also, scrub land has never earned economic returns before, so we have not directly estimated the effect of scrub returns on land use shares. Obtaining data and analysing how the carbon returns for forest and scrub are actually being valued would be a useful avenue for future research.

References

AsureQuality. "AgriBase Enhanced LCDB2," obtained by Motu Research 2008. Restricted data Details online at http://www.motu.org.nz/building-capacity/datasets.

de Klein, C. A. M.; R. M. Monaghan; S. F. Ledgard and M. Shepherd. 2010. "A System's Perspective on the Effectiveness of Measures to Mitigate the Environmental Impacts of Nitrogen Losses From Pastoral Dairy Farming", *Proceedings of the Australasian Dairy Science Symposium,* Proceedings of the 4th Australasian Dairy Science Symposium, August 2010, pp. 14-28.

Kerr, Suzi; Simon Anastasiadis; Alex Olssen; William Power; Levente Timar and Wei Zhang. 2012. "Spatial and Temporal Responses to an Emisisons Trading Scheme Covering Agriculture and Forestry: Simulation Results From New Zealand", *Forests,* 3, pp. 1133-56.

Kerr, Suzi and Alex Olssen. 2012. "Gradual Land-Use Change in New Zealand: Results From a Dynamic Econometric Model," *Motu Working Paper 12-06,* Motu Economic and Public Policy Research, Wellington. Available online at http://www.motu.org.nz/publications/detail/gradual_land-use_change_in_new_zealand_results_from_a_dynamic_econometric_m.

Landcare Research. "Ownership Map of New Zealand 2002," obtained by Motu Research 2008. Restricted dataset Details online at http://www.motu.org.nz/building-capacity/datasets.

Landcare Research. "Land Cover Database v3.0," obtained by Motu Research 1-11-2012. Unrestricted dataset Details online at http://www.motu.org.nz/building-capacity/datasets.

Landcare Research New Zealand. "Average Carrying Capacity (CCAV)," obtained by Motu Research 2002. Unrestricted Data Details online at http://www.motu.org.nz/building-capacity/datasets.

LIC and DairyNZ. "New Zealand Dairy Statistics 1999 to 2008," obtained by Motu Research 2010. Unrestricted data Details online at http://www.motu.org.nz/building-capacity/datasets.

Meat and Wool Economic Service. "Sheep and Beef Farm Survey: Sheep/Beef Data 1980 - 2009," obtained by Motu Research 2009. Restricted dataset Details online at http://www.motu.org.nz/building-capacity/datasets.

Ministry for the Environment. 2010. *New Zealand's Greenhouse Gas Inventory 1990-2008,* Wellington: Ministry for the Environment. Available online at http://www.mfe.govt.nz/publications/climate/greenhouse-gas-inventory-2010/.

Ministry of Agriculture and Forestry. 2011. *A Guide to Look-Up Tables for Forestry in the Emissions Trading Scheme,* Wellington: Ministry of Agricultrue and Forestry. Available online at http://www.mpi.govt.nz/portals/0/documents/forestry/forestry-ets/2011-ETS-look-up-tables-guide.pdf.

Statistics New Zealand. 2008. "Agricultural Production Statistics: 2008," . Available online at http://www2.stats.govt.nz/domino/external/omni/omni.nsf/bf3c32a862ae07cd4c25656e000031c6/52acfb136d61b179cc2575b50013985d?OpenDocument.

Timar, Levente. 2011. "Maori Land and Rural Land Use in New Zealand," New Zealand Association of Economists Annual Conference, Wellington, 29 June - 1 July 2011.

Woods, Ross; Vince Bidwell; Brent Clothier; Steve Green; Sandy Elliott; Ude Shankar; Simon Harris; Allan Hewitt; Robert Gibb; Roger Parfitt and David Wheeler. 2006. "The CLUES Project: Predicting the Effects of Land-Use on Water Quality - Stage II," National Institute of Water and Atmospheric Research, Hamilton.

Zhang, Wei and Suzi Kerr. 2012. "Creating New Zealand Forestry Age Maps in 2002 and 2008 and Estimating and Projecting Plantation Forest Removals and Emissions in LURNZ," Motu Economic and Public Policy Research, draft.