II. Modeling the impact of Carbon Farming on a New Zealand landscape

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Abstract

Policies that create the opportunity for private landowners to receive carbon credits from reforestation, or "carbon farming," will change the relative value of land uses for landowners, potentially having an impact on land-use decisions and the character of landscapes. We constructed a spatial model to evaluate the potential scale and location of carbon farming in a New Zealand landscape, the potential size of resulting carbon stocks, the economic trade-offs for landowners considering carbon farming, the effect of other policies on the attractiveness of carbon farming, and the level and timing at which certain sequestration activities become economically viable. We modeled the carbon accumulation, economic value, and potential uptake of a carbon farming management system, in which landowners utilized a least-cost approach by encouraging native forest regeneration on set-aside land.

For the study area, the Gisborne District of New Zealand, we found that the unassisted regrowth of native species on estimated Kyoto-eligible marginal pasture has the potential to store 121.7 Mt CO_2-e over 70 years. We examined several price scenarios for carbon and found the potential economic revenues from carbon for the area could be around NZ$590m during the 70 years of regeneration. However, comparing a baseline projection of carbon revenue to expected values of grazing on eligible land shows that reforestation could out-compete grazing on only about 40,000 ha in the study area, bringing an increase in net present value of NZ$18M to the region. Sensitivity analysis using several price trajectories shows that the scientific uncertainty about the scale and rate of carbon sequestration can have a sizeable effect

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on the profitability of carbon forestry, but potential profits are more strongly affected by the uncertainty of the future value of carbon credits and the continuing existence of a carbon market.

A. Introduction

New policy incentives for land management activities that sequester carbon create a shift in the rewards for different land uses available to landowners. In particular, the rewards from existing or newly-established forests may increase considerably. Here, we develop an approach to estimate the impact of these rewards on land use for a New Zealand landscape by 1) developing a modeling methodology for quantifying the spatial and temporal dynamics of potential carbon sequestration, 2) examining the revenue potential under a variety of carbon price scenarios, 3) exploring the impact of concurrent incentives for reforestation, as well as transaction costs, and 4) comparing the expected revenue from reforestation with expected returns from grazing.

New Zealand adopted a policy in 2007 called the Permanent Forest Sink Initiative (PFSI), which creates a mechanism for landowners to receive carbon credits for eligible forests on their lands. Under New Zealand's domestic rules, any net conversion of land use to new forests after the baseline date of January 1, 1990 is considered "additional" and therefore eligible to receive carbon credits. This boundary creates a policy-relevant classification of forests:

Ineligible forests: lands forested in 1990, which met the definition of forest;

Kyoto forests: lands not forested in 1990, but which meet the definition of forest during the Kyoto commitment periods;

Kyoto-eligible land: lands not forested in 1990 and which are not currently in forest cover.

Accounting for carbon credits in Kyoto forests is dependent on several factors: the effective age of the forest during the Kyoto commitment periods, the rate of carbon sequestration during the commitment periods, and the fate of these forests during or after the period in which the sequestered carbon is credited to NZ (or some other entity through trade).

The availability of carbon credits to private landowners will increase the economic value of reforestation on eligible lands. Other incentives, such as non-timber forest products or government subsidies for erosion control or biodiversity protection, can provide additional revenues for permanent forests. Therefore, landowners who manage their land to comply with one or more of these programs can earn multiple revenues from a single block of land. For some lands, the additional revenue earned from carbon credits may make forest regrowth economically competitive with other land uses. To encompass all of these possibilities, we use the broad term "carbon farming" to refer to *any land use in which landowners capture economic benefit from carbon sequestration*.

Although this definition could also include timber plantations, in the analysis presented here, we examine a land management system that utilizes native forest restoration to earn carbon credits through the New Zealand policy called the Permanent Forest Sink Initiative. We analyze native forest regeneration for several reasons: 1) because the potential for carbon policy to trigger expansion of the extent of native forests is important ecologically and culturally, 2) because native forests deliver a greater variety of ecological co-benefits than timber plantations, and 3) because the conditions necessary for earning credits would require substantial changes to the current management regimes of timber forests, which is not the focus of this work. Nevertheless, we recognize that under some conditions, a modified system of timber forestry to include carbon credits may be optimal.

Our purpose is to identify areas and conditions where a carbon management system could compete economically with grazing. By mapping these areas in space, we estimate the areas of potential conversion and the total carbon sequestration in the region, as well as identify areas of higher or lower revenue potential from carbon farming. Identifying the spatial locations favorable for carbon sequestration is important for landowners making decisions about land-use allocation, as well as for policymakers who need to understand the land-use impacts of policy choices.

Research Objectives

We carried out several objectives in this analysis:

1. Model the amount of Kyoto credits that could be generated by the conversion of eligible land in the Gisborne District to native forest;
2. Model the economic revenue potential of these credits under several price scenarios;

3. Model how complementary incentives add to the value of native reforestation as a "carbon farming" land management system;
4. Observe how potential carbon farming revenues were distributed among different land blocks;
5. Compare carbon farming as a land use with the opportunity cost of grazing;
6. Calculate a supply curve for carbon in the Gisborne District and compare it to other sources of supply for carbon offsets;
7. Investigate the impact of program costs on the uptake of carbon farming.

B. Study area: Land-use and policy interactions

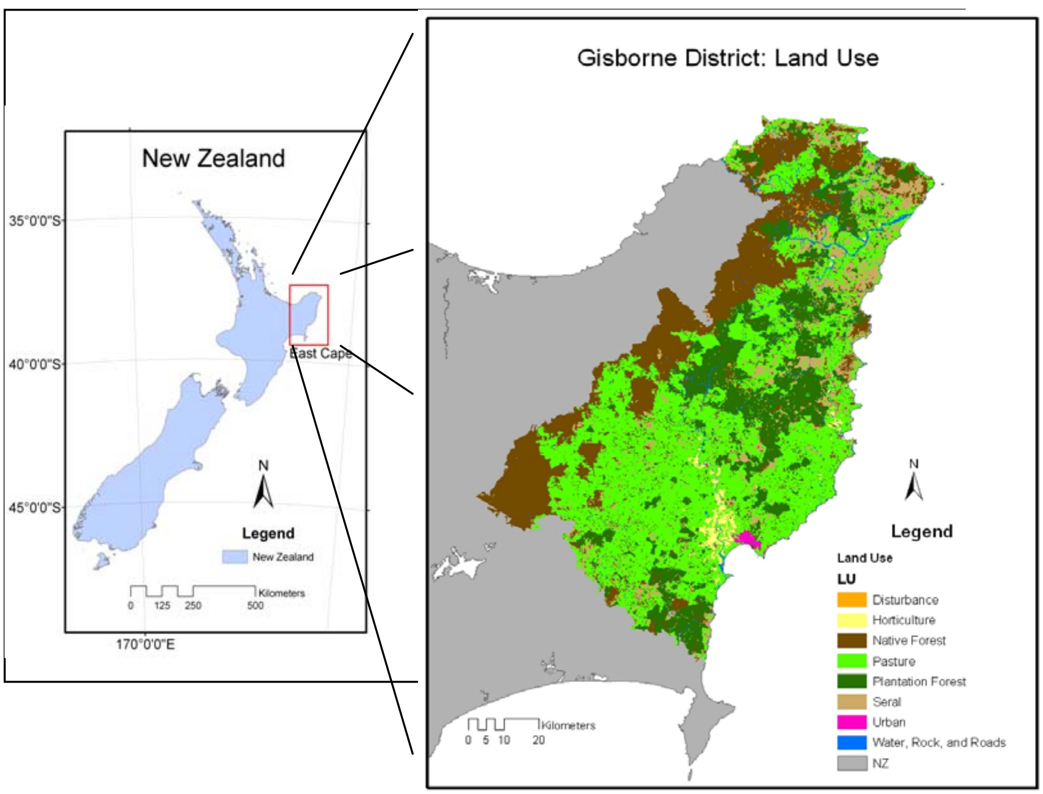

Figure 2. Location and land use of the Gisborne District.

In the Gisborne District (Fig. 2), the reversion process predominantly begins with the invasion of manuka (*Leptospermum scoparium*) or sometimes kanuka (*Kunzea ericoides*). Manuka typically sprouts from wind-dispersed seeds in pastures, grows through a shrub phase, and eventually matures as a small tree (6-10m in height;

Wardle 1991). Without periodic clearing or with low grazing pressure, manuka can invade a pasture and form closed canopy "scrub" quickly (Stephens, Molan, and Clarkson 2005). Its rapid establishment and growth in this region mean some areas that were still pasture in 1990 were closed-canopy scrub by the beginning of the first Kyoto commitment period in 2008.

In the Gisborne District, native forests in various stages of maturity offer economically valuable goods and services. For instance, residents use native forests and scrub as a source of fuelwood, medicine, and food (Stephens, Molan, and Clarkson 2005). Wild pigs, goats, and deer are popular game for hunters. The native forest and wild landscape are also an attraction for tourists. Local Māori collect *rongoa*, or forest medicines. The manuka tree (*L. scoparium*), which dominates scrub, is used for medicinal tea and oil and supplies honey with unique antibacterial properties (Stephens, Molan, and Clarkson 2005, Allen, Molan, and Reid 1991, Molan and Russell 1988). Harvesting manuka honey has become a growing industry in the Gisborne District. Manuka oil and honey from the East Coast are produced commercially and marketed internationally (Kerr, M., personal communication, 2006).

Native forest cover also provides indirect benefits to farmers and timber foresters. For example, fencing the most marginal land and allowing it to regenerate forest can often improve the efficiency of farm and forest activities by eliminating the most costly and hazardous areas of management.

Government programs also provide incentives for new forest establishment. In 1992 the government initiated the East Coast Forestry Project (ECFP) for the Gisborne District, administered today by the Ministry of Agriculture and Forestry (Ministry of Agriculture and Forestry 2006). This program offers grants to private landowners to stabilize erodible land, mainly through plantation forestry. The program allows an option for native forest reversion, which we utilize in this analysis. If a native reversion application is accepted by the ECFP, the landowner receives half of the payment up front and the remainder once the project area passes an inspection in year 5.

In 2008, the government introduced the Afforestation Grant Scheme, a tender process for receiving grants to plant exotic or indigenous tree species (Ministry of

Agriculture and Forestry 2008). Under the Afforestation Grant Scheme, the landowner retains the right to harvest the trees and the government retains the rights to the carbon credits. As a result, this program is not consistent with the definition of carbon farming.

Other programs are targeted at biodiversity protection. Under the Department of Conservation (DoC), landowners may enroll in one of two programs for retiring land for biodiversity conservation: the Queen Elizabeth II Trust (QE2) and *Nga Whenua Rahui* (NWR). (The NWR program applies only to Māori land.) These programs provide landowners with financial assistance for fencing and pest management. In many cases, landowners also receive an up-front payment. The payments are determined on a project-by-project basis, according to the program's estimate of the conservation value of the set-aside land.

We analyze the financial implications of adding each of these programs to the potential revenues received by landowners under the PFSI, because landowners could receive supplementary revenues or reduce costs by utilizing these other options without incurring any additional restrictions on their land use.

C. Methods

<u>Data</u>

To model the carbon sequestration potential in the Gisborne District, we used the following datasets:

1. Land Cover Data Bases for 1996 (LCDB1) and 2002 (LCDB2). These databases are classified from Landsat 7+ ETM and SPOT satellite imagery and ground-truthed (Thompson, Gruner, and Gapare 2003). The minimum mapping unit is 1 ha and the assessed accuracy has been reported as 93%.

2. Land Use Capability (LUC) classification, a ranking system of land quality for different productive uses, including forest productivity (Jessen et al. 1999).

3. NZ Land Resources Inventory (NZLRI):

a. Average Stock Carrying Capacity (CCAV). A layer of the NZLRI indicating the sustainable numbers of animal units that can be maintained on each hectare.

b. Average Annual Rainfall.

c. Soil fertility.

4. Political boundaries, roads, rivers, and lakes.
5. Cadastral database of property boundaries.

Carbon Model

We constructed a spatial and temporal model of carbon accumulation, using data from the LUC and NZLRI databases. Our model uses soil fertility and average annual rainfall as spatial parameters in a forest growth model. The model is based on empirical work by Trotter et al. (2005).

Soil fertility class layer

Productivity of the land was estimated using the Land Use Capability classification system. For exotic pine plantations (*Pinus radiata*), the land use capability classes fall into five categories (shown in Table 1), reflecting the site index for different soil types.

Table 1. Soil fertility classes for the Gisborne District.

Fertility Class	Site Index	LUC Classes
1	>35	Iw1; Ic1; IIe1; IIs1; IIs2
2	30-35	IIw2; IIs3; IIIe1; IIIe2; IIIe4; IIIe5; IIIs1; IIIs2; IIIs3; IVe1; IVe4; IVs1; IVs2; VIe1; VIe2; VIe3; VIe4; VIe6; VIe7; VIe10; VIe11; VIe12; VIe13; VIe14; VIe15; VIe16; VIe21
3	25-29	IIIw4; IIIc1; IVs3; VIe5; VIe8; VIe9; VIe17; VIe18; VIe22; VIe23; VIs3; VIIe1; VIIe2; VIIe3; VIIe4; VIIe5; VIIe6; VIIe7; VIIe8; VIIe9; VIIe10; VIIe11; VIIe13; VIIe14; VIIe15; VIIe16; VIIe18; VIIe19; VIIe20; VIIe21; VIIe27
4	20-24	IIIw1; IIIw2; IIIw3; IIIc2; IVe2; IVe5; IVc1; VIe19; VIe20; VIe24; VIe25; VIs2; VIIe12; VIIe17; VIIe22; VIIe23; VIIe24; VIIe25
5	<20	IIIw5; IVw1; IVw2; VIw1; VIs1; VIIe26; VIIw1; VIIs1; VIIs2; VIII

We used these same five categories of soil fertility as discrete classes in our native forest growth model. We spatially intersected this layer with rainfall classes to produce a productivity layer for carbon accumulation in regenerating forest.

Rainfall class layer

The effect of rainfall variation was captured in discrete classes for areas of similar mean annual precipitation, rounded to the nearest 100mm increment. For native forest regeneration estimates, all areas with mean annual precipitation greater than 1450mm were grouped into one class, based on empirical measures indicating no increase in growth response for manuka above 1500mm annual precipitation (Trotter, C., unpublished data). This resulted in 8 unique classes, ranging from 900mm to 1500mm per year. Actual values range from 900mm to over 4000mm per year.

Carbon growth model

Following Trotter et al. (2005), we constructed a model of tree growth and carbon sequestration, using empirically-derived relationships. The accumulation of carbon within each age class was estimated using a Gompertz equation for a sigmoidal growth curve, of the form:

$$Y(t) = \alpha \times e^{\beta \times \left(\frac{1 - e^{(-\chi \times t)}}{0.1} \right)} \qquad (1)$$

where: t is time, in years

$Y(t)$ is accumulated CO_2-equivalents, in tons.

We fit the following parameters for the model using Trotter's empirical data:

$\alpha = 2.93$

$\beta = 0.46$

$\gamma = 0.07$

To estimate the distribution of age classes within each hectare of land, we assumed the area of each age class would also follow a sigmoidal curve. Starting with bare ground in year 0, we constructed a curve that would result in total coverage by age 10. This equation was of the form:

$$f(t) = 1 - \frac{1}{1 + 1/e^{-t+5}} \qquad (2)$$

where t is the number of years since establishment.

This model was the standard for soil of average productivity (class 3) and high rainfall (1500 mm). For other soil and rainfall classes, we assumed each soil class difference resulted in a 6% change in carbon sequestration. Each 100mm decrease in rainfall from the highest class (1500mm) resulted in a 5% decrease in carbon sequestration (see Trotter et al. 2005).

The model was calculated using Microsoft Excel and output tables were imported into the spatial attribute files for the productivity layer.

Management Scenarios

The potential for overlapping revenue streams means the uptake of carbon farming will depend upon more than the revenue of carbon credits. It will also depend on the value of other management activities in the areas set aside for forest regeneration. In the Gisborne District, these other activities include other ecosystem services such as biodiversity and erosion control incentives, and private markets for manuka honey and tourism.

We attempted to explicitly incorporate some of these economic benefits in our model. We apply the following values to these activities:

- *East Coast Forestry Project*: We model a total payment of $1376 per ha, with a payment of $688 in year 1 and a payment of $688 in year 5, as accepted in the revised Project guidelines released in 2007 (Ministry of Agriculture and Forestry 2007a).

- *Manuka honey*: We model payments of $50 per ha per year, starting in year 20 and continuing through year 70. Actual revenues from honey production are difficult to estimate for biological reasons (bees access many different areas and are not constrained by property boundaries; manuka honey production varies in quality and quantity from year to year) and for economic reasons (this is also a relatively new market, so the size of the market and the price it will bear are still unknown). Also, the area that can supply manuka honey is limited. We use a conservative estimate of the area that can supply honey: an area equivalent to the Kyoto-eligible land within 1km of existing roads. Beekeepers generally require road access to service hives, and they report that bees generally do not forage efficiently beyond 1km of the hive (though this may change in response to topography, prevailing winds, and other factors; Satchell, H., personal communication, 2006). Landowners often lease land for hives in exchange for shares of honey revenue. In our approach, we investigate the additional marginal revenue to landowners from honey related to the allocation of pasture land to native forests. We do not account for areas of existing manuka that are not currently in production but may become economic when new native forests are added.

- *Nga Whenua Rahui/QE2 Trust*: $150 in years 10, 35, and 60. Actual payments per hectare from these programs depend on the quality of the habitat being protected (Mohi, M., Nga Whenua Rahui, personal communication, 2006). Often these payments are earmarked for fixed costs of project establishment (e.g., fencing). Through negotiation, landowners and the program reach agreements about areas to set aside and the payment that will be delivered. Both programs aim to pay no more than half of the total cost of fencing and initial pest control. In some cases, an additional payment is made to secure a high-value habitat. To investigate the potential impact of these programs on landowners' decisions today, we adopt a simple case of enrolling land in one of these programs 10 years after establishment and receiving a payment every 25 years of $150 per ha.

We used spatial data to analyze the potential for different areas to yield revenue from carbon farming, incorporating the timing of revenues into the NPV calculation. We present the analysis of the following scenarios:

A: Carbon alone: We estimate the area eligible for the PFSI and calculate the potential revenue from carbon, under a range of price scenarios.

B: Carbon + ECFP: We estimate the area eligible for both the PFSI and the ECFP and estimate the potential revenue available from the combination of these programs.

C: Carbon + ECFP + **Conservation Program + manuka honey**. We estimate the area eligible for each of these sources of revenue, then we estimate the present value of the revenue that landowners would receive by taking advantage of as many of these sources as they can.

D. EBEX21 + ECFP: We estimate the combined impact of these two programs. The EBEX21 Program offers a guaranteed payment of $12 per ton CO_2-e and applies a model of constant annual accumulation of carbon at a rate of 3 tons per ha per year, resulting in an annual payment of $36 per ha per year. We assume that all Kyoto-eligible land would qualify for the program, and then we add the value of the ECFP program on land that meets its eligibility criteria.

The purpose of this analysis is to compare the area of conversion using the EBEX21 program to the area of conversion when landowners receive a higher share of revenue and account for the forest growth dynamics and spatial heterogeneity.

E. EBEX21 + ECFP + Conservation Program + manuka honey. We estimate the combined impact of all of these programs.

Carbon Price Scenarios: Creation and Application

The value of carbon sequestration for farmers will vary depending on the future price of carbon offsets. There are many plausible scenarios for the future price of carbon, including a set of studies that use general equilibrium modeling to calculate an expected shadow price for carbon under various policy constraints (van Vuuren et al. 2007, Tol 2005, Nordhaus and Boyer 2000). We incorporated recent projections of the real price of carbon into different price scenarios, using a baseline scenario starting at NZ$15 and rising at a rate of 3.8% per year to reach NZ$200 per ton in 2100.

Related scenarios examined sensitivity to the path of carbon price over time, uncertainty in the carbon model, and deviations from the base price trajectory. We explore one “pessimistic” scenario in which the market for carbon crashes after 20 years, but landowners are “locked in” the program, simulating a scenario in which international climate policy collapses, but forest commitments continue to be maintained (Scenario 4). We also explore two "optimistic" scenarios (from the perspective of landowners): one in which the price of carbon rises steeply (Scenario 5) and one in which the price makes a sudden shift upward in year 20 (Scenario 6), simulating, the kinds of price dynamics that landowners might see if scientists found that climate change was worse than anticipated and international carbon markets acted upon that information.

The following price trajectories were created for carbon:

1. real price starts at $15 per ton CO_2-e and increases by 3.8% per year.
2. real price or productivity is 20% higher than Price Scenario 1 in all years.
3. real price or productivity is 20% lower than Price Scenario 1 in all years.
4. same as 1, but in year 20 the price drops to $0 and remains at $0.
5. real price starts at $15 per ton CO_2-e, increases by $2 per year until it reaches $100, and then remains at a constant price of $100.
6. same as 1, but after year 20 the price shifts to $25 per ton higher than Price Scenario 1.
7. price remains constant at $15 per ton.

Combining Management Scenarios with Carbon Price Scenarios yields a two-part scenario nomenclature (e.g. A1, B4, E7), facilitating comparisons across management scenarios (by letter, e.g. A1-E1) or across price scenarios (by number, e.g. A1-A7).

Comparison Scenarios for Grazing

We calculated the comparative income from grazing using a combination of grazing productivity and gross margins. Grazing productivity was calculated on a per hectare basis using the Average Stock Carrying Capacity layer for the Gisborne District. The gross margin for each stock unit was multiplied by the stock unit carrying capacity for each hectare, yielding the expected stream of grazing revenue under each scenario. To compare these grazing scenarios to carbon revenue scenarios, we discounted each revenue stream to obtain the present value.

We used a range of expected gross margins to test the sensitivity of land conversion to farmers' expectations about their ability to earn profits. Gross margins are defined as "the gross income from an enterprise less the variable costs incurred in achieving that income" (Rae 2003). Gross margin does not include fixed or overhead costs, which do not vary in proportion to the size of the enterprise, and can vary from farm to farm depending on each farm's past investment, efficiency, and (stock) losses.

If we assume that carbon farming has no variable costs other than the costs of enrollment, we effectively compare grazing gross margins to carbon gross margins. If carbon farming incurs other variable costs and those cannot be subsidized (e.g., inspection and auditing costs), direct comparison is no longer valid. In addition, each farm must account for its fixed costs for carbon farming relative to its fixed costs for grazing. We expect these fixed costs to be lower for carbon farming than grazing, on average, because of reductions in 1) labor units, 2) costs of capital, and 3) depreciation of capital inputs. However, on some farms the relative reductions in costs from converting grazing to carbon farming may be offset partially or completely by the fixed costs of 1) additional fencing, 2) specialized labor from certifiers, and 3) application and audit processing in the PFSI.

For grazing, we used the following scenarios:

S1. Constant real gross margin of $20 per stock unit.

S2. Constant real gross margin of $40 per stock unit.

S3. Constant real gross margin of $60 per stock unit.

S4. Constant real gross margin of $80 per stock unit.

The Meat and Wool/Economic Service Farm Survey, conducted in participating farms, reported weighted average pre-tax revenue across all farm classes in New Zealand ranging from $46.16 to $58.75 per sheep stock unit and $52.95 to $61.30 per beef stock unit in the years 2002-2007. In the same period, pre-tax farm profit per stock unit ranged from $6.82 to $21.53. For comparison, the pre-tax farm profit per stock unit on the East Coast (Gisborne District) ranged from $4.65 to $19.88 per stock unit (Meat and Wool Economic Service 2008).

Discount Rates

For each of these scenarios, we applied a range of real discount rates to simulate the decision parameters of different landowners. These rates were 1, 3, 4, 5, and 8%. Applying each of these rates to alternative land management systems allows us to compare today's land allocation decisions on an equivalent basis, even though revenues from each system will differ from year to year. The selection of discount rates reflects the potential variation in landowners' real rate of time preference. Since the flow of income from carbon farming varies over time, discounting the stream of income from carbon farming and the comparable stream from the current land use, we can compare the relative value of the different options when viewed from the perspective of landowners with different internal expectations. Each decision could meet the criteria for economic efficiency, because under each option we assume that landowners have perfect information about future markets and their own ability to earn gross margins from their land in the future. What we test here is the extent to which efficient landowners with perfect information would convert their land to carbon farming.

The purpose of applying different discount rates to the analysis is to investigate the possible impact of landowners' preferences and expectations about themselves and future markets. Different discount rates and gross margins combine to represent landowner profiles that we have observed in the Gisborne District. For instance, some landowners take into account the impacts of land-use decisions far into the future. They are represented by applying a low discount rate of 1%. Other landowners may be "capital starved" and have opportunities to invest in farm improvements with a high rate of return once they get access to capital. These landowners are represented by applying a high discount rate of 8%. Discount rates in the intermediate range represent landowners who have access to capital and may have other low- to moderate- risk opportunities for investment (not necessarily on their own farms). These landowners may be slightly risk-averse.

To estimate the alternative real rate of return for farmers, we used the current rate of return on 30-year Treasury bonds (6.5%) and compared it to two indicators of inflation: the average annual Producer Price Index (PPI) for New Zealand for all industries, which was 2.9% over the period March 2004 to March 2006; and the average New Zealand Consumer Price Index for all commodities, which was 2.3% from June 1999 to June 2006. We estimate potential inflation rates of 1.5, 2.5, and 3.5

into the future, yielding discount rates of 3, 4, and 5%. In our land-use model, we apply all five rates to landowners' decisions and compare the results in terms of the different areas allocated to carbon farming.

Spatial Integration

For each area of analysis, the present value (PV) of revenue per hectare from each scenario was calculated and mapped. We compared the PV of each grazing scenario to each carbon farming scenario, under all management options, using the same landowner discount rate to compare each pair of land-use options. These are not the exhaustive set of all price possibilities, but they are useful for showing how a range price scenarios affects the revenue from carbon farming. We also projected the expected difference in revenue for each year on each unique area of land.

Estimating Eligible Land and Modeling Carbon Sequestration Potential

We estimated the extent of eligible land using the 1996 LCDB data on land cover (Table 2). This is an approximation of the actual eligible land because data is not yet available for 1990, the baseline year for establishing eligibility under Kyoto and PFSI rules.

We selected the following LCDB classes for "eligible" land: alpine grass/herbfield, gorse and/or broom, herbaceous freshwater vegetation, herbaceous saline vegetation, high producing exotic grassland, low producing exotic grassland, short-rotation cropland, tall tussock grass, vineyard. Within these areas, we restricted eligibility to land within 1km of appropriate seed sources. We considered seed sources to be any of the following land cover classes: broadleaf indigenous hardwoods, deciduous hardwoods, fernland, flaxland, grey scrub, indigenous forest, major shelterbelts, manuka/kanuka, mixed exotic shrubland, sub-alpine shrubland.

In addition, areas eligible for ECFP were considered. The target land for ECFP is based on Land Use Capability classification: LUC classes 7e18 and higher, and all of class 8. These are highly erodible lands that qualify for funding under the ECFP. We mapped these areas and created attribute fields with values corresponding to the PV of grant payments (on a per hectare basis) announced in July 2007 (Ministry of Agriculture and Forestry 2007a). We created fields with the discounted value of these payments, evaluated at discount rates of 1, 3, 4, 5, and 8%.

We performed similar procedures for manuka honey production and conservation. We considered areas of Kyoto-eligible land within 1 ha of an existing road "eligible" for honey production. We considered all Kyoto-eligible land eligible for conservation incentives.

Table 2: Estimated extent of eligible land in the Gisborne District.

Gisborne District: Kyoto-Eligible Land		
1996 Land Cover Class	Area (ha)	Area within 1km of seed sources (ha)
Alpine grass/herbfield:	37.2	37.2
Gorse and broom:	4540.5	4384.1
Herbaceous freshwater veg:	680.0	642.9
Herbaceous saline veg:	52.0	10.5
High Producing exotic grassland:	396,279.2	383,470.2
Low Producing exotic grassland:	13,538.3	13,298.4
Short-rotation Cropland:	6947.0	5023.4
Tall tussock Grassland:	227.7	227.7
Vineyard:	2483.1	1539.2
Total:	424,785.1	408,633.6

Intersection with Cadastral Boundaries and Comparison to Other Options

Next, we investigated the distribution of benefits from carbon sequestration. After calculating quantities and value of carbon sequestration for all isoquants, we overlaid these areas with property boundaries. We summed the value under each scenario for each parcel, multiplying the areas within the parcel by the *per hectare* value of each isoquant. The result gave an estimate of the value of carbon from converting all eligible land to carbon farming. This allowed us to verify the distribution of benefits among farms of different sizes, as well as between Māori and non-Māori land.

We then added the total expected value of compatible activities for each parcel with eligible land in the Gisborne District. We overlaid the cadastral database with the map of expected value per hectare, calculated the area of each unique value within the parcel, multiplied the area by the expected value, and summed up over the entire area of eligible land within the parcel. We summed this amount with the value of carbon to yield an expected value of carbon farming, utilizing the compatible activities modeled in different scenarios, assuming all eligible land within the parcel was converted.

Comparison to grazing price scenarios.

Similarly, we modeled the expected value of grazing under the price scenarios S1 to S4. We used the Average Stock Carrying Capacity (CCAV) layer to map the sustainable stock density across the landscape. We then applied an expected gross margin of $20-$80 per stock unit (depending on the scenario). Grazing gross margins were discounted at each of the rates applied to the carbon scenarios.

We compared the present value of grazing gross margins to the present value of carbon farming revenues under all scenarios. This comparison makes the implicit assumption that carbon farming will not incur any additional costs beyond those incurred by grazing. The fixed costs of production for each farm would have to be deducted from the gross margin of each production system and the change applied on a per hectare basis to the proposed area of conversion on the entire farm. We do not have information about fixed costs of different production systems for individual farms, nor do we have information about the areas farmers might set aside. In particular, the cost of establishing reserves depends greatly upon the need for new fencing, and farmers can site new fences to strategically utilize existing fences to enclose reserve areas. These considerations are also at a farm-by-farm level, and without further information we cannot account for these factors across the modeled landscape.

Comparison of carbon farming value to property tax value.

Māori land may face different expectations and management strategies. For instance, the legal conditions that regulate transfers of ownership rights are highly restrictive, creating economic barriers for Māori land. These barriers both protect Māori land from alienation and restrict Māori landowners' access to credit. These conditions create a dual perspective, offering freedom from market pressures but also denying investment that could lead to higher economic returns (Fox, C., Māori Land Court, personal communication, 2006). These rules were deliberately created to allow

Māori landowners to maintain their right to self-determination without the threat of banks foreclosing on their lands. As a result, Māori landowners are free to exercise decisions with long time horizons, considering several generations into the future. We approximate this type of evaluation by applying a low discount rate of 1% in one of our comparisons. On the other hand, the lack of access to credit for investment means Māori are often faced with the need for capital. New revenues might be reinvested in the land in ways that earn higher returns than other market investments. Or, landowners might feel pressure to act in ways that reflect a preference for money sooner rather than later. We approximate this situation by applying a high discount rate of 8%.

For Māori land blocks, we compared the value of carbon farming to the expected value of property taxes over the 70-year modeling period. We attempted to err on the side of high estimates for taxes. To calculate the expected tax rate, we took the existing property tax and increased it each year by the historical rate of property value increase for rural land in New Zealand. According to Stillman (2005), rural land has increased in value between 9-11% per year from 1990 to 2002. We project these rates to continue over the 70 years.

We compare the present value of carbon farming scenarios to the expected present value of property taxes at the land block level. Where the value of carbon farming is higher, we suggest that carbon farming would be a strategy that could assist in meeting Māori goals of land retention, native habitat restoration, and increasing the supply of natural medicines.

Testing the Impact of Projected Program Costs

The last analysis we conducted was an examination of the potential impact of program costs on the uptake among landowners. In all scenarios analyzed previously, we included the variable costs of enrollment proposed in the consideration document of the PFSI (Ministry of Agriculture and Forestry 2007b). For this analysis, we removed the effect of those costs and observed changes in the area of land where carbon farming out-competes grazing under our various scenarios.

D. Results

Carbon Potential on Eligible Land

Using our carbon model, we estimated that if all eligible land were reforested, it would store about 121.4 Mt CO_2-e over the 70-year time period. For comparison, New Zealand's total greenhouse gas emissions in 2007 was 75.55 Mt CO_2-e, and if current trends continue, it is projected to overshoot its Kyoto target by about 100 Mt CO_2-e in the first 5-year commitment period (Ministry for the Environment 2009). Thus, even reforestation of all eligible land in the Gisborne District would only offset slightly more than one commitment period.

On eligible land, our model predicted a range of total carbon storage between 191.2 and 347.6 t CO_2-e per ha. The maximum in any one year on the most productive land was 12.8 t CO_2-e per ha. The area-weighted mean sequestration after 70 years was 297.55 t per ha. The distribution reflects the spatial distribution of land with different cumulative carbon storage capacity across the District (Fig. 3).

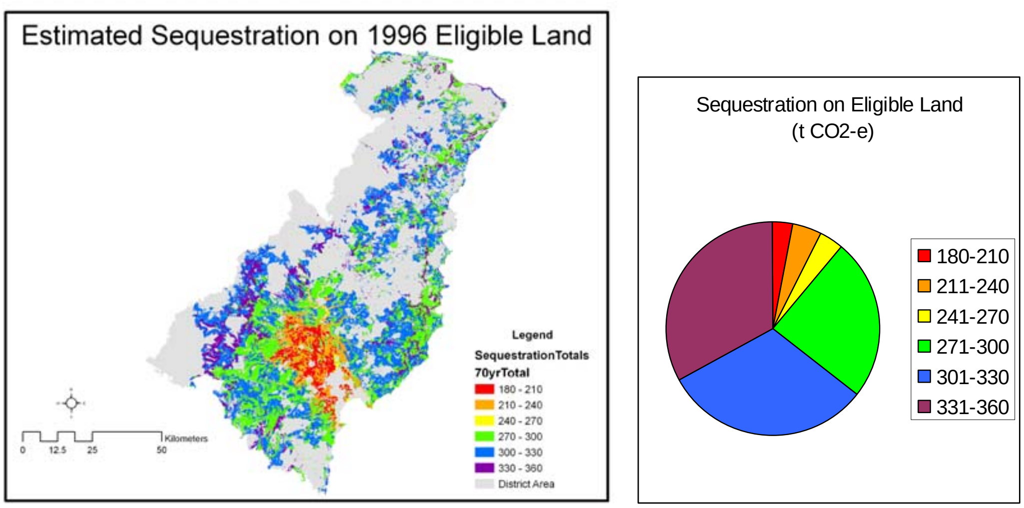

Figure 3. Map of cumulative CO_2-e storage after 70 years and fraction of eligible land in each sequestration range.

Value of Carbon Farming on Eligible Land

Under Price Scenario A1, if all estimated eligible land were reforested, the total expected revenue from carbon credits over 70 years for the Gisborne District would exceed NZ$4.69 billion, or an average annual revenue of NZ$67 million (NZ$165 per ha per year). The spatial distribution of the revenue reflects the pattern of carbon accumulation (Fig. 4) because the spatial factors affecting sequestration (soil quality, rainfall) are static in the model.

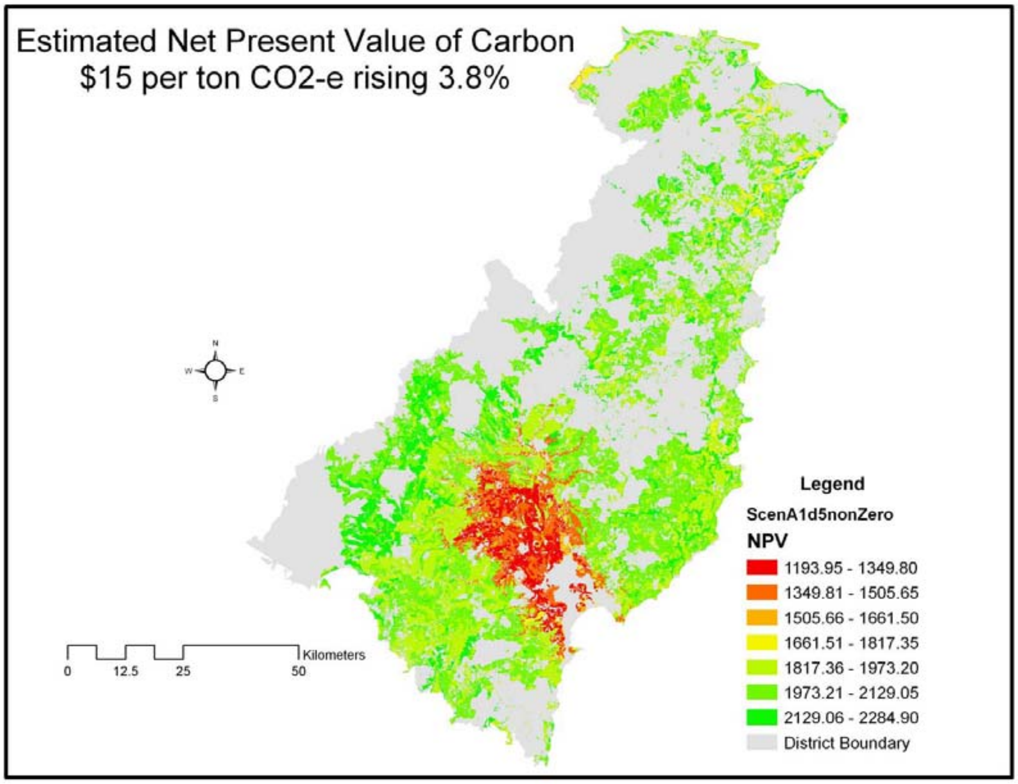

Figure 4. Spatial distribution of net present value per ha on eligible land under Price Scenario A1 using a discount rate of 5%.

Differences in revenue arise from absolute and temporal differences in the price of carbon credits under each price scenario. The relative ranking of revenue for five of the seven modeled scenarios remains constant in our analysis, though this need not be true for all scenarios under all discount rates, due to the framework of the price scenarios. For instance, the set of scenarios A1, A2, and A3, are expected to have the same relative ranking under any conditions, as are the set A1, A5, and A6. A7 will always be below A1, A2, and A4. In our analysis, the ranking of undiscounted value for the scenarios is A4>A6>A2>A1>A3>A5>A7>A5 (Table 3). Under high discount rates, A5 surpasses A7.

Table 3. Total expected revenue and discounted revenue under different price scenarios for afforestation of all LCDB 1996 pasture (includes proposed PFSI variable costs).

Price Scenario	Total Revenue (0% discount rate) (in $ millions)	% of A1	1% discount rate (in $ millions)	% of A1	4% discount rate (in $ millions)	% of A1	8% discount rate (in $ millions)	% of A1
A1	4,695	100	3,441	100	1,518	100	623	100
A2	5,675	121	4,158	121	1,835	121	756	121
A3	3,716	79	2,724	79	1,201	79	491	79
A4	7,095	151	5,325	155	2,465	162	1,043	167
A5	882	19	788	23	537	35	317	51
A6	6,501	138	4,752	138	2,054	135	807	129

The effect of discounting revenues allows us to evaluate the relative importance of price scenarios into the future. Comparing Scenario A1 across discount rates, we see that the discount rate has a strong effect on the value of a decision to enter carbon farming today. Landowners may express different discount rates across the Gisborne District (or even apply different discount rates to different decisions), but the impact of applying a uniform discount rate to the district creates important results.

Comparing price scenarios within discount rates, we see that higher discount rates diminish the relative impact of market collapse (Scenario A5) in the future on today's decision, as expected. On the other hand, the steady increase of scenario A4 makes it even more appealing from today's perspective under higher discount rates, even though prices eventually become level at $100 under that scenario. Interestingly, the effect of a sudden shift upward in future prices (A6) is lessened by higher discount rates, even though the shift comes at a time when carbon credit production would be at its peak. However, the expected benefit is still higher than a 20% increase in prices over the whole time period (A2).

The Impact of Complementary Incentives on the Value of Native Reforestation

By adding supplemental revenues to the carbon farming management system, complementary incentives increase the total revenue on some areas of land, and potentially increase the area converted to carbon farming. With certain areas of land eligible for multiple revenues, the attractiveness of carbon farming increased, shifting revenues upward in those areas. What we examined here is the impact of layering revenues, and whether the combined revenues are sufficient to make carbon farming competitive on more land.

Comparing total potential revenues from carbon credits to these other revenues, we see that none of them approach the same impact on the District as carbon revenues (Table 4). However, these additional revenues, in some cases, add substantially to the PV per hectare on eligible areas. For comparison, we have listed the revenue available from the EBEX21 program, which currently provides a fixed annual revenue of $36 for each hectare of land enrolled.

Table 4. Present value of complementary incentives for carbon farming in the Gisborne District and their value per ha on applicable Kyoto-eligible land.

Revenue Source	Total Present Value at 4% discount rate	Eligible Area (ha)	Present Value per ha at 4% discount rate
ECFP	$57 million	45,885	$1251
Honey	$125 million	235,637	$530
Conservation	$62 million	407,416	$154
EBEX21	$362 million	407,416	$891

<u>Comparisons of Carbon Farming to Grazing</u>

To the extent that economics determine land use, the impact of carbon farming on land use will depend on its value relative to other land-use options. As a result, we must compare the present value of carbon farming to the present value of competing land uses. Here, we compare the present value of 70 years of carbon farming to the present value of 70 years of grazing on estimated Kyoto-eligible land.

Grazing potential varies widely across the Gisborne District (Fig. 9). Using the CCAV value (stock units per ha) and multiplying it by expected gross margins for grazing ($ per stock unit), we calculated the expected gross margins per hectare on Kyoto-eligible land. We then applied discount rates of 1, 3, 4, 5, and 8% and calculated the PV of grazing on each hectare of land.

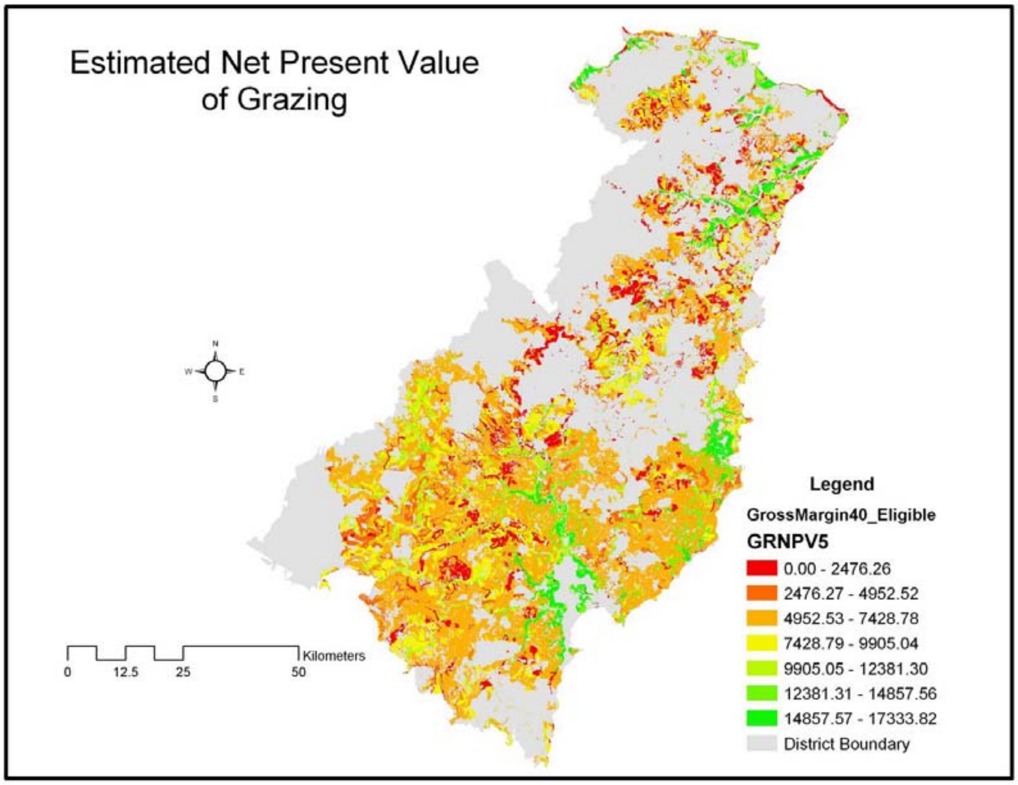

Figure 5. The estimated net present value of grazing on Kyoto-eligible land, assuming constant margins of $40 per stock unit and a discount rate of 5%.

We made a spatial comparison of carbon farming revenue to grazing revenue, by overlaying and subtracting the PV of grazing from the PV of carbon farming. We then selected areas where the PV of carbon farming exceeded grazing. This estimate of land that earns higher returns from carbon farming provides us with an estimate of potential land-use conversion (Fig. 6).

For Scenario A1, we estimate 40,700 ha of conversion if only carbon revenue is considered. However, when other revenues are considered, this figure rises to 55,400 ha (Fig. 7).

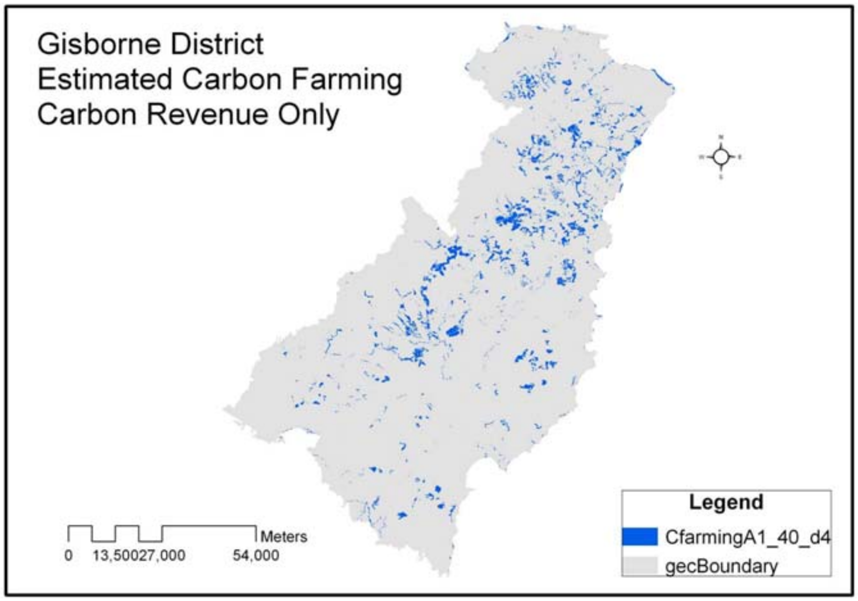

Figure 6. Estimated areas of conversion from grazing to carbon farming with farmers utilizing carbon revenue only, under Carbon Price Scenario A1, and assuming gross margins of $40 per stock unit. Total area = 40,700 ha.

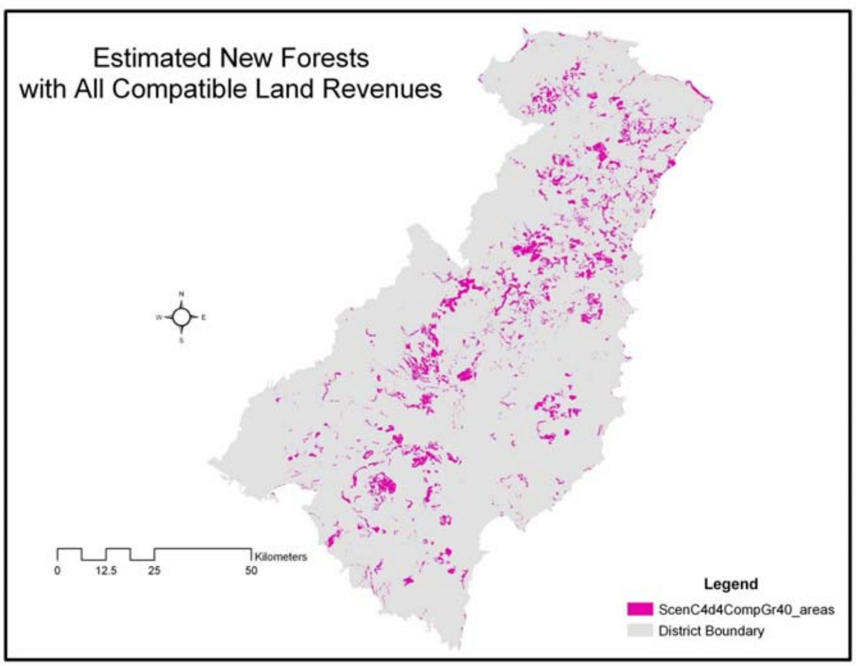

Figure 7. Estimated areas of conversion with all complementary revenues. Total area = 55,400 ha.

Estimated Price of Carbon at which Land Would Convert

The previous examples compare the revenues from carbon farming with the revenues from grazing under specific prices trajectories. An alternative approach is to look at the value of carbon farming and to project the estimated indifference point for land use, expressed in terms of carbon price. Such an approach illustrates the (constant real) price of carbon that would earn a higher income than grazing on a particular block of land.

Using this approach, it is possible to compare the indifference point between carbon farming and grazing for every hectare of eligible land in the Gisborne District, using a constant price for carbon. The result can be expressed as a supply curve for carbon credits, or the price at which carbon farming exceeds the opportunity cost for a particular hectare (Fig. 8).

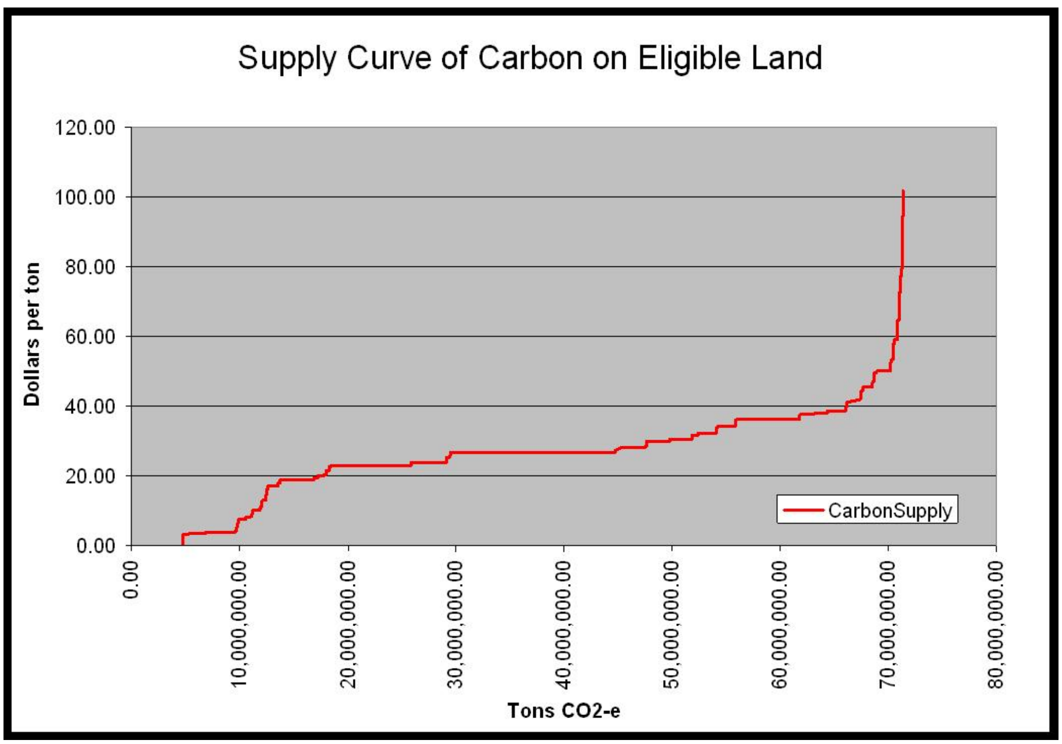

Figure 8. Supply curve for carbon credits in the Gisborne District, calculated using the net present value of grazing as of the opportunity cost of land.

Māori Land: Implications of Carbon Farming for Land Retention

We investigated the impact of carbon farming on land use under different management objectives, notably a minimum-earning-level objective found among Māori landowners pursuing a satisficing strategy for land retention. In this case, we evaluate whether the PV of carbon revenue alone (Scenario A1) would offset the PV of increasing property taxes (rates) on Māori land over the next 70 years.

The results indicate that revenue from conversion of all eligible Māori land to carbon farming would likely exceed the costs from rates on about 350 Māori land blocks (Fig. 9). This suggests carbon farming could be part of a strategy for land retention, while preventing land degradation. Such landowners would need assurances of long-term carbon prices and have confidence in their ability to guarantee the permanence of forests. The revenue from selling carbon credits may be sufficient to pay rates and ensure land retention, but the potential liabilities created by selling carbon credits may exceed the benefits, putting landowners at risk for incurring other kinds of debt. It is not known whether these carbon liabilities could be used to alienate the land from owners, or whether the owners themselves would have to bear the debt.

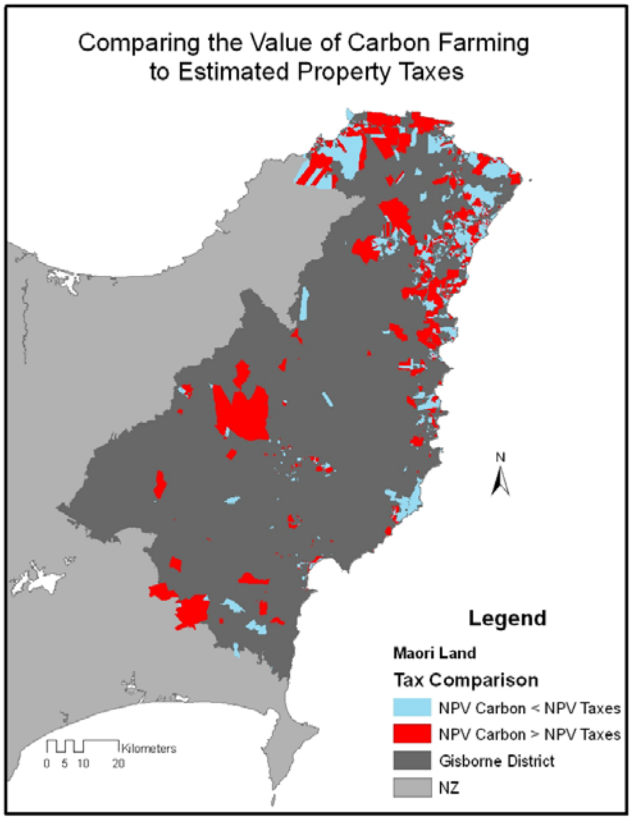

Figure 9. Estimated Māori land blocks where expected carbon farming revenues under Scenario A1 are greater than expected property taxes.

The Impact of PFSI Costs on Uptake

We assessed the possible changes in uptake when PFSI costs are factored in. The proposed costs for maintaining PFSI enrollment and per hectare costs for participation were applied to all the preceding scenarios. Fixed costs for application fees (which vary according to the size of the proposed reserve) and audit processing were not included in the analysis, because they apply to the entire reserve and cannot be evaluated on a per hectare basis.

Removing these costs from the analysis resulted in an increase in land retirement only under specific circumstances. Applying a model of landowners with low expectations for future grazing returns and a high time preference for money today, the increase in expected uptake changed from 76,200 ha (Fig. 10) to 107,400 ha (Fig. 11). However, if we apply a model of landowners with normal or below-average discount rates, PFSI costs had little impact on the area of land retired.

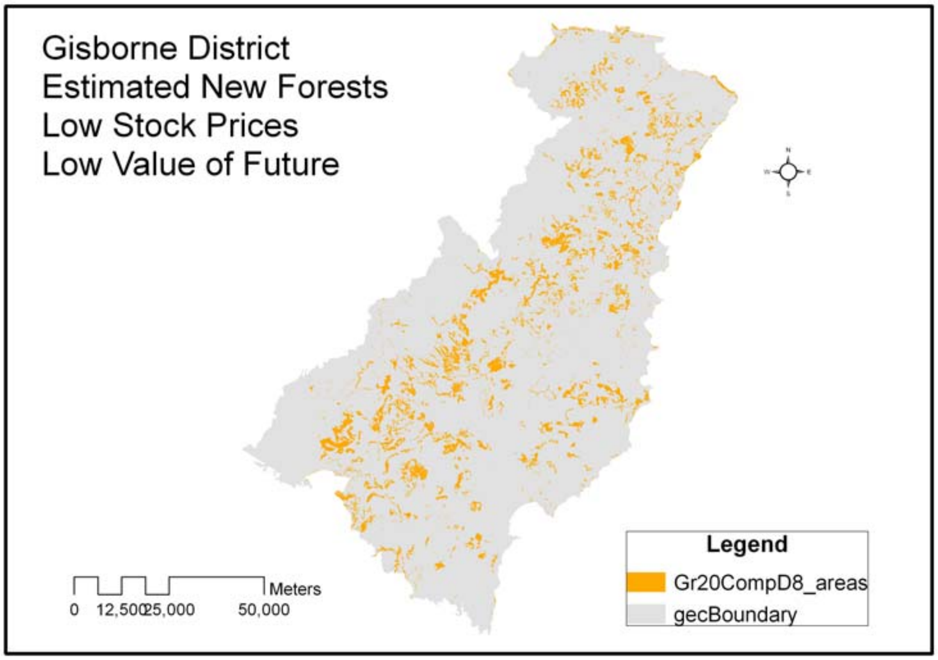

Figure 10. Estimated areas of conversion, comparing Carbon Price Scenario A1 revenues to gross margins of $20 per stock unit, using a real discount rate of 8%. Total area = 76,200 ha.

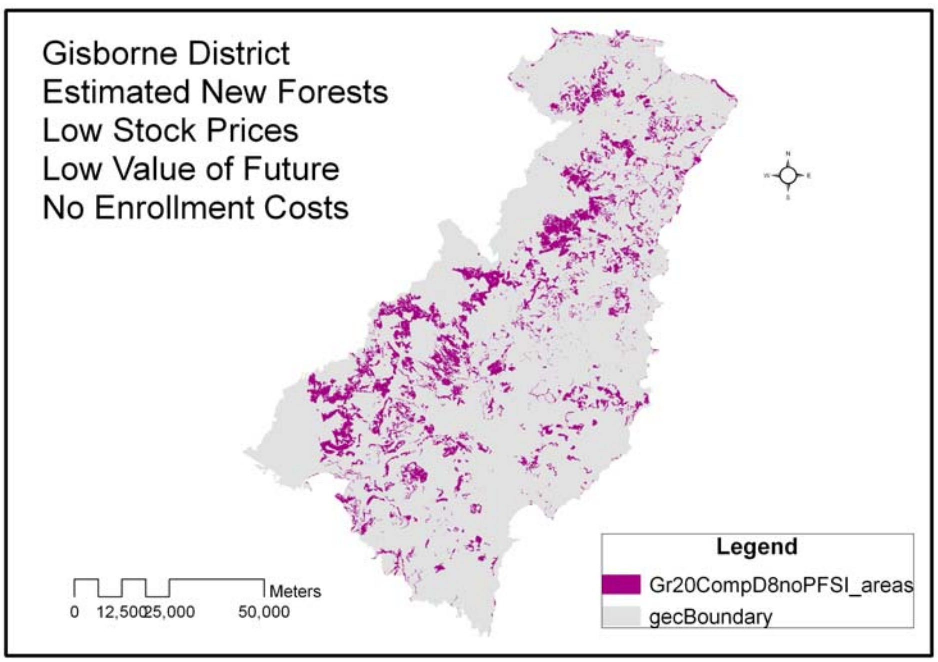

Figure 11. Estimated areas of conversion, comparing Carbon Price Scenario A1 revenues without PFSI costs to gross margins of $20 per stock unit, using a real discount rate of 1%. Total area = 107,400 ha.

E. Discussion

Implications for land use and rural development

Carbon farming in the Gisborne District is not a panacea for New Zealand's climate obligations. Carbon sequestration in forests can only provide a temporary solution for New Zealand, and the Gisborne District does not have the capacity to offset all of NZ's emissions for very long. With existing incentives and certainty that carbon markets will continue, landowners in the Gisborne District would potentially be better off converting about 40,000 ha to carbon farming. Within these 40,000 ha are over 30,000 ha of erodible land eligible for the ECFP. The addition of carbon revenue will make conversion of this erodible land more attractive to landowners, potentially leading to better protection of soil, waterways, and downstream infrastructure.

Reasonable expectations about farmers' behavior would suggest that uptake will be far below the total eligible amount of land. Allowing farmers' expectations of future gross margins to vary only creates a small impact on the overall area of conversion. Farmers' time preference (expressed in the discount rate) has a larger impact under our baseline scenario (A1), in which farmers expect carbon prices to rise at a real rate of 4%, because the high value of carbon in the future carries greater weight with low discount rates. With high time preferences, grazing represents a better option, because it yields greater value in the near term. Such variations in expressed time preferences (in both directions) might be found more commonly among Māori landowners because of cultural values and *de facto* institutional barriers to credit.

Proposed costs of the PFSI application and enrollment would not decrease the uptake of landowners under typical assumptions about gross margins and discount rates. However, they would decrease the uptake of the program among farmers with higher time preference for money and lower expectations about margins. Elimination of these costs could increase uptake among such farmers at a significant scale within the District. For well-capitalized farmers who expect normal or above-average margins, the PFSI costs would have little impact on their decisions to retire land.

At low prices for carbon, Māori land would potentially receive a greater proportion of carbon revenue, due to the fact that a greater proportion of Māori land is marginal for grazing.

The addition of carbon revenue does not greatly increase the area of erodible land that would be retired. However, the additional revenue does make land retirement more attractive to eligible landowners (raises the NPV of carbon farming), and so the combination of the programs increases the likelihood that landowners with erodible land will choose to retire that land sooner, but it may not have much effect on the area ultimately retired because the failure to enroll this uneconomic land already cannot be explained by economic factors alone.

Changes in the average carbon price has a small effect on predictions of conversion in the model under typical conditions. Analyses of scenarios with sudden price increases or crashes show that volatility in the future average price of carbon has a greater effect. This implies that stability in the carbon market may play an important role in determining land-use change in the Gisborne District.

The impact of markets for manuka honey, conservation, and tourism are difficult to quantify on a per hectare basis. Projected changes under the scenarios described here result in an increase in conversion to carbon farming of an additional 10,000 ha when revenues from honey and conservation are added. The dynamics of the honey market, in particular, may play an important role, due to the fact that it requires little input by the landowner, it pays back on an annual basis, and landowners can easily take advantage of large increases in the market over the next few years. Whether these short-term dynamics will stimulate the conversion of land to forest is uncertain, but could strongly mitigate the problem of short-term revenue for carbon farming. We have conservatively modeled the availability of honey revenue 20 years after setting aside clear pasture, but farmers may incorporate adjacent areas of existing scrub, smoothing the stream of income over time and increasing their cash flow during the period of conversion from forest to pasture. These dynamics could lead to strategic timing of land retirement, to achieve a steady stream of income from carbon credits by enrolling land as it approaches peak sequestration rates, 15-20 years after establishment. This would reduce the impact of enrollment costs, while allowing farmers to continue grazing some pastures. Enrollment in the ECFP could accelerate this process on land eligible for that program.

Where landowners are willing to sacrifice economic returns for the sake of non-economic benefits from forests, the area of uptake might increase markedly. Many landowners – both Māori and non-Māori – find value in protecting areas of native forest. The opportunity to earn carbon credits during the process may be enough of an incentive to make large-scale conversions worthwhile. This raises intergenerational equity issues, because today's owners will benefit from selling carbon credits, but future owners will inherit large liabilities. However, if carbon prices rise as predicted by some models, the overall benefit may be economically worthwhile, especially under long time horizons. If the cultural value of forests is high among owners – as is evident among many Māori landowners – then native forest reversion might be taken up broadly. If it occurred over a large fraction of the available land, the decrease in scale of farming activities in the Gisborne District could have important implications for the District's tax base, as well as infrastructure and services for grazing operations. Negative impacts of retiring land could be mitigated, at any scale, by investing carbon farming revenues into the intensification of production on other land. This raises questions about leakage from these projects, but under current rules any additional emissions from reinvestment would not be counted as leakage.

The greatest value of land-use conversion in the Gisborne District may be in other areas besides climate mitigation. The impact of reforestation for providing unpriced benefits from ecosystem services may add to or even surpass the value of forests for climate mitigation. These impacts depend largely on the spatial location of reforestation. In erodible catchments, increasing forest area may reduce sediment loading to streams, improving water quality and freshwater habitat, as well as reducing peak flows and sediment transport downstream, which affects infrastructure such as bridges and roads. Evapotranspiration from these forests helps dewater areas prone to landslides, reducing the risk of mass wasting (although, in certain areas, this may also decrease stream flow).

Increases in forest cover may also provide other important biological benefits. Where new forests extend existing forests or provide corridors between them, they may create dispersal pathways for species to reach new habitats. However, if these areas of new habitat are not properly managed, they may become dominated by pest species, such as the brushtail possum, deer species, feral goats and pigs, and may not provide additional benefit to endemic species because of the presence of introduced predators, such as stoats, weasels, rats, and feral cats. The beneficial outcomes of newly established forests will depend on the extent to which pests are controlled.

Limitations on the predictive power of the model

The analyses presented here are subject to a variety of uncertainties, including the following:

1) Uncertainty in the modeled amount of carbon sequestration. Trotter et al. (2005) estimate that uncertainty at the site level may be as high as 20%. We know of no further projects to measure the accumulation of carbon in regenerating forests, but landowners participating in the PFSI will report such data and, over time, estimates may improve.

2) Uncertainty in the eligible area. Our estimate, based on 1996 land cover data, will be affected by changes that occurred between 1990 and 1996. These changes could go in either direction, as post-1990 clearing would increase our estimate of eligible land, and pre-1996 afforestation would decrease our estimate, relative to the actual land cover in 1990. In addition, some areas of existing scrub in 1990 could be eligible under the PFSI rules, if they were not managed as forests.

The Ministry of the Environment (MfE) already has an initiative underway to establish a baseline dataset for 1990 land cover for the country. The MfE dataset uses remote sensing data from, at, or near 1990, including aerial photographs, to provide better estimates of the eligible area.

3) Uncertainty in future market and price of carbon. This is by far the largest uncertainty, because it is linked to the long-term expectation of climate damages, the function of carbon markets (either domestic or global), the implementation of alternative strategies for emissions reductions, and the uptake of reforestation and production of forest credits in other areas of the world.

The most recent Intergovernmental Panel on Climate Change (IPCC) reports on global climate change have increased both the certainty of climate change impacts and the scale of expected impacts (IPCC 2007). One approach breaks down impacts into three types: immediate, intermediate, and long-term (Kirschbaum 2003). Forests have varied abilities to mitigate these different impacts. If predictions of future impacts continue to rise, carbon prices may also rise, potentially with high variability.

The function of carbon markets depends upon national commitments to targets, institutions for reporting and certification, and cooperation among enough countries to have an effect on the climate system. With continuing carbon markets, the development and implementation of other strategies for reducing emissions and the uptake of reforestation in other parts of the world could affect the price of carbon in the long term. The models developed by Nordhaus and Boyer (2000) and von Vuuren et al. (2007), for instance, attempt to account for these changes by assuming efficient implementation of known technologies (and land uses), but information in these areas is limited.

4) Uncertainty in market prices for other production systems. Predicted market prices for other management systems play a role in forming landowners' expectations about future revenues, and the tradeoffs of committing land to permanent sequestration. Volatile prices in livestock markets would discourage farmers from committing land to permanent carbon sinks, because they may keep marginal lands in production in anticipation of windfall gains in years with high prices. As a result, uncertainties about the economic value of carbon and the opportunity cost of carbon farming will remain, unless there are concerted efforts to provide certainty and control volatility (Stern 2007).

Nevertheless, the scenarios developed in this paper provide useful information for planning at the district scale, as well as pointing toward tools for efficient management at the farm scale. Our model gives insight about the scale of land-use change that local authorities might expect under a broad range of conditions. Further testing and variation of model parameters can expand these insights, while better information in other areas can be incorporated to improve the accuracy of predictions. The relatively inelastic range of conversion at estimated carbon prices gives local authorities an idea of where they might target efforts to address particular problems (erosion) or resources (biodiversity). Application of this model at the national scale could help improve predictions of forest contributions to New Zealand's greenhouse gas inventory. In addition, this model gives insights about the scale of incentives required to shift farmers' land-use practices, and demonstrates how land-use decisions might be affected by combining complementary incentives with carbon credits.

F. Conclusions

In this analysis, we demonstrated that approximately 40,000 ha of land could earn higher gross margins from carbon farming than from grazing under reasonable expectations. However, most of this area is truly marginal for grazing, supporting less than two stock units per ha. At the farm level, some of this land may even be earning negative returns, implying that land abandonment is the best alternative.

Expectations about the adoption of carbon farming under the PFSI or other initiatives in the Gisborne District must be framed by a variety of factors relevant to land-use decisions. Our analysis shows substantial potential for carbon sequestration, due to favorable biophysical factors, including 1) rapid regrowth rates, 2) large area of eligibility, and 3) areas with low productivity for other uses. Under reasonable expectations for carbon prices, conversion of Kyoto-eligible land from grazing to carbon farming could generate competitive income on 20,000-55,000 ha, with higher conversion expected when landowners also utilize complementary incentives.

Landowners have reasons for caution, due to scientific uncertainties in measurements and models, market uncertainties about the price of carbon, and policy uncertainties, which could lead to a collapse of carbon markets or substantial changes in the price of carbon. Policy-makers could encourage more certainty by standardizing and simplifying enrollment procedures in multiple sustainability initiatives, establishing guidelines for monitoring procedures, establishing durable rules for trading carbon credits in order to improve landowners' ability to make land-use commitments based on long-term expectations. Flexibility in commitments for landowners, such as rewarding temporary storage of carbon, could also encourage participation.

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