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Theme: Environment and Social

Task No: F60404
Milestone Number: 3.04.02

Report No. : ES015

Developing a Forest Investment Finder for New Zealand

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Date: July 2012

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EXECUTIVE SUMMARY

This work provides industry and government with a tool for investigating the viability of future forest plantations in New Zealand. The modelling capability that has come from the research is known as the Forest Investment Finder (FIF). It can already provide meaningful results for strategic level planning objectives around a number of radiata pine future forestry regimes.

This project performs a spatial economic analysis of future radiata pine forests in New Zealand. It draws on previous published work for FFR under the Environmental and Social theme that mapped the location of these same future forests accounting for factors such as current land use, climate and soil type[1]**.** This study went a step further by including economic factors, such as cost of land, management costs, roading, carbon credits and log grade prices. These combined land and economic criteria were used to assess the viability of converting pastoral land to forestry under a range of potential radiata pine-based afforestation scenarios.

The future forest scenarios highlighted non-arable land classes in New Zealand that have limitations under perennial pasture vegetation. Three scenarios were outlined according to erosion limitations, these ranged from slight to extreme erosion (2.9 million ha), moderate to extreme erosion (1.1 million ha) and severe to extreme erosion (0.7 million ha). The forestry regimes modelled were for a pruned, structural, biomass and solely carbon regime.

The results show that, based on our assumptions;

1. Many of the 2.35 M ha[1] of future forest scenarios in New Zealand are not economically viable for a forest grower to plant, when the cost of purchasing land is factored in and a typical forest valuation discount rate of eight percent is used and a carbon price of NZ$8.
2. Although biomass and carbon regimes face lower costs than pruned and structural regimes, there are very few situations where, under our pricing assumptions, they are economically viable.

It is important to understand that these results are based on specific assumptions and data around product prices, forestry costs, and discount rates, among others and do not account for possible future changes to this data (i.e. the price for carbon/timber may go up or down in the future). It therefore should not be used for small scale planning but rather as a regional and national strategic level planning tool to investigate variations in viability across regions and nationally.

In a future project, the current national forestry estate could be modelled. This tool then lays the foundation for future capability to explore, visually (on regional or national maps) and quantitatively, many questions of importance to the forest industry, such as;

- Climate change impacts (for example, a 1° change in temperature) on forest siting and forestry returns.
- The effect of increased regulation on possible location of new forests and viability of current forests, for example the effect of a surcharge on roading in steepland areas.
- The policy mechanisms required to achieve an efficient balance of forest grower benefits and benefits to the public from potential land use changes to and from forestry.
- The economics of new forest species to achieve various objectives on marginal lands.
- The value of environmental benefits from current forest estates.
- Forestry options on more productive landscapes.
- Various changes in product prices (timber, carbon, bioenergy, etc.) on forest locations/yields.

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[1] This differs from the 2.9M ha mentioned above because many areas of future forest that occurred on New Zealand's outlying islands were excluded as were any forest areas under 1 hectare in size. The reason being that commercial forestry would be uneconomic due to the added cost of transporting raw materials and timber to and from these islands by boat. Furthermore areas under 1 hectare are not eligible for carbon credits under the New Zealand Emissions Trading

- The effect of a technology change on forestry viability, which may, for example, open new areas for harvesting as a result of a drop in harvesting costs on various types of slope.
- Modelling location and end user payments, for example, siting or removal of a port or mill. This could be used to place a mill or tailor a forest regime based on port/mill locations.
- Assess the impact of a disease infestation on forestry returns

INTRODUCTION

Barriers to invest in new planted forests include: regulation, land value and distance to markets. In this project we calculated the future profitability of forests developed from existing marginal pastoral land and mapped these for New Zealand. We used future forest scenarios previously developed by Scion [1]. These scenarios focus on marginal (non-arable) lands, with slight to extreme erosion severity, for afforestation, that have limitations for sustainable land use under perennial pasture vegetation. This project maps the viability of afforestation for these future forest scenarios in New Zealand, by calculating the baseline revenue for the forest grower. This lays the foundation necessary for a strategic assessment of the efficiency and effectiveness of payments for ecosystem services. This will help to inform regulatory frameworks that often impact upon forest industry's "license to operate".

METHODS

Future Forest Scenarios

The approach used Future Forest Scenarios developed by Scion[1] as templates to determine the economic viability of land in New Zealand that could be potentially afforested. The scenarios essentially targeted non-arable land classes that have limitations under perennial pasture vegetation and ranged from slight to extreme erosion severity. Conservation estate and current planted forests were excluded as were regions that were unsuitable for radiata pine growing, e.g. areas with an average daily temperature below 7.9 degrees (see Appendix 1).

From these scenarios a model was created for estimating radiata pine plantation costs that include the establishment of plantation forests, the construction of roads and landings, harvesting and transport to markets using representative 25m resolution surfaces. The returns from forestry were estimated from predictive surfaces of volume (radiata pine productivity, 300 Index), tons of biomass (bioenergy) and carbon sequestration (CO_2 equivalents, tonnes ha^{-1}). A full report describing the spatial modelling can be found in Palmer et al. 2011[2].

Economic Scenarios

The future forest scenarios modelled (Table 1) four different regimes

1. **structural** (framing) regime (thinned to 600 stem ha^{-1} from initial planting of 900 stem ha^{-1}),
2. **pruned** regime (720 stem ha^{-1} thinned to 380 stem ha^{-1}, pruned to 6.4 m),
3. **biomass** regime (833 stem ha^{-1}, no thinning), and
4. **carbon** regime (1020 stem ha^{-1}).

The rotation lengths were **28 years** for the pruned and structural, **20 years** for biomass and **90 years** for carbon.

Discount Rate

A discount rate of **8%** was used as it represents the range of discount rates used currently by forest growers for forest market valuations[3]. A discount rate of **4%** was also used to explore sensitivity and because it represents a more appropriate rate for public investment projects. The choice of discount rate is often an arbitrary exercise, 8% may be quite high by international standards but represents the actual figure used for decision making by potential forest growers, while 4% is more conservative.

Prices

Prices for timber were based on an average price for each grade over the last 16 quarters (March 2008 – December 2011, inclusive) taken from MAF indicative domestic radiata pine log prices [4]. The transport surface predicts the cost to the nearest mill or port. These surfaces have the potential to differentiate between supply for domestic markets and international export, this differentiation and analysis is an area for future modelling work. Carbon price used was a rounding of the current carbon price to **$8**/tonne CO_2 equivalents[5], with one tonne of CO_2 being equal to one carbon credit/New Zealand Unit (NZU). Biomass is traded as bioenergy and therefore the tonnes of biomass ha^{-1} had to be converted to gigajoules ha^{-1}. Industry officials put the conversion of a wet tonne at approximately one cubic metre and one cubic metre at approximately 8 gigajoules. The current price for coal was estimated at **$5**/gigajoule. This was considered to be the cheapest substitute price for energy and was thus used as the price for biomass.

Table 1: Forest investment scenarios modelled and prices paid for forest products or services.

Regime	Timber $/tonne	Carbon $/NZU	Bioenergy $/gigajoule
Structural (framing) regime	S1 $93 S2 $85 S3 $75 Pulp $51	$8	
Pruned regime	P1 $133 P2 $110 S1 $93 S2 $85 S3 $75 Pulp $51	$8	
Biomass regime		$8	$5
Carbon regime		$8	

Economic Analysis

For each regime the Net Present Value (NPV) of forestry in perpetuity was determined using discounted cash flow analysis. The economic analysis follows largely from that of Polglase et al (2008) [6], with the goal to estimate the Land Expectation Value (LEV[2])[7] comparison with current land value prices. Calculating the NPV of one rotation into perpetuity allows direct comparison with land value data. The NPV represents the difference between costs and revenues, all related to the same time period; the present. Each cost and revenue surface was discounted to the present depending on the year for which the cashflow occurred. The cashflow analysis followed that of Boardman et al. 2001 [8].

Generally using the LEV assumes that costs and revenues are identical across all rotations, however, in reality the first rotation would incur greater costs for road and landing construction than subsequent rotations. Therefore, following consultation with a forest roading engineer, costs associated with internal roads and landings for subsequent rotations were estimated at about forty-five percent of the initial construction costs. A list of the cashflow variables for the different regimes in the model is presented in Table 2.

Table 2: Cashflows discounted for economic analysis

Costs (C)	**Revenues** (R)
Establishment	Timber
Silviculture	
Access road construction	Bioenergy
Internal landings	Carbon
Internal road construction	
Harvesting	
Transport	
ETS compliance	

[2] The land expectation value (LEV) is the net present value (NPV) of an investment in an even aged stand from the time

Carbon

A standard annual compliance cost of $60/ha for the ETS was added to costs to cover reporting and measurements [9]. To estimate the carbon revenue, we assumed that the forest was managed to provide a non-declining yield [10], based on volume control [11]. The revenues from carbon are received as carbon credits or New Zealand Units (NZUs). One NZU is equivalent to one tonne of carbon dioxide (CO_2) [12]. The productivity surfaces for carbon measured the total carbon sequestered in tonnes ha^{-1}. This was then converted to CO_2 equivalents using the mass ratio of carbon to CO_2 (1:3.67) [13]. The annual carbon revenue is then the non-declining yield times the price of carbon[3].

Land Value

The key question to be answered from this project is **whether or not it is economically viable for a potential investor to purchase land under the Future Forest Scenarios and afforest into perpetuity.** To do this we compare the returns from a variety of forestry regimes in perpetuity to the capital value of the land. The capital value of the land is the probable price that would have been paid for the property if it had sold at the date of the last general revaluation, this data was obtained from the property information specialist, PropertyIQ [14]. If the returns from converting land to forestry and growing radiata pine in perpetuity are greater than the upfront cost of purchasing the land then it would be worth the investment. This implies that if the land was already owned by the investor (therefore, no need to buy the land) and the Land Expectation Value (LEV) was positive then it would be a viable option[4].

Using ArcGIS 10[15] meshblocks[5], the smallest geographic unit for which statistical data is collected, were identified which contained future forest areas. Each meshblock has a corresponding code; this code was sent to PropertyIQ who identified property data relating to each mesh block. The associated land values were summed and divided by the area of the meshblock to give a dollar per hectare value for each mesh block. This dollar per hectare value was then divided by 16 to give a dollar value per 625m², the same scale as all GIS surfaces used in the model. This data was used to create a raster layer in ArcGIS 10 which could be used in the calculation of the economic model.

Concept

The full process to determine future forest viability can be seen below in Figure 2. The varying spatial layers can be seen which fed into the final surface for the viability of the future forest scenarios. The blue layer represents the potential for future work. For example in the area of valuation of ecosystem services which can be compared against the private gains from forestry to help in policy decision making or to aid further research on 'license to operate' issues.

The decision rule therefore is that **the potential forest grower should buy the land and establish forestry if the land expectation value is positive and greater than or equal to the land value** (i.e. LEV ≥ 0 and LEV ≥ LV).

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[3] Carbon is calculated using an annuity rather than actual estimates of carbon sequestered and emitted over time. The former was used for ease of evaluating the economics of carbon within the GIS, and that the two accounting approaches lead to similar, though not the same estimates of NPV of carbon credit revenues. The former provides a lower estimate NPV than the latter so it is more conservative.

[4] The future forest scenarios were selected as areas that would likely not be viable for agriculture, therefore if forestry is not viable, agriculture would also probably not be viable.

[5] Meshblocks were used as the identifying area for land values instead of primary parcels as each code equated to a search for PropertyIQ. Each search was charged; by using meshblocks IDs considerable savings were made as a meshblock contains many primary parcels. However not all primary parcels within each meshblock were identified by PropertyIQ, meaning that in some cases the dollar value per hectare may have been underestimated. Also some meshblocks where forests were located returned no data from propertyIQ and therefore these forests have been

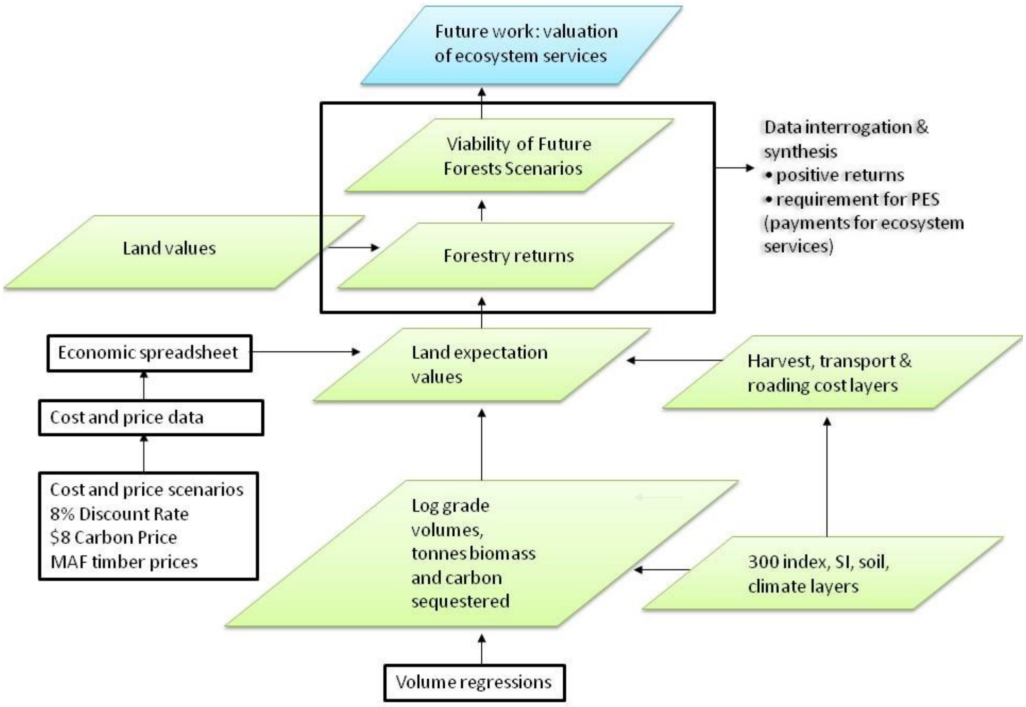

Figure 2: Forest Investment Finder (FIF) process diagram

RESULTS & DISCUSSION

The results below present spatial maps of the scenarios modelled (Table 1) and show the viability, when including land value as an upfront cost, of Future Forest scenarios across New Zealand. Therefore, when viewing the spatial maps, the decision to afforest should be made where the NPV in perpetuity (LEV) including the cost of purchasing the land (LV) is greater than or equal to zero:

$$LEV - LV \geq 0$$

Table 3 provides an overview of the area of future forests in hectares and the percentage area of these future forests that are economically viable. As can be seen, many of the 2.35 M ha[6] of future forest scenarios in New Zealand are not economically viable for a forest grower to plant, when the cost of purchasing land is factored in and a typical forest valuation discount rate of eight percent is used and a carbon price of NZ$8. Although biomass and carbon regimes face lower costs than pruned and structural regimes, there are very few situations where, under our pricing assumptions, they are economically viable.

Table 3: Future Forest (FF) area in New Zealand and viable areas of forestry under four forestry regimes and two discount rates.

	Viable Area (ha)							
	Pruned				***Structural***			
Total FF Area (ha)	**4% Discount rate**	**% Area of FF viable**	**8% Discount rate**	**% Area of FF viable**	**4% Discount rate**	**% Area of FF viable**	**8% Discount rate**	**% Area of FF viable**
2,350,008	923,541	39	149,306	6	1,111,720	47	334,461	14
	Carbon				***Biomass***			
Total FF Area (ha)	**4% Discount rate**	**% Area of FF viable**	**8% Discount rate**	**% Area of FF viable**	**4% Discount rate**	**% Area of FF viable**	**8% Discount rate**	**% Area of FF viable**
2,350,008	18,878	1	0	0	7,362	<1%	0	0

Figure 3-6 show maps of potential New Zealand future forests. The fine resolution of the surfaces created ($/625m^2) makes it difficult to grasp this detail at a national level so an example for East Cape has also been provided. This represents an area with significant soil erosion problems where afforestation would provide a high public benefit. The areas of green to blue represent viable areas, with blue having higher viability, while the areas in yellow to red represent non-viability, with red being the lowest. Visually it is still difficult to assess with certainty the regional breakdown of viability thus table 4 provides a breakdown by region of the viable areas of future forests.

[6] This differs from the 2.9M ha mentioned previously because many areas of future forest that occurred on New Zealand's outlying islands were excluded, as were any forest areas under 1 hectare in size. The reason being that commercial forestry would be uneconomic due to the added cost of transporting raw materials and timber to and from these islands by boat. Furthermore areas under 1 hectare are not eligible for carbon credits under the New Zealand

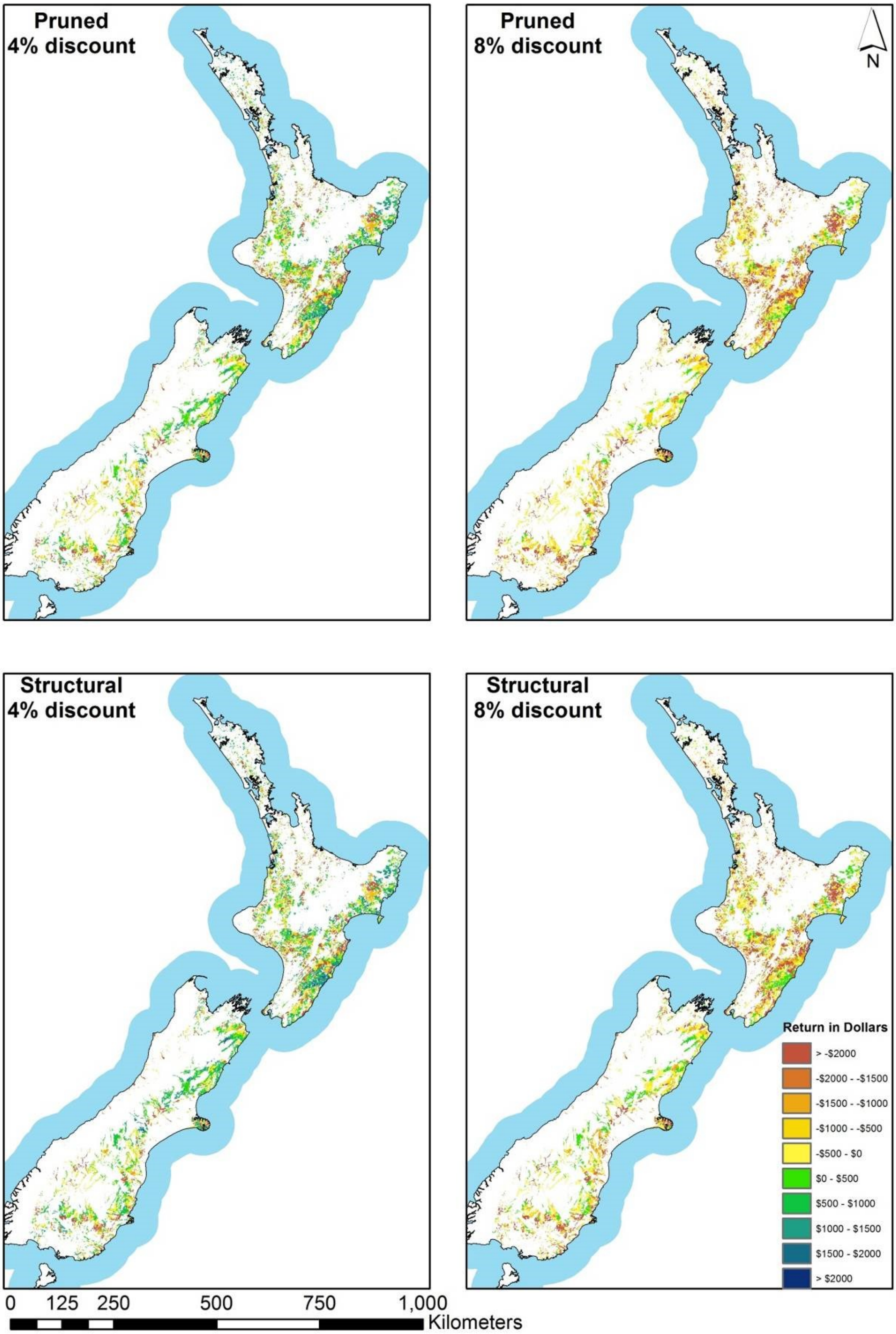

Figure 3: Profit ($/ha per year) of new forests managed as either pruned and structural regimes for New Zealand under four and eight percent discount rates

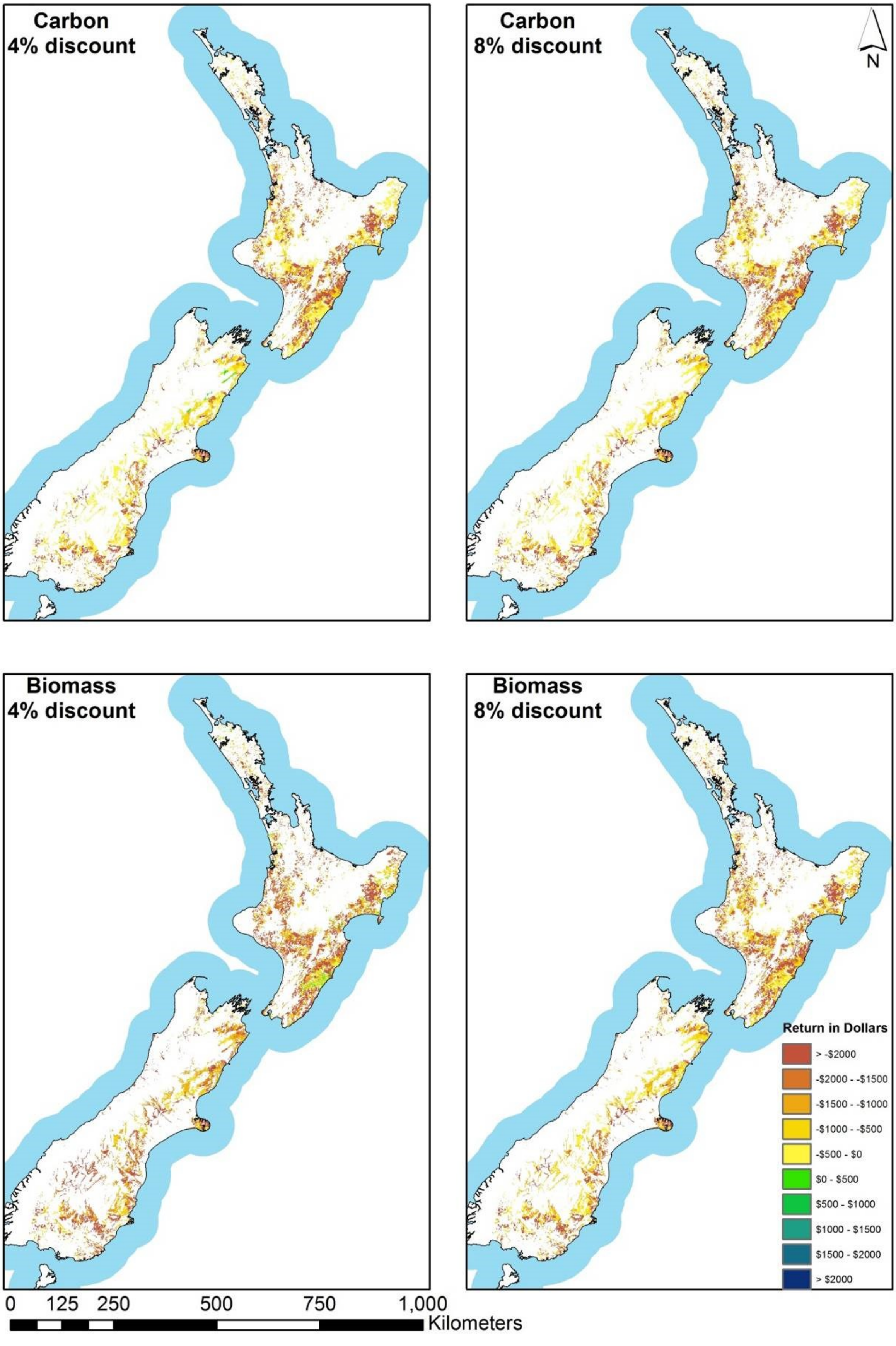

Figure 4: Profit ($/ha per year) of new forests managed as either biomass and carbon regimes for [redacted]

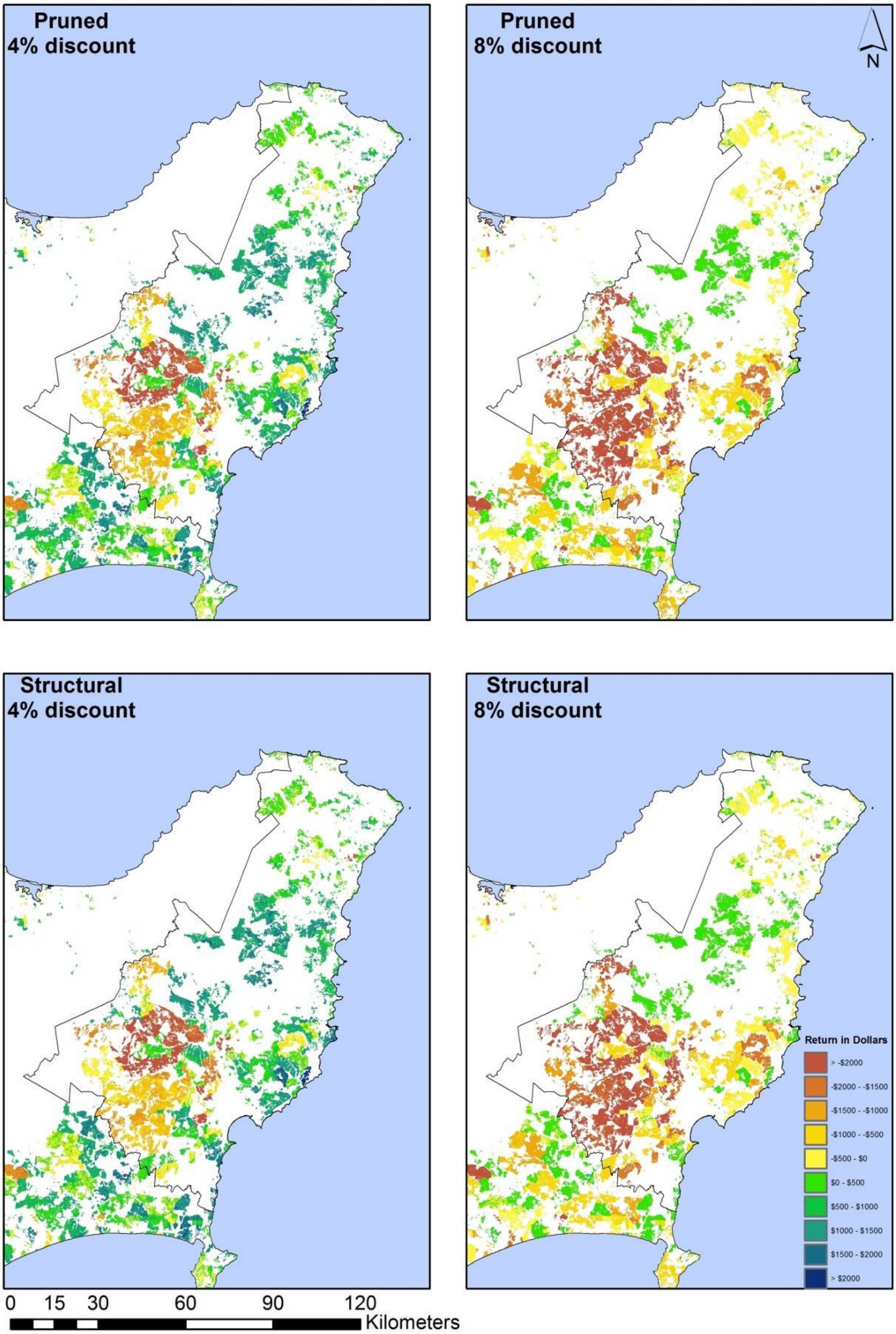

Figure 5: Profit ($/ha per year) of new forests managed as either pruned and structural regimes for East Coast future forests under four and eight percent discount rates

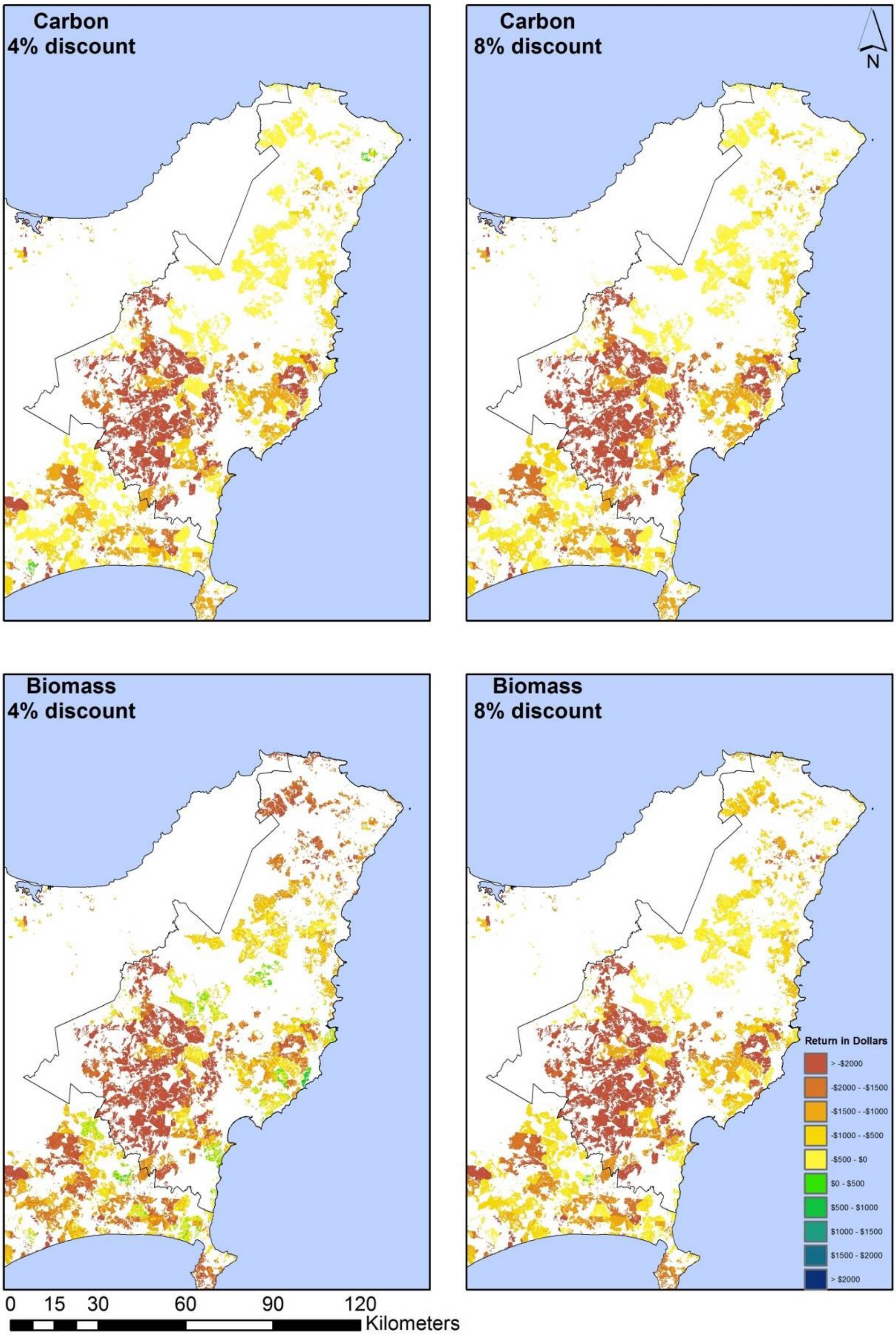

Figure 6: Profit ($/ha per year) of new forests managed as either biomass and carbon regimes for

[redacted]

The maps in figures 3-6 highlight the mapping capability of the tool for selecting regions and areas where further investigation could be carried out for forestry objectives. For instance we can see that there are similar viability trends nationally with the structural and pruned regimes and that the discount rate used for each plays a significant role in economic viability. Furthermore we can see the significant reduction in viability when planting for carbon with no harvesting or short rotation biomass regimes compared to a structural or pruned timber regime.

Table 4: Future forest area by region and the area (ha) and percentage area of viable future forest for four forest regimes.

North Island

Region		Area Viable by Regime							
		Struc 4%		Struct 8%		Pruned 4%		Pruned 8%	
	Area (ha)	Total area	% of area	Total area	% of area	Total area	% of area	Total area	% of area
Auckland	18,254.0	4,693.00	25.71	249.00	1.36	4,478.00	24.53	117.00	0.64
Bay of Plenty	19,913.0	7,278.00	36.55	1,148.00	5.77	7,241.00	36.36	658.00	3.30
Waikato	179,652.0	61,940.00	34.48	11,900.00	6.62	61,168.00	34.05	6,253.00	3.48
Manawatu	380,641.0	164,270.00	43.16	20,584.00	5.41	150,143.00	39.44	7,606.00	2.00
Gisborne	196,011.0	99,231.00	50.63	40,272.00	20.55	98,317.00	50.16	35,979.00	18.36
Hawkes Bay	195,931.0	106,883.00	54.55	23,065.00	11.77	89,849.00	45.86	15,464.00	7.89
Welligton	119,801.0	64,656.00	53.97	6,718.00	5.61	35,522.00	29.65	2,967.00	2.48
Northland	47,776.0	28,040.00	58.69	6,837.00	14.31	27,817.00	58.22	4,212.00	8.82
Taranaki	64,509.0	21,626.00	33.52	6,297.00	9.76	21,843.00	33.86	4,306.00	6.68
Total North Island	**1,222,488.00**	**558,617.00**	**45.70**	**117,070.00**	**9.58**	**496,378.00**	**40.60**	**77,562.00**	**6.34**

		Carbon 4%		Carbon 8%		Biomass 4%		Biomass 8%	
	Area (ha)	Total area	% of area	Total area	% of area	Total area	% of area	Total area	% of area
Auckland	18,254.00	0.00	0.00	0.00	0.00	5.00	0.03	0.00	0.00
Bay of Plenty	19,913.00	19.00	0.10	0.00	0.00	237.00	1.19	0.00	0.00
Waikato	179,652.00	0.00	0.00	0.00	0.00	1,929.00	1.07	0.00	0.00
Manawatu	380,641.00	0.00	0.00	0.00	0.00	654.00	0.17	0.00	0.00
Gisborne	196,011.00	368.00	0.19	0.00	0.00	1,236.00	0.63	0.00	0.00
Hawkes Bay	195,931.00	90.00	0.05	0.00	0.00	1,368.00	0.70	0.00	0.00
Welligton	119,801.00	0.00	0.00	0.00	0.00	22.00	0.02	0.00	0.00
Northland	47,776.00	0.00	0.00	0.00	0.00	777.00	1.63	0.00	0.00
Taranaki	64,509.00	303.00	0.47	1.50	0.00	1.00	0.00	0.00	0.00
Total North Island	**1,222,488.00**	**780.00**	**0.80**	**1.50**	**0.00**	**6,229.00**	**0.51**	**0.00**	**0.00**

South Island

		Struc 4%		Struct 8%		Pruned 4%		Pruned 8%	
	Area (ha)	Total area	% of area	Total area	% of area	Total area	% of area	Total area	% of area
Malborough	126,782.00	77,780.00	61.35	33,667.00	26.56	55,166.00	43.51	12,752.00	10.06
Nelson	1,579.00	1,562.00	98.92	1,265.00	80.11	1,558.00	98.67	1,035.00	65.55
Tasman	28,399.00	10,812.00	38.07	1,895.00	6.67	5,812.00	20.47	434.00	1.53
Canterbury	479,553.00	252,046.00	52.56	135,035.00	28.16	211,572.00	44.12	48,322.00	10.08
West Coast	13,687.00	22.00	0.16	29.00	0.21	71.00	0.52	0.00	0.00
Otago	344,541.00	143,350.00	41.61	30,396.00	8.82	95,780.00	27.80	5,217.00	1.51
Southland	132,979.00	67,531.00	50.78	15,104.00	11.36	57,204.00	43.02	3,984.00	3.00
Total South Island	**1,127,520.00**	**553,103.00**	**49.05**	**217,391.00**	**19.28**	**427,163.00**	**37.89**	**71,744.00**	**6.36**

		Carbon 4%		Carbon 8%		Biomass 4%		Biomass 8%	
	Area (ha)	Total area	% of area	Total area	% of area	Total area	% of area	Total area	% of area
Malborough	126,782.00	7,126.00	5.62	0.00	0.00	95.00	0.07	0.00	0.00
Nelson	1,579.00	0.00	0.00	0.00	0.00	252.00	15.96	0.00	0.00
Tasman	28,399.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Canterbury	479,553.00	10,740.00	2.24	0.00	0.00	621.00	0.13	0.00	0.00
West Coast	13,687.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Otago	344,541.00	227.00	0.07	0.00	0.00	18.00	0.01	0.00	0.00
Southland	132,979.00	5.00	0.00	0.00	0.00	147.00	0.11	0.00	0.00
Total South Island	**1,127,520.00**	**18,098.00**	**7.93**	**0.00**	**0.00**	**1,133.00**	**0.10**	**0.00**	**0.00**

These results highlight the economic viability and indicative areas for afforestation for four future forest scenarios. These may be used for strategic level planning but should therefore not be used to make investment decisions on a small scale. The areas of viability vary significantly depending on the assumptions made. Similar studies in Australia have found that sensitivity analysis around, discount rates, land values and product prices showed that viability ranged from 100% to 0% [6]. Land value is one barrier to this viability. Overvalued rural land poses a constraint to the success of any proposed strategy to afforest. Thus forest growers face many hurdles in establishing a business case for these marginal lands in New Zealand.

The spatial surfaces produce mixed results under different regimes. Due to the number of spatial surfaces that underpin the results from the Forest Investment Finder it is difficult to determine the main drivers for viability. Some sensitivity around discount rates showed that under structural and pruned regimes with an 8% discount rate, 14% (334,461 ha) of the total future forest area for a structural regime and only 6% for the pruned regime (149,306 ha) would be viable. Under a 4% discount rate this changes quite dramatically, the total viable area for the structural regime increases to 47% (1,111,720 ha), while the pruned regime increases to 39% (923,541 ha). Thus more areas may be available under a public afforestation scheme because of the lower interest a government would have to pay if it borrowed money to finance a project. Figures 5 and 6 show a more detailed example for the East Cape.

Future Work

Expand the model to cover all of New Zealand, not just the future forest scenarios. This would involve further data collection of land values, for example, and forest age-class distributions. Outlined in the blue layer in Figure 2, further work could determine the tangible and intangible values of different ecosystem services (carbon sequestration is already included as there is a market for which revenue can be received) to determine the potential for payments for these ecosystem services. If a forest grower was to plant in these areas there would be many benefits for the public in terms of soil protection, cleaner water and carbon sequestration. However, when forestry is not a viable option the rational forest grower will choose not to plant and these services do not get provided.

This tool lays the foundation for asking much bigger questions which have important implications for government. As further data is collected to define and value environmental benefits this may be compared against the benefit to the forest grower to highlight areas that may require government intervention to help encourage afforestation where there is no direct profit to be made. The framework[16] that underpins this approach also has important ramifications for the forest industry and their 'license to operate'. For example, if this tool and same framework is applied to the current forest estate, the viability can be compared against the environmental benefits that these plantations provide. In areas where forestry costs are prohibitively expensive, through increased regulation perhaps, then land use change will become a rational outcome. However accounting for the potential loss in environmental benefits from forestry to a new land use would help to highlight the true cost of further regulatory barriers on current forest plantations. Work at Scion is underway to value some of the environmental benefits from forestry using FIF[17, 18] and the framework for comparing private and public net benefits of afforestation[16].

This tool has further potential as a research tool to investigate the relative values, both to the public and the forest grower, from different species planting. As research continues on the productivity modelling and collection of economic data of species other than radiata pine, so too does the potential for modelling the spatial economic differences of species and potentially assessing the combinations of different species for multifunctional forests. As climate data acts as a component of tree productivity then also modelling climate changes into the future may provide a valuable insight into the future economic viability of forestry in New Zealand.

It is important to understand that these results are based on specific assumptions which maybe discretionary, for example the appropriate discount rate can be argued until one is blue in the face.

It therefore should not be used for small scale planning but rather as a regional and national strategic level planning tool to investigate variations in viability across regions and nationally.

CONCLUSION

For the first time, a tool is now developed that combines:

- Spatial data, such as, slope, soil type, other impedances such as waterways, current infrastructure (roads, ports, mills), 300 index, site Index, temperature
- Economic data, such as, labour costs, other operating costs for forestry, land values and product prices
- Industry infrastructural requirements, such as, new roads to the forests, internal forest roads, landing construction, harvesting equipment.

to build a picture of economic viability of forestry currently for future forest regimes in New Zealand.

This tool currently has the potential to provide meaningful results for strategic planning objectives, around a number of radiata pine future forestry regimes. This tool also lays the foundation for future capability to explore;

- Climate change impacts on forest profitability
- The viability of the forest growing sector
- The policy mechanisms required to achieve an efficient balance of forest grower benefits and benefits to the public from potential land use changes to and from forestry.
- The economics of new forest species to achieve various objectives on marginal lands.
- The value of environmental benefits from current forest estates.
- Forestry options on more productive landscapes.

Key limitations of this tool are:

- Complexity of input data means that the smaller the scale or result interpretation, the more subject to variability these interpretations will be.
- Assumptions have been made for the modelling of the results in this report, such as the discount rates to use and the price of carbon, and should not be taken as future predictions for the New Zealand forest industry.
- These results predict economic viability of afforestation and do not predict land use change. If a project is viable it will still be subject to microeconomic, temporal and sociocultural impacts, such as land owner identity, transaction and learning costs, changes in product prices and land use competition over time. All of these will have an effect on whether afforestation occurs or not.
- Modelling complexity has led to the necessary simplification of assumptions, for example carbon is calculated as an annuity using non-declining yield, which will have a further effect on results.
- It is not currently a widely available tool and therefore any further investigation of scenarios requires expert use.

ACKNOWLEDGEMENTS

We would like to acknowledge Lucy Manning and Charlie Hawkins for their initial contribution to the project using the spatial planning and investment framework. Richard Deakin and PropertyIQ for their excellent service in providing the property data necessary for this analysis. Les Dowling, is also thanked for his contribution towards regime development for timber outputs. We would like to acknowledge Mina van der Colff for her contribution in developing the statistical relationships between Site Index, 300 Index and the dependent variables carbon sequestration and biomass for bioenergy models. Finally to Richard Yao, Marie Heaphy, Peter Clinton, Andrew Dunningham, Tim Barnard, and Tim Payn, of Scion, for their valuable contribution also.

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APPENDICES

Appendix 1: Future Forest Criteria

- The sub-categories from 1st order classes grassland, and scrub and shrubland, from the AgriBase™ enhanced Land Cover Database 2 (LCDB2) [19] were selected.
- Removal of sub-categories for fernland, manuka and or kanuka, matagouri, broadleaved indigenous hardwoods, sub alpine shrubland, and grey scrub from scrub and shrubland and tussock from grassland, to minimise further ecosystem loss.
- Shrubland classes were excluded as they are considered native carbon sinks.
- Land with the potential for high returns was excluded, this was everything except beef, deer, grazing other peoples' stock, not farmed-idle, sheep, mixed sheep and beef, and unspecified for low producing grassland and beef for high producing grassland.
- Land use capability (LUC) classes were used to exclude arable and slightly limited non-arable land classes and to differentiate between the three scenarios on the basis of erosion severity [20].
- Using a 500m resolution normalised climate surface [21], regions with annual temperature below 7.9^{o}C were excluded, as productivity for *Pinus radiata* is very low below this threshold.
- Areas were limited to a predicted 300 Index of 5m^3/ha/yr and a site index of 13.5m [22] as productivity values have not been recorded below these parameters.
- Grassland and shrubland areas that have unique biodiversity value and would not naturally support trees were excluded using a number of predicted vegetation classes [23].
- Department of Conservation estate and current plantations were also excluded.

Appendix 2: Economic Analysis

To calculate the NPV for forestry in perpetuity firstly, the NPV for a single forest rotation (*F*) must be estimated. The NPV is the sum of the discounted revenues (*R*) and costs (*C*) over one rotation.

$$NPV_F = PV_R - PV_C$$

A GIS layer was created for each discounted cashflow depending on the year it occurred. The present values for intermittent costs and revenues are below, where *t* is the year the cashflow occurs and *r* is the discount rate used.

$$PV_C = \sum_t \left(\frac{C_t}{(1+r)^t}\right) \quad PV_R = \sum_t \left(\frac{R_t}{(1+r)^t}\right)$$

Carbon revenue is an annuity and was therefore calculated slightly differently. It was assumed that the forest is managed to provide a non-declining yield [10], based on volume control [11]. This non declining yield is defined as:

$$NDY = \frac{\bar{S}}{T}$$

Where $\bar{S}$ is the average expected carbon stock (t/ha), assumed to be half the total carbon stock at rotation end ($0.5S_F = \bar{S}$), where S_F is the total carbon stock at rotation end. The revenues from carbon are received as carbon credits or New Zealand Units (NZUs). One NZU is equivalent to one tonne of carbon dioxide (CO_2) [12]. The productivity surfaces for carbon measured the total carbon sequestered in tonnes/ha. This was then converted to CO_2 equivalents by using the mass ratio of carbon to CO_2 (1/3.67) [13]. The annual carbon revenue (*AR*) is then the non-declining yield times the price of carbon (P_{CO2}):

$$AR = NDY(P_{CO2})$$

The present value calculation for the carbon revenue annuity using a rotation length of *T* years is therefore calculated as:

$$PV_{AR} = AR\left(\frac{1}{r} - \frac{1}{r(1+r)^T}\right),$$

While the annual carbon cost for monitoring and administration of \$60 ha^{-1} [9] is an annuity cost calculated similarly as:

$$PV_{AC} = AC\left(\frac{1}{r} - \frac{1}{r(1+r)^T}\right), \text{ such that:}$$

$$NPV_F = PV_R + PV_{AR} - PV_C - PV_{AC}$$

Generally using the LEV assumes that costs and revenues are identical in all rotations, however to provide a more realistic scenario, it should be acknowledged that the first rotation (*F1*) would incur greater costs for road and landing construction than subsequent rotations (*FS*). Therefore, following consultation with a roading engineer subsequent internal road and landing costs were estimated to cost about forty-five percent of the initial construction costs. Hence the LEV is adapted from Bettinger et al. (2008) to be:

$$LEV = NPV_{F1} + \left(\frac{NPV_{FS}}{(1+r)^{T}-1}\right)$$

Whereby NPV_{F1} represents the net present value from the first rotation and NPV_{FS} represent the net present value of subsequent forest rotations which is then discounted into perpetuity with discount rate r and rotation length T.