Ministry for Primary Industries
Manatū Ahu Matua

Valuing the Benefits of Forests

Final Report

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Executive Summary

This report is the product of a Ministry for Primary Industries (MPI) commissioned project to explore the benefits of permanent forests compared with plantation forests and other land uses. The project is related to the Permanent Forest Sink Initiative (PFSI), which was established in 2008 and acts as a mechanism for landowners to access the value of carbon sequestration in exchange for establishing a forest sink covenant on their land. New Zealand has a variety of national and regional priorities associated with afforestation, which can assist the country in achieving its domestic and international climate goals. There are also a range of other related benefits, including water quality improvement, native species habitat, and other ecosystem services.

MPI commissioned Landcare Research NZ to perform several analyses related to afforestation in erosion-prone pastoral hill country. A range of quantitative geographic, biological, and economic models were integrated, with several related qualitative assessments. Following the specifications set out by MPI, the report first conducts a broad analysis at the national level, and then performs a more detailed analysis in the Manawatū catchment in the lower North Island. There are three afforestation scenarios evaluated in both the national and Manawatū analyses. The first scenario assumes that land identified for afforestation is converted to exotic pine plantations. The other two scenarios assume that the land is converted to indigenous forest, with one scenario maintaining permanent indigenous forest with no production activities and the other allowing some productive uses of the land, e.g. honey production.

The national-level analysis estimates the opportunity cost of the land use conversion to permanent forest, in terms of lost agricultural revenue and land value. In addition, the increased revenue from the afforestation scenarios (if applicable) was estimated alongside the change in greenhouse gas emissions.

In the Manawatū analysis, opportunity costs and increased revenue from the afforestation scenarios were estimated using a similar approach to the national level analysis. Carbon values, however, were estimated using a time path of forest growth. Water quality benefits were also monetized. A 50-year time horizon was used to estimate the net present value for these scenarios for the Manawatū catchment. In addition to these monetised values, changes in biodiversity values were quantified and an ecosystem services framework was used to quality describe the impacts of the afforestation scenarios on a range of ecosystem services.

Even under the most conservative policy assumptions, whereby the full value of afforested land is included as an opportunity cost, two out of three afforestation scenarios had a positive net present value across 50 years in the Manawatū catchment. When an alternate policy is used, and the full value of land is not included, all three afforestation scenarios have positive net benefits, with the highest benefit cost ratio at 9.2.

The monetised benefits and costs analysis would suggest that exotic afforestation would be the best approach to pursue given it has the highest NPV and benefit-cost ratio. However, there were many benefits that could not be monetized, including biodiversity, recreation, cultural values, and broader impacts on ecosystem services.

Several important limitations with current data and models were encountered in the course of this analysis and these limitations are outlined to illustrate where additional analysis could be undertaken in the future.

1 Introduction

This report is the product of a Ministry for Primary Industries (MPI) commissioned project to explore the benefits of permanent forests compared with plantation forests and other land uses. The project is related to the Permanent Forest Sink Initiative (PFSI), which was established in 2008 and acts as a mechanism for landowners to access the value of carbon sequestration in exchange for establishing a forest sink covenant on their land. However, to be more widely applicable, the analysis does not fully adhere to the conditions required under the PFSI. New Zealand has a variety of national and regional priorities associated with afforestation, which can assist the country in achieving its domestic and international climate goals. There are also a range of other related benefits, including water quality improvement, native species habitat, and other ecosystem services.

With carbon prices increasing, PFSI forest or alternative afforestation programs could represent the most economically and environmentally viable land use for some of New Zealand's most erosion-prone pastoral hill country. To help inform discussions surrounding the PFSI and these erosion-prone areas, the current report explores several scenarios related to those lands. The main goals for this report, as laid out by MPI, are to determine the:

- additional forest land cover across NZ that could be realised and the proportion that would most suit long-term forest cover, along with an estimate of the opportunity costs;
- and the economic, environmental, and sustainable land management co-benefits of permanent forest plantings over a period of 50 years compared with benefits of plantation forestry and other land uses using an ecosystem services approach. Where possible, these benefits are monetised to enable a cost-benefit ratio to be determined for the different types of land uses.

MPI commissioned Landcare Research to perform these analyses, which are summarized in this report. To achieve these goals, we integrate quantitative geographic, biological, and economic models, with several related qualitative assessments. Following the specifications set out by MPI, the report is structured around the following central components:

1. Identification of potential new areas suitable for afforestation across New Zealand.
2. Catchment analysis of ecosystem services of different land uses.
3. Non-market valuation of ecosystem services and cost-benefit analysis.

The main analysis in this paper takes place in Section 2 in the Manawatū Catchment, where two policy scenarios are analysed across 50 years. In that analysis a variety of ecosystem services are explored in a spatially explicit manner, with several monetized or quantified. However, to give a rough idea of potential impacts at the national level, we also present a national analysis in Section 1. The national analysis is presented for a single year instead of 50, where we assume that the policy is fully implemented (so no transition path is presented). There are therefore some differences in the methods between the 50 year analysis and the one year analysis.

In the national analysis (Section 2) we identify marginal lands across New Zealand that could be converted to long-term forest cover. These afforestation areas were identified using several geospatial maps and models from previous New Zealand literature. Throughout this report these additional marginal land areas identified for afforestation are referred to as 'new afforestation areas.' However, in some cases the identified areas will not be new. For example, some identified marginal lands already have exotic or indigenous forestry on them. In that case, those lands will be assumed to remain in their current (forest) state.[1]

As directed by MPI, two main policy scenarios were developed, which are applied throughout this report:

- **Scenario E** assumes that exotic plantation forestry is planted on the new afforestation areas While this rotational plantation model would not be eligible for PFSI registration, the inclusion of this scenario provides an alternative 'forestry' land use, which will deliver some of the benefits of forest with different rates of return, including additional forestry-related revenue.
- **Scenario I** assumes that the new afforestation areas are afforested with permanent, non-rotation indigenous forest.
  - In order to capture alternate production methods, Scenario I is further subdivided:
    - **Scenario Ia** assumes the new afforestation areas are removed from production and converted to indigenous forest.
    - **Scenario Ib** assumes the land suitable for mānuka/kānuka in the new afforestation areas remain in mānuka/kānuka and are used for enterprises such as medical or commercial honey production.

After identifying the new afforestation areas, Section 2 identifies the areas of indigenous forest that would require active planting versus passive afforestation. In order to estimate productive potential of the indigenous forest areas, the areas suitable for mānuka/kānuka are identified. The opportunity costs of the afforestation scenarios can then be estimated, as well as the annual carbon-related benefits.

Section 3 analyses the afforestation scenarios in more detail for the Manawatū catchment in the Manawatū-Wanganui Region of the North Island. The majority of the land area in the Manawatū catchment is covered by pasture, as much of the previous indigenous forest was cleared for farming over the last 150 years or so. This has caused erosion and other problems on steep slopes in the area. There is also significant variation in current land use, serving as a good setting for this case study. In order to identify, at a finer resolution, the additional land suitable for afforestation, areas for passive regeneration, and areas suitable for mānuka/kānuka, similar analyses as Section 2 are undertaken in the Manawatū Catchment. The analysis in Section 3 goes into greater detail for the economic analysis and uses an ecosystem services approach to classify the estimated costs and benefits. For the Manawatū analysis, benefits and costs are projected over a 50 year period.

2 National analysis

This section focuses on national economic and environmental impacts of the afforestation scenarios. GIS maps and empirical models are first used to identify the marginal pasture land across New Zealand that is suitable for afforestation. Some of the new afforestation areas may not naturally revert to indigenous forest because of distance to other native forest which

[1] This initial identification of marginal land assessment identifies areas likely to be suitable for afforestation and earning carbon credits. However, there are particular conditions for eligibility under the PFSI, the Emissions Trading Scheme or other carbon schemes which may not necessarily be met. This limitation applies to all analysis within this report.

would act as a seedbank. Therefore, we identify areas that would require active planting for Scenario I and those areas that would passively revert. For Scenario Ib, we also identify areas suitable for mānuka/kānuka, as these areas could have a productive use, e.g. for honey production.

The focus of the national analysis is on the annual costs and benefits from a representative year where the policy scenario is fully implemented. The two policy scenarios are compared to the baseline land uses, assuming that the current land use is roughly representative of what may have happened in the absence of the policy. A more detailed analysis at the national level would require significantly more modelling, data, and analysis beyond the scope of this project.

Using the New Zealand Forest and Agriculture Regional Model (NZFARM; Daigneault et al. 2016) and several other inputs, we are able to estimate the opportunity costs related to these afforestation scenarios. As a reminder, in Scenario E all new afforestation areas are converted to exotic plantation forestry. In scenario I, all new afforestation areas are converted into indigenous forest. The opportunity cost contains two main inputs – (1) the value of the earnings in the previous land use, and (2) the value of the converted land. We also calculate the carbon-related benefits of these scenarios using several different valuation methods. Although these carbon-related benefits are likely some of the larger impacts, it is important to recognize that they are only one of a range of potential ecosystem service benefits. This broader range of ecosystem service benefits can be difficult to quantify and monetize, particularly at the national level. The reasons for this are explained in more depth in the Manawatū case study.

2.1 Generation of national maps of areas most suitable for plantation forestry and most likely indigenous species

To identify areas of marginal land most suitable for afforestation, we drew heavily from maps produced by Watt et al. (2011) (a previous project funded by the SLMACC programme[2]). This earlier work identified three potential options for afforestation, depending on assumptions about land suitability which was based on Land Use Capability (LUC) classes.[3] LUC classes 5-8 are designated as unsuitable for arable land use, and have slight (LUC 5), moderate (6), severe (7), and extreme (8) erosion. The afforestation scenarios developed in Watt et al (2011) focus mostly on differences in land in LUC 6, where forestry is a suitable land use to control erosion. Each scenario also includes lands from LUC 7 and 8 that would be suitable for forest.

The most conservative scenario option in Watt et al. (2011) assumed that only the least versatile land classes with severe to extreme erosion would be afforested, the second option included lands with moderate to extreme erosion, and the third included slight to extreme erosion area. Using the most recent land cover map (2012–2013), we have reproduced these three options. For all our analysis below, we use the first scenario of Watt et al. (2011), which represents the most conservative assumptions on areas suitable for afforestation – and has the

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[2] Sustainable Land Management and Climate Change (SLMACC) Research Programme: https://www.mpi.govt.nz/funding-and-programmes/farming/sustainable-land-management-and-climate-change-research-programme/

[3] For more information on LUC's, see http://www.landcareresearch.co.nz/publications/books/luc. A GIS map of LUC's can be found here: https://lris.scinfo.org.nz/layer/76-nzlri-land-use-capability/.

smallest afforestation area of the three options. That land is less likely to face competition for other higher value agricultural uses, and it is therefore the least disruptive policy option.

To identify the new afforestation areas, high resolution national-level GIS datasets are used that cover land use, terrain attributes, and a range of environmental variables. The primary data source was the New Zealand Land Cover Database (LCDB), which is a digital map of land cover created by grouping together similar classes that were identified from satellite images.[4]

A map of additional areas suitable for afforestation, based on the conservative option described in Watt et al. (2011) is found in Figure 1. Potential areas for afforestation appear in black. A total of 695,566 ha of afforestation area were identified for our preferred option. Of that area, approximately 26,000 ha are classified as "reserves." Excluding the reserve land, there are 669,966 ha available for afforestation. Of that area, 531,051 ha, or 79%, is on the North Island, while 138,914 ha (22%) is on the South Island.[5] To compare across the updates of the different scenarios from Watt et al. (2011),
Table 1 illustrates the total area in each scenario, as well as the distribution across the North and South islands.

[4] The most recent version of the NZ LCDB, which was released across 2012/2013, can be found at: https://lris.scinfo.org.nz/layer/423-lcdb-v41-land-cover-database-version-41-mainland-new-zealand/.

[5] In comparison, the two less conservative options had 1,094,361 ha and 2,834,962 ha of land being afforested.

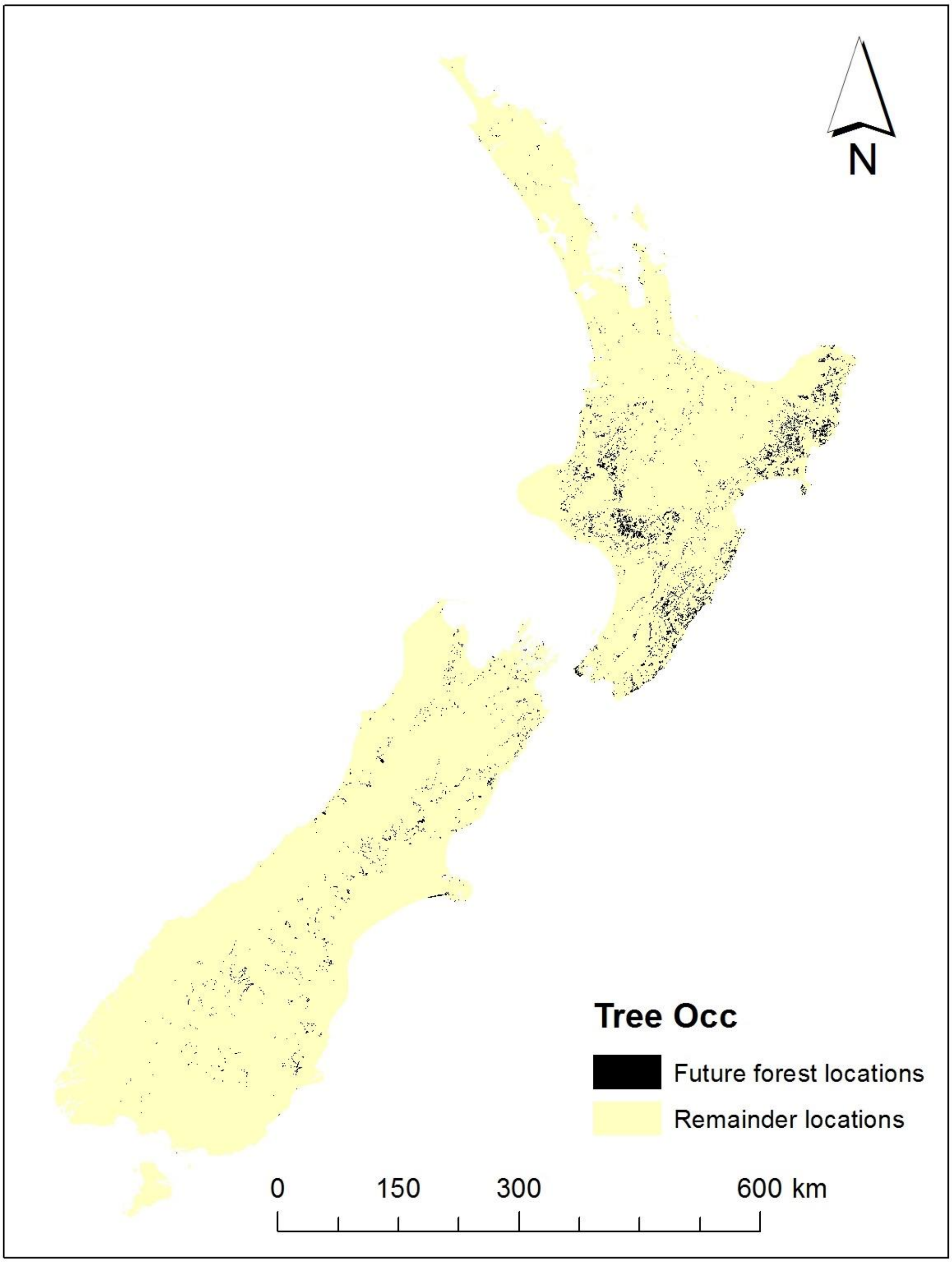

Figure 1: New afforestation areas

Table 1: Updated afforestation scenarios from Watt et al. (2011)

	Option 1	Option 2	Option 3
LUC 6 erosion assumptions	Severe to extreme	Moderate to extreme	Slight to extreme
North Island Area ('000 ha)	531	756	1,640
South Island Area ('000 ha)	138	375	1,283
Total Area ('000 ha)	670	1,131	2,923

2.2 Identification of areas of passive regeneration and active afforestation for indigenous areas

The previous section identified potential areas for new afforestation. In scenario E, these areas will be actively planted and managed for *Pinus radiata* timber production. In Scenario I, however, some areas are likely to revert naturally to indigenous species, while other areas will require active management to convert to indigenous forest. The probability of natural reversion depends on landscape and location-based factors. In this section we estimate which of the new afforestation areas will passively revert as opposed to those areas which will require active planting and management for indigenous afforestation. Mason et al. (2013) provides the foundation for our analysis of passive versus active afforestation for indigenous forest.

Mason et al. (2013) selected 10,061 plots from New Zealand's National Vegetation Survey Databank, and analyzed them to identify central environmental and land cover influences that affect the occurrence probability of indigenous vegetation. Plot surveys were conducted between 1982 and 2008. LCDB also played a central role in this effort, in addition to a range of environmental and land cover GIS datasets. Mason et al. (2013) found that the most important environmental variable was mean annual temperature, while the most predictive land cover variables were local woody cover and distance to forest. We use GIS maps from Mason et al. (2013), and link them with our other analyses and maps to identify the areas that are more suitable for active or passive indigenous afforestation.[6]

Figure 2 shows the potential areas of indigenous afforestation, split into areas of active and passive afforestation. The pink areas represent active afforestation, while the blue areas indicate passive afforestation. The importance of temperature found by Mason et al. (2013) is noticeable in the map, as colder areas at higher elevation fall more generally into the areas that require active afforestation.

To summarize the content of Figure 2 in an alternative format, Table 2 illustrates breakdown between active and passive areas in hectares (for the identified afforestation areas). Across New Zealand, approximately 581,070 ha are in areas of passive afforestation, while 88,895 ha are in areas that require active afforestation. Although the actual success of natural reversion depends on a variety of factors, as emphasized by Mason et al. (2013), areas of passive afforestation would be expected to revert to natural forest with a high probability after the land was no longer actively managed for its current use.

[6] Note that the Mason et al. (2013) work produced a probability map describing the probability of passive afforestation, based on a range of inputs. Based on recommendations from the authors of that work, we used a probability cutoff of 0.6 to differentiate between the two areas. Greater than 0.6 was delineated as passive afforestion areas while less than 0.6 was active afforestation areas.

Table 2: Areas requiring active verus passive afforestation to indigenous species

Indigenous afforestation	Total (ha)	Passive (ha)	Active (ha)
North Island	531,051	480,429	50,622
South Island	138,914	100,641	38,273
Total	**669,966**	**581,070**	**88,895**

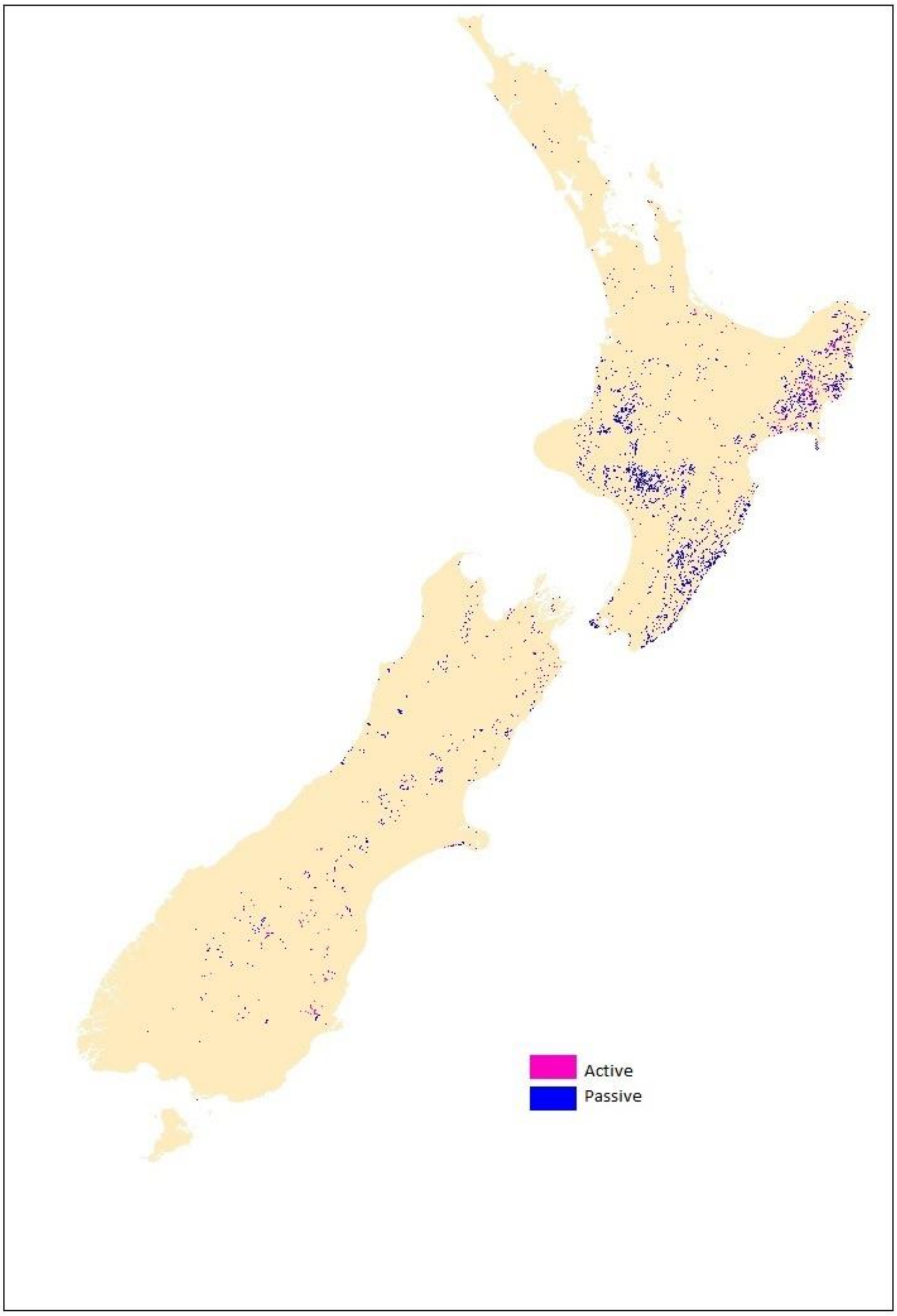

Figure 2: Potential areas of active and passive indigenous afforestation

2.3 Mānuka and Kānuka suitability

In the two indigenous scenarios analyzed in this report, Scenario Ia and Ib differ by their assumptions around the use of indigenous forest. Scenario Ia assumes all new afforestation areas are not used for any production uses, whereas Scenario Ib assumes that some of that land can be used for (non-harvested) production. For our analysis, we assume this productive use relates to mānuka/kānuka-related products such as honey. For Scenario Ib, we also estimate where mānuka/kānuka is more likely to occur, and changes the opportunity cost estimations between Scenarios Ia and Ib.

We adapted the work of Watt et al. (2012) as they included a predictive model of those two species. The growth of mānuka/kānuka stands were modelled using a physiologically based growth model (CenW 4.0) that explored the relationship of mānuka/kānuka stands to environmental conditions and other related factors. Mean annual temperature and precipitation were identified as the best predictors, with mānuka/kānuka completely absent from sites below 5^{0}C. Therefore, we used the temperature and precipitation prediction equations from Watt et al. (2012) to define the probability of occurrence of mānuka/kānuka as a function of temperature and precipitation.[7]

For temperature:

(1) $\text{ProbTemp(Occur)} = 7.159 \times (\text{TempC}) - 30.734$

Where TempC is the mean annual temperature in degrees Celsius, and ProbTemp(Occur) is the probability of occurrence, based on temperature.

For precipitation, where mean annual precipitation is below 1,550 mm/yr:

(2a) $\text{ProbPrecip(Occur)} = 0.060 \times \text{Precip} - 16.5$

For annual precipitation greater than 1,550 mm/yr:

(2b) $\text{ProbPrecip(Occur)} = -2(E-10) \times \text{Precip}^3 + 5(E-6) \times \text{Precip}^2 - 0.0418 \times \text{Precip} + 119.57$

In areas where the probability is based on precipitation and temperature, both of which are greater than 50%, the land is designated as having the potential for mānuka/kānuka stands. Table 3 outlines where mānuka/kānuka afforestation is likely to occur, where green areas are suitable for mānuka/kānuka, while red areas are not. Approximately 52% of the new afforestation area is suitable for mānuka/kānuka (Table 3), with a larger percent of the North Island being suitable for mānuka/kānuka than the South Island.

[7] Given the difficulty in predicting mānuka and kānuka, it is important to emphasize that this model may miss other characteristics related to their growth, such as soil conditions.

Table 3: Summary of afforestation areas and mānuka/kānuka suitability

	Total new afforestation area (ha)	Area suitable for mānuka/kānuka (ha)	Percent suitable for for mānuka/kānuka
New Zealand	669,966	348,055	52
North Island	531,051	337,172	63
South Island	138,914	10,883	8

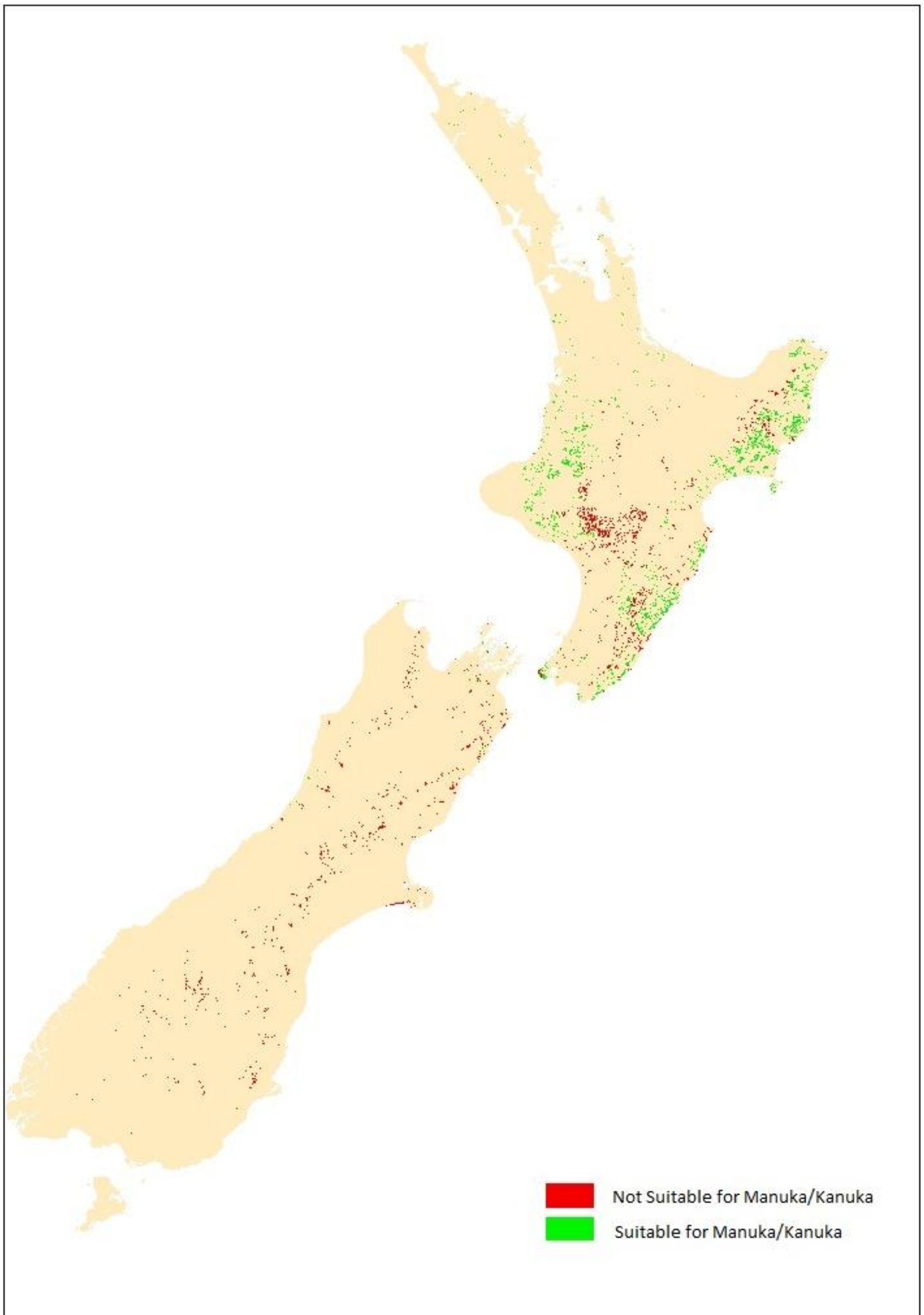

Figure 3: New afforestation areas suitable for mānuka/kānuka species.

2.4 Opportunity cost of converting from existing land use to permanent forest

The opportunity cost for each scenario is estimated as:

- **Scenario E**: the new afforestation areas convert from pasture production to exotic forestry, so the land remains in productive use. The opportunity cost is represented by the profit from the previous land use.
- **Scenario Ia**: the new afforestation areas convert to indigenous forest. The land is removed from production. The opportunity cost is composed of the profit from the previous land use plus the value of the converted land.
- **Scenario Ib**: the new afforestation areas convert to indigenous forest with those areas suitable for mānuka/kānuka being used for used for productive purposes. In this instance for medical or edible honey production. The opportunity cost is composed of the profit from the previous land use plus the value of the converted land. Due to the honey production, there is less land opportunity cost than Scenario Ia.

To estimate the opportunity cost associated with changes in profitability, we employed the NZFARM, along with related data on land value. First, the change in agricultural profits resulting from Scenario E and Scenario I, which is a main component of opportunity cost, is estimated. Agricultural profits are represented as average annual lost EBIT (earnings before interest and taxes) for each scenario.

The agricultural EBIT opportunity cost estimates were derived using NZFARM. NZFARM incorporates data and estimates from economic and land use databases and biophysical models. The model is a non-linear, partial equilibrium, mathematical programming model of New Zealand land use. Current land uses were derived from a national land use map (based on AgriBase and the NZ Land Cover Database version 4 (LCDBv4)). Economic returns were obtained by integrating several sources on farm budgets for relevant enterprises (Newsome et al. 2008; MPI 2013a, b; Lincoln University Budget Manual 2013). Net farm revenues vary by the farm/enterprise type, size, and location and can be aggregated by region and land use. The model enables the comparison of EBIT between the current land use baseline and each scenario.

The foregone EBIT from previous land uses is a part of the opportunity cost for all scenarios, as they all assume that the same marginal land is converted from its existing use.[8] Where land moves from a productive use to a non-productive use we assume the land is purchased from the current land owner and retired from its productive use.[9] This is the value of the land portion of the opportunity cost estimation.

To estimate the value of the land opportunity cost, we use the median sales price per hectare for farm land from the Real Estate Institute of New Zealand (REINZ). REINZ differentiates

[8] There is, however, one important caveat. We assume that existing forest remains as it is. So in Scenario E, which replaces marginal land with exotic plantation forestry, we assume the existing indigenous forest is not converted. Likewise, for the indigenous Scenarios Ia and Ib, we assume that existing exotic forestry remains plantation forestry.

[9] Note that there are several alternative policy instruments that could effectively sideline land for afforestation. For instance, placing a covenant on the land to dedicate it to forest. Our chosen policy instrument likely represents a conservative upper bound on the potential opportunity cost of land, as the others will keep some land under citizen ownership and potentially allow for other productive and related activities.

land value regionally and by farm type. These estimates represent an upper bound, since the profitability of the land is normally factored in its value. Therefore, profit (as represented by lost EBIT) is not likely independent of the value of the land. In treating land value and profitability as additive we assume that they are independent. To calculate the annual opportunity cost, the value of land is annualized, so can be interpreted as foregone rent on the land.[10]

2.4.1 EBIT opportunity costs

Table 4 contains information about the current land uses in areas identified as the new afforestation areas. The current land uses are dominated by sheep & beef (72%), native forest (12%), and scrub (4.5%), while dairy, arable, and grapes represent less than 1% of the total area. The majority of the sheep & beef farms are generating minor or no profits, while dairy, fruits, vegetables, and grapes are generating the highest profits. Comparing the amount of land to the net revenue figures, the more profitable enterprises are fruit, viticulture (grapes), vegetables and dairy. Note that the minor difference between the total ha at that bottom of Table 4 and the total afforestation area of 695,566 ha identified section 2.1 are due to slight differences in the underlying GIS datasets.[11]

Table 4: Distribution of area and EBIT of current land use, by farm type

Current land use in new afforestation area	Corresponding area (ha)	Corresponding agricultural EBIT ($NZ)	Corresponding EBIT per ha ($NZ/ha)
Arable	37	61,750	1,669
Dairy	5,325	13,247,235	2,488
Deer	5,203	5,177,032	995
Exotic Forestry	20,357*	11,421,411*	561
Fruit	71	522,605	7,361
Native Forest	87,240*	0	0
Other	18,563	0	0
Other pasture	20,204	388,594	19
Pig	7	9,612	1,373
Scrub	31,175	0	0
Sheep & beef	501,992	31,088,779	62
Tussock	2,637	0	0
Vegetables	111	361,388	3,256
Grapes	1,920	9,224,887	4,805
Total	**694,844**	**71,503,293**	
Total Without Exotic and Native	**587,245**	**60,081,882***	

* Note that we assume that in Scenario I, exotic forestry is not converted into indigenous forest. Similarly, in Scenario E, native forest is not converted to exotic forestry.

[10] So in the case of the producer owning the land, they are essentially "renting" to themselves.

[11] Also, the approximately 26,000 ha of reserves discussed in Section 2.1 is classified as either "Native forest" or "Other" here.

2.4.2 Total opportunity costs by scenario

Table 5 presents the opportunity costs of converting existing land in the new afforestation areas. The table lists these opportunity costs by region. As explained below, the shaded columns represent the total opportunity costs for the three scenarios – E, Ia, and Ib.

For Scenario E, the total opportunity cost of converting is the lost EBIT, approximately $60 million. Since the land stays in production – as it is converted to exotic forestry – there is no opportunity cost of the value of the land. This Scenario E total opportunity cost is displayed in the second column, and is approximately $60 million. Note that this value differs from the total of Table 4, as that table includes existing exotic forestry (which is not converted).

The third and fourth data columns outline the value of converted land for Scenario Ia and Ib, respectively. These are estimated from the REINZ land value data mentioned above. The total value of a property is the net present value of future returns, so to get annual values the REINZ data are annualized. To annualize the data we use an 8% rate. There are several potential interest rates that could be used. New Zealand Treasury recommends a 4-6% rate for social benefit-cost analysis, although they previously recommended an 8% rate for the social cost of capital.[12] The opportunity cost of Scenario Ib is less than Scenario Ia because the proportion of the land assumed to stay in mānuka-related production (except for Otago and Southland, which had no afforestation areas suitable for mānuka/kānuka) don't have the same opportunity cost of the value of converted land, since it is still in a productive use. The final two columns contain the opportunity costs for Scenarios Ia and Ib, which are the sum of lost EBIT and value of converted land.

It is important to note that the opportunity costs for Scenarios Ia and Ib, in reality, will depend on the policy used to implement those scenarios. If the policy implemented involves the government purchasing the land from the current owner, then the opportunity cost is as illustrated in Table 5. However, if an alternative policy is deployed, such as placing permanent forest covenants on the land, then the opportunity cost is less straightforward. In this policy context, the original land owner may still be able to generate carbon credits from the land, or other ecosystem services, and this portion of the opportunity cost is no longer the full value of the land. As stressed earlier, the estimates in this report likely represent an upper bound, since the profitability of the land is normally factored in its value, and hence the profit (as represented by lost EBIT) is probably not independent from the value of the land. In treating them as additive here, we assume they are independent.

[12] In this report, we use a wider range of rates to illustrate the full range of potential estimates, so consistently report values using 3% and 8%. The 4-6% rates currently recommended by Treasury should fit within this range, while allowing for a wider range of estimates. Other countries frequently use 7%, such as the US and Britain. http://www.treasury.govt.nz/publications/guidance/planning/costbenefitanalysis/currentdiscountrates. The 8% used here for the social cost of capital should yield more conservative estimate of net benefits, since many of the costs occur closer to the present than the benefits.

Table 5: Annual opportunity costs by region ($NZ) of converting the new afforestation area

Region	Total afforested area (ha)	Lost agricultural EBIT ($NZ) Scenario E Opportunity Cost	Value of converted land Scenario Ia	Value of converted land Scenario Ib	Lost EBIT + converted land value Scenario Ia Scenario Ia Opportunity Cost	Lost EBIT + converted land value Scenario Ib Scenario Ib Opportunity Cost
Auckland Region	1,364	148,726	3,568,367	152,689	3,717,093	301,415
Bay of Plenty Region	5,385	2,103,301	37,541,507	5,722,285	39,644,808	7,825,586
Canterbury Region	71,755	4,509,952	73,185,872	72,081,232	77,695,824	76,591,184
Gisborne Region	104,254	1,044,412	148,737,670	33,377,089	149,782,082	34,421,501
Hawke's Bay Region	66,805	15,999,711	67,652,921	26,048,800	83,652,632	42,048,511
Manawatū-Wanganui Region	169,005	11,029,688	100,661,686	59,031,742	111,691,374	70,061,430
Marlborough Region	15,422	2,143,932	16,500,500	11,683,279	18,644,432	13,827,211
Nelson Region	1,122	77,753	1,451,508	545,750	1,529,261	623,503
Northland Region	4,449	261,838	4,338,391	108,156	4,600,229	369,994
Otago Region	29,616	2,244,047	38,717,878	38,717,878	40,961,925	40,961,925
Southland Region	3,693	784,665	7,686,860	7,686,860	8,471,525	8,471,525
Taranaki Region	21,620	2,714,981	24,996,834	1,035,058	27,711,815	3,750,039
Tasman Region	10,486	2,078,737	12,683,781	10,011,865	14,762,518	12,090,602
Waikato Region	29,807	5,392,166	63,053,003	10,380,983	68,445,169	15,773,149
Wellington Region	44,466	7,110,840	30,164,709	14,226,323	37,275,549	21,337,163
West Coast Region	7,997	2,437,132	5,209,318	4,047,616	7,646,450	6,484,748
Total	**587,247**	**60,081,881**	**636,150,805**	**294,857,604**	**696,232,686**	**354,939,485**

2.5 Increases in exotic forestry earnings

In Scenario E the afforested land will be converted from its previous land use into exotic forest production. Using NZFARM, we calculate the average annual EBIT expected from the new forestry operations. In this part of the analysis, we are focusing on annual values. These values are the estimated EBIT for forestry operations, assuming that the local area has the proper infrastructure to support the increase in forestry, and assuming that local farmers are willing to change their land use. The results of these estimates are outlined in Table 6. The largest increase in EBIT is the Manawatū-Wanganui Region, while the smallest is the Nelson area. An important caveat to these estimates is that the modelling uses current profitability; they do not reflect any changes in market conditions that may be affected by the increase in forested areas.

Table 6: Estimated national increase in forestry earnings, annual average

Region	Gains from timber ($NZ)
Auckland Region	1,037,278
Bay of Plenty Region	3,333,665
Canterbury Region	19,178,675
Gisborne Region	61,909,180
Hawke's Bay Region	33,980,225
Manawatū-Wanganui Region	100,972,455
Marlborough Region	5,546,250
Nelson Region	364,031
Northland Region	3,448,134
Otago Region	7,638,856
Southland Region	1,411,443
Taranaki Region	14,220,458
Tasman Region	3,394,194
Waikato Region	18,434,312
Wellington Region	24,800,276
West Coast Region	2,892,839
Total	**302,562,270**

Table 7 presents the change in EBIT from converting to exotic forestry by previous land use instead of region. Note we assume that the areas of indigenous forest are not converted to exotic forestry operations, and the existing exotic plantations remain as they were.

Table 7: Estimated increase in forestry earnings, annual average by previous land use

Enterprise	Total afforested area (Ha)	Gains from timber ($NZ EBIT)
Arable	37	20,196
Dairy	5,325	3,012,997
Deer	5,203	2,252,974
Exotic forestry	0	0
Fruit	71	40,217
Native forestry	0	0
Other	18,563	0
Other pasture	20,204	11,005,215
Pig	7	4,210
Scrub	31,175	9,865,897
Sheep & beef	501,992	274,590,924
Tussock	2,637	800,010
Vegetables	111	38,412
Grapes	1,920	931,218
Total	**587,245**	**302,562,270**

2.6 Changes in carbon

Reductions in greenhouse gasses can yield a wealth of benefits, most importantly human health benefits, but also including aesthetic and habit impacts (US EPA, 2014). NZFARM provides outputs related to greenhouse gas emissions and carbon sequestration, which can be used to identify some of those benefit categories. For both scenarios E and I, we calculate the additional carbon sequestration in the new afforestation areas, as well as the greenhouse gas (GHG) emissions avoided from moving from the previous land use to a forest use. These represent the average carbon stock change as the forest reaches a steady state of carbon under the new afforestation scenarios, where the new scenario is assumed to be fully implemented, and the annual values depict a representative year.[13]

[13] At the national level, we do not go into detail about the transition path to these new steady state values. In the later case study on the Manawatu, we more explicitly estimate the transition from the existing land use to the new afforestation areas.

Table 8 outlines the avoided GHG emissions and carbon sequestered in the new afforestation areas for Scenario E. The avoided GHG emissions are the emissions that would have occurred if the land remained in its previous use, while the carbon sequestration is from the new plantings of exotic forestry.

Table 8: Annual GHG emissions and carbon sequestration for Scenario E (exotic forest)

Land use	GHG avoided (tons CO_2e)	Carbon sequestration (tons CO_2e)	Total GHG avoided and carbon sequestered (tons CO_2e)
Arable	62	429	491
Dairy	10,969	61,004	71,973
Deer	879	59,604	60,483
Forestry	0	0	0
Fruit	41	808	849
Native	0	0	0
Other	0	212,653	212,653
Other pasture	17,550	231,451	249,001
Pig	18	86	104
Sheep & beef	120,006	5,750,587	5,870,593
Vegetables	31	1,266	1,297
Grapes	1,313	21,993	23,306
Total	**150,869**	**6,339,881**	**6,490,750**

Table 9 outlines the results of Scenario I where the new afforestation areas are converted to indigenous forest. Based on the forestry literature, indigenous forest sequesters less carbon than exotic plantation forestry. This is mainly due to the higher density and volume of timber in exotic plantations as compared to indigenous forest, among other things.[14]

[14] See, for example, the NZ ETS lookup table estimates of carbon storage for several species across time: http://www.mfe.govt.nz/climate-change/reducing-greenhouse-gas-emissions/new-zealand-emissions-trading-scheme

Table 9: GHG emissions and carbon sequestration for Scenario I (indigenous forest)

Land use	GHG avoided (tons CO_2e)	Carbon sequestration (tons CO_2e)	Total GHG avoided and carbon sequestered (tons CO_2e)
Arable	62	22	84
Dairy	10,969	3,195	14,164
Deer	879	3,122	4,001
Forestry	0	0	0
Fruit	41	42	83
Native	0	0	0
Other	0	11,138	11,138
Other pasture	17,550	12,123	29,673
Pig	18	4	23
Sheep & beef	120,006	301,195	421,201
Vegetables	31	66	97
Grapes	1,313	1,152	2,465
Total	**150,869**	**332,061**	**482,929**

There are several assumptions that underpin this analysis. To reflect current production, the NZFARM model assumes that the forest area was planted pre-1990. This may induce some uncertainty with the new afforestation areas, since they will be new plantings. To annualize profitability estimates, the model also assumes a small harvest each year instead of one large one at the end of a rotation (see Daigneault et al. 2016 for more details). These assumptions may produce some differences with the estimates for the Manawatū catchment presented below, which better account for the time path of forest growth.

The reduction in net GHG emissions can be valued using several different methods. GHG emissions have diverse impacts. These impacts have been explored in a range of international research projects, and many OECD member countries estimate the monetary impact of carbon emissions (OECD 2013). Focusing specifically on carbon dioxide emissions, some countries use an estimate of the "Social Cost of Carbon" (SCC) in regulatory impact analysis to monetize the benefits or costs of regulation (Marten et al. 2015). The SCC represents the present value of the future stream of damages associated with marginal carbon emissions.[15]

Under a set of strict equilibrium assumptions, a properly functioning carbon market can provide insights about marginal abatement costs of carbon, and potentially the marginal benefits of emissions to firms. Active trading in a competitive carbon permit market can theoretically price carbon at the value at which the marginal abatement cost of a unit of emissions are equal to the marginal benefit. Several countries, and even some US states, have implemented carbon permit markets to mixed results. Other countries, such as Ireland, have an explicit tax on carbon (with a current tax rate of €20/ton CO_2e). For more background on

[15] Note that the SCC is a global figure, so contains benefits from outside of New Zealand. Additionally, the

these different approaches, the New Zealand Treasury provides an overview: http://www.treasury.govt.nz/publications/research-policy/wp/2005/05-02/06.htm.

As a result of the Climate Change Response Act of 2002 and subsequent amendments , New Zealand has an active carbon trading market: the New Zealand Emissions Trading Scheme (NZETS). The NZETS also puts a price on carbon.[16] Forestry is already covered in the NZETS along with several other economic sectors. However, agriculture is not currently covered (Daigneault et al. 2017).

Due to the uncertain nature of the future impacts of climate change, as well as uncertainty about future international agreements related to carbon pricing and trading, there are a wide range of estimates for the social cost of carbon in the literature. To simplify our analysis, we use two data sources to value the GHG emission reductions associated with each scenario. First, we use the current carbon price in the New Zealand Emissions Trading Scheme (ETS) approximately $17. This price, however, is likely an underestimate, as it only captures current trading and does not directly incorporate the potential for future agreements, regulations, and impacts that might increase (decrease) the demand for (supply of) carbon credits and therefore raise their price. In addition, we are not modelling the potential revenue that could be gained from the afforestation scenarios at the national level, which would require more data and modelling. We are simply using the ETS price as a proxy for the value of emissions reductions. In modelling the impact of its target under the Paris Agreement (on Climate Change), New Zealand assumed a global carbon price of $50 by 2030.[17]

For a wider sensitivity analysis, we also employ the United States estimates for the SCC, which vary by several factors and provide a fairly wide range of valuations.[18] An important feature of the US estimates is that they capture the range of many other current estimates, such as the UK traded carbon values,[19] the Irish Carbon Tax, and various EU estimates. Furthermore, a 2010 report commissioned for the New Zealand Parliamentary Commission for the Environment estimated future New Zealand ETS prices, and those future prices fit within the US SCC estimates.[20]

Table 10 shows the range of value estimates for the reduction in net GHG emissions for Scenarios E and I. The 2020 US SCC estimates are used for these annual values, alongside the current New Zealand ETS price. The SCC estimates vary by the discount rate applied (such as 5%, 3%, or 2.5%). For Scenario E, with approximately an 8 million tonne reduction in net GHG emissions, the value of carbon benefits ranges from $137 million to $833 million (NZ) dollars. It is again important to note that this represents an average year, which masks

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[16] http://www.mfe.govt.nz/climate-change/reducing-greenhouse-gas-emissions/new-zealand-emissions-trading-scheme

[17] See http://www.mfe.govt.nz/sites/default/files/media/Climate%20Change/INDC_cabinet_paper_for_public_release.pdf, as well as http://www.mfe.govt.nz/climate-change/international-forums-and-agreements/united-nations-framework-convention-climate-0

[18] See https://www.epa.gov/climatechange/social-cost-carbon

[19] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/600710/Updated_short-term_traded_carbon_values_for_appraisal_purposes_2016.pdf

[20] http://www.pce.parliament.nz/media/1292/covec-final-report-19-07-10.pdf

important temporal fluctuations in carbon sequestration. The Scenario I benefits are estimated to range between $10 million and $58 million.

Table 10: Value of the reduction in net GHG emissions

	2020 SCC US$/tonne (2007 $US)	NZ$/tonne (2017)	Scenario E (2017 $NZ)	Scenario I (2017 $NZ)
	Reduction in GHG emissions (tonnes CO_2e)			
	-	-	6,490,750	482,929
	Value of reductions in net GHG emissions			
Current NZ emissions price	-	$17	$110,342,748	$8,209,797
US SCC 5% average	$12	$19.94	$129,404,783	$9,628,063
US SCC 3% average	$42	$69.78	$452,916,739	$33,698,221
US SCC 2.5% average	$62	$103.01	$668,591,376	$49,744,994

Notes: Estimates for SCC are dollar-year and emissions year specific. We first convert from 2007 to 2017 dollars (assuming 1.17% increase), and then from US to NZ dollars (assuming 1.42 NZD: 1 USD exchange rate). For additional information on the estimates, see https://www.epa.gov/climatechange/social-cost-carbon. Note that we do not use the high impact, 95th percentile estimates, which are $123 (US) per ton.

2.7 Summary of the national analysis

Three afforestation scenarios were analysed in this section, which vary by their assumptions about the post conversion land use. We identified new afforestation areas based on previous work by Watt et al. (2011). Within the new afforestation areas we also identified land suitable for mānuka and kānuka species, as well as identified those areas which would passively revert to indigenous forest and those areas that would need active management for indigenous afforestation.

We used NZFARM and related resources to calculate several notable national afforestation impacts. These include the opportunity costs for each of the three scenarios, increases in exotic forestry earnings, and carbon-related changes. The agricultural opportunity cost of lost production was estimated to be approximately $60 million for each scenario. The opportunity cost of land was highest for Scenario Ia, at approximately $600 million. Scenario Ib had an opportunity cost of land of approximately $300 million. The land opportunity costs are directly dependent on the policy used to implement afforestation, so are more uncertain than the opportunity cost of lost EBIT.

The afforestation scenarios are expected to produce a range of benefits. We have only monetized two in this national analysis: increases in timber earnings and the value of carbon. We monetize and quantify several additional impacts in the Manawatū catchment case study below, including the value of honey production and water quality benefits.

Scenario E is estimated to produce $300 million in increased *Pinus radiata* profits, as well as $140 million in carbon benefits. Scenarios Ia and Ib are estimated to result in approximately $10 million in carbon-related benefits.

2.8 National-level analysis: limitations, uncertainties, and assumptions

Some of the important uncertainties and assumptions in the national-level analysis are outlined in Table 11. As noted in the text, we have attempted to be conservative in our assumptions where possible.

Table 11: Uncertainties and assumptions

Issue	Impact on estimate	Notes
Only annual values are presented	Uncertain	In some analyses, such as opportunity costs, the average annual value is likely a good proxy. However, for other impacts, such as carbon or other ecosystem services that have a distinct time path, annual values may be a poor representation.
Use most conservative afforestation scenario from Watt et al. (2011)	Underestimate the total potential land for afforestation	The area of land afforested could be higher, depending on the Watt et al (2011) scenario chosen or incentivised.
Assume value of land and lost EBIT are additive	Overestimate opportunity costs	This addition may be double counting some opportunity costs, so represents an upper bound.
Missing a range of ecosystem services and other costs	Underestimate benefits	For this analysis, it was only possible to quantify or monetise a portion of the changes in ecosystem services, although several others are described.
Carbon valued using NZ ETS	Underestimate of full welfare impacts of climate change	We use a fairly conservative value for a tonne of carbon, which based on current rates. Several sources in the literature indicate that the actual welfare-based value is larger, and other sources indicate that the ETS price may increase significantly in the coming years.
Carbon valued using steady state average emissions/sequestration from NZFARM	Effect depends on scenario	The estimates of carbon sequestered are based on assumptions from NZFARM that were made to annualize estimates, such as a small annual harvest. More details can be found in Daigneault et al. (2016).
In Scenario Ia, we assume that all land is purchased from landowners.	Overestimate opportunity cost of land	Other policy mechanisms might be used to incentivise permanent afforestation, such as covenants on the land. In that case, the opportunity cost of the land will be significantly less.

3 Manawatū catchment analysis

To explore the potential impacts of the three afforestation scenarios in more detail, we undertake a related analysis in the Manawatū catchment. However, in this analysis we explore impacts over time and consider the transition path to the new land use. In comparison, the previous national results portrayed a representative year once the policies were fully implemented.

The Manawatū catchment is located in the Manawatū-Wanganui Region in the North Island (Figure 4), which is the region with the largest area of new afforestation (Table 4). Most of the Manawatū catchment is covered by pasture, as much of the original indigenous forest has been cleared for farming over the last 150 years or so. The clearing of the indigenous forest has led to erosion and other problems on steep slopes in the area (Ausseil et al. 2013). The Manawatū catchment overlaps some of the area of six Territorial Authorities (TA): Central Hawke’s Bay, Horowhenua, Manawatū, Masterton, Palmerston North City, and Tararua.

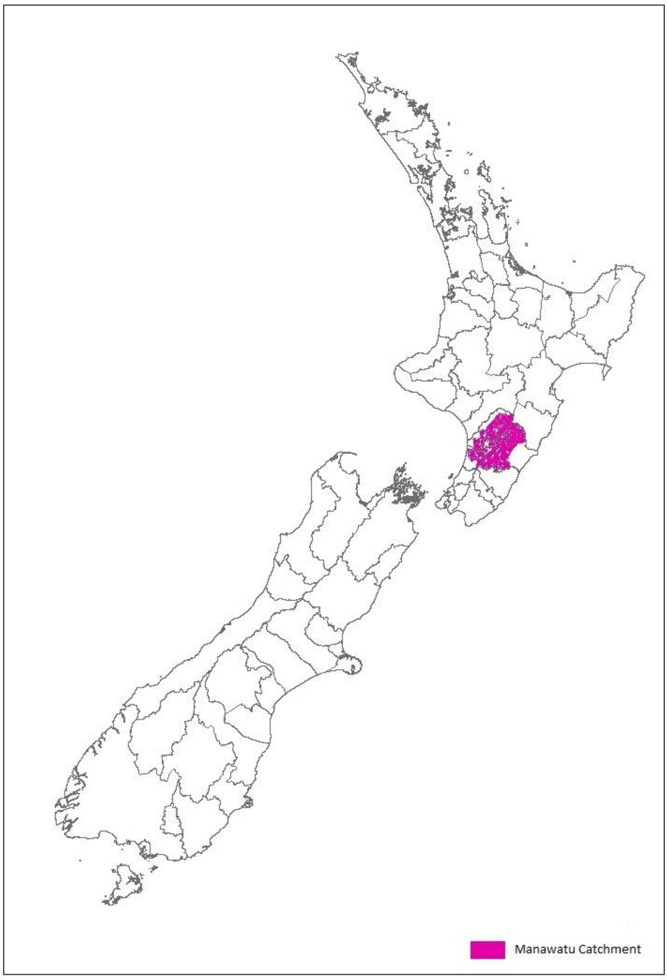


Figure 4: The Manawatu catchment.

3.1 Identification of suitable areas for plantation and indigenous forest in the Manawatū catchment

Using the same process described in the national analysis in Section 2, we identified the areas in the Manawatū catchment for new afforestation using the most conservative afforestation scenario in Watt et al. (2011) (Figure 5, where dark green represents the new afforestation areas). Similar to the national analysis, we omit all conservation and reserve land from the analysis. Approximately 40,000 ha of land were identified for new afforestation in the Manawatū catchment. The distribution of current land uses in the new afforestation areas is found in

Table 12. The most prevalent existing land use is sheep & beef, at approximately 32,000 ha.

Table 12: Current land use area for future afforestation within the Manawatū catchment

Enterprise Class	Area (ha)
Dairy	800
Deer	362
Forest	642
Native	637
Other	416
Other pasture	1,326
Sheep & beef	31,606
Scrub	3,608
Arable	< 1

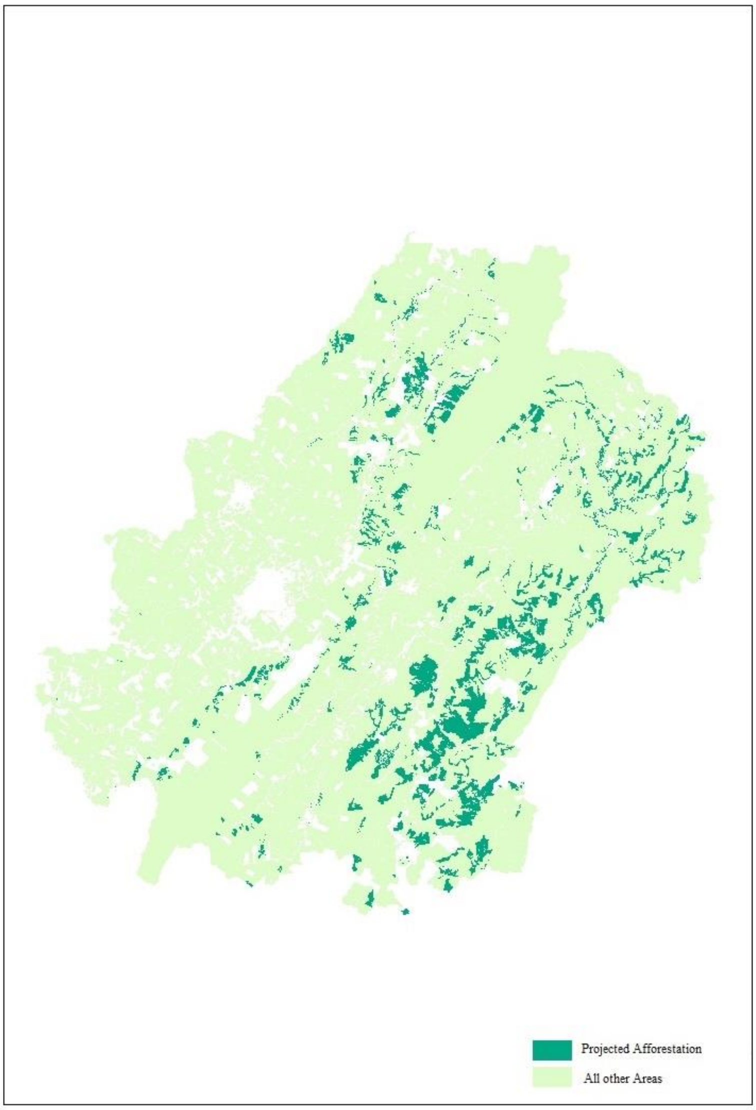
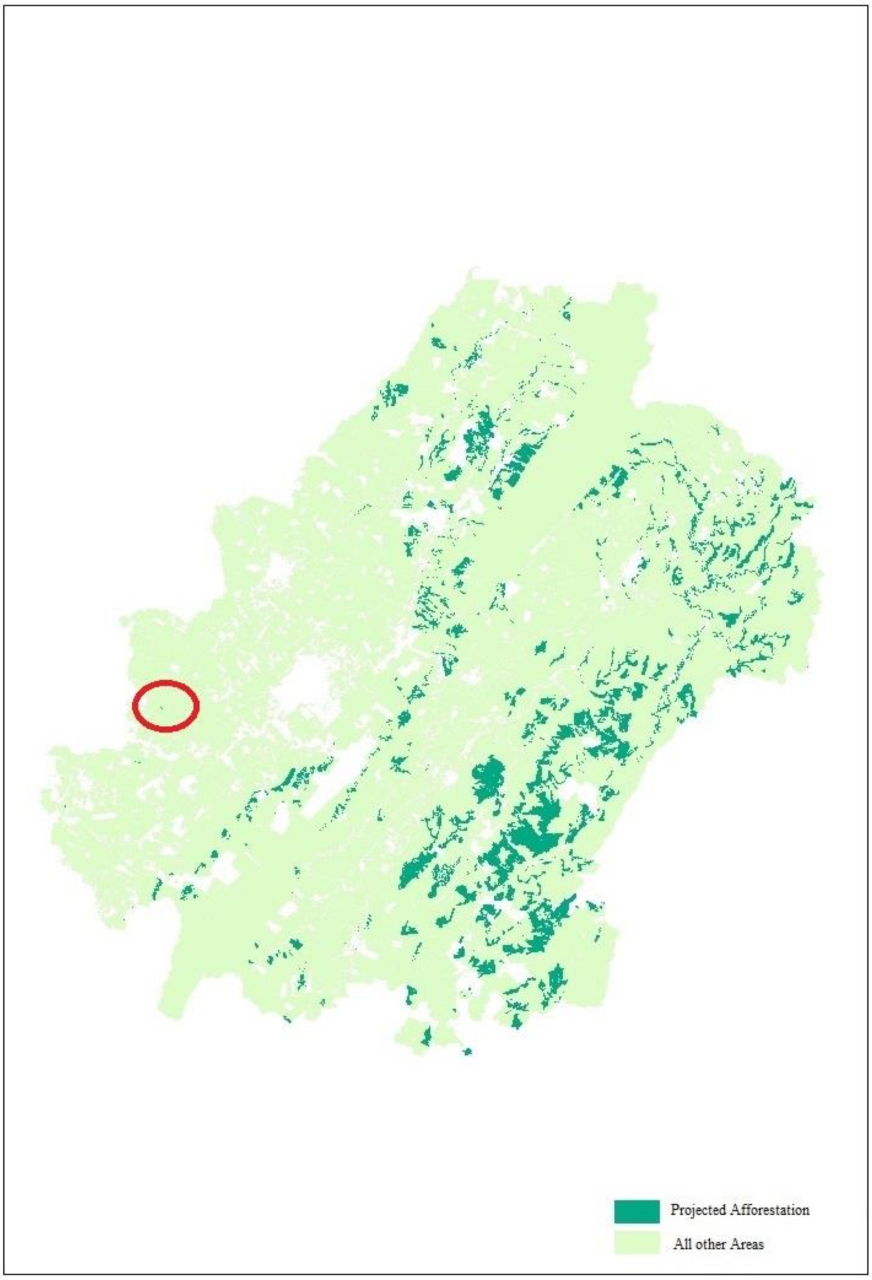


Figure 5: Afforestation areas in the Manawatu catchment.

3.2 Active and passive indigenous afforestation in the Manawatū catchment

For the new afforestation areas (Figure 5), we estimate which areas would require active afforestation in Scenarios Ia and Ib. The approach for identifying these areas is described for the national analysis in Section 2. There were only four small land areas (total 3.3 ha) identified as requiring active afforestation.[21] These are all located in the southwest of the Manawatū catchment (red circle in

Figure 6). The average cost of indigenous afforestation would be lower in the Manawatū compared to the national average cost.



[21] These four areas may be an artefact of overlaying multiple GIS layers, and under certain policies might not qualify for carbon credits.

Figure 6: Active indigenous forest areas for the Manawatu catchment.

3.3 Areas suitable for Mānuka/kānuka in the Manawatū catchment

As with the national analysis, we use the models from Watt et al. (2012) to identify the new afforestation areas suitable for mānuka/kānuka (Figure 7). Of the almost 40,000 ha identified as new afforestation areas, approximately 24,000 ha are suitable for mānuka/kānuka. The identified areas are coloured purple in Figure 7, while the new afforestation areas not suitable for mānuka/kānuka appear in dark green.

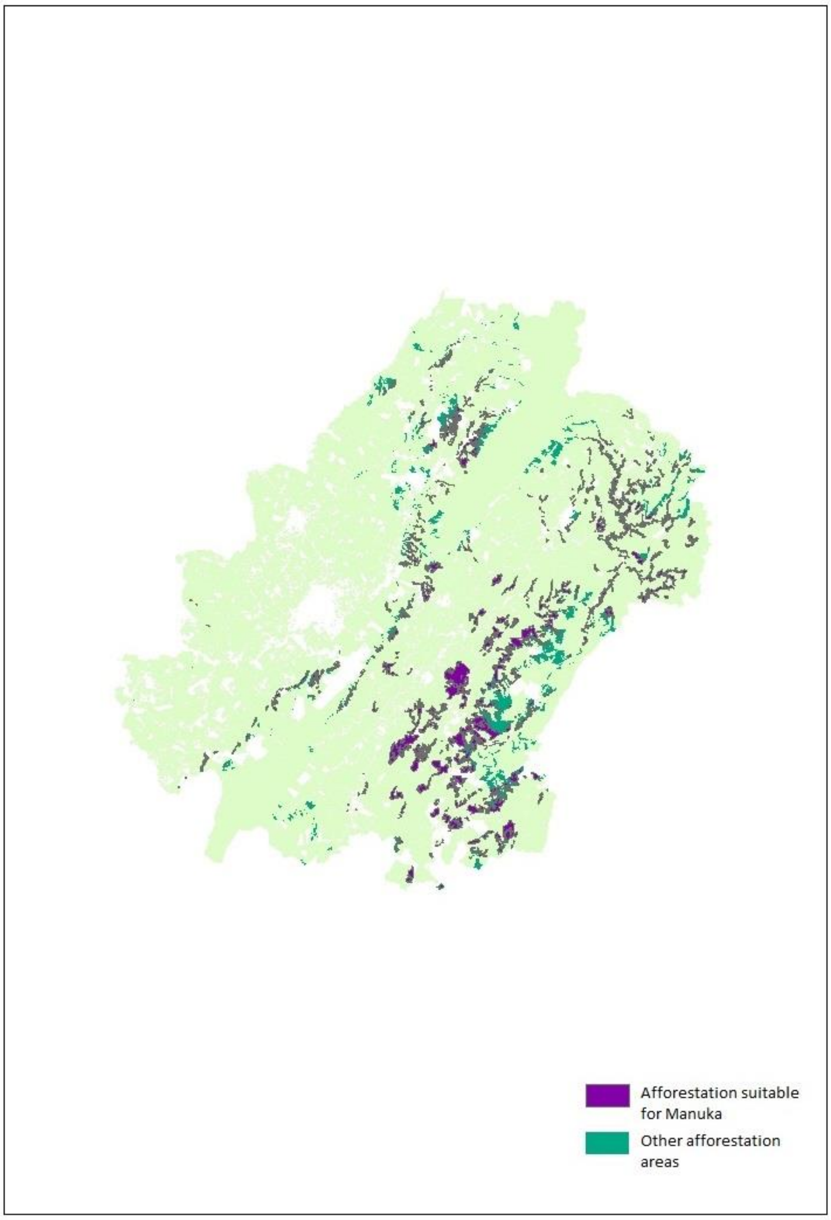


Figure 7: Areas suitable for mānuka/kanuka in the Manawatu catchment.

3.4 Ecosystem services classification

To better evaluate the full range of costs and benefits for the afforestation scenarios, we use the ecosystem services classification (MA 2005). The Millennium Ecosystem Assessment (MA)[22] defined ecosystem services as "the benefits people obtain from ecosystems," which the MA classify as provisioning, regulating, supporting, and cultural services (Table 13).[23]

Table 13: Ecosystem services categories

Provisioning Services	Regulating Services	Cultural Services
Crops	Air quality regulation	Recreation & eco-tourism
Livestock: milk	Climate regulation	Ethical & spiritual values
Livestock: meat	Water regulation: flow	Educational & inspirational values
Capture fisheries	Water regulation: quality	
Wildfoods: honey	Erosion control	
Timber & wood	Water purification & waste treatment	**Supporting Services**
Fibres & resins	Biological control	Habitat Provision
Ornamental resources	Disease regulation	
Biomass fuel	Pollination	
Freshwater	Natural hazard regulation	
Genetic resources		
Biochemicals, natural medicines & pharmaceuticals		

a: adapted from MA (2005).

Provisioning services include the direct products from ecosystems that people use. Many of the agricultural products, such as meat, milk, and honey fit into this category (MA 2005). According to Statistics NZ, approximately 8 percent of New Zealand's GDP was derived from primary industries in 2009, which includes agriculture, fishing, forestry, and mining, illustrating the large amount of resources dependent on these ecosystem services.

Regulating services include the impacts from the ecosystem people obtain that help regulate ecosystem processes, such as the regulation of air pollution by trees, the control of erosion by tree roots, and the purification of water by plants (MA 2005). The NZETS creates a market for the climate regulating services provided by nature.

Cultural services are the non-material benefits that people receive from ecosystems (MA 2005). New Zealand has a variety of sites that have specific cultural significance to many people, and rapid landscape change is likely to affect these values. There are many areas with a history of spiritual practices, experiences, and values that depend on the composition of the landscape. For instance, historic vistas might be significantly altered by large exotic forestry plantations. In elevated, erosion prone areas these areas' visibility may be quite expansive. A transition from pasture farming to forestry may also affect farming lifestyle and the

[22] The MA was created by an active group of scientists, along with representatives from governments, private sector, and nongovernmental organizations.

[23] For more information on the MA, see http://millenniumassessment.org/en/index.html

associated cultural experience. Similarly, the degradation/improvement in water quality from changing land uses will affect cultural values. Recreation-related benefits were recently found to have a very high value in Turner et al. (2011), although those benefits were related to mountain biking and walking trails, which were quite unique to the setting of their study.

Finally, supporting services are seen as inputs into the other ecosystem services categories, which can be necessary for their production (MA 2005). For instance, the provision of habitat for pollinators is a necessary input to a range of agricultural products.

Although the term "ecosystem services" was formalised and popularised by the 2005 MA report, economists have valued many of these services for decades (Freeman 2003; Atkinson et al. 2012). Estimating these values serves an important role in policy analysis, and is enshrined in the official requirements for regulatory analysis in several countries.[24] Placing values on these services helps to convey their importance, and the integral role they can play in various sectors of the economy. For instance, Gallai et al. (2009) suggest that insect pollinators contribute approximately ($US) 190 billion to the pollination of crops used for human consumption. However, significant challenges continue in this research, especially in the areas of ecological production functions and related complexities in quantifying changes in environmental outputs (Boyd & Banzhaf 2007; Ferraro & Hanauer 2011; Atkinson et al. 2012).

The analysis and valuation of ecosystem services has progressed significantly since the initial 2005 MA report. When monetising ecosystem service values, some economists such as Boyd and Banzhaf (2007), recommend classifying ecosystem services as either intermediate or final services to avoid double counting. Water quality, for example, is an intermediate service for the production of fish. However, the issue is nonetheless quite complex, as water quality is also a final service for recreators such as swimmers.

The concept of ecosystem services is being used in New Zealand to provide a consideration of the wider impacts of land management decisions.[25] Greenhalgh and Hart (2015), for example, detail several important lessons from recent New Zealand applications, and find that it holds considerable promise for future policy analysis and planning.

[24] See, for example, the US EPA's Guidelines for Preparing Economic Analysis: https://www.epa.gov/environmental-economics/guidelines-preparing-economic-analyses

[25] http://www.landcareresearch.co.nz/science/portfolios/enhancing-policy-effectiveness/best/integrating contains several recent examples of ecosystem service approaches in applied policy.

3.5 NZFARM Opportunity cost estimates for the Manawatū catchment

We use NZFARM[26] to estimate a range of the provisioning services (Table 13), in particular those related to agricultural or forestry land uses, for each of the three afforestation scenarios. The opportunity cost, by TA, for each of the scenarios is outlined in Table 14 (represented by the grey shading). As with the national analysis, the opportunity cost for each scenario is estimated as:

- **Scenario E**: the new afforestation areas convert from pasture production to exotic forestry, so the land remains in productive use. The opportunity cost is represented by the profit from the previous land use.
- **Scenario Ia**: the new afforestation areas convert to indigenous forest. The land is removed from production. The opportunity cost is composed of the profit from the previous land use plus the value of the converted land.
- **Scenario Ib**: the new afforestation areas convert to indigenous forest with those areas suitable for mānuka/kānuka being used for used for productive purposes. In this instance for medical or edible honey production. The opportunity cost is composed of the profit from the previous land use plus the value of the converted land. Due to the honey production, there is less land opportunity cost than Scenario Ia.

Table 14: Opportunity costs in the Manawatū catchment (2017 NZ dollars)

	Lost EBIT ($NZ) Scenario E opportunity cost	Value of converted land Scenario Ia	Value of converted land Scenario Ib	Lost EBIT + converted land value Scenario Ia Scenario Ia opportunity cost	Lost EBIT + converted land value Scenario Ib Scenario Ib opportunity cost
Central Hawke's Bay	59,213	223,062	164,913	282,274	224,126
Horowhenua	28,949	299,046	159,939	327,995	188,888
Manawatū	1,268,287	3,380,893	2,232,817	4,649,180	3,501,105
Masterton	0	5,638	2,891	5,638	2,891
Palmerston North City	43,166	367,483	195,845	410,649	239,011
Tararua	1,843,688	16,670,522	5,560,100	18,514,210	7,403,788
Total annual values	**3,243,303**	**20,946,644**	**8,316,505**	**24,189,946**	**11,559,808**
Total value over 50 years (using 8% discount rate)	**42,851,048**	**276,750,447**	**109,879,029**	**319,601,526**	**152,730,078**

Table 14 indicates that for Scenario E the opportunity cost for the catchment is approximately $3.2 million/year in lost EBIT. For Scenario Ia, the opportunity cost is approximately $24

[26] The version of NZFARM we use has the most up-to-date input data available. For instance, we are now using the most recent version (4.1) of the New Zealand Land Cover Database (LCDB).

million/year as the value of the converted land is included in the opportunity cost estimate. This assumes the new afforestation areas are purchased by the government and set aside for indigenous afforestation. Scenario Ib, has an opportunity cost of about $11.6 million as some of the new indigenous afforestation is being used for productive purposes, e.g. honey production.[27]

The last row of Table 14 contains estimates of opportunity cost projected over 50 years. This estimate assumes the same annual EBIT figures are earned for 50 years. Since we do not have any *a priori* assumptions or forecasts about trends in profitability, a constant flow of EBIT likely represents the best estimate of those values. The 50-year estimate uses an 8% discount rate, as suggested by the New Zealand Treasury for cost benefit analysis of this type. All figures are presented in 2017 NZ dollars.

Table 15 shows the change in EBIT by land use. The highest land uses occupying the new afforestation areas are dairy and sheep & beef.

Table 15: EBIT in afforestation areas, by previous land use

Land use	EBIT ($/yr)	Area (ha)
Arable	115	< 1
Dairy	1,550,303	804
Deer	365,178	367
Exotic forestry[a]	403,314	658
Fruit	110	0
Native forestry	0	4,303
Other	0	419
Other pasture	26,973	1,353
Sheep & beef	1,299,791	31,548
Vegetables	833	0

a: The exotic forestry is presented for illustrative purposes. The areas in already in exotic forest are assumed to remain in exotic forestry for all scenarios.

3.6 New revenue sources

The afforestation scenarios will result in several new streams of revenue, some of which we can quantify or monetise. In Scenario E, the new afforestation areas will be planted with exotic forestry, in this case *Pinus radiata*. Under similar assumptions about production discussed for the national assessment, we use NZFARM to model the increase in EBIT derived from to the additional exotic forestry areas. This increase in EBIT represents the monetised change in timber and wood ecosystem services. There are also several other ecosystem services that can either be quantified or described qualitatively. The new exotic forest area may directly or indirectly effect a number of cultural services. For example,

[27] Note again that these estimates represent an upper bound, since the profitability of the land is normally factored in its value, and hence the profit (as represented by lost EBIT) is probably not independent from the value of the land. In treating them as additive here, we assume that they are independent.

nearby recreational opportunities may increase such as birdwatching and hiking. Alternatively, aesthetic values (related to scenic views) may increase or decrease as some people prefer indigenous vegetation over exotic vegetation (Brown & Mortimer 2012). Moving from a pastoral land use to forested land may increase aesthetic values.[28]

3.6.1 Exotic forestry

The increase in exotic forestry in the Manawatū catchment in Scenario E is estimated to increase EBIT by more than $17 million/year (Table 16). The Tararua district is expected to experience the largest gain in EBIT from the new afforestation areas while Masterton gains the least.

The third column in the table shows the difference between a full conversion to exotic forestry and the previous earnings. The bottom row of Table 16 shows the total net present value across 50 years, using an 8% discount rate. All of the other figures in the table represent annual values.

There are some important caveats to these results. First, a large expansion in forestry would require a parallel expansion in the underlying local infrastructure, such as nearby mills, durable roads, and skilled workers.[29] Second, the likelihood of farmers converting pastoral land to exotic forestry is probably mixed. The large upfront costs and long lag time before the trees are harvested means that exotic forestry may not be considered a viable option for some farmers, particularly those more risk averse farmers. Risk-averse farmers tend to be the older and more experienced farmers – who are becoming the majority.[30] On the other hand, current and future carbon prices may send strong incentives for the conversion of marginal lands to exotic forestry. All our scenarios, however, assume that all land identified for new afforestation will be afforested.

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[28] See http://www.doc.govt.nz/Documents/conservation/human-values/evaluating-non-market-impacts-of-wilding-conifers-on-cultural-values.pdf for further discussion of cultural values and views.

[29] A recent New Zealand Herald article discussed future infrastructure problems with the current forestry rotation: http://www.nzherald.co.nz/business/news/article.cfm?c_id=3&objectid=11692463.

[30] See the results from the Survey of Rural Decision Makers http://www.landcareresearch.co.nz/science/portfolios/enhancing-policy-effectiveness/srdm2015/15-demographics-education-and-community/15-1-demographics

Table 16: Increases in exotic forestry EBIT for Scenario E

Territorial Authority	EBIT ($) from exotic afforestation	EBIT ($) from existing land use[a]	Difference
Central Hawke's Bay District	220,618	61,920	158,698
Horowhenua District	349,148	51,851	297,298
Manawatū District	3,142,778	1,324,465	1,818,313
Masterton District	6,043	0	6,043
Palmerston North City	363,589	69,693	293,896
Tararua District	17,072,045	2,138,689	14,933,356
Total annual EBIT	**21,154,221**	**3,646,617**	**17,507,604**
Total EBIT over 50 years (8% discount rate)	**279,493,023**	**46,858,483**	**231,313,325**

a: This EBIT differs from Table 14 as it also includes the EBIT from existing exotic forestry areas. For instance, the previous land use EBIT for Central Hawke's Bay is $61,920 here, as compared with $59,213 in Table 14, because of the $2,708 in existing forestry EBIT.

3.6.2 Honey production

In Scenario Ib, we assume that some of the new afforestation area will revert to mānuka/kānuka and be used for mānuka honey production. Mānuka honey falls under the wildfoods provisioning service as well as the biochemicals, natural medicines and pharmaceuticals provisioning service. Our analysis for the Manawatū catchment uses the mānuka prediction equations outlined in Section 2. Estimating honey revenue is difficult, as there is limited information on the profitability of honey production in New Zealand. There also appears to be significant variability in profits and honey quality.[31]

For our analysis, we use information gathered from trade associations and beekeepers by Daigneault et al. (2015) to estimate the EBIT from honey.[32] Based on that report, we developed three profitability types for honey production. The least profitable honey operation is a self-managed operation. The next most profitable operation involves hiring a beekeeper, which is marginally more profitable than a self-managed operation. The most profitable honey operation involves the use of a beekeeper and the production of high UMF honey, which is quite rare. There is unfortunately a dearth of information in the literature and from the trade associations about predicting UMF level on a particular landscape. Discussions with Apiculture New Zealand indicated that some of the central influences on UMF include: past history of production from a landscape, soil quality, rainfall, climate and altitude, and genotype.[33]

[31] For instance, the April 2017 issue of *New Zealand Beekeeper* highlights significant variation in honey yields over the past year, even on the same plot of land.

[32]The final report can be found at: http://www.maniapoto.iwi.nz/wp-content/uploads/2016/04/1.-Economic-Analysis.pdf

[33] There is a new MBIE programme "Building resilience and provenance into an authentic Māori honey industry" led by Landcare Research that is starting to address some of these challenges.

Since several of those factors are included in the Watt et al. (2012) prediction equations we use to identify land suitable for mānuka/kānuka, we have adapted them to predicting the potential of honey operations. Those equations produce probability scores for each area on the ability to support mānuka. As a fairly conservation assumption, we assume that only the 99th percentile of mānuka afforestation areas, in terms of rainfall and temperature probability, are suitable for high UMF production. The remaining area with mānuka is assumed to be split between the other two profitability types.

The estimated annual honey-related profit, by TA, is listed in Table 17, along with the discounted net present value of those profits over a 50-year period. This calculation assumes that the returns will remain constant over the 50 years.

Table 17: Increases in honey EBIT for Scenario Ib

Territorial Authority	EBIT ($)
Central Hawke's Bay District	23,580
Horowhenua District	186,853
Manawatū District	484,053
Masterton District	1,730
Palmerston North City	79,116
Tararua District	4,920,116
Total annual EBIT	**5,695,448**
Total over 50 years (8% discount rate)	**75,249,196**

3.7 Water quality valuation

Increased afforestation will affect several important regulating ecosystem services, such as water quality and water quantity. Water quality should improve as land is converted from agricultural uses to forested land. Afforesting land can reduce nutrient runoff, mitigate erosion, and prevent excess stormwater runoff. On the other hand, afforestation reduces water yield, meaning there may be less water available for irrigation and other activities (Ausseil et al. 2013). Due to data and time constraints for this analysis, we focus primarily on the changes in water quality. Additionally, the changes in water quantity produce uncertain changes in values. On one hand, it may be more expensive for farmers to irrigate their crops. However, that may only have an impact at certain levels of existing water which are hard to predict. On the other hand, recent literature indicates that citizens may have a positive willingness to pay for water going to forests instead of to agriculture (Baskaran et al. 2009).

To value the benefits of water quality improvements, we employ a benefit transfer approach. Benefit transfers use estimated non-market values from a study (or studies) to evaluate another area or policy (Freeman 2003). Benefit transfer is commonly employed when time or budget constraints prevent original analysis. Although there are a variety of water quality valuation in the US and Europe, the New Zealand literature is much thinner. There are several different types of benefit transfers, including unit transfers, function transfers, and meta-analysis function transfers (US EPA 2014).

We use a function transfer, which allows us to correct for the characteristics of the local population. Function transfers are generally recommended over unit transfers, as they allow for some correction between the population of the original study and that of the site the values are being transferred to (US EPA 2014). Unfortunately, there are not enough water quality valuation studies in New Zealand that use comparable measures of water quality, to construct a meta-analysis function transfer solely based on New Zealand studies.

In choosing water quality valuation studies for benefit transfer purposes, there are several central criteria. Most important, the studies must use water quality parameters that match the outputs of our policy simulations. From NZFARM, we have data on the projected reduction in nutrient loadings, so studies that value changes in nutrients are ideal. We are also looking for stated preference studies in order to capture more aspects of people's willingness to pay (WTP) for water quality improvements. It is also important that the study is done in New Zealand, ideally in an area similar to the Manawatū.

After reviewing a range of potential studies, we selected Baskaran et al. (2009) for our benefit transfer.[34] Baskaran et al. (2009) estimates the value of percentage reductions in nitrate leaching from agricultural activities, which is a good match to the outputs of NZFARM. Baskaran et al. (2009) ask respondents about their WTP for either a 10% or 30% reduction in nitrate leaching. Their econometric model estimates different WTP values at different income levels, which then allows us to tailor their results to the Manawatū area. We use TA median household income data from the 2013 New Zealand Census to derive incomes for the Manawatū catchment.

In their paper, Baskaran et al. (2009) present WTP values for 10% and 30% nitrate reductions at several different income levels. We harness the variation in their estimates to create linear and non-linear approximations of their WTP functions at different income levels to estimate the WTP for the NZFARM estimated changes in nutrient runoff. Our preferred results are the non-linear approximations, since they allow for diminishing WTP as the percent change in water quality decreases, and because they allow WTP to approach zero as the percent change approaches zero. Both the linear and non-linear approximations are shown in Figure 8, where the lighter lines represent the linear approximations and the darker lines are the corresponding non-linear approximations. They show the relationship between the percent change in nutrients and the estimated WTP.

[34] In addition to general internet searches, we used the New Zealand Non-Market Valuation Database (http://selfservice.lincoln.ac.nz/nonmarketvaluation/default.asp), the Environmental Valuation Reference Inventory (https://www.evri.ca/Global/Splash.aspx), and the University of Waikato working paper "Review of freshwater Non-Market Value Studies" (https://www.waikatoregion.govt.nz/assets/PageFiles/30275/2997672Review_of_Freshwater_Non-Market_Value_Studies.pdf).

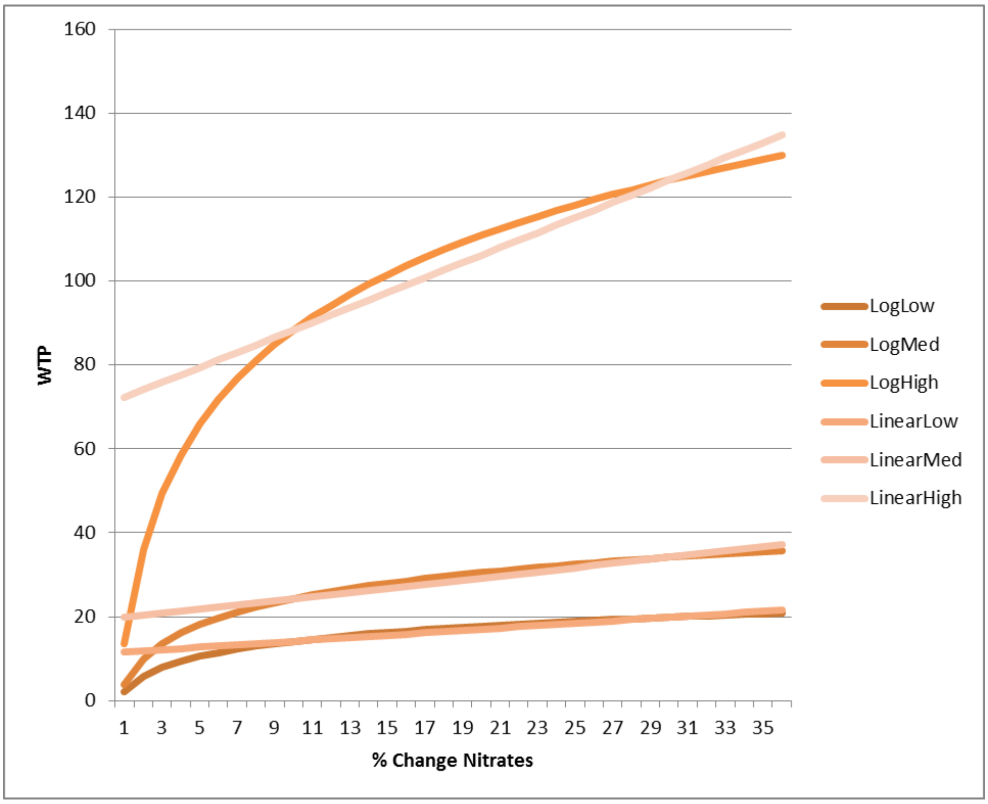

Figure 8: Baskaran WTP approximation functions.

We calculate the total WTP for water quality changes at the TA level, based on the water quality outputs of NZFARM. To estimate the water quality benefits across a 50 year timeframe, we also need an estimate of population growth for each TA. For this, we base our population growth estimates on the most recent Census. Table 18 contains the NZFARM results for predicted reduction in nitrogen (N) leaching. The first three columns show the total N leaching based on current land use and the two afforestation scenarios. The next two columns convert the change from baseline to each scenario into a percent. However, this percent assumes that all new afforestation areas have been afforested. To estimate the annual change, the total change is split into time increments, which depend upon the time a tree species takes to reach maturity. For this analysis, we assume it takes 30 years for exotic forest to reach full maturity, and 50 years for an indigenous forest to reach full maturity (Carver and Kerr, 2017). Based on those assumptions, the exotic areas see reductions in nitrogen leaching for the first 30 years, and none thereafter, which is why the Scenario E annual reductions in the last two columns are larger than the Scenario I reductions – they are spread over a shorter time period.[35]

[35] It is also likely that there is a pulse of nutrients during and shortly after harvesting, followed by some additional reductions. Modelling that change is outside of the scope of this work, so for simplicity we assume that it is zero leaching after the first harvesting

Table 18: Predicted changes in nutrients

	N Leaching (kg)			Estimated % Change		Annual % Change	
Territorial Authority	Current	Scen. E	Scen. I	Scen. E	Scen. I	Scen. E	Scen. I
Central Hawke's Bay	5,251	789	473	0.850	0.910	0.028	0.018
Horowhenua	5,929	1,390	834	0.766	0.859	0.026	0.017
Manawatū	69,776	12,479	7,488	0.821	0.893	0.027	0.018
Masterton	128	40	24	0.686	0.812	0.023	0.016
Palmerston North City	6,516	1,507	904	0.769	0.861	0.026	0.017
Tararua	370,242	62,701	37,621	0.831	0.898	0.028	0.018

We apply the benefits transfer function to the water quality change in each TA[36] in each year to calculate annual WTP. The WTP figures were then applied at the household level, which is the unit of analysis in the Baskaran et al. (2009) study. The 2013 Census population growth figures are used to extrapolate population out 50 years to calculate the full path of benefits (Table 19). Finally, the net present value of the benefits stream is calculated using two alternate discount rates. The first discount rate, 8%, is the recommended rate by the NZ Treasury. The second discount rate, 3%, is a common rate recommended in the general valuation literature to discount social welfare benefits (US EPA 2014). The alternate discount rate is used because the 8% figure is more representative of capital expenditures, and likely does not represent social discounting of WTP (US EPA 2014). At both discount rates, Scenario E has a higher WTP than Scenario I (Table 19).

Table 19: Total WTP for water quality benefits in the Manawatū catchment over 50 years (NZ$a)

	Scenario E 3%	Scenario E 8%	Scenario I 3%	Scenario I 8%
Central Hawke's Bay District	1,413,481	799,167	1,335,079	611,987
Horowhenua District	1,916,060	1,076,445	1,864,398	841,829
Manawatū District	3,061,206	1,697,848	3,032,572	1,327,608
Masterton District	2,364,891	1,320,119	2,391,795	1,063,530
Palmerston North City	7,716,217	4,348,821	7,454,413	3,391,467
Tararua District	1,749,103	1,001,482	1,614,293	762,041
Total WTP over 50 years	**18,220,958**	**10,243,883**	**17,692,549**	**7,998,462**

a: values are in 2017 New Zealand dollars

In terms of water quantity, the expected change in value is uncertain. On one hand, it may be more expensive for farmers to irrigate their crops, given there is likely less water available for irrigation. However, this may only be an issue at river low flow times. Without detailed hydrological modelling, the availability of water and when water restrictions may occur are difficult to predict. On the other hand, recent literature indicates that citizens may have a positive WTP for water going to forests instead of agriculture (Baskaran et al. 2009). The value of the water quantity reductions is therefore uncertain.

[36] This estimate uses 2013 Census data for income (inflated to 2017 dollars).

3.8 Carbon benefits

Using NZFARM, we estimate changes in net GHGs (avoided GHG emissions plus carbon sequestered) with each afforestation scenario. Scenario E has lower net GHG emissions than Scenario I (Table 20). For instance, in Central Hawke's Bay District there are approximately 960 tonnes CO_2e emitted under the existing land use. However, when Scenario E is fully implemented and the trees are mature, that district is a carbon sink of almost 5,000 tonnes. Under Scenario I, the district is only a 1,000 tonnes carbon sink

Table 20: Change in net GHGs in the Manawatū catchment

TA	Existing land use emissions (tonnes CO_2e)	Scenario E Sequestered (tonnes CO_2e)	Scenario I Sequestered (tonnes CO_2e)	Scenario E Total Change (tonnes CO_2e)[a]	Scenario I Total Change (tonnes CO_2e)[a]
Central Hawke's Bay District	960	–4,857	–237	5,817	1,197
Horowhenua District	586	–-8,226	–417	8,811	1,002
Manawatū District	11,614	–69,122	–3,744	80,735	15,357
Masterton District	16	–244	–12	260	28
Palmerston North City	597	–9,836	–452	10,433	1,049
Tararua District	62,945	–392,951	–18,810	455,895	81,755
TOTAL	**76,718**	**–485,236**	**-23,672**	**561,951**	**100,388**

a: a positive number means carbon is being sequestered.

The GHG figures presented in Table 20represent the steady state levels of GHG emissions. To estimate the benefits over 50 years, we need to know the emissions transition path rather than the steady state levels. In the absence of forest modelling to forecast the time paths for the afforestation scenarios (which are beyond the scope of this analysis) we use the 2015 New Zealand Ministry for Primary Industries ETS lookup tables[37] to estimate the growth of various tree species, including *Pinus radiata* and indigenous species. The lookup tables provide carbon sequestration rates for different regions of New Zealand.

For our calculations we assume that the exotic forest (Scenario E) is a harvest in year 30, while the indigenous forest (Scenario I) keeps growing over the 50-year time period. The lookup tables allow us to control for the size of the harvest, as well as carbon remaining after the harvest in stumps and the soil, which diminishes over time. We incorporate both effects in our estimates. The valuation assumes that credits generated are sold in the same year, and that credits have been purchased to cover any harvest-related GHG emissions.[38] Note that an estimate based solely on the ETS lookup tables is likely an underestimate, since it only values

[37] https://www.mpi.govt.nz/document-vault/4762

[38] Although common in the literature, these assumptions can affect the economic viability of these of these options, depending on whether the carbon price is expected to increase or decrease.

the carbon sequestered as a result of the new land use. The reductions in emissions from the previous agricultural land use are not included in these calculations.[39]

Similar to the national case, we use the NZETS price at discount rates of 3% and 8% and SCC at 3%. A constant NZETS price is a strong assumption, particularly if new sectors are covered by the NZETS in the future which changes market conditions. Additionally, future international agreements, and New Zealand's integration into them, could significantly affect the market price. A recent report by the Parliamentary Commission for the Environment projects that 2030 carbon prices could be as high as $150 per tonne CO_2e, with a low estimate of $20 per tonne CO_2e.[40] The US EPA SCC 3% is used to account for potentially higher future carbon prices. Exploring SCC values across time is somewhat more complicated than the annual values presented in the national analysis, since the social cost of CO_2e is both dollar year and emissions year dependent. We only use the 3% estimate here for comparison to the NZETS 3% estimate. There is a wide international literature recommending lower values for social welfare, particularly those related to environmental benefits (Pearce 2003; Guo et al. 2006; David et al. 2009). Given the PCE forecasts and the higher US EPA SCC values, our estimates are likely conservative and may therefore be underestimates of the true value of carbon for each of the afforestation scenarios.

The monetised benefits of carbon sequestration, by TA, for Scenario E are outlined in Table 21. All estimates in the table represent the net present value across 50 years. Depending on the price assumption, benefits range from approximately $105 million to almost $700 million for the Manawatū catchment.

Table 21: Carbon benefits for Scenario E over 50 years

	NZETS 3%	NZETS 8%	SCC 3%
Central Hawke's Bay District	1,732,879	1,046,857	7,071,811
Horowhenua District	3,052,358	1,843,973	12,291,778
Manawatū District	27,410,838	16,559,281	110,382,821
Masterton District	88,109	53,228	354,811
Palmerston North City	3,310,675	2,000,027	13,332,014
Tararua District	137,724,026	83,201,060	554,611,514
Total	**173,318,885**	**104,704,425**	**698,044,750**

Estimates are presented in 2017 dollars (NZ)

The benefits for Scenario Ia and Ib are outlined in (Table 22) and produce slightly lower carbon monetised benefits than Scenario E. For example, the NZETS 3% price is estimated to generate $118 million in carbon benefits in Scenario I as opposed to $173 million in Scenario E. Although the average tree density – and hence sequestered carbon – of exotic forests is more than indigenous forests, they are periodically harvested.

[39] To more accurately model the impact of a particular policy, such as the PFSI, would require a more detailed analysis. For instance, areas of forest over 100 ha would require a field measurement approach, which might differ from the lookup tables.

[40] http://www.pce.parliament.nz/media/1292/covec-final-report-19-07-10.pdf

Table 22: Carbon benefits for Scenarios Ia and Ib over 50 years

	NZETS 3%	NZETS 8%	SCC 3%
Central Hawke's Bay District	1,182,273	521,915	5,367,236
Horowhenua District	2,082,500	919,321	9,393,804
Manawatū District	18,701,300	8,255,702	84,358,394
Masterton District	60,113	26,537	271,159
Palmerston North City	2,258,739	997,122	10,188,790
Tararua District	93,963,502	41,480,252	423,853,425
Total	**118,248,428**	**52,200,848**	**533,432,808**

Estimates are presented in 2017 dollars (NZ)

3.9 Biodiversity-related benefits

To estimate changes in biodiversity, we employ a measure of 'ecological integrity.' This measure was originally defines by Lee et al. (2005) as ''the full potential of indigenous biotic and abiotic factors, and natural processes, functioning in sustainable communities, habitats, and landscapes" Carswell et al. (2015). Indicators of ecological integrity are now widely employed, and the New Zealand Department of Conservation uses ecological integrity as their primary biodiversity goal. Our measure of ecological integrity is based on catchment-scale natural regeneration of indigenous forests on agricultural lands, and has been used in several recent papers (Mason et al. 2012; Carswell et al. 2015; Mason et al. 2016). The measure is called the "restored significance," and it is a measure of the potential gain in environmental representation through natural regeneration. Larger restored significance values indicate that there is a larger potential increase in biodiversity from converting a particular plot of land to indigenous forest. The units of this indicator are parts per billion (ppb), where one billion represents the ideal ecological utopia of natural (prehumen) conditions (Carswell et al. 2015).

The distribution of restored significance (hereafter referred to as "SRS") throughout the Manawatū catchment is shown in Figure 9**.** The darker the blue indicates a higher SRS score, indicating that more biodiversity could be gained from allowing those areas to revert to indigenous forest. Similarly, the lighter blue areas indicate there is less to gain from allowing an area to revert to indigenous forest. The two large lighter areas in the map are areas that are already heavily forested and surrounded by other forested land, and hence have little to "gain" by being "converted."

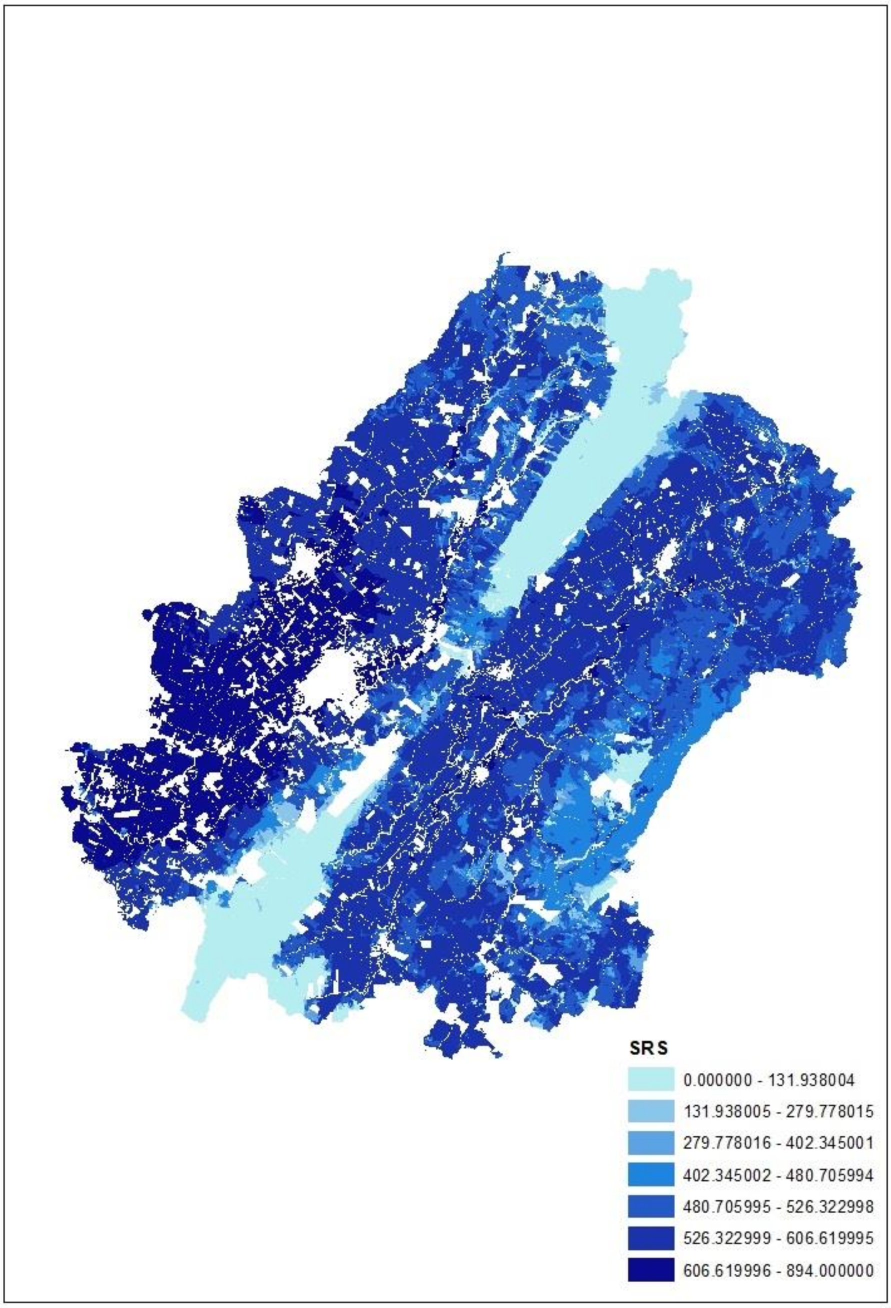

Figure 9: SRS in the Manawatū.

To gauge the potential biodiversity benefits from indigenous afforestation, we overlay the new afforestation areas with the SRS ecological integrity data. Table 23 contains several descriptive statistics on the new afforestation area. Table 23 applies specifically to indigenous afforestation, and hence represents the potential ecological benefits for Scenario I. Note that the SRS score is based on several detailed local criteria and assessed at the hectare scale. That detailed focus helps explain the average SRS scores for the areas previously classified as native and forest, which at first glance seem counter-intuitive. Average SRS for indigenous forest areas, for example, is higher than sheep & beef areas. As suggested by Figure 9, most of the new afforestation areas are on marginal lands that could see significant benefit from conversion to indigenous forest. These estimates also represent the maximum potential biodiversity once the area has been fully restored. These SRS calculations require two important caveats. First, although our SRS estimates are based on very spatially explicit underlying data, the actual realized biodiversity may differ from the predicted estimate. We therefore present multiple descriptive statistics to better gauge the distribution of potential benefits. In addition, the SRS estimates represent the full benefits once the plot of land is fully regenerated. According to the underlying studies the derivation of SRS is based on, regeneration is likely to take 40–50 years. Therefore, the SRS is approximating the biodiversity potential at the end of that time period.

Table 23: SRS in afforestation areas by existing land use, for Scenario I

Enterprise Class	Minimum SRS	25th Percentile SRS	Mean SRS	Max SRS	Std Dev. SRS
Scrub	0.0	426.901	455.3	647.9	99.8
Deer	114.9	398.513	455.7	633.7	113.3
Native	0.0	436.056	465.0	715.0	122.3
SNB	0.0	451.316	468.8	740.6	104.2
Other	0.0	473.2595	485.1	750.8	106.1
Forest	0.0	479.3905	497.3	655.0	88.2
Dairy	0.0	483.875	497.6	655.0	99.3
Other pasture	0.0	485.231	506.7	655.0	69.8

The estimates for Table 23 use an SRS value that was developed for indigenous afforestation. Biodiversity for Scenario E will differ from Scenario I due to differences in forest type. Scenario E will have much less plant diversity, which will support less diversity of other species. Another fundamental difference in exotic forestry is the periodic harvesting where land will be harvested shortly after reaching peak potential biodiversity potential. Harvesting is likely to damage biodiversity significantly. We, therefore, update the SRS estimate for exotic forest based on several studies that compare biodiversity under native and exotic forests, including Pawson et al. (2008) and Deonchat et al. (2009). The updated SRS values for Scenario E are outlined in Table 24.

Table 24: SRS in Afforestation areas by existing land use, for Scenario E

Enterprise Class	Minimum SRS	25th Percentile SRS	Mean SRS	Max SRS	Std Dev. SRS
Scrub	0.0	192.1055	204.9	291.6	44.9
Deer	51.7	179.3309	205.1	285.1	51.0
Native	0.0	196.2252	209.3	321.8	55.0
SNB	0.0	203.0922	211.0	333.3	46.9
Other	0.0	214.2	218.3	337.9	47.7
Forest	0.0	212.9668	223.8	294.8	39.7
Dairy	0.0	215.7257	223.9	294.8	44.7
Other pasture	0.0	217.7437	228.0	294.8	31.4

Assuming that the exotic forests will be harvested roughly twice in a 50 year period, the level of biodiversity presented in Table 24 are only likely to be achieved twice in this period. Therefore, the average annual biodiversity benefits will therefore be much lower.

4 Summary of benefits and costs in the Manawatū Catchment

When assessing the benefits and costs of the three afforestation scenarios for the Manawatū catchment it is important to consider those that can be monetised, those that can be quantified and those that can only be qualitatively described.

The previous sections outline a number of impacts related to the afforestation scenarios that can be quantified and/or monetised impacts. While it is possible to quantify and/or monetise other impacts, the budgetary and time constraints for this project mean that no additional primary data or ecosystem modelling could be undertaken. In terms of benefits and costs, the benefits are often more challenging to quantify. For instance, aesthetic values are difficult to quantify, and aesthetic preferences can vary significantly across the population and across time. To estimate those benefits properly, a stated preference survey would be ideal (Freeman 2003). Similarly, more advanced ecosystem modelling would be needed to quantify the indirect impacts of changes in biodiversity.

In the absence of additional data collection and ecosystem modelling we use an ecosystem services framework to describe the broader range of impacts and the subsequent benefits and costs of the afforestation scenarios. Table 25 presents a summary of ecosystem service impacts, including effects that can be quantified or monetised as well as a short narrative on the potential impacts. The narratives in the table, in particular for those ecosystem service impacts that are qualitatively described, are not comprehensive. The table does, however, draw on expected ecosystem service relationships and insights gained from other situations which are likely transferable to this context.

Table 25: Summary of ecosystem service impacts

Category	Ecosystem Service	Effect of Afforestation Scenario	Quantified	Monetized	Methods/ Notes
Provisioning	Crops	Reduced production	X	X	NZFARM was used to examine agricultural impacts
	Livestock: milk	Reduced production	X	X	NZFARM was used to examine agricultural impacts
	Livestock: meat	Reduced production	X	X	NZFARM was used to examine agricultural impacts
	Capture fisheries	Likely improvement			Fish habitat is expected to improve as water quality improves and with additional stream shading expected with the afforestation scenarios. Decreased stream flows associated with afforestation, however, may have some negative impacts on fish habitat. Improved fish habitat is likely to enhance commercial fishery harvest for freshwater species such as eel or recreational trout catch. To estimate the full effects would require hydrological and fish modelling which is beyond the scope of this project. Any impacts on the ocean fishery are unknown.
	Freshwater	Improvement in quality/decrease in quantity			Water quality is expected to improve due to decreases in nutrient inputs and other forms of farm runoff associated with pasture land, and thereby improving drinking and stock water quality. In addition, freshwater contact recreation should be improved, yielding human health impacts. Water yield, however, is expected to decrease with greater areas of forested land. This may affect irrigation in the area. Hydrological modelling is required to determine the spatial and temporal impacts on water flows.
	Wildfoods	Likely increase			Wildfood harvests should increase, particularly in indigenous afforestation scenarios (Scenario I). Trout and eel habitat should improve with better water quality leading to greater fish abundance and catch. Honey will increase particularly in Scenario Ib).
	Timber & wood	Increase in Scenario E	X	X	NZFARM was used to examine forestry impacts.
	Fibres & resins	Potential Increase			Afforestation may yield products in addition to timber.
	Biomass fuel	Potential increase			Forestry by-products could be used for biomass fuel.
	Ornamental resources	Potential increase			With indigenous forest (Scenario I) we expect greater availability of ornamental resources such as flax.
	Biochemical, natural medicines and pharmaceuticals	Potential increase			High-grade mānuka honey, among other products, has several medical applications. Mānuka is one of the first successional species that is anticipated after reversion from pastoral farming to indigenous vegetation. Rongoā is also likely to increase in Scenario I.
Regulating	Air quality and climate regulation	Improvement	X	X	NZFARM outputs and ETS materials are used to quantify and value changes in carbon, in particular the carbon sequestration potential of forests. Forests also improve air quality in terms of reduced particulates. Pine pollen, however, could be an issue in some areas.

Category	Ecosystem Service	Effect of Afforestation Scenario	Quantified	Monetized	Methods/ Notes
	Water regulation	Mixed			The afforestation scenarios will likely decrease water yield in the area as runoff from erosion-prone and pastoral areas is reduced. Alternatively, improvements in water quality will reduce water treatment costs for drinking and agriculture water.
	Erosion control	Improvement			Afforestation will improve erosion control.
	Water quality or purification	Improvement	X	X	NZFARM nutrient outputs are used for a benefit transfer of stated preference WTP values to monetise the value of improved water quality.
	Pollination	Potential improvement			We expect an increase in native pollinators with indigenous forest (Scenario I); the extent, however, will depend on the availability of floral resources. There is also an increase in honey production (from honey bees) under Scenario I that will likely have additional indirect pollination benefits.
	Natural hazard regulation	Improvement			A reduction in water yield should reduce stormwater impacts, such as stream scouring, and potentially reduce peak flooding flows
Cultural	Recreation and Ecotourism	May increase			Increased afforestation may induce greater local recreation, particularly in areas with greater public accessibility. This could be hiking, biking or similar recreation. Improvements in water quality should improve the swimability of streams and also improve the recreational experience and the health of the recreational fishery (e.g. trout). There is some evidence of aesthetic preferences for indigenous species over exotic species (Brown et al. 2012), which may mean greater recreation and ecotourism services are provided by indigenous forest (Scenario I).
	Ethical and spiritual	Expected improvement			With indigenous forest (Scenario I) there is an expected increase in the spiritual values associated with the landscape, especially when native species increase (e.g. taonga species).
	Aesthetic values	Expected improvement			Views will be changed, particularly when afforested areas are elevated. The local value of changing viewscapes depends on the local population and the particular scenario. In a farmer workshop on ecosystem services in the Manawatū in 2015, the farming community noted the importance of the aesthetic value of their catchment and how these attracted international visitors.
	Cultural heritage values	Expected improvement			Indigenous afforestation scenarios (Scenario I) may promote the return of indigenous species with particular cultural values. Water quality improvements in culturally important waterbodies should provide additional benefits.

Category	Ecosystem Service	Effect of Afforestation Scenario	Quantified	Monetized	Methods/ Notes
	Social relations	Mixed			There is likely to be a change in the rural population with afforestation. With less farm labour required there is likely to be an initial reduction of people in the catchment. However, over time different people are expected to move into the area, but with different employment preferences. Anecdotally, this is what happened in the Taupō catchment when a portion of the land was afforested leading to an initial decrease in social relations/cohesion followed by an increase when new people moved into the catchment (Mike Barton, Farmer Lake Taupō, March 2016).
	Sense of place	Mixed			The 'look' of the catchment will change with a move from pastoral land to forested land in the marginal areas. Therefore, the sense of place may be altered (and potentially reduced), especially for those who grew up surrounded by pastoral land. However, older generations may feel a greater sense of place with a reversion to forest.
	Cultural diversity	Unclear			The expected initial reduction in the rural population is likely to decrease cultural diversity. However, as noted above this will likely change over time as new people are expected to move into the catchment.
Supporting	Habitat Provision	Increase	X		The habitat for native species is expected to increase, particularly in the indigenous scenario (Scenario Ia and Ib).

A summary of the monetized benefits and costs for the Manawatū catchment for the three afforestation scenarios are provided in Table 26. All figures are in 2017 dollars, and use a discount rate of 8%.[41] There are a variety of issues (not presented here) involving the magnitude of the discount rate.[42]

Scenario I has the highest discounted net present value of the opportunity cost at approximately $317 million, whereas Scenario E has the lowest opportunity cost at $43 million. Each of the scenarios faces same loss of EBIT ($43 million) associated with the existing land use before afforestation. The opportunity cost for Scenarios Ia and Ib, however, also includes the additional converted value of land as well. This value reflects the policy context we used for this analysis which involved the government purchasing the land from the current owner. Other policy context, e.g. using covenant, may not include the converted value of land as part of the opportunity cost.

In terms of discounted benefits, Scenario E yields the largest monetized benefits, at approximately $400 million, which includes increased profit from exotic forestry, water quality benefits, and carbon-related benefits. Scenarios Ia and Ib have lower carbon and water quality benefits, as well as production-related revenue (which is zero for Scenario Ia). These differences in benefits between scenarios are important, as they each come with their own caveats. Future policy, climate change, and farmer preferences can significantly affect the benefits realised by each scenario in different ways.

The overall NPV and the benefit-cost ratio show all scenarios as having a positive benefit-cost ratio. However, Scenario Ia has a negative NPV of $190 million, while Scenarios E and Ib have a positive NPV. The negative NPV for Scenario Ia is largely driven by the opportunity cost of the converted value of land. As noted above, this portion of the opportunity cost is related to the policy context we used in this analysis. Therefore, these results should be viewed as the upper-bound of estimates.

In a different policy context that does not involve land sales, the opportunity costs are lower and only reflect on the loss of EBIT from the existing land uses. Where only lost EBIT is included in the opportunity cost, both the NPV and benefit-cost ratio increase for Scenarios Ia and Ib, but are unchanged for Scenario E. Overall, Scenario E has the highest NPV and benefit-cost ratio.

Although Scenario E has the highest monetised net benefits, there are many other benefits that were not monetised. For instance, biodiversity benefits were found to be considerably higher for indigenous forest, although they were not assigned dollar values. Cultural, recreation, aesthetic, and human health impacts were also not monetised or quantified. The preferable afforestation scenario therefore depends on the preferences and constraints of the policy makers. Overall, we find that both exotic and indigenous permanent forest have the

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[41] The traditional default discount rate recommended recommended by Treasury was 8%: http://www.treasury.govt.nz/publications/guidance/planning/costbenefitanalysis/discountrates/discount-rates-jul08.pdf. Note, however, that recent (2016) guidance has suggested alternate discount rates http://www.treasury.govt.nz/publications/guidance/planning/costbenefitanalysis/currentdiscountrates. A full comparison of these rates is outside the scope of this analysis. By using 3 and 8 percent in most sections, we should capture a wide range of sensitivity.

[42] For instance, higher discount rates may penalize “lumpy” effects that occur in the future, as opposed to up-front costs.

potential to produce significant benefits. With flexible policy that provides balanced incentives to producers, both types of forest can achieve multiple regional and national goals.

Table 26: Monetized benefits and costs across 50 years (8% discount rate)

	Scenario E	Scenario Ia	Scenario Ib
Opportunity Costs			
Lost EBIT	42,851,048	42,851,048	42,851,048
Converted value of land		276,750,447	109,879,029
Total opportunity cost	42,851,048	316,660,879	152,730,078
Increases in EBIT			
Forestry	279,493,023		
Honey			75,249,196
Ecological Benefits			
Water quality	10,243,883	7,998,462	7,998,462
Carbon Benefits			
Carbon valuation (Current NZ ETS price)	104,704,425	118,248,428	118,248,428
Total monetized benefits	394,441,331	126,246,890	201,496,086
Overall NPV	351,590,283	-190,413,989	48,766,008
Benefit-cost ratio	9.2	0.40	1.3
Sensitivity Analysis			
Overall NPV – Lost EBIT only	351,590,283	83,395,842	158,645,038
Benefit-cost ratio – Lost EBIT only	9.2	3.0	3.7

4.1 Assumptions and uncertainties

Although we have attempted to be comprehensive within the time and budget constraints of the project, this analysis does not include all benefits and costs associated with the afforestation scenarios. It is important to acknowledge these limitations, as well as some uncertainties with the analysis.

Issue	Impact on estimate	Notes
Discount rates used are relatively high	Underestimate benefits and costs, at different rates	The choice of discount rate can affect constant values across time (i.e., a constant annual cost) differently than "lumpy" values. Future analysis might explore these differences in additional sensitivity analysis.
Use most conservative afforestation scenario from Watt et al. (2011)	Underestimate the total potential land for afforestation	The area of land afforested could be higher, depending on the Watt et al. (2011) scenario chosen or incentivised.
Assume value of land and lost EBIT are additive	Overestimate opportunity costs	This addition may be double counting some opportunity costs, so represents an upper bound.
Not all impacts on ecosystem services (or costs) are quantified or monetised	Underestimate benefits	It was only possible to quantify or monetise a portion of the changes in ecosystem services in this analysis. A qualitative description was provided of likely relationships and impacts.
Carbon valued using NZ ETS	Underestimate of full welfare impacts of carbon	We use a fairly conservative value for a tonne of carbon, based on current rates. Several sources in the literature indicate that the actual welfare-based value is larger, and other sources indicate that the ETS price may increase significantly in the coming years.
Climate change assumptions	Uncertain	Several of the models are based on current and historical information, which may not reflect future climate change. For instance, predictions of tree growth from the ETS lookup tables might be affected by different climate change scenarios.
Population and income growth assumptions	Uncertain	For our analysis of water quality, we assume a constant population growth rate based on current projections, as well as current income levels. Since the WTP depends on population and income, and those variables may change across time, it can affect the estimated value of water quality.

Limitations

Several important limitations with current data and models were encountered in the course of this analysis. These limitations illustrate where additional analysis could be undertaken in the future. These include:

- Better forecasts of carbon prices and values across time.
- The incorporation of the benefits and costs of erosion were not feasible within time and budget constraints. Some issues encountered were due to differences in land use and land cover databases within New Zealand. Many erosion databases are based on current land cover, whereas this report is focused on land use. These issues were further complicated by erosion projections for hill country areas. Spatially explicit predictions and modeling in those areas were limited.
- The literature on the value of water quality improvements in New Zealand is somewhat thin. Our benefit function transfer was done on only one study. Although international sources might be used in the future, there are concerns with the transferability of benefits

estimates to New Zealand. There are also only limited sources for the cultural values around water quality.
- Only a small subset of ecosystem services was able to be monetised with the data, time, and resources available for this report. Additional analysis related to those ecosystem services would be beneficial. This may involve the collection of primary data as well as ecosystem modelling.

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