

Trade-offs between indigenous forest and exotic production forest in New Zealand

Patrick J. Walsh¹ , Tarek Soliman² and Adam Daigneault³

¹US EPA, National Center for Environmental Economics, Washington, DC, USA, ²Scotland's Rural College, Edinburgh, Scotland and ³University of Maine, School of Forest Resources, Orono, ME, USA

Corresponding author: Patrick J. Walsh; Email: walsh.patrick.j@epa.gov

(Received 30 July 2022; revised 4 January 2023; accepted 15 March 2023; first published online 30 June 2023)

Abstract

With its varied landscape of hills and mountains, New Zealand has an abundance of marginal land on its slopes. This land is currently used in a variety of enterprises, such as pasture and farmland. However, marginal land is typically associated with higher rates of erosion, shallow topsoil, expensive fencing, and other issues like livestock deaths from falls. There is currently interest in deploying these marginal lands to different uses to align with several environmental and production-related goals. This paper contributes to the discussion on marginal land by exploring three different scenarios related to afforestation in the Manawatu catchment area. To analyze these scenarios, we bring together several complex and spatially explicit data sets which are linked using economic modeling tools and benefits transfer methods. The combination of these tools and data sets allows us to produce several important quantitative and qualitative outputs. Where possible, quantitative predictions are monetized, allowing a benefit-cost analysis of the proposed scenarios.

Keywords: ecosystem services; land use modeling; economic analysis; nonmarket valuation

1. Introduction

With its varied landscape of hills and mountains, New Zealand has an abundance of marginal land, which tends to have significant physical limitations like steep slopes and low ability to support productive uses (Lynn et al. 2009). This land is currently used in a variety of enterprises, such as pasture and farmland; but it is also associated with higher rates of erosion, shallow topsoil, expensive fencing, and environmental externalities (Lambie et al. 2021; Tran et al. 2022). There is currently interest in deploying these marginal lands to different uses to align with several environmental and production-related goals.¹ The government aims to reduce emissions and expand agricultural and primary industry production, which will involve important trade-offs. For instance, several

¹For instance, New Zealand's updated (2022) emissions reduction plan can be found at: <https://environment.govt.nz/publications/aotearoa-new-zealands-first-emissions-reduction-plan/>

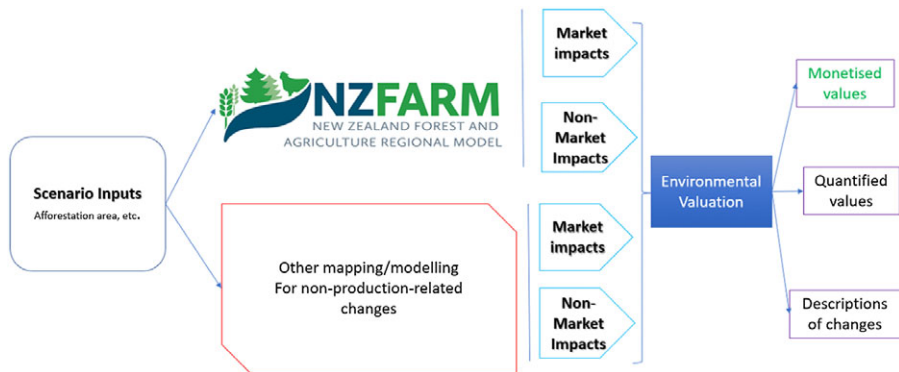


Figure 1. Manawatu catchment afforestation study framework.

local sources have had success with exotic forestry and Manuka production, which provide important ecosystem services. Both exotic plantation forestry operations and indigenous afforestation represent carbon sinks, with several important trade-offs in marginal costs, production revenue, and complementary ecosystem services.

This paper contributes to the discussion on marginal land by exploring several of the central costs and benefits of different land options. To illustrate these impacts, we use several data sets from an area of the Manawatu–Whanganui Region, at the bottom of the North Island. The area has historically had forestry and pasture as primary sources of employment, and contains large areas classified as hill country. The area therefore faces several notable environmental issues, such as erosion and nutrient runoff from farming.

Economic and environmental modeling are combined with environmental valuation to analyze three different scenarios related to afforestation in the Manawatu area. The combination of these tools and data sets allows us to produce several important quantitative and qualitative outputs. Where possible, quantitative predictions are monetized, allowing a benefit-cost analysis of the proposed scenarios. One scenario replaces all existing marginal land with exotic (*Pinus Radiata*) forestry. The second uses indigenous forestry instead, allowing honey production on some of the land.

We model several important outcomes related to each of these two scenarios, including several ecosystem services associated with afforestation, as well as opportunity costs associated with land conversion. After using several spatial resources and models to identify potential marginal land for our afforestation scenarios, we use benefit transfer to assign nonmarket values where possible. Overall, we find that our two scenarios have net benefits. This is important to qualify, however, since there are several important benefit categories, such as cultural services, which were not monetized in this analysis.

2. Methods

This paper uses a mix of economic modeling, market, and nonmarket impact assessment, and environmental valuation to quantify the potential effects of two afforestation scenarios in the Manawatu catchment, New Zealand. An overview of the study framework is presented in Figure 1. More details on each component are provided below.

2.1 Study site and marginal lands

Due to the prevalence of marginal lands in New Zealand, there have been concerns about its use for many years. A symposium by the Royal Society of New Zealand in 1951 on Forestry and Marginal lands gave the following definition “those lands which over a long period of years would yield sufficient production to constitute an economic gain to the nation if developed, but from which the return over a short period would not be sufficient to enable the ordinary individual farmer to carry out the development.”² Meanwhile, the current OECD definition is: “land of poor quality with regard to agricultural use, and unsuitable for housing and other uses.”³

The Manawatū catchment is located in the Manawatū-Wanganui Region in the North Island (Figure 2). 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 Taranaki.

2.2 Afforestation potential

We drew heavily from maps produced by Watt et al. (2011) to identify areas of marginal land most suitable for afforestation. This earlier work identified three potential options for afforestation, depending on assumptions about land suitability which was based on land use capability classes.⁴ For all our analysis, we use the first scenario of Watt et al. (2011), which represents the most conservative assumptions on areas suitable for afforestation – and has the 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 GIS data sets 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.⁵ Note that we omit all conservation and reserve land from the analysis, as it is highly unlikely that those lands would be converted.

2.2.1 Natural afforestation

We also explored the potential of these lands for natural afforestation. In some areas of New Zealand, active afforestation is required for indigenous forest. The probability of natural reversion depends on landscape and location-based factors. We use models from Mason et al. (2012) to identify areas of active afforestation. Mason et al. (2012) selected 10,061 plot surveys from New Zealand’s National Vegetation Survey Databank conducted between 1982 and 2008 and analyzed them to identify central environmental and land

²http://www.nzjf.org.nz/free_issues/NZJF06_3_1951/FFB8C0CB-B25A-4780-97B1-1C449389AC93.pdf, page 244.

³<https://stats.oecd.org/glossary/detail.asp?ID=1591>

⁴For more information on LUCs, see <https://soils.landcareresearch.co.nz/tools/nzlri-soil/nzlri-development/>. A GIS map of LUCs can be found here: <https://iris.scinfo.org.nz/layer/76-nzlri-land-use-capability/>.

⁵The most recent version of the NZ LCDB, which was released across 2012/2013, can be found at: <https://iris.scinfo.org.nz/layer/423-lcdb-v41-land-cover-database-version-41-mainland-new-zealand/>.

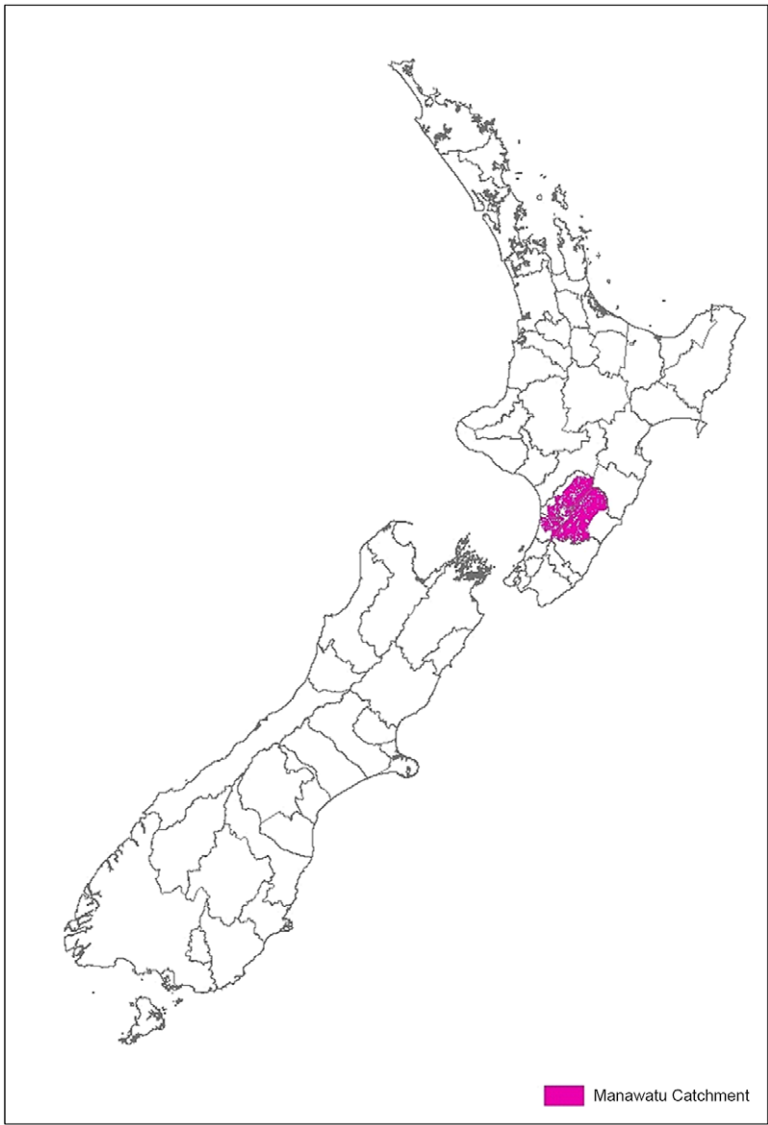


Figure 2. Manawatu catchment, North Island, New Zealand.

cover influences that affect the occurrence probability of indigenous vegetation. LCDB also played a central role in this effort, in addition to a range of environmental and land cover GIS data sets. Mason *et al.* (2012) 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. Following this, we estimate that the Manawatu is quite suitable for indigenous afforestation, with only a few hectares in the southwest of the region needing active afforestation (less than 4 ha of identified afforestation areas were

identified as needing active planting, so for our purposes this was assumed to be effectively zero).

2.2.2 Mānuka and Kānuka suitability

Honey production has received significant attention in New Zealand due to the recent expansion of Mānuka honey products. In addition to its use as a luxury sweetener, Mānuka honey has antibacterial properties that lend it to several surgical and medical applications. Very high-grade honey can sell for a significant premium over traditional honey. The number of registered beekeeping enterprises rose from 3,267 in 2011 to 6,735 in 2016.⁶ Due to this rapidly increasing production, which depends on indigenous trees, we model the potential for the afforestation land to support Mānuka operations.

We adapted the work of Watt (2012) as they included a predictive model of those two species. The growth of Mānuka/Kānuka stands was modeled 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°C. Therefore, we used the temperature and precipitation prediction equations from Watt (2012) to define the probability of occurrence of Mānuka/Kānuka as a function of temperature and precipitation.⁷

For temperature:

$$\Pr(\text{Occur}_{\text{Temp}}) = 7.159 \times \text{TempC} - 30.734 \quad (1)$$

where TempC is the mean annual temperature in degrees Celsius, and $\Pr(\text{Occur}_{\text{Temp}})$ is the probability of Mānuka/Kānuka occurrence, based on temperature.

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

$$\Pr(\text{Occur}_{\text{Rain}}) = 0.06 \times \text{prec} \times \text{prec} - 16.5 \quad (2a)$$

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

$$\Pr(\text{Occur}_{\text{Rain}}) = -2x(E^{-10}) \times \text{prec}^3 + 5(E^{-6}) \times \text{prec}^2 - 0.0418 \times \text{prec} + 119.57 \quad (2b)$$

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.

2.3 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)⁸ defined ecosystem services as “the benefits people obtain from ecosystems,” which the MA classifies as provisioning, regulating, supporting, and cultural services. 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

⁶See the apiculture reports at <https://www.mpi.govt.nz/news-and-resources/publications/> for more information.

⁷Given 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.

⁸The MA was created by an active group of scientists, along with representatives from governments, private sector, and nongovernmental organizations.

(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).

Native and exotic afforestation can produce a range of ecosystem services. Both types of forest sequester carbon, and both types can be used for timber harvest, but Indigenous timber harvest is much less common.⁹ Roughly, 80% of the country's indigenous forests are publicly owned, with the remaining privately owned land under strict sustainable harvesting limits and policies (McGlone *et al.* 2022).¹⁰ Yao *et al.* (2016) summarize the current state of exotic forests across New Zealand and describe the provisioning, regulating, cultural, and supporting ecosystem services provided by them. There are over 200 native tree species in New Zealand, which vary significantly across the different ecoregions of the two islands (Allen *et al.* 2016). There are ongoing efforts to increase Māori ownership of indigenous forests, with emphasis on *kaitiakitanga* (guardianship) and *mātauranga* (traditional knowledge) (Allen *et al.* 2016).

Given the important role of forests in New Zealand, there have been several past efforts to value their services. Kotula (2022) summarizes past valuation literature in New Zealand and provides an overview of some of the central benefits associated with forests in New Zealand, including carbon sequestration, recreation, habitat, biodiversity, and cultural services.¹¹ Out of 17 studies in their paper, ranging from 1983 to 2019, biodiversity and recreation were the most common focus, with six studies each. Contingent valuation was the most common valuation method, with 5 studies using it, followed by choice modeling/discrete choice (4) travel cost (4), real options/optimization (2), and other approaches (2). Tuahine (2018) summarizes some of the additional benefits of native forest, including Manuka honey, erosion control, water quality, tourism, recreational use, biodiversity, and habitat.

Cultural services are the nonmaterial 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 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. Similarly, Dhakal *et al.* (2012) have estimated the economic value of recreation activities in Rotorua's Whakarewarewa forest in New Zealand. They found that walking and mountain biking were valued at NZ\$8 million per year. Finally, supporting services are seen as inputs into the other ecosystem services categories, which can be necessary for their production. For instance, the provision of habitat for pollinators is a necessary input to a range of agricultural products.

⁹Radiata pine comprises 90% of plantation forests in NZ, with Douglas fir, Eucalypts, and others making up the remaining 10% <https://www.canopy.govt.nz/plan-forest/why-plant-trees/harvest/>.

¹⁰See <https://www.mpi.govt.nz/forestry/native-indigenous-forests/> for additional information.

¹¹Kotula (2022) also describes an example Payments for Ecosystem Services (PES) scheme that was deployed in Gisborne, although low participation and a high drop-out rate forced the end of the program.

Yao et al. (2019) use estimates from a past studies in a simplified benefit transfer that compares the benefits and costs of biodiversity.¹² The paper provides a wealth of information on biodiversity values in New Zealand forests, as well as evidence for people's willingness to pay (WTP) for biodiversity improvements. New Zealand's endemic species are very unique, with significant government funds dedicated to conservation.¹³ This reflects significant public interest in protecting indigenous species, as illustrated by past nonmarket valuation studies (Dymond et al. 2013; Tait et al. 2017; Yao et al., 2014).

2.4 Economic and ecosystem service analysis

The economic analysis is conducted using a spatially explicit agri-environmental economic land use model (NZFARM) and nonmarket valuation methods to monetize changes in land use based on varying afforestation scenarios. Opportunity costs from conversion of current land to forests were estimated as changes in net land revenue or earnings before interest and tax (EBIT) in NZFARM. More details on NZFARM are provided in Daigneault et al. (2018). All monetary values in this analysis are reported in 2017 New Zealand dollars (NZD).

2.4.1 Mānuka/Kānuka honey

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.¹⁴ For our analysis, we use information gathered from trade associations and beekeepers by Daigneault et al. (2015) to estimate the EBIT from honey.¹⁵ 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 unique Manuka factor (UMF¹⁰⁰⁺). There is unfortunately a dearth of information in the literature and from the trade associations about predicting UMF¹⁰⁰⁺. Discussions with Apiculture New Zealand indicated that some of the central influences on UMF include past history.¹⁶

¹²However, to connect conservation costs to impacts and valuation results, the paper uses several unrealistic assumptions that thwart its use in a policy application. For instance, they feature a stated preference valuation study that had people value kiwi calls being heard in 1, 10, or 20 out of 200 planted forests, or Geko being cited in 1, 3, or 5 out of 50 walks. Although the results demonstrate that people have values associated with both species, they are density-independent and would require modeling of recreation behavior and kiwi monitoring to be fully useful. Additionally, they assume that pest control in kiwi areas is always successful in restoring kiwi populations.

¹³An overview of the Department of Conservation's 2022 budget can be found at: <https://www.doc.govt.nz/news/issues/budget-2022-overview/#:~:text=Budget%202022%2C%20which%20included%20%24400,expenditure%20excluding%20tagged%20contingent%20funding.>

¹⁴For 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.

¹⁵The final report can be found at: <http://www.maniapoto.iwi.nz/wp-content/uploads/2016/04/1-Economic-Analysis.pdf>

¹⁶There is a new MBIE program "Building resilience and provenance into an authentic Māori honey industry" led by Landcare Research that is starting to address some of these challenges. <https://www.landcareresearch.co.nz/discover-our-research/biodiversity-biosecurity/ecosystem-resilience/species-and-ecosystem-conservation/honey-landscape/>

Since several of those factors are included in the Watt (2012) prediction equations we use to identify land suitable for Mānuka/Kānuka, we have adapted them to predict the potential of honey operations. Those equations produce probability scores for each area on the ability to support Mānuka. As a fairly conservative 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.

2.4.2 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 improve water quality by reducing nutrient runoff and mitigating erosion (Hu *et al.* 2022). It can also prevent excess stormwater runoff and slow down flood flows leading to reduction in flood damage (Thomas and Nisbet 2016). In addition, afforestation can provide drought mitigation service by conserving water in dry season (Pattanayak and Kramer 2001). On the other hand, afforestation in temperate places like New Zealand is likely to reduce water yield, meaning there may be less water available for irrigation and other activities (Ausseil *et al.* 2013, Filoso *et al.* 2017; Hua *et al.* 2022). Due to data and time constraints for this analysis, we focus primarily on the changes in water quality. There are also several sources of uncertainty about the changes in water quantity, as well as the sign and magnitude of their effects. 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 WTP 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 nonmarket 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 (Barry *et al.* 2014). 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, 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 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.

To monetize these impacts, we use a recent study that estimated people's WTP for improvements in three water quality parameters (Walsh *et al.* 2022). Their econometric model estimates WTP values for each regional council in New Zealand, which 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.

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.

To estimate the greenhouse gas reduction (i.e., climate regulation) benefits over 50 years, we need to know the emissions transition path rather than the steady-state levels. In the absence of forest modeling 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 tables¹⁷ 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 changes in biodiversity, we employ a measure of “ecological integrity.” This measure was originally defined 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 (Carswell et al. 2015; Mason et al. 2012, 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. This indicator is estimated at a 1 hectare grid and its units are parts per billion (ppb), where one billion represents the ideal ecological utopia of natural (pre-human) conditions (Carswell et al. 2015).

2.4.3 Cultural services and nonmonetized benefits

There are many important cultural services from forests, especially for Māori communities. By some estimates, roughly half of the commercially planted forests are owned by Māori.¹⁸ There are also several options to protect indigenous forest land with government support, including the Māori Land Court and Ngā Whenua Rauhi covenants.¹⁹ Native forest is seen as a central component of Māori whakapapa, or lineage (Pohatu et al. 2020). Miller et al. (2005) note that indigenous forests are important to Māori since they provide food, medicines, building materials, shelter, clothing, tools, and handicrafts, while “exotic commercial forestry” is the “adopted son” that provides employment, economic benefits, and the protection of lands. A good example of local cultural services from forests is rongoā, a traditional Māori healing system that includes plant-based medicines (rongoā rākau), spiritual prayers, and songs (karakia).²⁰ Pohatu et al. (2020) describe recent work on engaging Māori communities to learn about their decisions to participate in native forestry. They recommend better tailoring government policy to respect and accommodate traditional methods of forestry. To compare cultural

¹⁷<https://www.mpi.govt.nz/document-vault/4762>

¹⁸See <https://www.scionresearch.com/work-with-us/partnering-with-maori> for more information.

¹⁹<https://maorilandcourt.govt.nz/>, more information about covenants is available here: <https://www.doc.govt.nz/get-involved/funding/nga-whenua-rahui/>

²⁰<https://www.canopy.govt.nz/ngahere-maori/species/rongoa/>

services and other nonmonetized benefits, we use estimates of potential impacts between native and exotic forests for several categories of benefits, based on recent literature. This allows an ordinal ranking of several benefit categories that could not be monetized.

2.5 Scenario analysis

This paper evaluates ecosystem service and economic impacts across two primary scenarios:

- **Scenario E:** exotic (*E*) plantation forestry is planted on all new afforestation areas
- **Scenario I:** new afforestation areas are afforested with permanent, nonrotation indigenous (*I*) forest. Where possible, land suitable for Mānuka/Kānuka in the new afforestation areas remains in Mānuka/Kānuka and is used for enterprises such as medical or commercial honey production.

3. Results

3.1 Afforestation potential

Approximately 39,400 ha of land were identified for new afforestation in the Manawatū catchment (Figure 3), where the most prevalent existing land use is sheep & beef, at approximately 31,600 ha. Of the almost 40,000 ha identified as new afforestation areas, approximately 24,000 ha are suitable for Mānuka/Kānuka. This was based on the probability thresholds that these areas can meet specific environmental (temperature and precipitation) conditions (Watt 2012).

3.2 Opportunity costs and afforestation revenue benefits

The opportunity cost of provisioning services from converted agricultural or forest land estimated in NZFARM for each of the scenarios is outlined in Table 1. The opportunity cost for the indigenous scenario represents the lost profits from the previous productive uses of the land. In the exotic scenario, the opportunity cost differs by the existing exotic forestry land, which is kept in that land use. The total opportunity cost for the catchment under Scenario E (exotic) is approximately \$3.2 million/year in lost EBIT, with \$3.6 million in Scenario I.

Table 2 shows the change in opportunity costs by previous land use. The highest land uses occupying the new afforestation areas are sheep & beef (31,548 ha), while dairy lands face the highest loss in net revenue (\$1.6 million) due to its high baseline earning potential. The table also highlights a difference between Scenarios E and I: the exotic forestry is converted to indigenous in Scenario I; hence, the difference in opportunity costs of 400 thousand dollars.

The afforestation scenarios will result in several new streams of revenue, some of which we can quantify or monetize. In Scenario E, the new afforestation areas will be planted with exotic forestry, in this case *Pinus radiata*, which results in an increase in net land revenue from timber. There are also several other ecosystem services that can either be quantified or described qualitatively. The new exotic forest area may directly or indirectly affect a number of cultural services. For example, nearby recreational opportunities like birdwatching or hiking may increase. Alternatively, esthetic values (related to scenic

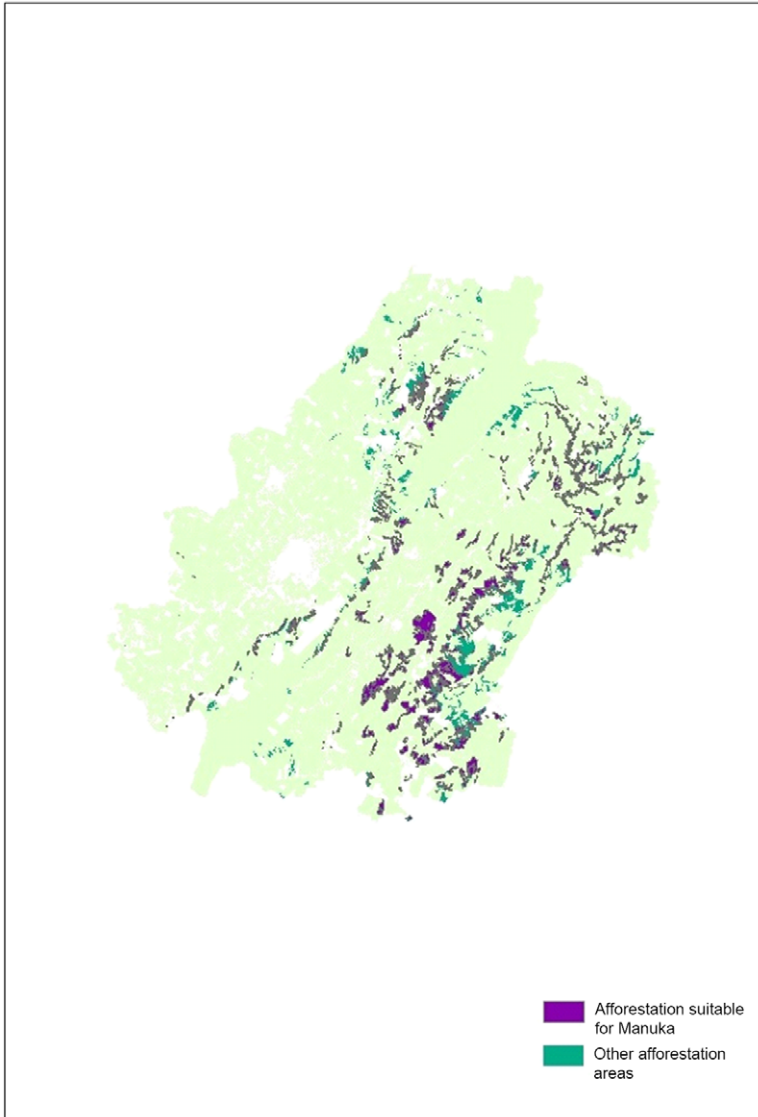


Figure 3. Areas suitable for afforestation in the Manawatu catchment.

views) may increase or decrease as some people prefer indigenous vegetation over exotic vegetation (Brown et al. 2012). Moving from a pastoral land use to forested land may increase esthetic values.²¹

The increase in exotic forestry in the Manawātū catchment in Scenario E is estimated to increase EBIT by approximately \$18 million/yr (Table 3). The Tararua district is expected

²¹See <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.

Table 1. Afforestation potential and opportunity costs from converting current provisioning services to forest in the Manawatū catchment, by territorial authority

Territorial authority	Scenario E (Exotic)	Scenario I (Indigenous)
Central Hawke's Bay District	\$59,213	\$61,920
Horowhenua District	\$28,949	\$51,851
Manawatū District	\$1,268,287	\$1,324,465
Masterton District	\$0	\$0
Palmerston North City	\$43,166	\$69,693
Tararua District	\$1,843,688	\$2,138,689
Manawatū catchment total	\$3,243,303	\$3,646,617

Table 2. Area and annual opportunity costs for indigenous afforestation in Manawatū catchment, by current land use

Land use	Area (ha)	Opportunity cost (\$/yr)
Arable	< 1	\$115
Dairy	804	\$1,550,303
Deer	367	\$365,178
Exotic forestry	658	\$403,314
Fruit	0	\$110
Native forestry	4,303	\$0
Other	419	\$0
Other pasture	1,353	\$26,973
Sheep & beef	31,548	\$1,299,791
Vegetables	0	\$833
Total	39,542	\$3,646,617

to experience the largest gain in EBIT from the new afforestation areas while Masterton gains the least. Overall, we estimate that the total net present value (NPV) of EBIT earned or lost from converting current land use to exotic forestry across 50 years using a discount rate (r) of 8% increases by more than \$200 million (552%).

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.²² 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

²²A 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.

Table 3. Estimated EBIT (net land revenue) impacts from afforestation scenarios

Territorial authority	Total EBIT (\$)			Total Change (%)	
	<i>Current land use</i>	<i>Scenario E</i>	<i>Scenario I</i>	<i>Scenario E</i>	<i>Scenario I</i>
Cen. Hawke’s Bay District	\$59,213	\$220,618	\$23,580	273%	−60%
Horowhenua District	\$28,949	\$349,148	\$186,853	1106%	545%
Manawatū District	\$1,268,287	\$3,142,778	\$484,053	148%	−62%
Masterton District	\$0	\$6,043	\$1,730	n/a	n/a
Palmerston N. City	\$43,166	\$363,589	\$79,116	742%	83%
Tararua District	\$1,843,688	\$17,072,045	\$4,920,116	826%	167%
Manawatū catchment total	\$3,243,303	\$21,154,221	\$5,695,448	552%	76%
Total EBIT over 50 years (<i>r</i> = 8%)	\$41,386,990	\$269,943,802	\$75,249,196	552%	82%

tend to be the older and more experienced farmers – who are becoming the majority.²³ On the other hand, current and future carbon prices may send strong incentives for the conversion of marginal lands to exotic forestry, especially given the large increases in the ETS price over the last few years. Indeed, there was a recent governmental consultation on exclusion of exotic permanent forestry from the ETS system as there was a worry that high carbon prices could encourage fast-growing permanent exotic forests to replace indigenous forests.²⁴

While converting current land use to indigenous trees will reduce earnings from nonforestry operations, we assume that some of the new afforestation area in Scenario I will revert to Mānuka/Kānuka and be used for Mānuka honey production (Table 3). The estimated annual honey-related profit is expected to increase by nearly \$2.5 million/yr (76%), while the total NPV over 50 years (*r* = 8%) is estimated to increase by \$33.8 million (82%).

3.3 Water quality benefits

Table 4 lists the estimated reductions in nitrogen (N) leaching from NZFARM. 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. Note that this percent assumes that all new afforestation areas have been afforested.

Walsh et al. (2022) demonstrate a benefit transfer of their results, which we follow here, with a few adaptations. We have changes in nitrogen leaching from NZFARM, which we need to translate to changes in the three parameters from Walsh et al. (2022): nutrient criteria achieved, E. coli criteria achieved, and clarity. To translate changes in nutrient loading into changes in in-stream nutrient criteria, we assume a proportional relationship.

²³See 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>

²⁴<https://www.mpi.govt.nz/consultations/managing-exotic-afforestation-incentives>

Table 4. Estimated nitrogen leaching impacts from afforestation scenarios

Territorial authority	N leaching (kg/yr)			Total change (%)	
	<i>Current land use</i>	<i>Scenario E</i>	<i>Scenario I</i>	<i>Scenario E</i>	<i>Scenario I</i>
Gen. Hawke's Bay	5,251	789	473	−85%	−91%
Horowhenua	5,929	1,390	834	−77%	−86%
Manawatū	69,776	12,479	7,488	−82%	−89%
Masterton	128	40	24	−69%	−81%
Palmerston N. City	6,516	1,507	904	−77%	−86%
Tararua	370,242	62,701	37,621	−83%	−90%
Catchment total	457,842	78,906	47,344	−85%	−91%

Table 5. NPV of total WTP for water quality benefits in Manawatū catchment over 50 years

	Discount rate 3%	Discount rate 8%
Scenario E	\$50,413,704	\$23,422,725
Scenario I	\$55,520,134	\$25,608,827

Studies have shown that nutrient leaching has a large impact on local water quality. Julian *et al.* (2017) analyze the impact of a number of landscape and land use-related factors on local water quality in New Zealand. They find that several types of local land use have a significant impact on a range of water quality indicators. The study suggests that agricultural intensification and nutrient loads are significant contributors to water quality conditions, especially nutrients. Using Spearman correlation coefficients, they found that the correlation between the density of cattle and TN and TP was 0.85 and 0.72, respectively. Furthermore, stepwise multivariate regression models found that land use was the primary and secondary predictor for all five water quality variables that they analyzed.

Following those results, we assume a conservative 50% of the change in nutrient loading is passed onto local river and stream nutrient conditions. Following Walsh *et al.* (2022), we use a data set of several hundred thousand water quality observations to estimate the likely parallel changes in *E. Coli* and clarity. Using the projected changes in water quality and the values from the study for nutrients, clarity, and *E. Coli*, we obtain an annual benefit of \$1,857,249/yr for Scenario E and \$2,031,974/yr for Scenario I. The vast majority of those values are from clarity, with \$1,741,475 in annual clarity benefits for Scenario E and \$1,892,155 for Scenario I.

To project the values over 50 years, we need to control for increasing population. The 2013 Census population growth figures (which are the most representative of these data) are used to extrapolate population out 50 years to calculate total benefits (Table 5). The NPV 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). (Table 5).

Table 6. Change in annual net GHGs in the Manawatū catchment

Territorial authority	GHG emissions/sequestration (tCO ₂ e)			Total change (tCO ₂ e)	
	Current land use	Scenario E	Scenario I	Scenario E	Scenario I
Gen. Hawke's Bay	960	-4,857	-237	-5,817	-1,197
Horowhenua	586	-8,226	-417	-8,811	-1,002
Manawatū	11,614	-69,122	-3,744	-80,735	-15,357
Masterton	16	-244	-12	-260	-28
Palmerston N. City	597	-9,836	-452	-10,433	-1,049
Tararua	62,945	-392,951	-18,810	-455,895	-81,755
Catchment total	76,718	-485,236	-23,672	-561,951	-100,388

a: a negative number means carbon is being sequestered and on net there is a reduction in GHG emissions.

3.4 Climate regulation benefits

Using NZFARM, we estimate changes in net GHGs (avoided GHG emissions plus carbon sequestered) with each afforestation scenario (Table 6). Scenario E has lower net GHG emissions than Scenario I. For instance, in Central Hawke's Bay District there are approximately 960 tons CO₂e 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 tons. Under Scenario I, the district is only a 1,000 tons carbon sink.

The GHG figures presented in Table 6 represent the steady-state levels of GHG emissions, which can then be converted to annual fluxes to estimate sequestration rates.

For our calculations, we assume that the exotic forest (Scenario E) has 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.²⁵ Note that an estimate based solely on the ETS lookup tables is likely an underestimate, since it only values 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.²⁶

We use several different carbon prices to explore the impact of changes in GHGs. A lower bound of \$17 per ton of CO₂ (\$17/tCO₂e, in 2020 dollars) is used to represent the lower levels of the ETS price seen last decade. We also use US government's social cost of carbon (SCC) at 3%, translated into New Zealand Dollars (\$70/tCO₂ to start, but which changes over time). A constant NZETS price is a strong assumption, particularly if new sectors are covered by the NZETS in the future which changes market conditions. The large recent increases in the NZETS price are within the range of the US SCC. Future

²⁵Although common in the literature, these assumptions can affect the economic viability of these options, depending on whether the carbon price is expected to increase or decrease.

²⁶To 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.

Table 7. NPV of carbon benefits for Scenarios E and I over 50 years

Territorial authority	NZETS 3%	NZETS 8%	SCC 3%
<i>Scenario E</i>			
Cen. Hawke's Bay	1,732,879	1,046,857	7,071,811
Horowhenua	3,052,358	1,843,973	12,291,778
Manawatū	27,410,838	16,559,281	110,382,821
Masterton	88,109	53,228	354,811
Palmerston N. City	3,310,675	2,000,027	13,332,014
Tararua	137,724,026	83,201,060	554,611,514
Scen E Total	173,318,885	104,704,425	698,044,750
<i>Scenario I</i>			
Cen. Hawke's Bay	1,182,273	521,915	5,367,236
Horowhenua	2,082,500	919,321	9,393,804
Manawatū	18,701,300	8,255,702	84,358,394
Masterton	60,113	26,537	271,159
Palmerston N. City	2,258,739	997,122	10,188,790
Tararua	93,963,502	41,480,252	423,853,425
Scen I Total	118,248,428	52,200,848	533,432,808

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 ton CO₂e, with a low estimate of \$20 per ton CO₂e.²⁷ The US EPA SCC 3% is used to account for potentially higher future carbon prices, although future work should explore the 95th percentile values of the SCC, as well as other updates. Exploring SCC values across time is somewhat complicated since the social cost of CO₂ 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 (David *et al.* 2009; Guo *et al.* 2006; Pearce 2003). 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 monetized benefits of carbon sequestration for both scenarios outlined in Table 7. All estimates in the table represent the NPV across 50 years. Depending on the price assumption, benefits for Scenario E range from approximately \$105 million to almost \$700 million for the Manawatū catchment. Scenario I produces slightly lower carbon monetized 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.

²⁷<http://www.pce.parliament.nz/media/1292/covec-final-report-19-07-10.pdf>

Table 8. Restored significance scores for afforestation areas by existing land use by scenario

Enterprise class	Minimum SRS	25 th percentile SRS	Mean SRS	Max SRS	Std Dev. SRS
<i>Scenario I</i>					
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
<i>Scenario E</i>					
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

3.5 Biodiversity-related benefits

To gauge the potential biodiversity benefits from indigenous afforestation, we overlay the new afforestation areas with the scores of restored significance (SRS) ecological integrity data based on several detailed local criteria. 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. 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.

Biodiversity for Scenario I and E will differ due to differences in forest type (Table 8). 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 Deconchat *et al.* (2009). Assuming that the exotic forests will be harvested roughly once in a 50-year period, these levels of biodiversity are only likely to be fully achieved once in this period. Therefore, the average annual biodiversity benefits will be much lower. Recent nonmarket valuation studies indicate that the general public are willing to pay to protect and restore endemic species (for instance, Yao *et al.* (2019) demonstrate values associated with kiwi, giant kokopu, kakabeak, geckos, and bush falcons). However, practical difficulties, like available ecological and cost models for these species, prevent their use in policy analysis-focused benefit transfer.

When assessing the benefits and costs of the two afforestation scenarios for the Manawatū catchment it is important to consider those that can be monetized, 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 monetized impacts. While it is possible to quantify and/or monetize other impacts, the time and effort constraints for this study mean that no additional primary data or ecosystem modeling could be undertaken. In terms of benefits and costs, the benefits are often more challenging to quantify. For instance, esthetic values are difficult to quantify, and esthetic 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 modeling would be needed to quantify the indirect impacts of changes in biodiversity.

3.6 Cultural and other values

Although we cannot directly quantify changes in cultural values as a result of afforestation activities, it is possible to compare between exotic and native outcomes. The above biodiversity discussion noted the larger improvements associated with native forest. Although biodiversity itself is important, the types of species and habitat are also paramount. Native forests in New Zealand are renowned habitats for endemic species (Miller *et al.* 2005). Several of these endemic bird species have significant mana (roughly authority and prestige) with local Māori groups. For instance, the kererū is considered mana rangatira (noble bird) by the Tuawhenua people due to its traditional uses. Its abundance was considered by Māori to be an indicator of the mauri, or life force, of the forest (Timoti *et al.* 2017). Although kererū can be found in exotic forest, they do much better in those with native forests.²⁸ There are many other endemic species that evolved in native forests and hence do better in those habitats. A recent analysis of habitat factors for native birds found that native birds did much better in areas of continuous native forest (Barnagaud *et al.* 2014). This suggests that native forest has larger cultural values related to species than exotic forests. Native forests also produce more medicinal, craft, food, and other cultural goods than exotic forests.

While profits appear to be higher in exotic forests than native forests, it is also worth noting that there are several local, regional, and national programs aimed at increasing native forest. Grants and loans are available from the Department of Conservation, MPI, Te Uru Rākau, and other private groups.²⁹ Many of these programs emphasize the

²⁸For additional information on habitat: <https://nzbirdsonline.org.nz/species/new-zealand-pigeon>.

²⁹See, for example, <https://www.doc.govt.nz/get-involved/funding/nga-whenua-rahui/nga-whenua-rahui-fund/> and <https://www.canopy.govt.nz/ngahere-maori/>. Past funding programs can be found here: <https://www.mpi.govt.nz/forestry/funding-tree-planting-research/closed-funding-programmes/>

production of cultural services through afforestation. Tuahine (2018) describes some of this support in the context of the NZ ETS. These government and private programs illustrate the wide public support for native forests for their less-tangible benefits.

3.7. Ecosystem service summary

In the absence of additional data collection and ecosystem modeling, we use an ecosystem services framework to describe the broader range of impacts and the subsequent benefits and costs of the afforestation scenarios.

Table 9 presents a summary of ecosystem service impacts, using colors to indicate potential impacts, in order of negative to positive impact by red, orange, yellow, light green, and the most positive impacts in dark green.

A more complete ecosystem service table that describes impacts and sorts them into those that were quantified or monetized can be found in the appendix. 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.

4. Summary and conclusion

A summary of the monetized benefits and costs for the Manawatū catchment for the two afforestation scenarios is provided in Table 10. All figures are in 2017 dollars and use discount rates of 8 and 3 percent.³⁰ There are a variety of issues (not presented here) involving the magnitude of the discount rate.³¹

In terms of discounted benefits, Scenario E yields the largest monetized benefits, at approximately \$685 million, which includes increased profit from exotic forestry, water quality benefits, and carbon-related benefits. Scenario I has lower carbon benefits, slightly higher water quality benefits, and lower net production-related revenue. Total benefits for scenario I are \$226 million using a 3% discount rate. These differences in benefits between the two scenarios are important, as they each come with their own caveats. Future policy, climate change, and farmer preferences can significantly affect the benefits realized by each scenario in different ways.

The overall NPV and the benefit-cost ratio show all scenarios as having a positive benefit-cost ratio, and NPVs of several hundred million dollars. Although Scenario E has higher monetized net benefits, there are many other benefits that were not monetized. For instance, biodiversity benefits were found to be considerably higher for indigenous forest, although they were not assigned dollar values. Cultural, recreation, esthetic, and human health impacts were also not monetized or quantified. Available evidence suggests that many of these unquantified benefit categories are higher for indigenous forests. Cultural services, for instance, are much higher in indigenous forests than exotic forests. There is

³⁰The traditional default discount rate 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.

³¹For instance, higher discount rates may penalize “lumpy” effects that occur in the future, as opposed to up-front costs.

Table 9. Summary of ecosystem service impacts relative to baseline

Ecosystem service		Exotic afforestation	Indigenous afforestation	Impact
Provisioning	Crops	VH	VH	Very negative
	Livestock: milk	VH	VH	Negative
	Livestock: meat	VH	VH	Neutral/Minor
	Capture fisheries	M	M	Positive
	Freshwater	M	M	Very Positive
	Wild foods	H	VH	Confidence Level
	Timber & wood	VH	VH	VL = very low
	Fibers & resins	H	H	L = low
	Biomass fuel	VH	VH	M = medium
	Ornamental resources	VH	VH	H = high
	Biochemical, natural medicines, and pharmaceuticals	VH	VH	VH = very high
Regulating	Air quality and climate regulation	VH	VH	
	Water regulation	M	M	
	Erosion control	VH	VH	
	Water quality or purification	H	H	
	Pollination	VH	H	
	Natural hazard regulation	H	H	
Cultural	Recreation and Ecotourism	H	M	
	Ethical and spiritual	H	H	
	Esthetic values	VH	H	
	Cultural heritage values	M	H	
	Social relations	H	H	
	Sense of place	H	H	
	Cultural diversity	H	H	
Supporting	Habitat Provision	VH	H	

also more government and private support, in terms of grants, loans, and training, for indigenous forests.

The preferable afforestation scenario therefore depends on the preferences and constraints of the policy makers. The New Zealand government is currently supporting a blended approach to promote both types of forests. Exotic forestry is an important source of jobs and economic productivity while indigenous forest is associated with less economic benefit but higher cultural, recreation, and other benefits. Overall, we find that both exotic and indigenous forest have the potential to produce significant benefits. With flexible

Table 10. Monetized benefits and costs across 50 years ($r = 3$ and 8%)

Benefit	NPV 8%		NPV 3%	
	<i>Exotic</i>	<i>Indigenous</i>	<i>Exotic</i>	<i>Indigenous</i>
Net Land Revenue	\$228,556,811	\$26,144,628	\$460,843,693	\$52,715,938
Water Quality	\$23,422,725	\$25,608,827	\$50,413,704	\$55,520,134
Climate Regulation	\$104,704,425	\$52,200,848	\$173,318,885	\$118,248,428
Total Benefits	\$356,683,962	\$103,954,303	\$684,576,282	\$226,484,500

policy that provides balanced incentives to producers, both types of forest can achieve multiple regional and national goals.

Data availability. The economic modeling and land use data that support the findings of this study are available from Manaaki Whenua, Landcare Research. Restrictions apply to the availability of these data, which were used under license for this study.

Acknowledgment. The authors would like to thank participants at the 2022 NAREA Annual Conference and Manaaki Whenua LINK Seminar Series.

Funding statement. This work was partially funded by the New Zealand Ministry for Primary Industries, under Landcare Contract Report LC2788.

Competing interests. The authors declare none.

References

- Allen, R.B., P.J. Bellingham, R.J. Holdaway, and S.K. Wiser. 2016. "New Zealand's indigenous forests and Shrublands." In *Ecosystem Services in New Zealand – Conditions and Trends*, edited by John Dymond. Lincoln, New Zealand: Manaaki Whenua Press.
- Ausseil, A.G.E., J.R. Dymond, M.U.F. Kirschbaum, R.M. Andrew, and R.L. Parfitt. 2013. "Assessment of multiple ecosystem services in New Zealand at the catchment scale." *Environmental Modelling & Software* 43: 37–48.
- Barnagaud, J., L. Barbaro, J. Papaix, M. Deconchat and E.G. Brockerhoff. 2014. "Habitat filtering by landscape and local forest composition in native and exotic New Zealand birds." *Ecology* 95: 78–87.
- Barry, L.E., R. Yao, D.R. Harrison, U.H. Paragahawewa, and D. Pannell. 2014. "Enhancing ecosystem services through afforestation: How policy can help." *Land Use Policy* 39: 135–145.
- Baskaran, R., R. Cullen, and S. Colombo. 2009. "Estimating values of environmental impacts of dairy farming in New Zealand." *New Zealand Journal of Agricultural Research* 52(4): 377–389.
- Brown, P., C. Mortimer, and C. Meurk. 2012. Landscape preferences in the Canterbury Region. Landcare Report LC964.
- Carswell, F.E., N.W.H. Mason, J.M. Overton, R. Price, L.E. Burrows, and R.B. Allen. 2015. "Restricting new forests to conservation lands severely constrains carbon and biodiversity gains in New Zealand." *Biological Conservation* 181: 206–218.
- Daigneault, A., S. Greenhalgh, and O. Samarasinghe. 2018. "Economic impacts of multiple agro-environmental policies on New Zealand land use." *Environmental and Resource Economics*, 1–23.
- Daigneault, A., W. Wright, and O. Samarasinghe. 2015. "Economic analysis of land use opportunities in the Maniapoto rohe." Landcare Research Report LC2415. <http://www.maniapoto.iwi.nz/wp-content/uploads/2016/04/1.-Economic-Analysis.pdf>
- David, A., S.J.T. Richard, and W.Y. Gary. 2009. "Risk aversion, time preference, and the social cost of carbon." *Environmental Research Letters* 4(2): 024002.

- Deconchat, M., E.G. Brockerhoff, and L. Barbaro.** 2009. "Effects of surrounding landscape composition on the conservation value of native and exotic habitats for native forest birds." *Forest Ecology and Management* 258: S196–S204.
- Dhakal, B., R. Yao, J. Turner and T. Barnard.** 2012. "Recreational users' willingness to pay and preferences for changes in planted forest features." *Forest Policy and Economics* 17: 34–44.
- Dymond, J.R., A.-G.E. Ausseil, M.U.F. Kirschbaum, F.E. Carswell, and N.W.H. Mason.** 2013. "Opportunities for restoring indigenous forest in New Zealand." *Journal of the Royal Society of New Zealand* 43(3): 141–153.
- Filoso, S., M.O. Bezerra, K.C. Weiss, and M.A. Palmer.** 2017. "Impacts of forest restoration on water yield: A systematic review." *PLoS One* 12(8): e0183210.
- Freeman, M.** 2003. *The Measurement of Environmental and Resource Values*. Washington, DC: Resources for the Future Press.
- Guo, J., C.J. Hepburn, R.S.J. Tol, and D. Anthoff.** 2006. "Discounting and the social cost of carbon: a closer look at uncertainty." *Environmental Science & Policy* 9(3): 205–216.
- Hu, Y., Q. Tian, J. Zhang, G. Benoy, N. Badreldin, Z. Xing, Z. Luo, and F. Zhang.** 2022. Effectiveness of Chinese pine (*Pinus tabulaeformis*) plantation at reducing runoff and erosion rates in Anjiagou Watershed in Semi-arid Region of Gansu, China. *Plos One* 17(7): e0271200.
- Hua, F., L.A. Bruijnzeel, P. Meli, P.A. Martin, J. Zhang, S. Nakagawa, X. Miao, W. Wang, C. McEvoy, J.L. Peña-Arancibia, and P.H. Brancalion.** 2022. "The biodiversity and ecosystem service contributions and trade-offs of forest restoration approaches." *Science* 376(6595): 839–244.
- Julian, J.P., K.M. de Beurs, B. Owsley, R.J. Davies-Colley, and A.G.E. Ausseil.** 2017. "River water quality changes in New Zealand over 26 years: response to land use intensity." *Hydrology and Earth System Sciences* 21(2): 1149–1171.
- Kotula, H.** (2022) Valuing forest ecosystem services in New Zealand, Motu Working Paper 22-11, Motu Economic and Public Policy Research, Wellington, New Zealand.
- Lambie, S., S. Awatere, A. Daigneault, M. Kirschbaum, M. Marden, T. Soliman, . . . P. Walsh.** 2021. "Trade-offs between environmental and economic factors in conversion from exotic pine production to natural regeneration on erosion prone land." *New Zealand Journal of Forestry Science*, 51.
- Lynn, I.H., A.K. Manderson, M.J. Page, G.R. Harmsworth, G.O. Eyles, G.B. Douglas, A.D. Mackay, and P.J.F. Newsome.** 2009. *Land Use Capability Survey Handbook, A New Zealand Handbook for the Classification of Land* (3rd ed.), AgResearch, Landcare Research, GNS Science, Hamilton, Lincoln, Lower Hutt.
- Lee, W.G., M. Mcglone, and E.F. Wright** 2005. "Biodiversity inventory and monitoring: A review of national and international systems and a proposed framework for future biodiversity monitoring by the department of conservation." Landcare Research Contract Report LC0405/122, Wellington, New Zealand. https://www.landcareresearch.co.nz/uploads/public/researchpubs/biodiv_inventory_system_review_framework.pdf
- MA.** 2005. Ecosystems and Human Well-Being: A Framework for Assessment. <http://www.millenniumassessment.org/en/Framework.html>
- Mason, N.W.H., A.-G.E. Ausseil, J.R. Dymond, J.M. Overton, R. Price, and F.E. Carswell.** 2012. "Will use of non-biodiversity objectives to select areas for ecological restoration always compromise biodiversity gains?" *Biological Conservation* 155: 157–168.
- Mason, N.W.H., D.J. Palmer, V. Vetrova, L. Brabyn, T. Paul, P. Willemse, and D.A. Peltzer.** 2016. "Accentuating the positive while eliminating the negative of alien tree invasions: a multiple ecosystem services approach to prioritising control efforts." *Biological Invasions*: 1–15.
- McGlone, M.S., P.J. Bellingham, and S.J. Richardson.** 2022. "Science, policy, and sustainable indigenous forestry in New Zealand." *New Zealand Journal of Forestry Science* 52(8): 1–25.
- Miller, R., Y.L. Dickinson, and A. Reid.** 2005 *Māori Connections to Forestry in New Zealand*. Forestry for Indigenous Peoples: Learning From Experiences with Forest Industries, XXII. Brisbane, Australia IUFRO World Congress 2005, 13–22.
- New Zealand Treasury.** 2008. Public sector discount rates for cost benefit analysis. New Zealand Treasury, Wellington.
- OECD.** 2013. *Climate and carbon, aligning prices and policies, OECD Environmental Policy Paper No.* 2013-1.

- Pattanayak, S.K. and R.A. Kramer.** 2001. "Worth of watersheds: a producer surplus approach for valuing drought mitigation in Eastern Indonesia." *Environment and Development Economics* 6(1): 123–146.
- Pawson, S., E. Brockerhoff, E. Meenken, and R. Didham.** 2008. Non-Native plantation forests as alternative habitat for native forest beetles in a heavily modified landscape. *Biodiversity and Conservation*. <https://doi.org/10.1007/s10531-008-9363-y>
- Pearce, D.** 2003. "The social cost of carbon and its policy implications." *Oxford Review of Economic Policy* 19(3): 362–384.
- Pohatu, P., S. O'Brien and L. Mercer.** 2020. Challenges and Opportunities with Native Forestry on Māori Land. Motu Working Paper 20-13, Motu Economic and Public Policy Research, Wellington.
- Tait, P., C. Saunders, G. Nugent, and P. Rutherford.** 2017. "Valuing conservation benefits of disease control in wildlife: A choice experiment approach to bovine tuberculosis management in New Zealand's native forests." *Journal of Environmental Management* 189: 142–149.
- Thomas, H. and Nisbet, T.R.** 2016. Slowing the flow in Pickering: Quantifying the effect of catchment woodland planting on flooding using the soil conservation service curve number method. *International Journal of Safety and Security Engineering* 6: 12–20.
- Timoti, P., P. O'B Lyver, R. Matamua, C.J. Jones, and B.L. Tahi.** 2017. "A representation of a Tuawhenua worldview guides environmental conservation." *Ecology and Society* 22(4): 20.
- Tran, D.X., D. Pearson, A. Palmer, D. Gray, J. Lowry, and E.J. Dominati.** 2022. "A comprehensive spatially-explicit analysis of agricultural landscape multifunctionality using a New Zealand hill country farm case study." *Agricultural Systems* 203: 103494.
- Tuahine, H.** 2018. Supporting Native Plantation Forestry in the NZ ETS: Combining Revenue from Carbon, Native Timber, and Cobenefits. Report for Tāne's Tree Trust, Motu Economic and Public Policy Research, Wellington, February 2018.
- Turner, J.A., B. Dhakal, R. Yao, T. Barnard, and C. Maunder.** 2011. "Non-timber values from planted forests: recreation in Whakarewarewa forest." *New Zealand Journal of Forestry* 55(4): 24–31.
- US EPA.** 2014. Guidelines for preparing economic analysis. U. EPA. Washington DC, [https://yosemite.epa.gov/ee/epa/eeerm.nsf/vwAN/EE-0568-50.pdf/\\$file/EE-0568-50.pdf](https://yosemite.epa.gov/ee/epa/eeerm.nsf/vwAN/EE-0568-50.pdf/$file/EE-0568-50.pdf).
- Walsh, P.J., D. Guignet, and P. Booth.** 2022. National Water Quality Values in New Zealand: Policy-Relevant Stated Preference Estimates, US Environmental Protection Agency National Center for Environmental Economics Working Paper Series, Working Paper 22-02, Washington, DC.
- Watt, M.S.** 2012. Future forest systems. MPI Technical Paper No 2012/40. Prepared for the Ministry for Primary Industries by Scion.
- Watt, M.S., D.J. Palmer, and B.K. Hock.** 2011. "Spatial description of potential areas suitable for afforestation within New Zealand and quantification of their productivity under *Pinus radiata*." *New Zealand Journal of Forestry Science* 41: 115–129.
- Yao, R. T., R. Scarpa, J. Turner, T. Barnard, J. Rose, J. Palma, and D. Harrison.** 2014. "Valuing biodiversity enhancement in New Zealand's planted forests: Socioeconomic and spatial determinants of willingness-to-pay." *Ecological Economics* 98: 90–101.
- Yao, R.T., L.E. Barry, S.J. Wakelin, D.R. Harrison, L.-A. Magnard, T.W. Payn.** 2016. "Planted forests." In *Ecosystem services in New Zealand – Conditions and Trends*, edited by John Dymond. Lincoln, New Zealand: Manaaki Whenua Press.
- Yao, R.T., R. Scarpa, D.R. Harrison, and R.J. Burns.** 2019. "Does the economic benefit of biodiversity enhancement exceed the cost of conservation in planted forests?" *Ecosystem Services* 38(1000954): 1–14.

Appendix

Detailed afforestation ecosystem service description

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 modeling 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, 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 modeling is required to determine the spatial and temporal impacts on water flows.
	Wild foods	Likely increase			Wild food harvests should increase, particularly in indigenous afforestation scenarios (Scenario 1). Trout and eel habitat should improve with better water quality leading to greater fish abundance and catch. Honey will increase particularly in Scenario 1b).

(Continued)

(Continued)

Category	Ecosystem service	Effect of afforestation scenario	Quantified	Monetized	Methods/Notes
	Timber & wood	Increase in Scenario E	X	X	NZFARM was used to examine forestry impacts.
	Fibers & 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.
	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 monetize 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.

(Continued)

(Continued)

Category	Ecosystem service	Effect of afforestation scenario	Quantified	Monetized	Methods/Notes
	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 esthetic preferences for indigenous species over exotic species (Brown <i>et al.</i> 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).
	Esthetic values	Expected improvement			Views will be changed, particularly when afforested areas are elevated. The local value of changing views 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 esthetic 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.

(Continued)

(Continued)

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 labor 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 1a and 1b).

Cite this article: Walsh, P.J., T. Soliman, and A. Daigneault (2023). “Trade-offs between indigenous forest and exotic production forest in New Zealand.” *Agricultural and Resource Economics Review* 52, 379–405. <https://doi.org/10.1017/age.2023.7>