Article

Assessing the Broader Value of Planted Forests to Inform Forest Management Decisions

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Abstract: This study highlights the importance of incorporating objectively quantified, non-market environmental values (such as avoided erosion and carbon sequestration) into land use decision making for sustainable forest management. A continuously developing approach that has facilitated discussions between researchers, industries, and governments on the quantification of non-market values is the ecosystem services (ES) framework. Using a spatial economic tool, called Forest Investment Framework, this study is, to the best of our knowledge, the first assessment of the market (timber) and non-market (carbon sequestration, avoided nitrogen leaching and avoided erosion) ES values of the 1.75 million-hectare New Zealand planted forest estate. To collect the views of key planted forest industry representatives on ES assessment/quantification, we interviewed 14 forest managers representing 60% of the planted forest area. Results from the spatial economic analysis indicated that the non-market ES values can be more than four times the timber profit nationally, and up to 12 times higher in New Zealand's most erosion-prone region. These estimated values are indicative and should be treated with caution. From a sensitivity analysis, we found that different discount rates significantly impact ES values, ratios, and distributions. Results from the interviews indicated that ES quantification helped inform decision making by supporting license to operate, while also signaling the development of a reward system for sustaining ES. Sixty-four percent of survey respondents identified the importance of quantifying ES in ecological terms and describing other non-market ES in spatial, qualitative, or binary forms. Overall, this study provided evidence of how estimated non-market ES values compare with market values and highlighted the importance of including them in decision making processes. Future cost benefit analyses that incorporate these non-market monetary ES values would complement multi-criteria analysis that integrate additional dimensions and allow decision makers to rank options based on their particular criteria.

Keywords: ecosystem services; planted forests; sustainable forest management; decision making; forest certification; New Zealand; spatial economic tool; non-market values

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1. Introduction

1.1. Global Context and Ecosystem Services Frameworks

Pressure from increasing global population and a changing climate is placing excessive demands on the Earth's resources. Unchecked, we are looking at an unsustainable future where increasing production gives rise to environmental degradation and adverse social impacts—we are breaching our planetary boundaries in many areas [1]. The 17 United Nations' Sustainable Development Goals were established to stimulate global action towards a sustainable future—and these herald the need for a more complex and integrated response [2]. Multiple actions can contribute to multiple goals, none more so than in Goal 15 "Life on Land", where land use tensions between food and fiber production,

biodiversity conservation, poverty reduction, and climate action all intersect. Land use decisions are often based predominantly on economic criteria and in isolation from other land uses [3]. This is often the case in countries with free market economies. However, globally, government policies are increasingly considering interaction between land uses, and including the four pillars of sustainability—economic, environmental, social, and cultural [4]. As an example, the New Zealand (NZ) government has recently pioneered a national “wellbeing” budget based on a living standards framework that has all four pillars represented [5,6]. This shift in policy requires a common approach across all land uses to effectively connect environmental resources with human well-being [7]. One approach that has gained increasing attention is the concept of ecosystem services (ES) [8,9].

The global Millennium Ecosystem Assessment (MEA) defined the term “ecosystem services” as the “benefits that people derive from ecosystems” more than a decade ago (MEA 2005). Since then, the science of ES has developed further with its use for assessing the goods and services provided by both natural and modified ecosystems (e.g., natural forests, planted forests, pasture, urban, and built environment). From those initiatives, the ES definition has become more inclusive, that is “goods and services provided by natural and modified ecosystems that benefit, sustain and support human well-being”. More than 15 ES frameworks have been developed globally with the most widely used, including the MEA, The Economics of Ecosystems and Biodiversity (TEEB), the Common International Classification of Ecosystem Services (CICES), Mapping and Assessment of Ecosystems and their Services (MAES), and the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) [10–14]. Each of the five frameworks above provides a system to organize the management of ES with a typology for classification, valuation, and description of ES. The frameworks, in general, highlight the importance of combining appropriate valuation techniques (e.g., monetary, deliberative, and multicriteria methods) with ecological and spatial approaches in the quantification of the flow of non-market ecosystem service values from nature over time [15–17]. Examples of ES tools that combine spatial, ecological, and economic approaches to quantify and represent non-market services values in decision making include ARTificial Intelligence for Ecosystem Services (ARIES), Integrated Valuation of Ecosystem Services and Tradeoffs (INVEST), and Forest Investment Framework (FIF) [18–20].

Gross Domestic Product (GDP) is the standard measure of the size and growth of the economy of a nation or city. However, it only accounts for exchange values that consider neither environmental degradation nor human well-being [4]. Ecosystem services, such as water filtration, biodiversity protection, carbon sequestration, avoided erosion, and recreation, benefit, sustain, and support human well-being, but usually do not have a market value. In this regard, the quantification and incorporation of non-market ES in decision making has gained increasing attention [4,21–23]. Quantification using various ES frameworks has facilitated the conversations between researchers, industries, governments, and other stakeholders about the broader value of ecosystems [11,24–26]. The rapid development of the ES science has enabled leaders from public and private sectors to incorporate multiple values into decision making [9,12,27–29]. Application of the ES science has also provided a common language that enables the multiple values of planted forests and other land uses to be discussed across sectors [30,31].

Industry and business groups around the world are partnering with scientists and practitioners to develop methodologies to understand and use this understanding of broader values for reporting and decision making [32]. Planted forest owners and managers both globally and in NZ have started to use ES science to help improve their knowledge and capability to sustainably manage forests [30,33]. Sustainable forest management can also be demonstrated through their environmental protection accomplishments to the market, and in meeting their goals around corporate social responsibility [18,28,30]. Quantifying and describing ES in planted forests has recently helped forest companies comply with product certification requirements of the Forest Stewardship Council (FSC) [30,34]. The FSC seal of certification provides market access for forest companies, while a few companies have

received a price premium for their certified products [35–37]. Consumers are also becoming increasingly environmentally and socially conscious as they tend to purchase certified forest products to support environmental protection and reduce illegal logging [38,39].

Many governments across the world have adopted the ES framework to support the development of policies for biodiversity conservation, and to measure their goals to achieve sustainable economic growth [27,40]. This in turn helps the public sector develop policies on partnering with the private sector that manages natural capital resources, such as planted forests. There have been increasing public-private partnerships to maintain and enhance ES provision to society [41]. Globally, a large number of businesses consider sustainability and partnering with the government and conservation groups as a key component of their success [42].

In NZ, results from econometric analyses suggest that rural land value has three main drivers: (1) land use profitability (e.g., profit from the production of agricultural, horticultural, or forestry products); (2) favorable climatic conditions (e.g., sunshine hours or rainfall); and (3) proximity to local infrastructure and amenities (e.g., processing, transport, and port facilities) [43,44]. In planted forests, the value of wood accumulation and the profit from the sale of logs (that benefits forest owners) have become the main determinant of land value [43]. However, non-market forest ES (that benefit the society), such as carbon sequestration, recreation, and avoided erosion, remain untested for their influence on land value. This uncertainty is further reason ES frameworks play a crucial role in addressing this lack of connectivity between market and non-market values. This connectivity issue has prompted government agencies and businesses to use ES frameworks to better understand the multiple costs and benefits of different land use options [45]. For example, the cost of converting a planted forest stand to another type of land use (e.g., pasture for dairy production) would have impacts on the economy, environment, and society. Quantification of ES helps to demonstrate these complementarities by objectively valuing the multiple impacts of different land uses [46]. Accounting for these multiple values in decision making has been embedded in recently developed guidelines of governments in NZ and worldwide [45,47,48].

Since 2014, more than 21 case studies have been undertaken across NZ using the Forest Investment framework (FIF) [18] to: (1) assess the afforestation potential of marginal land, which is often owned by indigenous groups; (2) support the modelling of policy scenarios focusing on regional economic development; (3) assess both market and non-market ES values of key landscape areas; and (4) provide a clearer description of the complementarity of planted forests with other productive land-uses, such as sheep and cattle farming [18,49].

New Zealand has approximately 1.75 million ha of planted forests, accounting for 22% of the country's total forest area [50]. For the year ending June 2019, the NZ forest industry exported NZ\$6.8 billion worth of forest products making it the country's third largest primary export earner (after dairy products (NZ\$42.7B) and meat and wool (NZ\$9.5B)) [51]. The NZ planted forest ecosystem is recognized, to a lesser extent, for providing other services like climate change mitigation [52], avoided erosion [23], habitat provision for native species [53], recreation [54], flood mitigation [55], and improved water quality through filtration of sediments and nutrient mitigation [56,57]. However, the non-market ES value of the entire NZ planted forest estate has not yet been fully evaluated, nor have the views of forest environmental managers on the quantification of non-market ES been studied. This is the first study that attempts to: (1) quantify the market and non-market values of existing NZ planted forests within a spatial framework; and (2) present the views of the key forest managers on how the quantification of forest ES can help in their forestry operations.

1.2. Assessment of Forest Ecosystem Services

A planted forest ecosystem provides multiple benefits that can be grouped into four categories. The first category is *provisioning* services, which represent the material benefits, for example, timber and understory crops. Secondly, *regulating* services are processes

that protect or maintain environmental quality that indirectly benefits the society (e.g., carbon sequestration). Thirdly, *cultural* services are the non-material social benefits that people can enjoy (e.g., recreation). Fourth is the ecosystem's biological, chemical, and physical mechanisms that collectively deliver *supporting* services (e.g., soil formation, nutrient cycling) that underpin the provisioning, regulating, and cultural ES that together contribute toward the components of well-being (e.g., materials for the good life and access to clean air and water). The suite of ES provided by planted forests is shown in Figure 1.

Figure 1. Ecosystem services provided by planted forests and their contributions to human well-being (Adapted from MEA [10], Yao, Barry [58], and Haines-Young and Potschin [12]).

NZ's planted forests are mainly recognized for provisioning services [30,58]. The value of these tangible benefits is often reported in the accounting system (e.g., revenue from sale of logs). Some planted forests can produce understorey crops like *Panax ginseng*, providing financial benefits greater than the production and sale of logs alone [59]. Planted forests can also provide firewood to landowners and nearby residents, where the non-market value of the firewood collected can be imputed by multiplying the firewood volume by its retail price. Valuation of provisioning services is straightforward, especially those that have physical quantities traded in the market, for example, US\$112 per JASm³ of an NZ A-grade export log [60].

Regulating services from NZ planted forests include carbon sequestration, avoided erosion, nutrient mitigation, flood mitigation, and water filtration [33]. Despite the importance of these services, they remain poorly understood and often ignored in decision making [27]. However, we can put together data from related studies, while also developing research tools that combine spatial, ecological and economic approaches, to quantify these services [31]. A hectare of NZ planted forests can sequester up to 807 tonnes of CO₂ over a 28-year period considering the amount of biomass accumulated below- and above-ground [61]. Planted forest stands stabilize the soil on steep slopes while improving the quality of water supply for downstream users [62,63]. They also regulate water flow from catchments. While some research results suggest that planted forests or afforestation can reduce water supply to downstream communities compared to pasture areas [64–66],

long-term research in South Africa has indicated that mature planted pine and eucalypts were not harmful to water yield [67].

Cultural services include recreational walking and mountain biking, viewing of iconic native species, a sense of place, and educational field trips that people derive pleasure from (Figure 1). These services are deeply interconnected with each other and often connected to provisioning and regulating services. The public recreational value of an iconic NZ planted forest has been estimated using the travel cost economic valuation technique [54]. In that study, the distribution of the non-market values of recreational visits was estimated based on the survey responses of more than 700 repeat visitors of the 5667-ha Whakarewarewa Forest in Rotorua. Based on the cost of travelling to and time spent in the forest, as well as other factors, the value of a walking and a mountain biking visit was estimated to be about NZ\$40 and NZ\$56, respectively (in 2020 NZ\$). These values can be multiplied by the number of visits per year resulting to an aggregated recreational value of NZ\$11 million per year. This should be interpreted as the public value of recreation that is provided over and above the production and sale of logs. Additionally, the forest management has been harvesting and planting on selected forest compartments so that recreation still occurs in most parts of the forest.

New Zealand planted forests also provide habitats for at least 118 native species, including the iconic brown kiwi (*Apteryx mantelli*) [53]. The perpetual value of a potential five-year brown kiwi conservation program in NZ's planted forests has been estimated by combining economic, spatial and ecological approaches [17]. That study estimated this value in perpetuity to be approximately NZ\$15.2 million where it is assumed that the program sustains the brown kiwi population in the long run. Spiritual, educational services, and cultural heritage values remain a challenge to either monetize or quantify. However, some frameworks have been developed to provide approximations of cultural health indices and non-monetary indigenous metrics, while other methods provide qualitative descriptions of other cultural values (e.g., life force, connection with place) for incorporation in decision making [68–70].

Ecosystem services from NZ planted forests contribute to various components of human well-being, such as improved human health through reduction in stress from forest recreation as well as access to clean air and water (Figure 1). The non-market value of health benefits of forests have been estimated overseas [71]. Other international studies have quantified the non-monetary contributions of forests to physical and mental well-being [72,73]. Family-owned forests in Sweden have been studied for their provision of multiple social values [74]. Similar health and social value studies have not yet been done for NZ planted forests but would make interesting future research.

The above estimated monetary values of non-market ecosystem services of NZ planted forests are indicative (and not absolute) and should be treated with caution. The intention of the above non-market valuation studies was to represent those important non-market values in cost benefit analyses to inform policy and to address market failure. The objective of this present study was to describe how ES can be quantified and represented in decision making. Our focus here was to provide evidence of how estimated non-market environmental values compare with market values, as well as to highlight the importance of including them in decision making processes.

1.3. Valuation of Non-Market Forest Ecosystem Services

The development and application of economic valuation methodologies to ES has grown significantly as market failure continues to become a major issue in decision-making processes [7,15,75]. There have been several attempts to estimate non-market values using the survey-based technique choice experiment to estimate the willingness to pay or acceptance of people for the change in the levels of cultural forest ecosystem services [17,76]. Other studies have combined spatial, biophysical, and economic approaches to approximate the non-market monetary value of regulating services provided by forests, such as carbon sequestration, avoided erosion, and avoided nutrients [77–79]. These regulating

services provided by forests are of major concern in NZ and worldwide and are expected to increase in importance giving the growing issue of climate change, water scarcity, water pollution and biosecurity [80–84]. As the public value of these services is often poorly understood, they should be quantified and represented in decision making [85,86].

Monetary valuation of non-market ES values has been criticized as inherently reducing their complexity and failing to account for their multi-dimensional nature [16,87]. However, economic valuation of non-market ES, such as regulating services, can help ensure that they are considered alongside the provision of timber in decision making based on cost benefit analysis (CBA). This therefore supports future CBA studies to account for the non-market ES values of planted forests. Such CBA studies would complement other methods, such as multi-criteria analysis, that integrate additional dimensions and allow decision makers to rank the different options based on their particular criteria [88,89].

2. Materials and Methods

The ES values from planted forests vary across space because they are affected by multiple factors such as terrain, soil type, climate, and temperature. To account for this variation, the quantification and valuation of ES requires the use of a spatial framework that combines biophysical, productivity, and economic data while also accounting for impedance factors, such as slope and soil type. In this section we describe how we quantify the four ES provided by existing planted forests—timber, carbon sequestration, avoided erosion, and avoided N leaching. To gain an understanding of the relevance of ES quantification from the perspective of the NZ forest industry, we interviewed forest managers using a semi-structured interview instrument.

2.1. Study Area

We used Land Cover Data Base (LCDB) version 4.1 spatial data to identify planted forests locations across the country [90,91]. LCDB is a multi-temporal, thematic classification of NZ's land cover developed from satellite imagery captured in different points in time (1996, 2001, 2008, 2012). LCDB was used to identify existing exotic forests and harvested forests representing the year 2012. Because LCDB also identifies areas that may not be large enough to be classified as “forests” (e.g., shelter belts and small woodlots), we used ArcGIS version 10 to identify and remove forest areas smaller than 5 ha. The result is a spatial layer of the planted forest estate consisting of currently planted and bare land likely to be reestablished as planted forests. Regional boundaries of the map were identified based on the StatsNZ's regional council boundaries that was released on 1 January 2018 [92]. The map created shows the distribution of existing planted forests across the NZ regions (Figure 2).

2.2. Spatial Quantification of Ecosystem Services

We used the FIF [18] to undertake the spatial economic analysis of the four ES across NZ. This framework utilizes a wide range of spatial environmental and non-spatial economic inputs. The formulas used to spatially calculate the ES values are described below.

Figure 2. New Zealand planted forest distribution by region using Statistics New Zealand's regional council boundaries [67].

2.2.1. Timber

Forest Investment Framework's validated timber viability component was used to quantify the market value of timber of the spatially identified NZ's planted forest estate. This timber component provides spatial approximations of crop productivity, and the costs and revenues of both current and future forests [93,94]. Timber viability is assessed by assuming a *Pinus radiata* structural (framing) or unpruned regime (thinned to 600 stems ha^{-1} from initial planting of 900 stems ha^{-1}) with a rotation length of 28 years, which is standard practice in NZ. A range of financial discount rates was used to account for the time

value of the cost and returns of producing the timber products. To calculate the cost of producing logs, we developed spatial cost functions for plantation establishment, silviculture management regimes, landing development, road construction and maintenance, log harvesting operations, and transport of logs to the point of sale (e.g., shipping port or timber mill). Impedance factors, such as slope and soil type, affect the cost of forest operations. Considering these factors enables us to account for the impacts of steeper slopes on harvesting cost as well as road construction and maintenance. To calculate the log revenue, we multiplied the different log grades based on the productivity layer by the 36-month average log prices reported in AgriHQ (<https://agrihq.co.nz/forestry>—Accessed on 19 May 2020). The formula used to calculate the net present value (NPV_g) or profitability of timber from a rotation of *P. radiata* for each spatial grid g with a 100×100 m (1 ha) cell size resolution is

$$NPV_g = \sum_{t=1}^T \frac{R_t - C_t}{(1+i)^t} \quad (1)$$

where R_t represents a vector of revenues (sum product of the volume of logs by log grade and the price per log grade per cubic metre) for the different log grades harvested in grid g , C_t is a vector of various costs that include establishment, silviculture, harvesting, and transport incurred across time t . The revenue and costs are all expressed on a per ha basis. As timber is a private benefit realized by forest owners, we used the standard industry discount rate of $i = 6\%$ as our main discount rate. To account for potential fluctuations in industry discount rates, we have also used 4% and 8% based on the results of a survey of NZ experts [95].

2.2.2. Carbon Sequestration

To calculate the non-market carbon sequestration value, we used an approximate volume of carbon that can be sequestered across a 28-year rotation unpruned regime of *P. radiata*. The carbon layer utilized by FIF was generated from the Carbon C-change model [96,97]. This layer is the net sequestration rate per rotation considering gains due to forest growth and losses due to harvest. This layer helps estimate the monetary value of carbon sequestration by using the price per tonne of carbon dioxide equivalent recognized in NZ's Emissions Trading Scheme (ETS), which was NZ\$23 per tonne at the time of the study. For more details of FIF's assumptions and formulas for carbon sequestration value, please refer to Barry et al. [23].

As more than 60 percent of the existing planted forests are on their second, third, or fourth rotation [98], the sequestration service provided by these older forest areas are not fully recognized in NZ's Emissions Trading Scheme as they are categorized as "pre-1990 forests" [99]. Consequently, the monetary value that we estimate in this study should be considered as a non-market ES value. This represents the public value of managed carbon in planted forests. We therefore assigned "social" discount rates of 2%, 2.5%, and 3% (based on Maseyk et al. [100] and Shepherd et al. [101]) to represent the long-term importance of this climate change mitigation value.

2.2.3. Avoided Soil Erosion

To quantify the non-market erosion mitigation services of planted forests, FIF uses spatial data from the New Zealand Empirical Erosion Model (NZeem[®]) [102]. This enables the estimation of erosion rates of land covered in woody vegetation (e.g., native forests and planted forests) and non-woody (e.g., bare land, pasture) vegetation across the landscape. The FIF considers that the difference in sedimentation levels between forest and bare land represents the quantity of avoided erosion across the landscape. The NZeem[®] calculates the amount of sediment generated under the current woody vegetation in tonnes of sediment per square kilometer per year and calculates the sedimentation rate associated with non-woody land use. Under a planted forest setting, FIF assumes full canopy cover when *P. radiata* reaches a stand age of 7 through to 27 years, and therefore maximum protection against soil erosion is achieved. It also considers the periods over which tree establishment

(years 0 to 6) and harvesting (year 28) occur, when the protection from soil erosion function of planted forests is low. The modelling of avoided erosion value is informed by a decay function based on Fahey and Marden [62], which suggests that the overall net effect of planted forests in reducing erosion is positive.

The economic data used to approximate avoided sedimentation of water ways consists of avoided flood damage (NZ\$0.90/tonne) and avoided water treatment costs to consumptive water (NZ\$5.60/tonne) [23]. This total avoided erosion value of \$6.40 was calculated in 2012 NZ\$ and inflating this to 2020 NZ\$, we readjust to NZ\$6.82 [23,79,103]. This approximate value of avoided erosion per tonne represents a lower bound value estimate similar to the off-site cost of erosion of NZ\$7.25/tonne (in 2020 NZ\$) [103]. The combined value of avoided cost of water filtration and avoided flood damage can serve as proxy for the public value of avoided biodiversity loss [23,79]. Despite avoided filtration cost and avoided flood damage are not a perfect measure (as some areas in NZ do not process surface water for drinking and not all areas are flood prone), they can still represent an indicative value of avoided sedimentation of water ways.) The economic value of avoided erosion is calculated as

$$ASE_g = \sum_{t=1}^T \frac{(S_{pg} - S_{fg})(S_t)(W)}{(1 + i_s)^t} \quad (2)$$

where ASE_g is avoided soil erosion value over a 28-year rotation of *P. radiata* in grid g , S_{pg} is the rescaled sedimentation coefficient from NZeem[®] measuring tonnes of sediment lost for land use p (pasture) (f for forest) in grid g . W is the estimated price per tonne of avoided sediment, S_t is a vector of the sedimentation ratio of pasture to forestry at time t , while i_s is the social discount rate where we also used 2%, 2.5%, and 3% [100,101,104]. The true value of avoided erosion (in NZ\$/tonne) would likely vary across NZ due to a number of factors; however, we have assumed here that the avoided cost in water filtration and avoided flood damage is the same throughout the country.

2.2.4. Avoided Nitrogen Leaching

We used a simplified avoided nutrient function based on the average leaching rates under planted forests and bare land following the review report by Menneer et al. [105]. The FIF utilizes the change in nitrate-nitrogen (N) leaching ($\text{kg N ha}^{-1} \text{ yr}^{-1}$) due to land use change as an indicator of ES value. The non-market value of avoided N leaching is calculated by taking the difference between the leaching rate under *P. radiata* with that under pasture (i.e., livestock). To calculate for the change in leaching rate, we deduct the leaching rate under forestry of 3 kg per ha per year based on the work by Yao and Velarde [49] with the current leaching rate which we assumed to be under pasture. (The average N leaching rate of 3 kg per ha applies for undisturbed NZ forests and this rate can increase to 28 kg per ha at harvest of radiata pine forest in a particular NZ region [105]. An important future study should estimate the value of avoided N leaching by accounting for the variation in leaching rates across NZ.) For the price of avoided N (P_n) in Equation (3), we used the annualized price of NZ\$25 per kg per year of N, which we derived from a one-off payment of NZ\$400 per kg reported in Duhon et al. that we adjusted to account for inflation [106]

$$\text{Avoided_}N_g = (N_{pg} - N_{fg})(P_n) \quad (3)$$

where N_{pg} is the amount of nitrate-N leaching under pasture in kg N per ha in grid g , N_{fg} is the nitrate-N leaching under forestry in kg N per ha, P_n is the one-off payment for one credit of avoided N (i.e., reduction of 1 kg of N leaching per ha). Similar to avoided erosion value above, the value of avoided N leaching would likely vary across the country, however, we have used here a strong assumption that it is fixed throughout NZ.

2.2.5. Conversion to Annualized Values and Sensitivity Analysis

The ES values for timber, carbon sequestration, avoided erosion, and avoided N were all calculated based on a 28-year rotation of forestry (and we assume that forest areas

will be replanted after harvest). To allow the comparison of these forestry values with competing land uses (e.g., sheep and cattle production), there is a need to annualize the values (A_V) by using the equivalent annual value formula

$$A_V = \frac{i * V}{1 - (1 + i)^{-h}} \quad (4)$$

where i is the discount rate, V is the calculated value of a forest ES, and h is the rotation length (set at 28 years). To calculate the annualized values of timber and non-market ES, we used two sets of discount rates. For the market value of timber, we used 4%, 6%, and 8% which fall within the range of discount rates identified in a recent survey of 23 forest valuation experts in New Zealand [95]. We used 6% as our main discount rate for our timber valuation analysis. For the annualized values of carbon sequestration, avoided N, and avoided erosion, we used the social discount rates of 2%, 2.5%, and 3% that we identified based on Maseyk et al. [100] and Shepherd et al. [101].

2.3. Interview with Forest Managers

We surveyed the environmental managers of 14 NZ forest companies consisting of two large-scale (>150,000 ha), nine medium-scale (15,001 to 150,000 ha), and three small-scale (<15,000 ha) forest companies. The managers were responsible for the sustainable management of their respective forest assets. Activities within their role include environmental management, maintain and sustain social license to operate, and engaging with government agencies, research institutions and community groups related to their forest management activities. All medium- and large-scale forest companies were FSC-certified, while only one small-scale company was FSC-certified [107]. Two large-scale and one medium-scale forest companies were also certified under the Program for the Endorsement of Forest Certification (PEFC) [108].

A face to face or phone semi-structured survey was carried out with the forest managers between July 2019 and June 2020. The survey focused on the managers' awareness of the ES framework; relevance of the framework to forest operations, management, and forest certification; key forest ES considered in forest management; benefits they had experienced, opportunities or challenges they could see associated with ES quantification. Finally, they identified which ES they saw most important to quantify and the reasons for this. Survey interviews took between 25 and 45 min to complete. In total, the area covered by the survey was between 55% and 60% of NZ planted forests and were distributed across both islands.

We focused on analyzing the responses of the 11 forest managers medium- and large-scale forest companies in Sections 3.2.1 and 3.2.2 as the study focuses on medium to large scale sustainable forest management and certification. Responses from the three small-scale companies were only included in Section 3.2.3 which describes the benefits, opportunities, and challenges of ES quantification.

3. Results

3.1. Quantification of Forest Ecosystem Services

Results of the assessment of the value of the four ES are presented region by region, as NZ\$/ha/year to allow comparison with other agricultural land uses, such as beef cattle production and sheep and wool production (which normally report NPVs on an annual basis). We report here spatially detailed (i.e., 1 ha cells) results for timber and carbon sequestration values. The results for avoided nutrients and avoided erosion are presented as aggregated non-market ES values at the regional level.

3.1.1. Timber

The boxplot in Figure 3a indicates that timber production from existing planted forests varies in profitability with annualized NPVs ranging between -NZ\$200 and NZ\$900 per ha per year. (Outliers in the boxplots were excluded for clear illustration of NPV distributions by region. We used the package Stata version 15 to create the box plots.) Results also

suggest that forests areas are generally profitable across all NZ regions with almost all (96%) of the 1.75 million ha having positive NPVs. Based on FIF's spatially explicit timber profitability analysis, Auckland, Hawke's Bay, Bay of Plenty, and Southland are the regions with the highest annualized median NPV (greater than NZ\$400 per ha per year); while the West Coast has the lowest at median NPV (less than NZ\$200 per ha per year). In terms of average profit per hectare, Southland (NZ\$756), Hawke's Bay (NZ\$450), and Auckland (NZ\$405) are the top three regions (Table 1). Gisborne (NZ\$402), the region where high soil erosion rates have been reported to occur [23,109], has the fourth highest average profit, while Otago (NZ\$131) has the lowest average profit.

Figure 3. (a) Distribution of the annual timber profitability values by region (excludes outside values). (b) Distribution of the non-market values of carbon sequestration by region (excludes outside values).

Table 1. Calculated values of the four forest ecosystem services by region.

Region	Area * (ha)	Ecosystem Service Values (NZ\$ per Year) **					Ecosystem Service Values (NZ\$ per ha per Year)				
		Timber (6%)	Carbon (3%)	Avoided N (3%)	Avoided Erosion (3%)	Total	Timber	Carbon	Avoided N	Avoided Erosion	Total
Northland	160,770	53,677,085	70,310,382	72,346,351	178,594,507	372,034,472	334	437	450	1111	2314
Auckland	42,658	17,272,256	17,355,340	19,196,250	2,220,847	55,276,842	405	407	450	52	1296
Waikato	275,492	59,731,007	67,864,659	123,971,431	13,316,163	259,924,404	217	246	450	48	943
Bay of Plenty	258,693	68,497,998	72,082,334	116,412,073	15,206,076	267,541,998	265	279	450	59	1034
Gisborne	156,557	62,976,427	78,332,099	70,450,737	641,337,027	850,278,261	402	500	450	4097	5431
Manawatu-Whanganui	122,564	35,823,303	49,376,578	55,153,678	18,274,562	156,421,974	292	403	450	149	1276
Hawke's Bay	138,486	62,359,001	66,697,897	62,318,807	35,641,209	224,524,161	450	482	450	257	1621
Taranaki	20,680	7,460,829	9,587,874	9,306,214	5,064,856	31,047,525	361	464	450	245	1501
Wellington	64,241	23,845,471	27,940,849	28,908,631	39,284,938	118,823,544	371	435	450	612	1850
Marlborough	74,583	21,594,763	33,838,817	33,562,132	5,172,835	92,826,062	290	454	450	69	1245
West Coast	37,125	4,978,312	10,046,533	16,706,079	13,115,588	44,178,270	134	271	450	353	1190
Canterbury	95,612	30,246,800	32,313,868	43,025,544	3,634,519	107,499,710	316	338	450	38	1124
Otago	120,511	15,817,441	17,810,020	54,230,017	4,040,369	89,728,646	131	148	450	34	745
Southland	78,244	59,170,697	53,987,992	35,209,749	2,317,995	149,278,043	756	690	450	30	1908
Nelson/Tasman	103,783	26,647,271	36,393,674	46,702,307	13,127,954	121,003,115	257	351	450	126	1166
New Zealand	1,750,000	550,098,664	643,938,916	787,500,000	990,349,447	2,940,387,026	314	368	450	566	1680

* Area was estimated using Land Cover Data Base (LCDB) version 4.1. ** Numbers in parentheses are discount rates.

3.1.2. Carbon Sequestration

With a carbon price of NZ\$23 per tonne of carbon dioxide, Gisborne, Hawke's Bay, Taranaki, and Auckland provide the highest median non-market values of carbon sequestration (i.e., >NZ\$460 per ha per year) (Figure 3b). The South Island regions of West Coast and Otago have the lowest median carbon values. Planted forests in the Canterbury region provides a median carbon value of >NZ\$360 per year per ha, but the region's carbon values have the highest variation (i.e., standard deviation \$79). In terms of average carbon sequestration value per hectare, like timber values, Southland has the highest while Otago the lowest (Table 1).

3.1.3. Avoided Nitrogen Leaching

In contrast to the spatially explicit calculation of timber, carbon sequestration and avoided erosion values, the avoided N leaching calculation was not spatially explicit. The calculation was simply based on the difference between average leaching under forestry and under pasture area, and then multiplied this difference by the annualized price of a kg of avoided N, and that we arrived at a value of NZ\$432 per hectare per year. This makes the Waikato (NZ\$119 million) and Bay of Plenty (NZ\$112 million) regions to have the highest avoided N values as they have the two largest planted forest areas in the country (Table 1). Developing a robust, spatially explicit avoided N valuation function for FIF is a future work.

3.1.4. Avoided Erosion

Amongst the 15 NZ regions, planted forests in Gisborne stand out as a highest provider of avoided erosion values. FIF's spatially explicit avoided erosion value calculation suggests that, on average, a ha of existing planted forest in Gisborne provides about NZ\$4097 (Table 1). (The avoided erosion value estimate of NZ\$4097 is significantly lower than Barry et al. [23] which also used FIF to estimate the avoided erosion value (NZ\$10,671 per ha) of establishing *P. radiata* forests in moderate to severely eroding marginal areas in Gisborne.) Northland and Wellington are a distant second and third with NZ\$1111 and NZ\$612 per ha, respectively. The average avoided erosion value in NZ planted forest is approximately NZ\$566 per hectare. This makes avoided erosion value in Gisborne to be seven times the country's average. In contrast, planted forests in Otago (NZ\$34) and Southland (NZ\$30) provide the lowest avoided value.

3.1.5. Analyzing Ecosystem Services Values and Sensitivity Analysis

The calculated values of the four ES across NZ regions can be added up following the approach by von Hase and Cassin [110] to illustrate the distribution of ES values by region (Figure 4). "Stacking" shows that the proportion of timber profit accounts for only about 7% to 40% of the total value of the four ES across regions. Timber profit is the primary reason for planting these forests and this market value is included in the national accounting system. Although forest companies are mandated to sustainably produce logs, they are also providing non-timber or non-market ES values. The stacked ES values in Gisborne shows that avoided erosion value erosion is about 75% of the overall value and this makes timber (7%) as a minor ES value. Calculating for the ratio between the non-market ES values (avoided erosion, avoided N leaching, carbon sequestration) and the timber value, we find that non-market values can be 12.5 times the timber value. This result is consistent with other studies [57,93,111]. For the entire NZ planted forest estate, the value of timber accounts for only 19% of the combined values of the four ES suggesting that the three non-market ES values are at least four times greater than timber.

Figure 4. Stacking up selected ecosystem services of planted forests by NZ region and for whole of NZ.

The above ratios and proportions are calculated based on a 6% discount rate for timber and a 3% discount rate for non-market ES. We now use a range of discount rates to evaluate their effects on the ratio between the non-market and timber ES. Assuming a 4% discount rate for timber, while holding the discount rate for non-market ES constant at 3%, the ratio between non-market and timber values in the Gisborne region rises (from 12.5) to 14.6 (Table 2). Using an 8% discount rate for timber, that ratio falls to 11.1. Keeping an 8% discount rate for timber and using a 2% social discount rate for non-market ES result to a further decline in the ratio to 10.1. Results above demonstrate how the ratios are impacted by the variation in the discount rates implying that the latter is a source of uncertainty in the calculation of ES values.

We have quantified the market and the non-market monetary values of the four ES. Based on our spatial economic quantification using FIF, the NZ planted forest estate provides annual ES values for timber of approximately NZ\$550 million (using a 6% discount rate); and non-market carbon sequestration, avoided N and avoided erosion values of NZ\$644 million, NZ\$788 million, and NZ\$990 million, respectively (using a 3% discount rate) (Table 1). Stacking up the four ES values together, the aggregated annualized timber value accounts for 19% while the three other ES respectively account for 22%, 26%, and 33% (Figure 5). Assuming a 4% discount rate for timber and 3% for the non-market ES, the timber value proportion declines to 17%, while the higher timber discount rate of 8% results to a rise in the timber value proportion to 20% (Figure 5—left column). Using social discount rates of 2.0% and 2.5% while holding timber discount rate constant at 6%, we find minimal changes in the ES value proportions (Figure 5—right column). This is because we used a smaller range of variation (i.e., 2%, 2.5%, and 3%) in the social discount rates that we derived from the literature.

Table 2. Impacts of using different discount rates on timber and non-market ES values and their ratios.

Region	Timber (T) Value (NZ\$ per Year)			Non-Market (NM) value (NZ\$ per Year)			Ratio (NM Value/T Value)								
	<i>Timber Discount Rate</i>			<i>Social Discount Rate</i>			<i>% Discount Rate Combination</i>								
	4.0%	6.0%	8.0%	2.0%	2.5%	3.0%	NM = 3; T = 4	NM = 3, T = 6	NM = 3, T = 8	NM = 2.5, T = 4	NM = 2.5, T = 6	NM = 2.5, T = 8	NM = 2, T = 4	NM = 2, T = 6	NM = 2, T = 8
Northland	46,208,556	53,677,085	60,558,031	291,751,016	306,458,656	321,251,241	7.0	6.0	5.3	6.6	5.7	5.1	6.3	5.4	4.8
Auckland	14,869,027	17,272,256	19,486,412	35,211,997	36,987,091	38,772,437	2.6	2.2	2.0	2.5	2.1	1.9	2.4	2.0	1.8
Waikato	51,420,147	59,731,007	67,388,015	186,313,299	195,705,653	205,152,254	4.0	3.4	3.0	3.8	3.3	2.9	3.6	3.1	2.8
Bay of Plenty	58,967,315	68,497,998	77,278,859	184,994,843	194,320,732	203,700,483	3.5	3.0	2.6	3.3	2.8	2.5	3.1	2.7	2.4
Gisborne	54,214,005	62,976,427	71,049,470	717,563,838	753,737,389	790,119,863	14.6	12.5	11.1	13.9	12.0	10.6	13.2	11.4	10.1
Manawatu-Whanganui	30,838,915	35,823,303	40,415,546	111,527,758	117,150,052	122,804,818	4.0	3.4	3.0	3.8	3.3	2.9	3.6	3.1	2.8
Hawke's Bay	53,682,486	62,359,001	70,352,895	149,537,518	157,075,946	164,657,912	3.1	2.6	2.3	2.9	2.5	2.2	2.8	2.4	2.1
Taranaki	6,422,744	7,460,829	8,417,244	21,758,815	22,855,712	23,958,945	3.7	3.2	2.8	3.6	3.1	2.7	3.4	2.9	2.6
Wellington	20,527,657	23,845,471	26,902,258	87,306,477	91,707,737	96,134,418	4.7	4.0	3.6	4.5	3.8	3.4	4.3	3.7	3.2
Marlborough	18,590,108	21,594,763	24,363,028	65,909,396	69,231,995	72,573,784	3.9	3.4	3.0	3.7	3.2	2.8	3.5	3.1	2.7
West Coast	4,285,639	4,978,312	5,616,489	36,207,138	38,032,398	39,868,200	9.3	8.0	7.1	8.9	7.6	6.8	8.4	7.3	6.4
Canterbury	26,038,317	30,246,800	34,124,183	71,721,823	75,337,436	78,973,931	3.0	2.6	2.3	2.9	2.5	2.2	2.8	2.4	2.1
Otago	13,616,631	15,817,441	17,845,102	69,094,008	72,577,148	76,080,406	5.6	4.8	4.3	5.3	4.6	4.1	5.1	4.4	3.9
Southland	50,937,797	59,170,697	66,755,878	83,111,925	87,301,731	91,515,736	1.8	1.5	1.4	1.7	1.5	1.3	1.6	1.4	1.2
Nelson/Tasman	22,939,620	26,647,271	30,063,225	87,387,774	91,793,133	96,223,935	4.2	3.6	3.2	4.0	3.4	3.1	3.8	3.3	2.9
New Zealand	473,558,965	550,098,664	620,616,635	2,199,397,626	2,310,272,810	2,421,788,362	5.1	4.4	3.9	4.9	4.2	3.7	4.6	4.0	3.5

Figure 5. Pie charts showing the impacts of different discount rate combinations on the distribution of the four ES values provided by NZ planted forests.

It is also important to provide indicative physical quantities of avoided N leaching and avoided soil erosion. Results from our calculations suggest, without accounting for any sources of uncertainty, that NZ planted forests provide approximately 32 million kg of avoided N leaching per year and approximately 46 million tonnes of avoided sediments going into the water ways every year.

3.2. Survey Results

Results from interviews of forest managers from medium to large scale companies indicate that nine out of eleven respondents were aware of the ES concept. Four respondents first became aware of the concept through participation in conferences, four learned from reading either technical papers and/or industry magazines, while only one became aware of the concept through conversing with colleagues. One respondent who was already aware of ES thought that it is as an old concept that has recently been restructured and relabeled. The two respondents who were not aware of ES had only recently (i.e., less than two years) held the position of forest environmental manager and therefore had limited exposure to the concept.

Responses to survey questions can be grouped into three categories: (1) relevance of ES to companies; (2) identification of ES that need quantification; and (3) benefits, opportunities, and challenges of ES quantification.

3.2.1. Relevance of ES to Medium- and Large-Scale Forest Companies

When asked about the relevance of the ES concept/framework to their respective companies, 82% of the medium and large forest companies reported that the application of the ES framework was relevant for the recognition of the broader value of their forests, which helps in maintaining their license to operate (Figure 6). Fifty-five percent reported that the framework helped in planning for sustainable forest management; 55% also reported its usefulness for informing the requirements of product certification. Thirty-six percent reported that the framework can be used to help communicate to the public that their respective forests provide a recreation amenity or a public attraction. Promoting forests' recreational amenity values applies mainly for planted forests near urban centers that provide free access for walking, mountain biking, horse riding, orienteering, and education field trips. Two out of the eleven respondents mentioned that the ES framework had been relevant for informing land use decisions, for example acquisition of a marginal pasture area for conversion to forestry. Using the framework allows one to get some indicative values of avoided N leaching, which can be used to inform the decision to join a nutrient trading scheme. This indicative nutrient value and other quantified non-market ES values could somewhat offset the reduction in land value due to conversion from pasture to forestry.

Figure 6. Relevance of the ES framework for the forestry business (n = 11).

One respondent reported that the framework had been useful to provide third-party evidence that privately operated planted forests provide carbon sequestration, soil protection and social benefits. These quantified non-market ES values can be incorporated in their reports for government policy compliance and annual reports to help demonstrate corporate ethics. One respondent believed that staff recruitment and retention was being enhanced because of the high-quality mountain biking and walking trails associated with their forests on their doorstep. Therefore, the quantification of the cultural value of recreation using ES and reporting these values on the company's website demonstrates well-being values for current and prospective staff members.

Respondents were then asked which ES values were considered in forest operational management, social license to operate, and forest certification. To help answer this, they were provided with a list of 17 NZ forest ES reported in Yao et al. [93]. They were also asked to identify other ES values not listed. About 82% of respondents reported that *biodiversity conservation* (i.e., sustaining and enhancing native birds and other native animal species) and *preservation of natural areas* (which include iconic high value native vegetation areas within the forest estate), were the two most important values (Figure 7). The third most important ES was water quality maintenance and enhancement, followed by recreational walking and mountain biking, hunting, cultural values, general access, and then scientific studies. Interestingly, most of these ES are related to engagement with (or providing access to) the local community. One forest manager reported that their FSC certification process had focused on the value of engagement of the forest company with local stakeholders, which included forest users, government agencies, and non-government conservation institutions. This indicates that this particular forest estate provides a “sense of place” that links the different stakeholders to the common goal of maintaining and sustaining the planted forest ecosystem to provide environmental and cultural benefits.

Figure 7. Ecosystem services considered important to social license to operate, sustainable forest management and forest certification by participating forest companies (n = 11).

Co-generation of heat and power, firewood, water quantity, and native tree timber were ES considered by at least one out of eleven respondents. This result suggests that assessment of these ES was less of a priority to support sustainable forest management, social license to operate and/or certification. However, these ES can be very important to downstream stakeholders and the wider public. Perhaps a future study can specifically explore the most important ES from the point of view of downstream stakeholders so that the provision of these important services could be prioritized or potentially be co-managed by the forest company with stakeholders.

3.2.2. Forest Ecosystem Services That Need Quantification

Ten out of eleven respondents agreed there was a need to quantify and/or describe ES provided by their forests. One respondent noted the classic quote of management guru Peter Drucker “What gets measured gets managed” [112]. This respondent emphasized the

importance of establishing a baseline measure to indicate whether the level of provision of an ES (e.g., recreation value expressed in number of visits per year) is improving or not over time. The top five ES that forest managers would like to quantify were biodiversity conservation (82%), recreation (82%), carbon sequestration (55%), improved water quality (55%), and water flow regulation (18%). One reason these services should be quantified was because respondents were already familiar on the methods valuing these ES. Most respondents had also engaged with scientists who provided some awareness of existing and developing tools for ES quantification (e.g., FIF). Forest Investment Framework currently has ES valuation functions that cover the first four ES (biodiversity, recreation, carbon, and water quality) that managers would like to quantify. The (fifth ES) water flow regulation valuation function in FIF is under development and our team will continue to engage with these forest manager respondents in designing the water flow valuation function over the next few years.

Respondents considered quantified ES values relevant for reporting, decision making and establishment of ES markets in the longer term. Interestingly, the top five ES they would like to quantify are listed on the FSC Ecosystem Services Procedure, which is envisioned to incentivize the restoration and conservation of forest ES [113]. This recent FSC procedure is not required for FSC certification, rather, it is intended to enable forest companies to verify specific positive impacts of forestry activities on ES that could potentially access the developing global market for ES provision.

One respondent commented that the amount of carbon dioxide sequestered by their older forest areas (i.e., those already on two or more 28-year forestry rotations) do not get fully credited in the NZ ETS because of the adherence to the Kyoto Protocol. Quantified carbon sequestration services from forests planted before 1990 need to be better recognized as establishing and maintaining them as planted forests (and not converting to pasture) still contributes significantly to climate change mitigation. Another respondent emphasized the need to estimate the multiple non-market values of planted forests in monetary form using economic valuation methods (e.g., stated preference, travel cost, hedonic pricing method, and production function), which are based on economic theory [114,115]. These methods are continuously improving and have been used to objectively quantify improved provision of non-market ES, such as indigenous biodiversity conservation, water quality, and recreation in NZ planted forests [54,56]. These estimated values can be included in cost benefit analysis or cost effectiveness analysis of decision makers.

It is also important to quantify non-market ES in non-monetary form. More than half (64%) of respondents not only support ES quantification of these values, but they also find it important to quantify in ecological terms (e.g., reduction of sedimentation (in tonnes per ha) of water ways) and/or describe non-market ES in spatial, qualitative/ordinal, or binary (yes/no) forms. This is to increase the visibility of these values, which are often neglected in decision making. One respondent added that a baseline measure of a forest ecosystem service (e.g., 400,000 recreational visits a year) could be included in both the short and long-term management planning of the forestry business and for forest certification compliance. Furthermore, this respondent mentioned that the high number of recreational visits to their urban planted forests contributed to their company achieving a high conservation value in the FSC certification process.

3.2.3. Benefits, Opportunities, and Challenges

All 11 respondents agreed that ES quantification is important as it enables the recognition, maintenance, and enhancement of those values in their respective forests. Respondents provided general comments on ES quantification. We have synthesized and categorized those comments into benefits, opportunities, and challenges below.

Benefits

Ecosystem services quantification has been found helpful in demonstrating and communicating the benefits of sustainable forest management, which include being a responsi-

ble forest grower. Three respondents highlighted that ES quantified values can be used to report the broader value of planted forests to shareholders (e.g., carbon sequestration, avoided erosion, and recreational hunting) of their planted forest estates. One of these three respondents reported that the ES quantification project (undertaken using FIF) in their planted forest estate helped renew their FSC certification. This respondent added that their company owners appreciate having the spatially explicit estimates of the non-market environmental values (e.g., carbon sequestration and avoided erosion) that their forest stands provide because it allows them to be more targeted in decision making.

Ecosystem services quantification also provides forest owners with a better understanding of the value of the production, conservation, and social functions of forestry. In the longer term, it can help develop reward systems for providing ES because maintaining and sustaining them can be costly (e.g., downtime in biodiversity conservation, hiring security to monitor forest recreational access and health and safety).

Opportunities

Having indicative values of non-market ES helps monitor and sustain their provision. Ecosystem services measures could help forest companies who allow public access in some parts of their forests to engage with the local communities (e.g., nearby residents and forest users). Such engagements would likely increase the awareness of communities on planted forests' broader values. In addition, the quantified values can be also used to report to the regulating agencies to explore the development of incentives for landowners or forest managers to sustainably provide public goods (e.g., tax rebate). This could provide an opportunity to develop a private-public partnership for resource conservation.

With the current trends in forest certification, it is highly likely that ES quantification will become more relevant in the forthcoming NZ and global FSC certification guidelines, which are expected to be released in late 2021. Knowing that ES modelling tools can be accessed to quantify ES assures that forest companies would be ready to comply with this potential certification requirement.

Quantification of ES values could help develop multiple land user interactions to offset environmental impacts. It could inform the conversation on how livestock and dairy farms could offset their N leaching impacts with avoided N credits from a planted forest area (i.e., offset site). Similarly, there is an opportunity to offset agricultural greenhouse gas (GHG) emissions by accounting for the carbon credits associated with a forest. If such mechanism were established, this could enhance the resale or market value of forestry lands. Development of ES trading systems and offset markets is a major opportunity for forestry.

Ecosystem services quantification frameworks may be helpful for other purposes, such as policy discussions and management of indigenous land. All the large exotic planted forest estates have native forest reserves. These reserves are not harvested and are serving as set asides that provide significant non-market ES (e.g., aesthetics, native species habitats, biodiversity conservation, cultural heritage, and sense of place). One respondent reported that they already have an established system for quantification and description of ES provided by their planted forest estate, including native vegetation. Another respondent reported that quantification and description of ES can also help with education and increasing awareness of communities on the broader value of the planted forest ecosystem. Furthermore, quantification of non-market ES values helps support social license to operate, engaging with local communities and with the understanding of the wider values of plantation forests at local, regional, and national scales.

Challenges

One challenge is the absence of a standardized system for quantifying ES values in NZ planted forests. Environmental (e.g., soil, climate, vegetation, biodiversity) and socio-economic (e.g., population, demographics, tourism, forest users) conditions vary across regions and therefore would likely result in heterogeneity in the quality of ES

provision. There are also different approaches to collecting and analyzing ES data. However, the United Nations and other international institutions have developed the System of Environmental Economic Accounting–Experimental Ecosystem Accounting (SEEA–EEA), which provides a framework to develop standardized measures to assess non-market ES values. The SEEA–EEA has already been considered in many countries including NZ in the development of natural accounts. Forestry manager respondents have expressed strong interest to work with NZ government agencies and others to develop standards for measuring and describing ES in NZ planted forests.

Small forest growers (fewer than 1000 ha) reported similar views on the benefits, opportunities, and challenges compared with larger forest companies. Key points that emerged included the relatively high expense of ES quantification for small forest areas and the need for tangible benefits from those services to make the expenses worthwhile. They did see benefits from quantifying their ES; mainly related to opportunities to benefit from the provision of these services to wider society and development of reward mechanisms such as tax breaks or other financial mechanisms. Quantifying ES will also allow demonstration and recognition of the public goods provided by forests to the wider community. Adding a spatial component to the quantification will allow targeted management of natural resources to sustain the provision of services.

4. Discussion

4.1. Quantification of Ecosystem Services

Studies on ES in NZ have been compiled in Dymond et al. (2013) [116] for a range of land uses (e.g., indigenous forests and shrublands, planted forests, orchard, livestock, and dairy) and ecosystems (e.g., marine, lakes, and wetlands). This paper presents the first national analysis utilizing a spatial ES quantification approach for existing planted forests in NZ, and as far as we are aware, internationally.

We assessed the national value and distribution of timber, carbon sequestration, avoided erosion, and nutrient loss mitigation. National statistics clearly demonstrate the value of the forest sector in terms of timber production with export earnings close to NZ\$7 billion per year from the planted forest estate [51]. Additionally, our ability to present results on an annual basis allows comparison with other land uses. Timber profitability ranges from NZ\$16/ha/yr to NZ\$451/ha/yr (this study), which falls within the range of annual drystock profitability (NZ\$126–NZ\$528 ha^{−1} yr^{−1}) reported in West et al. [83]. These indicative estimates suggest that both land uses provide virtually similar profitability on a per ha basis. However, with the inclusion of the three non-market ES values, the broader value of the planted forest option would support holistic land use decisions. With respect to carbon sequestration (considered here as a non-market value), the forest estate may be near steady state in terms of carbon stocks as the land area has been afforested for long periods of time with only small recent increases in area. The total value of carbon maintained is a good indicator of the distribution of carbon potential across the estate when using a standard regime. Presenting the carbon on an annual sequestration basis is not an ideal measure but is very important if considering land use change from forestry to pastoral or horticultural land uses, which maintain much lower stocks of carbon [117]. This will give an indication of what would be required to offset the carbon emissions from land use change at any location. The best estimate of actual national carbon stocks can be sourced from the national Land Use and Carbon Assessment (LUCAS) planted forest plot network [118] and these values reflect actual regime conditions on the ground.

New Zealand has some of the highest soil erosion rates in the world and if the existing forest estate which makes up ~7% of NZ's land area was in pastoral agriculture erosion rate would increase significantly, indicating very substantial avoided erosion benefits from the forest estate [55,109]. Similarly, if the forest estate were converted to pastoral agriculture as was done pre-2008 for areas in the Central North Island, the potential N leaching increases from this land use change would be significant—of between 13 and 57 kg/ha/year on land converted to drystock or dairy, respectively [105,119]. It is unlikely that all the forests

would be converted to pastoral uses, but if they were, this would equate to a significant increase in N leaching nationally [120].

4.2. Usefulness for the Forest Industry

The productive and regulating functions of the existing forests are very significant and, for the non-timber (non-market) ES, these functions are provided free of charge by the forest owners, providing a significant national good. When timber values and non-timber ES values are “stacked”, they make a very compelling case for planted forests economically and environmentally to complement other land uses that provide fewer non-market ES.

However, when asked, forest managers recognized factors other than the possible economic returns from provision of these services to be potentially more important. Managers identified the need to establish a reward or incentive mechanism to realize or sustain the provision of ecosystem services. This somewhat serves as a longer-term vision or aspiration of managers to have a reward system or payment mechanism for maintaining and enhancing forest ES that benefit the public, such as the water regulation service and protection against hydro-geological hazards that forests provide to downstream users. Grilli et al. [121] has recently developed a spatial-based tool that analyses the payments for forest ES related to hydrogeological protection in Italy.

The main opportunity identified by managers however was “provenance” or the ability to demonstrate the environmental credentials of their products in the market. They highlighted the need to quantify, describe and communicate the broader value of planted forests. Forest certification (such as FSC and PEFC) is one mechanism used internationally to demonstrate provenance. These third-party, independent product certification bodies have expanded across the world, and have become a global platform to provide incentives to forest managers to sustain and enhance the flow of ES from planted forests. The literature provides evidence that indicators and values of forest ES have been incorporated into strategies or plans of major product certification organizations to encourage the management of productive systems (e.g., planted forests) to protect natural areas to sustain the provision of the flow of these goods and services to society [108,122]. FSC has started to require forest managers to maintain and enhance the flow of ecosystem services provided by certified forests and this has been envisioned to increase the market value of FSC products [123]. FSC focuses on a subset of forest ES which are: (1) carbon sequestration and storage; (2) biodiversity conservation; (3) watershed services; (4) soil conservation; and (5) recreational services. The study also found that estimated ES values (e.g., carbon sequestration, avoided erosion) can contribute to the further development of forest certification schemes to sustain and enhance non-market ES provision in planted forests.

The third area recognized as important is the communication of the full value of forests to stakeholders, including investors and staff, and downstream communities. At least four major NZ forestry companies have either commissioned or supported the ES assessment of their respective forest estates. The objectives of the ES assessment included demonstration of the environmental and social values of forests to inform sustainable forest management renewal of certification and to incorporate the non-market values into investment decisions using the appropriate protocols. Forest managers surveyed also recommended future ES assessment schemes could include the quantification of other relevant ecosystem services (e.g., water flow regulation, recreation), and the identification of appropriate metrics for each non-market ES. ES approach helps to demonstrate forests’ full value (market and non-market), aid in license to operate, provide a better understanding of forest resources that benefits forest managers and landowners, while assisting in the recruitment of good employees.

4.3. Usefulness in National Policies

Forest managers see ES as predominantly important for sustainable business and market access. However, there are other potential benefits that could accrue both to them and to others. New Zealand is facing several environmental challenges related to water

quality degradation and climate change impacts. New legislation has been enacted with a new National Policy Statement for Freshwater Management and National Environmental Standards for Freshwater [124,125]. These are aimed at reversing degradation of NZ's waterbodies. Additionally, NZ is a signatory of the Paris Climate Agreement and passed the Climate Change Response (Zero Carbon) Amendment Act into law in 2019 [126]. Planted forests can play a major role in both these areas. Water quality in planted forests is close to the same quality of that in natural forest systems [63,105,127], and the provision of clean water is one potential benefit from planted forests, both existing and new. To meet new targets for water quality it is likely land use change will be required in some catchments—planted forests are a very positive option. Similarly, planting trees to offset GHG emissions is an immediate climate change response option and the Government established the One Billion Tree program to move NZ towards its Paris targets [128]. Again, afforestation and land use change will be required. Studies into the benefits of afforestation have been undertaken that clearly show the value of ES from planted forests [49,83]. These benefits do require new financial mechanisms, and these are developing nationally, both through Government (the carbon price in the ETS, the N leaching price in the regional nutrient trading scheme) and by investors and the public through impact investment initiatives (e.g., [106,129]). With such mechanisms, it is likely that significant land use change will occur. Given the multiple ES provided by planted forests, the overall benefits are likely to exceed the individual goals.

4.4. Gaps and Future Areas of Research

We have provided a national quantification of four of the 17 ES listed at the outset of this study. These were identified as the highest priority by participating organizations of the project (e.g., government agencies and forest companies). There is therefore scope to evaluate the benefits of the other ES to provide a more comprehensive “full value” for the existing planted forest estate. Significant work has been done on a number of those ES, including biodiversity enhancement [130], recreation [54], and some work on water regulation [127]. Of the remainder, a major area of opportunity is that of cultural services and working with Māori indigenous groups (or iwi) on aspects of this [70].

This current work focused on demonstrating the wider value of New Zealand's existing planted forests. We also evaluated a potential source of uncertainty in ES quantification by including a sensitivity analysis using two sets of discount rates. We found that different discount rates significantly impacted ES values, ratios, and distributions. An important future work is to include in the sensitivity analysis other potential sources of uncertainties by calculating the values using confidence intervals and accounting for key uncertainty factors based on the literature, deliberative valuation, economic valuation, and/or experts' opinion [76,131–133].

With the need to develop a low carbon economy and improved freshwater status, new knowledge that can assist with land use transitions to lower emissions states will be helpful [134]. A major challenge is the development of financial or other enabling mechanisms to facilitate this land use change. A big issue for landowners when considering planted forests is the time it takes to realize the return on investment. This suggests that the possibilities of different types of forests and regimes that enhance cashflow and/or recognize the environmental values and benefits need to be explored [30,59].

The low carbon landscapes of the future are likely to be more complex with multiple land uses and values. Consideration of individual services or land uses within landscapes will not be enough. Systems approaches based on spatial and numerical multi-criteria analysis will be necessary to explore the potential new landscapes, such as Analytic Hierarchy Process (AHP) and Analytic Network Process (ANP) in combination with Geographic Information Systems (GIS). These approaches, developed by Thomas Saaty [135,136], have been extensively used in decision making in fields such as land use assessment, planning, and sustainability [137–139]. Finally, ES need to be embedded within national accounting systems that encompass standardized environmental, social, cultural, and economic

metrics. Linking the land-based ES research into developments, such as the SEEA–EEA, could provide better account of the potential synergies and tradeoffs of multiple forest ES in decision making [140–142].

5. Conclusions

We have demonstrated here that the value of the non-timber ES supplied by NZ's planted forest estate is far greater than their timber returns alone. Every year, on average, the estate provides very significant erosion control, carbon sequestration, and reduction in N leaching that have a combined value of more than four times the timber profit. These services are provided over and above the sale of logs alone. These values vary regionally, both within individual forestry companies, and across the ES of interest. In the NZ region of Gisborne, non-timber ES values can be provided up to 12 times the value of timber returns. It is therefore important that services which provide significant public values be recognized more in policy. This is to sustain and enhance the provision of these values to society and to ensure that those land uses that provide such values do not face perverse outcomes and inadvertently be deterred. These policy mechanisms should enable the creation of incentives for forest owners to realize the value of ES provision to the wider society.

Forest owners and managers have found the use of an ES framework to quantify a range of services (including timber, carbon, erosion control, reduced N leaching, recreation, and biodiversity conservation) to be helpful in explaining the full value of forests. The range of benefits from their forests both to the local stakeholders, and overseas markets, can be seen in the demand for purchasing these sustainably produced goods.

The addition of non-timber ES values enhances the attractiveness and potential returns from planted forests within the wider landscape even further from sustainable forest management and environmental policy perspectives. Using an ES framework to evaluate land use decisions and frame policy could lead to significant changes in land use patterns across NZ (e.g., forests for erosion reduction, carbon sequestration, nutrient mitigation, and social benefits).

With the continuous improvement and application of the ES science over the past decades, the quantification of forest ES has continued to attract attention from both private and public sectors in NZ and globally. This study describes an example of a spatial economic framework that has been validated and refined to allow the inclusion of new ES in future assessment exercises. More importantly, it demonstrates increasing interest from the major forest industry players from across NZ highlighting the need for forest ES quantification to assist in understanding the broader value of forests. ES quantification and description has been found invaluable in informing decision making, supporting license to operate while also signaling the potential development of a reward system for sustaining ES in the longer term.

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