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Evaluating ecosystem services of Afforestation on Erosion-prone Land: A Case Study in the Manawatu Catchment, New Zealand

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Abstract: Land-use change from pasture to forestry can have multiple effects on the environment. In this project, we assessed the impacts of afforestation on erosion-prone land on several ecosystem services in the Manawatu catchment, New Zealand. For 500 high priority farms requiring soil conservation, the land mapped as highly erodible was assumed to be afforested, with two distinct scenarios: conversion of pasture into pine forest or indigenous shrubland. Several models were used to quantify indicators of different ecosystem services including carbon sequestration, non-CO_2 gas emission, sediment yield, nitrate export, natural habitat provision, and water yield. The results showed that the pine forest carbon stocks dropped at time of harvest, but rose rapidly after 50 years to be almost double that of the indigenous shrubland scenario. In both scenarios, the main environmental benefit was a large 50% sediment yield reduction from the catchment. As most afforestation occurred on sheep and beef hill country, where stock density is low, there was only a small decrease in nitrate export, and a small decrease in non-CO_2 emission. The provision of natural habitat was slightly lower for pine forest than for indigenous shrubland. The water yield relative to the possible range was reduced by 6% at the catchment scale.

Keywords: *land-use change, afforestation, ecosystem services, landscape modelling*.

1. INTRODUCTION

With climate change now recognised as a major threat to natural and socio-economic systems, the global community is searching for cost-effective ways to minimise the impact of greenhouse gases. The Kyoto Protocol has already instituted legally binding procedures to enhance carbon sequestration, and the New Zealand government is seeking means to sequester carbon. Converting pasture to forest has direct implications for carbon stocks, but carbon is usually not a sufficient incentive to divert the land use from agricultural production. One proposed solution is to afforest steep land that is marginal for long-term agriculture. Besides carbon sequestration, there are additional ecosystem services resulting from this land-use change that need to be assessed. For instance, afforestation on steep land generally decreases erosion risk. In New Zealand, Dymond et al. [2006] estimated that forest cover reduces landslide probability by 90%. Afforestation will also impact on water quality, as the loss of pasture implies a reduction in both fertiliser input and animal production, thus reducing nutrient inputs to rivers. Other issues of water management are more complex. Afforestation in a catchment can reduce surface water runoff [Zhang et al. 2001] and groundwater recharge [Benyon et al. 2006], which can result in lower water availability for agricultural uses. In addition, afforestation usually improves biodiversity values [Brockerhoff 2008]. Exotic plantations may, however, provide little biodiversity benefit compared with pastures, so afforestation has more chances of improving biodiversity if it contains indigenous species [Salt et al. 2004]. All together, afforestation on erosion-prone land typically has a range of associated benefits which makes it desirable.

However, comparing the relative impacts of these benefits is difficult, as they do not have the same physical unit.

Costanza et al. [1997] used monetary value as a unifying unit for ecosystem services: they estimated a much higher value per unit area for forest ecosystems than grasslands. Some studies have utilised econometric models to describe the economic impacts of carbon sequestration policies on the environment [Feng et al. 2007, Greenhalgh et al. 2003]. Others have focused on one specific service, such as the impact of carbon sequestration on bird habitat [Matthews et al. 2002] or water quality [Pattanayak et al. 2005]. Few formal analyses have considered the broader aspect of additional environmental benefits of afforestation, except for Plantinga et al. [2003] and McCarl et al. [2001], who measured carbon, soil erosion, and nitrogen pollution.

In this paper we evaluate various ecosystem services from afforestation of erosion-prone land. We consider climate regulation, protection of soil, maintenance of clean water, regulation of water flow, and natural habitat provision. The method section describes our study area, the Manawatu catchment in New Zealand, which is already subject to local policies on soil conservation. The results section shows the impacts of afforestation on these indicators, using a scaling method permitting comparison and identification of priority services. We discuss the advantages and limitations of the methods.

2. METHODS

2.1 Afforestation scenarios

The study area is the Manawatu catchment (585,000 ha), located in the lower North Island of New Zealand (see figure 1). The land cover is mostly pasture (17% dairy, 57% sheep and beef), as the majority of the indigenous forest has been cleared over the last 150 years (18% natural areas remaining). Following a major storm event in February 2004, the regional environmental authority implemented a regional plan to promote the implementation of conservation measures on highly erodible land. Previous research had focused on identifying farms most at risk of erosion using a land use map and an erosion risk map [Schierlitz et al. 2006].

We used the first 500 farms identified to explore afforestation scenarios where all the erosion-prone land on those farms would be afforested, and tested two types of land-use change:

- Conversion of erosion-prone land into planted forest. We assumed that the planted species was *Pinus Radiata*, which is 90% of planted tree species in New Zealand. *Pinus Radiata* has a much faster growth rate than indigenous forest species, which makes it attractive for timber production.
- Reversion of erosion-prone land into indigenous shrubland. In New Zealand, abandoned agricultural land would naturally regenerate into *Manuka/kanuka* shrubland, which can then act as a nursery for native forest species

The steep land considered resulted in about 32,000 ha of pastoral farm land being converted into forest land (5% of the catchment). At the farm scale, 20% of the farm land on average would be retired from production.

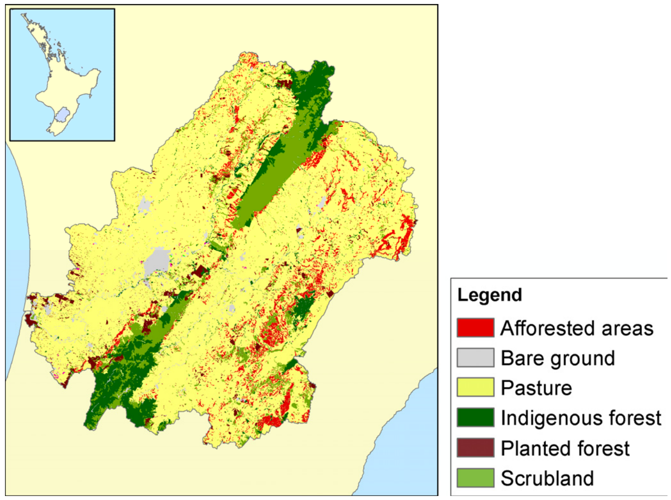

Figure 1. Current land cover with proposed afforestation of erosion-prone land scenario.

2.2 Ecosystem services indicators

We followed the classification from the Millenium Ecosystem Assessment [Millennium Ecosystem Assessment 2005] that divides ecosystem services into provisioning, regulating, cultural, and supporting services. We focused especially on regulating and provisioning services, including regulation of climate, protection of soil, maintenance of clean water , water-flow regulation, and provision of natural habitat. The services were assessed using quantitative indicators (table 1) to keep the approach transparent and repeatable. The possible range of values for each service depends on the land use in the catchment. We computed minimum and maximum values by considering the catchment completely covered in either pasture or forest.

Table 1. Ecosystem services and indicators.

Service type	Ecosystem service	Indicator	Unit
Regulation	Climate regulation	Carbon sequestration Methane and nitrous oxide emissions	tonnes of CO_2 equivalent/ha
	Soil protection	Sediment yield	tonnes of sediment/ha/yr
	Maintenance of clean water	Nitrogen and phosphorus export, *E. coli*	kg/ha, 10^{15} organisms /yr
	Water-flow regulation	Water yield	mm/year
Provisioning	Natural habitat provision	Conservation goal	unitless

2.2.1 Climate regulation

Three main gas emissions are affected by the land-use change from pasture to forest: methane, nitrous oxide, and carbon dioxide. Methane and nitrous oxide are predominantly emitted by the agricultural sector, through enteric fermentation from animals, livestock manure and fertiliser applications. Carbon dioxide is removed from the atmosphere and stored in woody biomass through tree growth.

We estimated the emissions from agricultural activities by modelling the spatial distribution of animal numbers (dairy, sheep, beef and deer) using a land-use map, and applying the country-specific emissions factors [Ministry for the Environment 2009] for the agriculture sector for methane and nitrous oxide.

Conversion of former agricultural land into forest generally causes some C losses from the soil. Tate et al. [2003] estimated a mean annual soil loss (C_{soil_loss}) of 17 t C/ha over a 10-year period. Aerobic soils have the ability to uptake a small but significant amount of methane from the atmosphere from soil methanotrophic bacteria activities. The oxidation rates ($C_{methane}$) vary according to the land-use type, and can be used to spatially extrapolate methane removal [Saggar et al. 2008].

The carbon stock per year (t) was therefore calculated as:

$$C(t) = f(t) - C_{soil\_loss}(t) + C_{methane}(t) \tag{3}$$

Where:

$f(t)$ = total CO_{2e} stock from the tree biomass (t CO_{2e}/ha) for year t.

C_{soil_loss} = 3.67 for the first 10 years (tCO_{2e} /ha),
= 0 after 10 years.

$C_{methane}$ = 100 x 10^{-3} (t CO_{2e} /ha) for pine forest
= 39 x 10^{-3} (t CO_{2e} /ha) for manuka/kanuka shrubland

For the exotic pine forest scenario, *f(t)* was based on regional growth curve [Ministry of Agriculture and Forestry 2009]. The carbon sequestration rates were based on the assumption of a first and second rotation (each of 28 years) with pruning.
For the indigenous *manuka/kanuka* shrubland scenario, *f(t)* was based on a Gompertz function [Goudriaan et al. 1994] adjusted to manuka/kanuka growth parameters [Trotter 2007]:

$$f(t) = c_f \times 2.93 \times \exp\left(\frac{(0.46 \times (1 - e^{-0.1t}))}{0.1}\right) \tag{4}$$

Where:
t is the age of the manuka/kanuka,
c_f is a cover factor calculated as:

$$c_f = 0.1 + \frac{0.85}{1 + e^{(5-t)}} \tag{5}$$

c_f is calculated to reflect that 95% cover of scrubland is reached after 10 years of reversion.

2.2.2 Soil protection

We estimated soil protection using a long-term erosion model, calibrated from New Zealand river data [Dymond et al. 2010]. Although it lacks a temporal aspect, this model estimates mean erosion rate from all sources of erosion, both mass-movement and surficial. The erosion rate denoted by $e(x, y)$, where x and y are geographic coordinates, was calculated as follows:

$$e(x, y) = \kappa(x, y)\, C(x, y) R^2(x, y) \tag{1}$$

Where:
$\kappa(x,y)$ is a constant depending on soil properties,
$R(x,y)$ is the mean annual rainfall based on a map from Leathwick et al. [2003],
and $C(x,y)$ is a cover factor relative to forest.

For each farm we calculated the annual sediment yield for the present management and for a fully implemented farm plan using a reduction factor based on Dymond et al. [2010] (70%).

2.2.3 Maintenance of clean water

Water quality parameters were estimated using the CLUES software [Woods et al. 2006], which combines SPARROW (spatially referenced regression on catchment attributes) and OVERSEER® (a nutrient budget tool at the farm scale). CLUES generates mean annual loadings of nitrogen, phosphorus and *E.Coli* at a reach scale based on spatially referenced catchment attribute data (including land use and soil properties). It was calibrated over New Zealand river data using the National Rivers Water Quality Network by fitting a regression (R^2 = 0.948).

2.2.4 Water-flow regulation

Changes in forest cover can reduce the amount of water received by rivers and aquifers, and could potentially restrict the availability of freshwater for other purposes. We used a model (WATYIELD) to predict the hydrological effects of land cover change [Fahey et al. 2004]. The model was calibrated to New Zealand conditions. It requires data on land covers, soil types and physical properties, and daily evaporation and rainfall. The reduction in available water for our scenario was calculated by comparing the WATYIELD predictions for the targeted land area under current land cover with the predictions when the land is afforested. The model was run for a 10-year time period and the average reduction in water yield found.

2.2.5 Natural habitat provision

A simple benefit function was used to assess the impact on natural habitat of conversion from pasture to forested land [Dymond et al. 2008]. We used an indicator (*CM)* that calculates the proportion of natural (pre-human) area remaining in a land environment [Leathwick et al. 2003], weighted by a condition index c_i. An indicator was calculated as follows:

$$CM = \sum_{i=1}^{m} P_i \sum_{j=1}^{n} \sqrt{\frac{c_j a_{ij}}{A_i}} \qquad (6)$$

where

$$P_i = A_i^{0.4} \qquad (7)$$

a_{ii} is the natural area remaining in land environment i and with land use j,
c_j is a condition index based on land use j (with n the number of land-use types),
A_i the original area of land environment i,
m is the number of land environments, and
n is the number of land-use types.

c_i is the driver as it depends on the land-use type (for example, a dairy land use has a c_i of 0.03 compared with 1 for indigenous forest). The condition indices were derived from expert knowledge (T. Stephens, pers. com., table 2).

Table 2. Condition index (c_i) per land-use type.

Land use	Condition *ci*
Natural areas	1.00
Exotic forest	0.28
Sheep and beef intensive	0.03
Sheep and beef hill country	0.08
Dairy	0.03
Deer	0.08
Arable land	0.01
Horticulture	0.14
Other	0.002

3. RESULTS

The carbon stocks from the forestry plantation scenario drop after 28 years, corresponding to the harvesting of the pine forest blocks (figure 2). The carbon stocks increase again with the second rotation and double the carbon stored in the manuka/kanuka shrubland scenario after 50 years.

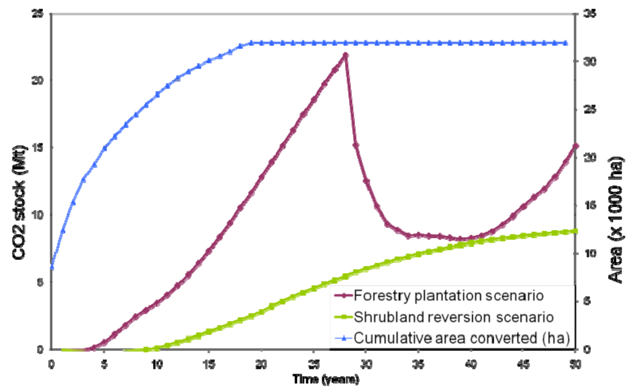

Figure 2. Carbon stock changes for the two afforestation scenarios.

As the afforestation is primarily located in hill country, with steep land that is usually not grazed, the effect of reducing the animal numbers only produces a 1% reduction of methane and nitrous oxide emissions. The avoided non-CO_{2e} emission equalled 1Mt CO_{2e} after 50 years. Overall, if we consider both the carbon sources and sinks at the farm scale, 80% of the annual animal emissions on average would be directly offset by the carbon sequestered in the growing forest.

Table 3. Ecosystem services indicators for the different scenarios

Ecosystem service	Indicator	All forest	All dairy	Current land-use	Afforestation scenario	% change
Climate regulation	Methane/nitrous oxide emissions ($MtCO_{2e}$/year)	0	3.3	1.94	1.92	-0.6%
	Carbon sequestration ($MtCO_{2e}$/year)	14	0	0.4	1.13 (forest) 0.68 (shrubland)	-5.2% -2%
Soil protection	Sediment yield (Mt/year)	0	4.7	3.8	2	-38%
Maintenance of clean water	Nitrogen yield (t/year)	1828	8140	4162	4064	-1.5%
	Phosphorus yield (t/year)	429	1354	731	699	-3.5%
	E coli (10^{15} organisms/year)	1	60	52	51	-1.7%
Water flow regulation	Water yield (mm/year)	295	461	427	418	-5.4%
Natural habitat provision	Conservation goal	562	176	220	226 (forest) 230 (shrubland)	-1.5% -2.6%

Table 3 summarises the changes in ecosystem services. The % change is calculated as the difference between the current and the afforestation scenario, relative to the extreme scenarios (all forest – all dairy), The erosion model predicts that after maturation of the soil conservation plantings the mean sediment yield of the Manawatu River would be reduced from 3.8 to 2.0 million tonnes per year. Previous work has also shown that the in-stream effect would also be a high reduction in sediment concentration at the outlet from 100 g/m^3 to 50 g/m^3 [Ausseil et al. 2008].

As the stock density was low, there was only a slight benefit in maintenance of clean water (1.5% reduction of N leached, P leached and 3.5% reduction in *E.Coli*). The water yield relative to the possible range was reduced by 5% at the catchment level, with some sub-catchments reaching over 20% reduction. The indicator of natural habitat provision differs for the two afforestation scenarios. The indicator increases by 1.5% and 2.6% respectively for pine forest and *manuka/kanuka*. *Manuka/kanuka* holds more biodiversity value as it is an indigenous vegetation cover.

4. DISCUSSION

In this paper, we analysed the implications of afforestation of erosion-prone land on multiple ecosystem services, using a case study in the Manawatu catchment. The scaling of results using the potential range allowed us to compare changes in ecosystem service one to another. The results showed that climate regulation and soil protection were the two main affected services. The changes in the other ecosystem services were limited in comparison. The potential issue of water interception by forest was also quantified, with a limited impact at the catchment scale. Some sub-catchments could however be highly affected, and should be targeted for future water allocation plans.

The different indicators were based on bio-physical models, but a number of assumptions were necessary to upscale to the catchment level. Further work is necessary to perform a sensitivity analysis of the indicators. Carbon sequestration rates at this stage were based on a single stand and do not reflect regional variability. We intend to use a comprehensive forest growth model that will provide spatially explicit growth rates for New Zealand. Depending on nearby native seed sources, *manuka/kanuka* shrubland is an important pioneer for forest regeneration, with the ability to supersede exotic shrub species. Future tree transitions have the potential to meet the carbon stock from the forestry scenario. The water quality indicators were solely based on the land cover change from pasture to forest. However, soil conservation measures also involve changes in management practices, which can have a large influence on water quality [Greenhalgh et al. 2003]. The indicator of natural habitat provision is based on the area of land uses. In reality, connectedeness of the natural patches is an important factor that should be further investigated.

This work does not account for the economic impacts of land retirement. As compensation, the costs of implementing the change are aimed to be shared between the farmer and the regional authority. The income from agricultural production should not, however, be significantly decreased, as the change is in a low productivity area and the reduction in animal numbers is small. There is also increased potential from timber sale and carbon credits. The reversion to indigenous cover has two advantages, no investment in infrastructure needed and an enhanced habitat provision. Although there wouldn't be any timber production, the economic return for indigenous forest could come from biodiversity credits [EBEX21 2010].

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