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An ecosystem services approach to the quantification of shallow mass movement erosion and the value of soil conservation practices

E.J. Dominati [a,*], A. Mackay [a], B. Lynch [b,1], N. Heath [b,1], I. Millner [b,1]

[a] AgResearch, Grasslands Research Centre, Tennent Drive, Private Bag 11008, Palmerston North 4442, New Zealand
[b] Hawkes Bay Regional Council, 159 Dalton Street, Private Bag 6006, Napier 4142, New Zealand

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ABSTRACT

This study characterises the loss of ecosystem services from a grazed pasture following shallow mass movement erosion and subsequent recovery of services. The influence of space-planted trees, a soil conservation practice, on the provision of services, was also assessed. The economic value of the services provided by an uneroded steep pasture grazed by sheep and cattle was estimated at NZD 3717 ha^{-1} yr^{-1}. This value dropped by 65% when the topsoil was lost in a single shallow mass movement. Fifty years after erosion, the services only recovered to 61% of uneroded value. In contrast, the same landscape type planted with soil conservation trees provided, after 20 years, additional (+22% in dollar value) services from the similar unprotected landscape.

A benefit cost analysis of soil conservation practices showed planting conservation trees is only profitable if the trees are harvested for timber (age 20), and low discount rates (<5%) are used. When the economic value of the extra services from conservation trees is included in the BCA, the Net Present Value of the investment is greatly positive at discount rates ranging from 0% to 10%. Analysis of this ecological infrastructure investment using an ecosystem service approach offers new insights for resource managers and policy makers.

1. Introduction

New Zealand is one of the only places in the world where hill country is grazed all year round. Almost 70% of the country has slopes greater than 12 deg., and is commonly called ‘hill country’. Geologically, the majority of the North Island, where this study takes place, is developed on soft rock and crushed soft rock terrain (McIvor et al., 2011). These combined with warm sub-tropical to cool temperate climates make the North Island hill country highly prone to shallow landslides, earthflow and gully erosion (Basher et al., 2008; McIvor et al., 2011). Nowadays, historical deforestation associated with pastoral land use, also plays a major role in determining erosion risk.

The Water and Soil Conservation Act was passed in New Zealand in 1941 to address hill country erosion associated with post-European settlement and deforestation. Catchment Boards, directed by central government policies, were tasked with soil and water conservation until 1988. In 1988, Catchment Boards were absorbed into Regional or Unitary Councils responsible for broader natural resource management, including soil erosion and flood control under the Resource Management Act (RMA) of 1991. Each year hill country erosion is estimated to cost between NZD 100 to 150 million (Eastwood et al., 2001). Part of this is through lost pasture production and nutrients (MfE, 2007), but does not include an estimate of the loss of soil natural capital stocks (Dominati et al., 2010). The investment in soil conservation continues today, as erosion remains a challenge threatening the long-term sustainability of agro-ecosystems. This is not unique to New Zealand but a threat to food security in many regions of the world (McBratney et al., 2014), heightened by uncertainties surrounding future climates.

Soil conservation practices aim to reduce the risk of soil erosion in hill and steep land country, downstream costs associated with sediment loadings in waterways, and damage to productive farmland and towns through siltation. In New Zealand, erosion control measures for pastoral hill country are established in the presence of the grazing animal, with permanent retirement from grazing recommended only in the most extreme situations. Tree-based control measures, which stabilise mass flows, are most of the time, the only affordable option on the scale required. Poplar (*Populus spp.*) and willow (*Salix spp.*) are two of the most suitable and most used tree species (McIvor et al., 2011).

Current evaluation of soil conservation policies are largely limited to the assessment of the reduction in soil erosion, soil loss, sediment, impacts on productive capacity and downstream

* Corresponding author. Tel: +64 63518216.
E-mail addresses: estelle.dominati@agresearch.co.nz (E.J. Dominati), alec.mackay@agresearch.co.nz (A. Mackay), barry@hbrc.govt.nz (B. Lynch), nathan@hbrc.govt.nz (N. Heath), millner@hbrc.govt.nz (I. Millner).
[1] Tel.: +64 68359209.

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community. However, evaluation needs to be broader in order to capture the wider benefits of soil conservation. For example the value of the full range of ecosystem services (ES), above- and below-ground, lost following shallow mass movements need to be considered, beyond the loss of selected provisioning services. Until the full range of services is considered in the analysis, the cost of land degradation and loss of natural capital stocks will remain unknown and the full value of an ecological infrastructure investment in soil conservation practices will not be available for land use decision-making.

The purpose of this study is to test and evaluate an ecosystem services approach for the quantification and economic valuation of the multiple benefits, provided by soil conservation practices using a study area on the East Coast of the North Island of New Zealand.

In April 2011, Hawke's Bay on the East Coast of the North Island was affected by a heavy rain storm (200 to 650 mm of rain in 12 hours). Subsequent widespread shallow mass movement erosion occured on hill slopes, including slips and reactivated earth flows, as well as gullying, along a 250 km coastal strip predominantly under permanent pasture grazed by sheep and cattle. Following that storm, Hawke's Bay Regional Council used satellite imagery to estimate the proportion of land affected by landslides. Overall 43 km^2 (4300 ha) of bare ground was classified from a total area of 5900 km^2, including 86% new bare ground resulting from the storm (Jones et al., 2011). Estimates of damage to infrastructure and land, personal and commercial property was NZD 39 million.

As part of a wider analysis, Hawke's Bay Regional Council was interested in investigating the long-term implications of the storm event on the region's natural resource base. This provided an opportunity to quantify and value the ecosystem services lost as a consequence of shallow mass movement erosion and at the same time the benefits of existing soil conservation practices. While this study produces economic values for ecosystem services, the main purpose of the research was to explore the merits of an ecosystem service approach in providing resource management decision makers with new insight into the long-term consequences of erosion and the costs and benefits of an ecological infrastructure investment. The objective was to determine if an ecosystem services approach offers a new tool for amending existing and shaping future policy.

In order to look at the impacts of shallow mass movement erosion and soil conservation practices, the contribution of soils to the provision of all ecosystem services was assessed using the theoretical natural capital-ecosystem service framework of Dominati et al., (2010). That framework builds on the millennium ecosystem assessment (MEA, 2005), and differentiates ecological processes, particularly soil processes, from the flow of ecosystem services, and integrates the relationships between natural capital stocks, the impacts of external drivers, and the provision of ecosystem services with human needs. Within the context of this study, the framework is used to account for below and above ground contributions of natural capital stocks to the provision of ecosystem services.

The ecosystem services considered include *provisioning services* such as the provision of food (quantity and quality), wood and fibre, the provision of support for human infrastructures and farm animals, and the provision of shade and shelter for livestock. The *regulating services* include flood mitigation, the filtering of nutrients and contaminants, the decomposition of wastes, net carbon accumulation in soils and conservation trees, nitrous oxide regulation, methane oxidation and the regulation of pest and disease populations. *Cultural services* (the nonmaterial benefits people obtain from ecosystems) (MEA, 2005) are recognised but not considered in this study. Their non-biophysical nature, requires the use of very different techniques for quantification and valuation and as such are outside the scope of this study.

Table 1
Farm size, landscape type, soil classification and properties, and nutrient inputs to a sheep and beef operation.

	Rolling landscape unit	Steep landscape unit
Area (ha)	255 (45%)	315 (55%)
Slope class	Easy hill	Steep hill
Slope	16–25°	> 26°
Relative productivity	1.6	1
NZ soil classification		
Order	Brown	Pallic
Group	Orthic	Immature
NZ Soil Series	Waimarama sandy loam	Wanstead clay loam
US soil classification		
Order	Inceptisols	Inceptisols
Suborder	Dystrudepts	Eutrudepts
Olsen P (mg/kg)	25	16
Anion storage Capacity (%)	43	21
N fertiliser applied (kgN/ha/yr)	20	0
P fertiliser applied (kgP/ha/yr)	20	15

2. Methodology

2.1. Study site: East Coast hill country sheep and beef operation

The dominant land use in Hawke's Bay region on the East Coast of the North Island of New Zealand is sheep and beef farming. Average farm monitoring data (MPI, 2012) for a summer-dry hill country breeding and semi-finishing sheep and beef operation were used for this study (Table 1). The farm characteristics include a 70:30 sheep to cattle ratio, 130% lambing rate, stocking rate of 10 stock units[2] per ha, and pasture growth of 9 t of dry matter/ha/yr. Average yearly Rainfall is 1000 mm, and the climate is described as summer-dry. Soil and landscape information was provided by Hawke's Bay Regional Council (Table 1). The farm has two dominant landscape units described as the rolling landscape unit, being flat to easy rolling country, and the steep landscape unit, being moderate to steep hill country.

To answer the study objectives, the following steps were taken:

- Quantify and value the provision of ecosystem services for a sheep and beef operation (Section 2.3).
- Quantify the impact of erosion on soil properties, the flow of ecosystem services and their recovery (Section 2.4).
- Quantify and value the impact of soil conservation practices on the flow of ecosystem services from a sheep and beef farm (Section 2.5).
- Undertake a benefit-cost analysis of an investment in soil conservation (Section 2.7).

For all the steps mentioned above, the provision of ecosystem services is calculated at the paddock scale (the ecosystem services source area) on a 1 ha basis.

To quantify the provision of ecosystem services at the paddock scale (1 ha), information from existing data bases and tools that support existing planning in the region, including data collected as part of soil quality monitoring, land use capability class maps (Lynn et al., 2009) and the OVERSEER® nutrient budget model

[2] A livestock unit (SU) is the feed requirement used as the basis of comparison for different classes and species of stock. It expresses the annual feed requirements, equivalent to one 55 kg ewe rearing a single lamb. 1 SU requires approximately 520 kg of good quality pasture dry matter per year.