THE VALUE OF SOIL SERVICES FOR NUTRIENT MANAGEMENT

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Abstract
A new framework for classifying and quantifying soil natural capital and ecosystem services is used to value the ecosystem services provided by an Allophanic soil (Horotiu silt loam), under a typical Waikato dairy farm operation. The services quantified included the provision of food, which includes the supply of water and nutrients and physical support to plants, the provision of support for human infrastructures and animals, flood mitigation, the filtering of nutrients and contaminants, detoxification and the recycling of wastes, carbon storage and greenhouse gases regulation, and the regulation of pests and diseases populations. The SPASMO model was used to explore the dynamics of soil properties and processes regulating each of the soil services and to quantify each service for each of 35 years using climate records from the Waikato from 1975-2009. The quantitative information on each service was valued using a range of neo-classical economic valuation techniques. The average annualized (10%) value of the ecosystem services for the Horotiu silt loam under a typical Waikato dairy farm operation calculated for each of 35 years was NZD 14,899/ha/yr, ranging from NZD 21,105 to 10,189/ha/yr , a two-fold difference. This study showed that the regulating services have a much greater value than the provisioning services. The framework provides for the first time economists and policy makers with an approach for quantifying and valuing the country's soil ecosystem services under a range of land uses.

Introduction
New Zealand's continued wealth generation is more than ever highly dependent on its soils. Almost half of New Zealand's land is farmed commercially, with over 40% of the total land area in pasture and arable cropping land and 7% in exotic forest. For the last 100 years agriculture and forestry have been New Zealand's main export earners. More than anywhere else in the world, soil is an essential factor in the economic status of the nation (Daily, 1997). Given land is a finite resource, analysis of the current and potential use of the country's land resource and its value to the economy is very limited.

Soil science has been very effective in quantifying the differences in the productive capacity and versatility of soils, but struggles to quantify the wide range of services that soils can provide to society. Some authors noticed early that soils play key roles beyond production. For example, Daily et al. (1997) and Wall et al. (2004) described in detail the services soils provide to human society beyond a substrate for plant growth, to include buffering floods or recycling wastes. Daily (1997) noted that soils are a very valuable asset that "takes hundreds to hundreds of thousands of years to build and very few to be wasted away" (Daily, 1997, p. 113). Current valuation of the land is determined by its current or potential productive capacity. In the quest for sustainable land management, there is an urgent need to include these other services in the valuation of the land resource and its contribution to economy. It is important to note here there are other factor influencing land values, including proximity to urban population centres or the coast through to competition between land owners for a common neighbour's operation.

The concepts of natural capital and ecosystem services come from the discipline of ecological economics. Natural capital refers to the extension of the economic idea of manufactured capital to include environmental goods and services and has been defined as the "stocks of natural assets (e.g. soils, forests, water bodies) that yield a flow of ecosystem goods or services into the future" (Costanza and Daly, 1992, p. 38). The concept of ecosystem services gained real momentum in 1997 thanks to Costanza et al. (1997). In 2005, the millennium ecosystem assessment introduced ecosystem services to the general public as "the benefits people obtain from ecosystems" (MEA, 2005). The millennium ecosystem assessment was very successful in informing people on the different roles of ecosystems and how much human societies depend on them, but it treated soils as a black box. The range of ecosystem services from soils are often not recognised and generally not well understood and neither are the links between soil natural capital and soil.

Many of the weaknesses of the MEA framework are addressed by Dominati et al. (2010), who developed a framework to classify and quantify soil natural capital and ecosystem services. Their conceptual framework provides a broader and more holistic approach than previous attempts to identify soil ecosystem services by linking soil services to soil natural capital. It shows how external drivers impact on processes that underpin soil natural capital and ecosystem services and how soil ecosystem services contribute to human well-being. The framework consists of five main interconnected components: (1) soils as natural capital embodied by inherent or manageable soil properties; (2) natural capital formation, maintenance and degradation processes; (3) natural and anthropogenic drivers of soil processes; (4) provisioning, regulating and cultural soil ecosystem services; and (5) human needs fulfilled by soil services (Dominati et al., 2010). The services detailed by this framework are listed in Table 1.

This paper uses the framework of Dominati et al., (2010) to quantify and value the ecosystem services provided by an Allophanic soil (Horotiu silt loam) under a typical Waikato dairy farm operation. Two of the soil services, the provision of support to animals and the filtering of N, are described in some detail to provide an insight into the process of quantification and valuation.

Table 1: Soil ecosystem services

Service		Definition
Provisioning services	Provision of food, wood and fibre	Soils physically support plants and supply them with nutrients and water. By enabling plants to grow, soils enable humans to use plants for a diversity of purposes.
	Provision of raw materials*	Soils can be source of raw materials (peat, clay), but renewability of these stocks is questionable.
	Provision of support for human infrastructures and animals.	Soils represent the physical base on which human infrastructures and animals (e.g. livestock) stand.
Regulating services	Flood mitigation	Soils have the capacity to store and retain water, thereby mitigating flooding.
	Filtering of nutrients and contaminants	Soils can absorb and retain nutrients (N, P) and contaminants (E-coli, pesticides) and avoid their release in water bodies.
	Carbon storage and greenhouse gases regulation	Soils have the ability to store C and regulate their production of greenhouse gases such as nitrous oxide and methane.
	Detoxification and the recycling of wastes	Soils can absorb (physically) or destroy harmful compounds. Soil biota degrades and decomposes dead organic matter thereby recycling wastes.
	Regulation of pests and diseases populations	By providing habitat to beneficial species, soils can control the proliferation of pests (crops, animals or humans) and harmful disease vectors (viruses, bacteria).

*This service was not considered in this study.

Materials and methods

The framework was implemented at the farm scale on a well drained Horotiu silt loam under a typical Waikato dairy farming operation. The studied farm covers 100 ha, and runs 330 milking cows producing 900 kg MS/ha/yr. Fertiliser N use is 100 kg N/ha/yr. Fertiliser P is 39 kg P/ha/yr. The farm does not have a stand-off pad.

For each soil service a proxy was defined to quantify the service. Each proxy was based on one or more soil properties (natural capital stock) at the origin of the provision of the service. Each proxy was then calculated from the outputs of a model and/or using data from the literature. The model used in this study was SPASMO from Plant and Food Research (Green et al., 2003). This is a a soil-plant-atmosphere system model, which describes soil processes, plant growth and aspects of farm management. Supporting and degradation processes make up the core of the SPASMO model. The model uses mathematical functions to describe each of the soil, plant, water and nutrient (N and P) processes and links them dynamically to each other and to soil properties using daily time steps. The model uses, as inputs, soil type (soil properties) and external drivers like climate, land use and management practises. It outputs daily measures of chosen soil properties and their dynamics according to these drivers and keeps stock of the flows of nutrients, matter and water. Simple allometric relationships are used to describe the feed, energy and nutrient budgets for the grazing animals, and to parameterize the returns of dung and urine to the grazed pasture.

In order to model a dairy farm and gather all the data needed to calculate the proxies behind each soil service, extra-functionality was added to the SPASMO model, including functions describing the impact of soil water content on pasture utilisation, the impacts of grazing regime on soil structure (macroporosity) and pasture growth (rate and recovery) (Betteridge et al., 2003), grazing rotation, the use of standoff-pads and extra routines to the P cycle. The SPASMO model was used to explore the dynamics of soil properties and processes regulating each of the soil services (Table 1) and to quantify each service for each of 35 years using climate records from the Waikato from 1975-2009. The quantitative information on each service was then valued using a range of neo-classical economic valuation techniques (Pearce et al., 2006).

Results

The method used to quantify and value two of the twelve ecosystems services provided by soils are described below.

Provision of support for farm animals

The provision of support to farm animals is based on the interaction between soil texture, structure and moisture and the soil's sensitivity to treading damage. To avoid soil deformation, and subsequent production losses, farmers are increasingly removing animals from pastures, onto standoff-pads, when wet soils fail to provide support. Winter and spring (May to October) which are associated with high soil moisture, have been identified as critical periods for soil damage on New Zealand dairy farms (Houlbrooke et al., 2009). As a general rule, the risk of grazing damage occurs when soil water content (SWC) is above field capacity. For the purpose of modelling, the number of days between May and October when the soil was dry enough to support animals without too much damage (SWC<Field Capacity) was chosen as a measure of the service. This number was calculated for each year using SPASMO model outputs. It was calculated that a Horotiu silt loam stocked at 3 cows/ha should provide adequate support for animals between 63 to 120 days, out of 184 days, for the 35 years modelled.

The value of the support provided by soils to animals can be determined by considering that if the cows cannot stand on the paddock then they have to stand elsewhere, for example on a standoff pad. The standoff pad provides an option for supporting animals when soils are too wet. The annualised costs of construction and maintenance of a standoff pad were used here as a proxy to calculate the value of the provision of support to animals. These costs were determined in the following way using recent data from farm case studies from the literature (Dexcel, 2005). The construction cost of the pad was annualised over a depreciating period (here 20 years) to correspond to the annual flow of the service measured. A discount rate of 10% was applied. The annualised construction costs were then added to the annual maintenance costs. The value of the service, determined using the provision costs method, was defined as the difference between the costs of having to use a pad for 184 days, and the costs of using it only when the soil was judged to be too wet for grazing.

For the Horotiu silt loam, the value of the provision of support to animal ranged from NZD 78/ha/yr to NZD 102/ha/yr, with an average of NZD 90/ha/yr, for the 35 years modelled (Table 2). To the knowledge of the author, no other study has attempted before to put a value on the provision of support to animals from soils.

Filtering of N

The ability of a soil to filter nutrients (N, P) and contaminants (pathogens, pesticides or endocrine-disrupting chemicals) is linked to the quality of fresh water bodies. The cation and anion exchange capacity of a soil, its texture, structure and water content are all factors contributing to this soil service. The amount of N lost by leaching, as modelled with SPASMO, was used to quantify the filtering of N. SPASMO generates N losses (nitrates (NO_3^-) and ammonium (NH_4^+)) from a daily calculation of the soil's water and nutrient budget, using local values of rainfall, detailed soil physical and chemical transport properties and processes, and typical farm management practices (e.g. fertiliser, grazing regime). For the model dairy farm on a Horotiu silt loam, the calculated N losses varied between 18.6 and 65.5 kg N/ha/yr with an average over 35 years of 36.8 kg N/ha/yr.

The N filtering service was calculated from SPASMO outputs using the difference between the potential maximum N loss (if the soil's anion storage capacity was set to very low in the SPASMO model) and the N loss that would otherwise occur using typical values for the Horotiu silt loam. This difference represents the amount of nutrients retained i.e. "filtered" by the soil.

The defensive expenditure method was chosen here to value the filtering of N. Defensive expenditures refers to the amount of money spent by farmers to avoid a degradation of the environment, in this case the amount of N leaching. The money spent to deal with the lack of provision of a service is used as a proxy for the value of the service. This method was chosen because a number of mitigation techniques are available to farmers, and data about their costs and efficiency is up to date, robust and easily accessible.

For the purpose of modelling, it was assumed that the amount of N retained by the soil, e.g. the measure of the service, would have to be mitigated by farmers if the soil didn't filter N. Thus, the cost of N mitigation was used as a proxy for the value of the service. Three techniques commonly used by New Zealand dairy farmers to mitigate N losses were considered: a standoff pad to limit urine deposition on pastures; replacing fertilisers with low N feed supplements; and using nitrification inhibitors to slow the transformation of ammonium into nitrate. A mitigation function was established from the OVERSEER® nutrient budget model (AgResearch, 2005), using the costs and efficiency of different mitigation techniques to reduce N leaching.

For pastures on a Horotiu silt loam studied the annualised value of the filtering of N service ranged from NZD 214/ha/yr to NZD 890/ha/yr, with an average of NZD 554/ha/yr, over the 35 years modelled. Porter et al. (2009) and Sandhu et al. (2008) valued 'N regulation' from agro-ecosystems, which is the provision of N to plants, but not the filtering of N by soils. To our knowledge, no study as attempted before to put a value on the filtering of N by soils. A similar methodology was applied to measure and value the other services provided by a Horotiu silt loam under a dairy use (results presented elsewhere).

Discussion

The capital and annualised value of the provisioning and regulating soil services for a Horotiu silt loam under a typical dairy farm operation are reported in Table 2. These values have been calculated here using either market prices when available or the costs of construction and maintenance of built infrastructures that could provide the services concerned. Construction costs of built infrastructures were annualised in order to represent the annual value of the flows of services provided each year. It should be noted here that the value of the ecosystem services provided by soils (annual flows) is different from the value of soil natural capital (stocks). These two metrics shouldn't be confused. An ecosystem services valuation characterise the value of the flows coming from natural capital stocks rather than the value of the stocks. On the one hand, it could be argued that the non-annualised costs of infrastructures therefore correspond to the value of the natural capital stocks they replace. However, this value is a lower bound estimate since built infrastructures are in no way as dynamic, renewable and inter-connected as natural capital stocks. Nonetheless, in the literature authors (Costanza et al., 1997; Kim and Dixon, 1986) have used the value of built infrastructure as a proxy for ecosystem services valuation. In our opinion, this approach is not in line with good accounting and economic theory.

Not all soil services can be provided by built infrastructures (e.g. C storage, N_2O regulation). For some relevant services (Table 2), the costs of built infrastructures could be used as proxies for natural capital costs. The summed value of the natural capital of a Horotiu silt loam under a typical dairy farm operation was NZD 66,884/ha/yr. The average annualised value of the ecosystem services for the Horotiu soil under a dairy operation was NZD 14,899/ha/yr, with a range spanning from NZD 10,189/ha/yr to NZD 21,105/ha/yr (Table 2). This twofold range reflects the interaction between climate and soil properties over 35 years used in SPASMO to quantify the soil services.

Dairy land in the Waikato in 2010 was valued around $45,000/ha. Farm infrastructures are generally worth, new, about $15,000/ha, which drops the value of unimproved land down to $30,000/ha. Considering that this land provides every year ecosystem services worth around NZD 14,899/ha/yr, it appears that the actual market price of farm land may be grossly undervalued.

The study showed that regulating services have a much greater value than provisioning services. Of these services, the filtering and flood mitigation services have the highest value. Loss of these two services would have a major impact on the wider environment both by increasing flood risk and increasing the risk of contaminants entering the ground and surface water bodies. Land management at the moment currently focuses on provisioning services, such as the provision of food and physical support. This is not surprising as these are services that are recognised and already valued by the market, although the provision of support for animals goes unvalued in many instances. Inclusion of the regulating services in the analysis could add a whole new dimension to exploring and valuing the interaction between land use and resource management.

An ongoing study is comparing the value of soil services for different soil types (Te Kowhai silt loam) as well as the impacts of different management practises (stocking rates up to 5 cows/ha and use of a standoff pad) on the provision of ecosystem services.

Table 2: Capital value (in NZD/ha/yr) of built infrastructures needed to provide soil services, and average (over the 35 years), maximum and minimum values (in NZD/ha/yr) of soil services from the Horotiu silt loam under a typical Waikato dairy farm operation.

		Capital value	Value of soil services		
			Average	*Max*	*Min*
Provisioning services	Provision of food Quantity	NA	4,155	*5,655*	*3,158*
	Provision of food Quality	NA	38	*38*	*38*
	Provision of support for human infrastructures	100	17	*17*	*17*
	Provision of support for farm animals	**487**	**90**	***102***	***78***
	Provision of raw materials	NV	NA	*NA*	*NA*
Regulating services	Flood mitigation	10,185	1,196	1,661	741
	Filtering of N	**NA**	**554**	**890**	**214**
	Filtering of P	NA	2,922	2,922	2,922
	Filtering of contaminants	56,112	5,659	9,373	2,885
	Decomposition of wastes	388	78	143	24
	Carbon flows	NA	-36	-36	-36
	N_2O regulation	NA	14.6	21.8	8.8
	CH_4 oxidation	NA	0.47	0.49	0.45
	Regulation of pests and diseases populations	NA	210	316	138
	Total	66884	14,899	*21,105*	*10,189*

NV: not valued, NA: not applicable

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