Modelling the provision of ecosystem services from soil natural capital

Estelle Dominati[A,B,C], Alec Mackay[B] and Murray Patterson[A]

[A]New Zealand Centre for Ecological Economics, Landcare Research, Private Bag 11052, Palmerston North 4442, New Zealand.
[B]AgResearch, Grasslands Research Centre, Tennent Drive, Private Bag 11008, Palmerston North 4442, New Zealand.
[C]Corresponding author. Email Dominatie@landcareresearch.co.nz

Abstract:
Soil ecosystem services and natural capital are often unheralded and generally not well understood. This paper draws on our scientific understanding of soil forming processes, soil classification and functioning and on current thinking about ecosystem services to develop a framework for classifying and quantifying soil natural capital and ecosystem services**.** The framework consists of five main inter-connected components: (1) Natural Capital, characterised by standard 'soil properties'; (2) Natural Capital Formation, Maintenance and Degradation Processes; (3) Provisioning, Regulation and Cultural Ecosystem Services; (4) Drivers (Anthropogenic and Natural) of soil processes and related services; (5) Human Needs fulfilled by soils' services. We then show how such framework is being used to build a model of the provision of soils' ecosystem services on New Zealand dairy farms.

Key Words
Soil properties, processes, capital formation, degradation, human needs, drivers.

Introduction
Soils across the globe are a significant and perhaps the most unheralded category of natural capital. Despite this lack of recognition, it is more important than ever to understand soils' ecosystem services and natural capital in order to meet the food and fibre demands of a growing global. Many authors (Daily 1997; Swinton *et al.* 2007; Turner and Daily 2008) agree that our ability to understand the ecosystem services and natural capital of our soils is incomplete, despite a good understanding of soil functioning. This paper draws on our understanding of soil science and current ecosystem services thinking to develop a framework for classifying and quantifying soils' natural capital and ecosystem services. The paper also shows how such framework is being used to build a model of the provision of soils' ecosystem services on New Zealand dairy farms.

Framework
A new conceptual framework for classifying, quantifying and modelling "soils' natural capital and ecosystem services" is presented in Figure 1. The framework provides a broad and holistic approach to identify soils' ecosystem services by: (1) linking soils' ecosystem services to soils' natural capital; (2) delineating how soils' ecosystem services meet "human needs"; (3) identifying how "external drivers" impact on processes that underpin soils' natural capital. The motivation for seeking to develop this framework lies in the inadequacy of existing frameworks for modelling soils' services provision. Existing frameworks tend to ignore the scientific knowledge about soils and pay little attention to those factors that managers of soils have control over and therefore have had limited utility as a practical management tool to explore the impacts of land use and practises on the provision of soils' services. The framework presented here consists of different components:

Natural Capital
Soils are dynamic systems consisting of components (abiotic and biotic) inter-connected by biological, physical and chemical processes that have been well studied by soil scientists. One way of comprehending these complex networks of soil components and their inter-dependencies is to analyse them in terms of the main soil biogeochemical cycles (e.g. water, nitrogen). Another complementary way of characterising and scientifically understanding soils' natural capital is the concept of soil properties. Properties influence the intensity at which the processes occur and are at the same time products of these processes. In soils, some properties are inherent and cannot be modified and some are more manageable (Lynn *et al.* 2009). Knowing what type of properties is involved in soil functioning, and therefore in the provision of services, is important when it comes to land management and land use changes. For this reason, in putting forward the conceptual framework of soils' natural capital and ecosystem services (Figure 1), we put a major emphasis on recognising and distinguishing the differences between "inherent" and "manageable" soil properties.

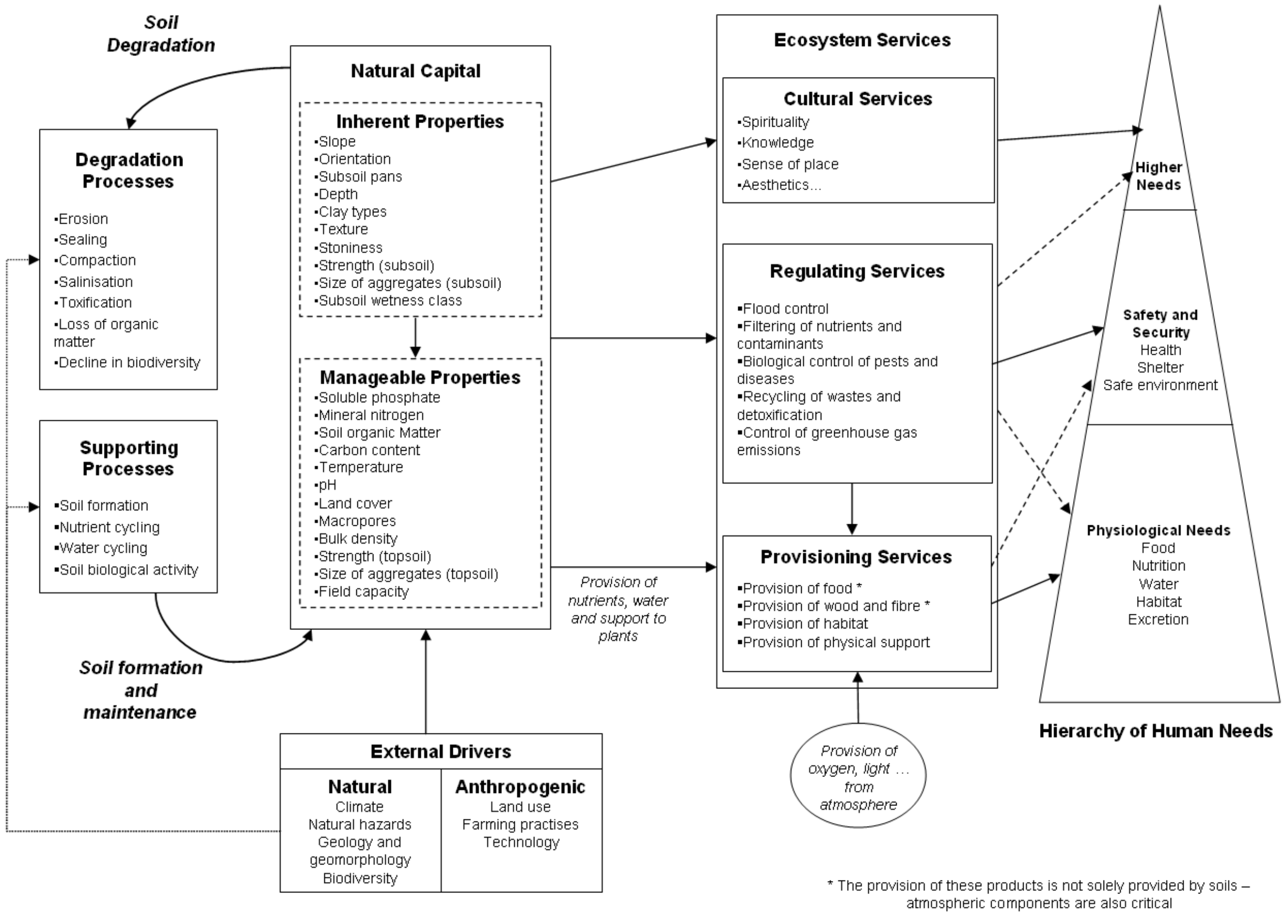

Figure 1. Framework for the provision of Ecosystem services from Soils Natural Capital.

Supporting Processes

We depart slightly from the Millennium Ecosystem Assessment framework (MEA 2005) by distinguishing between "processes" (biological, physical and chemical transformations of input into outputs) and "services" (human well-being derived from natural capital during a given time period). Almost always, an ecosystem service is derived from more than one process. "Supporting soil processes" ensure the formation and maintenance of soils' natural capital. They are the basic processes that enable soils to exist and function. Supporting processes included in our conceptual framework are: (1) Soil formation: chemical weathering, physical weathering and biological activities, with time, gradually build up and maintain soil properties and ensure the maintenance of the dynamic equilibriums underpinning soils' natural capital; (2) Nutrient cycling refers to the processes by which a chemical element moves through both the biotic and abiotic compartments of soils. Nutrient cycles maintain equilibriums which drive many processes such as plant uptake, exchange reactions or microbial immobilisation; (3) Water cycling refers to the physical processes enabling water to enter soils, be stored and released. Soil moisture is the driver of many chemical reactions and biological processes and is therefore essential in soil development and functioning; (4) Soil biological activity: Soils provide habitat to millions of species enabling them to function and develop. In return, the activity and diversity of soil biota is essential to soil structure, nutrient cycling and detoxification.

Soil Degradation Processes

Somewhat opposite to "Supporting Processes", that form and maintain the natural capital of soils, are "Degradation Processes", which degrade the natural capital of soils (Figure 1). There previously has been very little recognition of 'degradation' processes in the soils' ecosystem services literature (Palm *et al.* 2007). There are many processes that quantitatively and qualitatively degrade soils including: erosion, surface sealing, compaction, salinisation, loss of nutrients, acidification, toxification, loss of organic matter and decline in soil biodiversity. There is a real need to consider these degradation processes in soils' ecosystem services valuation exercises as the environmental impact they represent may well be greater, or at least, of similar magnitude to soils' ecosystem services. Furthermore, they are often caused by poor or inappropriate management practices that can in some instances be rectified.

Provisioning Services

According to the MEA (2005, p.40), provisioning services are "products obtained from ecosystems", including, for example, genetic resources, food and fibre, and fresh water. Soils specifically provide a number of 'products' useful for humans, including:

Provision of habitat for different species: Soils provide complete habitat to different species living in soil such as micro and meso fauna but they also contribute to the provision of a part of the habitat for plants, macro fauna and humans. The provision of habitat by soils is essential because soil biota is the driver of many ecosystem services coming from biological processes.

Provision of Food, Wood and Fibre: Humans use plants as a source of food, for wood and fibre, as a source of medicines, ornaments, and so forth. For plants to grow they need a number of elements provided by the atmosphere and soils. Soils provide nutrients, water and physical support to plants which strongly affects plant growth.

Provision of physical support: Soils provide physical support for human infrastructure (e.g. roads), plants and animal species used by humans (e.g. cattle). The integrity of soil structure will affect land use and farming practises.

Regulating Services

Regulating services enable humans to live in a stable, healthy, resilient environment therefore directly contributing to human welfare. Soils' regulating are therefore:

Flood control: Soils have the capacity to store and retain quantities of water and therefore can control and lessen the impacts of flood and drought events therefore contributing to the stability and resilience of human habitat.

Filtering of nutrients and contaminants: Soils have the ability to control water quality by , to some extent, absorbing and retaining solutes and 'contaminants', therefore avoiding their release in water bodies such as ground water, lakes and rivers.

Biological control of pests and diseases: By providing habitat to beneficial species, soils can control the proliferation of pests (crops, animals or humans pests) and harmful disease vectors (e.g. viruses, bacteria).

Recycling of wastes and detoxification: Soil biota activity degrades and decomposes dead organic matter and destroys chemical compounds that can be harmful to humans.

Limitation of greenhouse gas emissions: Soils play an important role in regulating the production of greenhouse gases like nitrous oxide (N_2O) and methane (CH_4) therefore impacting on air quality.

Cultural Services

Notably, none of the previous studies (Barrios 2007; Daily 1997; Lavelle *et al.* 2006; Wall *et al.* 2004) on soils' ecosystem services cover or identify "cultural services". This is a curious omission as soils alone, as part of landscapes, have across many cultures, always been a source of aesthetic experiences, spiritual enrichment and recreation.

External Drivers

External drivers impact on processes that underpin soils' natural capital and ecosystem services. External drivers of the soil system are divided into two categories:

Anthropogenic drivers include: (1) Land use: The type of land use (e.g. cropping, livestock) determines the type of pressures applied to the soil; (2) Farming practises: they determine the level of intensity of the pressures and the amount of inputs to the soil; (3) Technology: new technologies enable humans to manage soil processes to their advantage (e.g. nitrification inhibitors).

Natural drivers include: (1) Climate: the characteristics of local climate (rainfall intensity, temperature, sunshine) influence supporting processes, degradation processes and biodiversity by driving soil moisture and temperature; (2) Natural Hazards (earthquakes, volcanic eruptions) affect the integrity of soil structure and therefore supporting processes; (3) Geology and geomorphology: the type of parent material determines the original minerals in soils, which will drive soil development and properties. Landscapes are partly determined by geological history; (4) Biodiversity: the type and variety of species present in an area will determine the response of ecosystems, such as soils, to external pressures.

Fulfilling Human Needs

The very essence of the anthropocentric concept of ecosystem services is the fulfilment of human needs. Few studies in the ecosystem services literature, however, go as far as specifying how and what "human needs" are potentially or actually fulfilled by ecosystem services. One very notable exception is the Millennium Ecosystem Assessment (MEA 2005), that, although not explicitly acknowledging it, shows how ecosystem services contribute to human well-being by using a framework that resembles Maslow's "Hierarchy of needs" (1943).Ecosystem services relate to Maslow's hierarchy of needs on two different levels: (1) The Physical Level: ecosystems provide goods useful for the fulfilment of some physiological need (clean air, clean water, food, shelter), through provisioning processes; (2) The Non-Physical Level: ecosystems provide aesthetics, spiritual and cultural benefits.

Model

From the conceptual framework discussed above we developed a model of the provision of ecosystem services from soils. The model is based on the conceptual framework and uses pedotransfer functions to describe the biophysical processes at the origin of the provision of each services from soils showing how soils Natural Capital is embodied by soil properties and processes. An on-going part of the research is focusing at the farm scale. Scenarios are run on 2 typical New Zealand dairy farms situated on two soils showing very different natural capital: a sedimentary soil and a volcanic soil. The scenarios show how soils' natural capital, farming practises and soil management impact on the provision of ecosystem services from soils. This knowledge can provide management tools for economists and policy makers to better understand the provision of ecosystem services. An economic valuation of soils' services is also undergone. The results of the valuation could be use to build a management tool around payment for ecosystem services, e.g. for farmers, based on soils' natural capital and a better adequacy between land use and available natural capital.

Conclusion

The framework shows how soils' natural capital can be characterised by soil properties, how supporting processes ensure the formation and maintenance of that capital, how degradation processes influence natural capital depletion and how soils' ecosystem services play a role in fulfilling human needs. The framework is then used to develop a biophysical model of the provision of ecosystem services from soils, implemented on New Zealand dairy farms, followed by a valuation of soils' services that could enable economists and policy makers to weigh more carefully soils' natural capital in development processes. It is finally argued that much of the vast scientific modern-day understanding of soil processes and taxonomy needs to be more fully utilised in operationalising frameworks (such as the one proposed in this paper) that attempt to measure soils' ecosystem services and natural capital.

References

Barrios E (2007) Soil biota, ecosystem services and land productivity. *Ecological Economics* **64**, 269-285.

Daily GC (1997) 'Nature's Services: Societal Dependence on Natural Ecosystems.' (Island Press: Washington DC).

Lavelle P, Decaens T, Aubert M, Barot S, Blouin M, Bureau F, Margerie P, Mora P, Rossi JP (2006) Soil invertebrates and ecosystem services. *European Journal of Soil Biology* **42**, S3-S15.

Lynn I, Manderson A, Page M, Harmsworth G, Eyles G, Douglas G, Mackay A, Newsome P (2009) 'Land Use Capability Survey Hand-book - a New Zealand handbook for the classification of land - 3rd ed.' (Hamilton, Agresearch, Lincoln, Landcare Research, Lower Hutt, GNS Science).

Maslow AH (1943) A theory of human motivation. *Psychological Review* **50**, 370-396.

MEA (2005) 'Millennium Ecosystem Assessment: *Ecosystems and Human Well-being: Synthesis*.' (Island Press: Washington DC).

Palm C, Sanchez P, Ahamed S, Awiti A (2007) Soils: A contemporary perspective. *Annual Review of Environment and Resources* **32**, 99-129.

Swinton SM, Lupi F, Robertson GP, Hamilton SK (2007) Ecosystem services and agriculture: Cultivating agricultural ecosystems for diverse benefits. *Ecological Economics* **64**, 245-252.

Turner RK, Daily GC (2008) The ecosystem services framework and natural capital conservation. *Environmental & Resource Economics* **39**, 25-35.

Wall DH, Bardgett RD, Covich AP, Snelgrove PVR (2004) The need for understanding how biodiversity and ecosystem functioning affect ecosystem services in soils and sediments. In 'Sustaining biodiversity and ecosystem services in soils and sediments'. (Ed. DH Wall) pp. 1-12. (Island Press: Washington, DC).