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Mapping, Modelling and Managing Ecosystems Services in New Zealand

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Abstract: Central and local government agencies in New Zealand are calling for a paradigm shift in natural resource management. A unified approach is required to deliver a wide range of services and outcomes in a sustainable manner. Our new, 4-year research project aims to provide the scientific basis for such an approach. We are taking a three-phase approach. First, we will characterize, classify and quantitatively map past and current state of a comprehensive suite of ecosystem services nationally. We will use a tiered approach that reflects the level of knowledge available about various services. Second, we will explore how future changes in land use and land-use management, including consideration of multiple land use, alter the "basket" of services delivered. Third, we will develop a framework for integrating an ecosystem services approach into natural resources planning, policy, and reporting to ensure delivery of multiple benefits and outcomes. We are using the Millennium Ecosystem Assessment framework as a starting point for our work and will adapt and expand it to suit the conditions and needs in New Zealand.

Keywords*: ecosystem services; land-use change; mapping; New Zealand; policy frameworks*

1. INTRODUCTION

Ecosystems provide a range of goods and services to humans, many of which depend on processes and functions that would be difficult or impossible to replace. The recent Millennium Ecosystem Assessment (MEA) [2005] broadly classified services into four categories: supporting, provisioning, regulating, and cultural. It found that most ecosystems and their associated services are declining globally. The findings have triggered a wide range of new research that is intended to help characterise, quantify, track and in some cases value – economically or otherwise – ecosystem services across a range of scales [Chen et al. 2006, Metzger et al. 2006, Naidoo et al, 2008, Nelson et al. 2009]. Our paper outlines a new 4-year research programme that is undertaking a national level assessment of ecosystem services within New Zealand and developing new policy frameworks to ensure that the full range of ecosystem services are considered in a holistic and integrated manner.

2. NEW ZEALAND – BRIEF OVERVIEW

New Zealand is a small (~270,000 km^2) island nation in the southern Pacific Ocean that lies along the Australasian-Pacific plate boundary. The collision between the two plates generates high levels of tectonic activity, geothermal activity, and rates of uplift. As result, New Zealand's topography and landforms are highly varied and changing rapidly relative to geological time scales. It has a mild, oceanic climate with average temperatures from 0ºC to 15 ºC and west-east rainfall gradients (<300 mm to >10 m of rain per annum).

Given its variable environments and long isolation (~80 million years), New Zealand supports a diverse range of ecosystems and species. A global biodiversity hotspot, it is home to many endemic plant and animal species such as the kiwi, kakapo, and giant weta. Over a third of the country is protected in various national parks and reserves [Ministry for the Environment 2007], which helps attract over 2 million tourists annually [Statistics New Zealand 2009b].

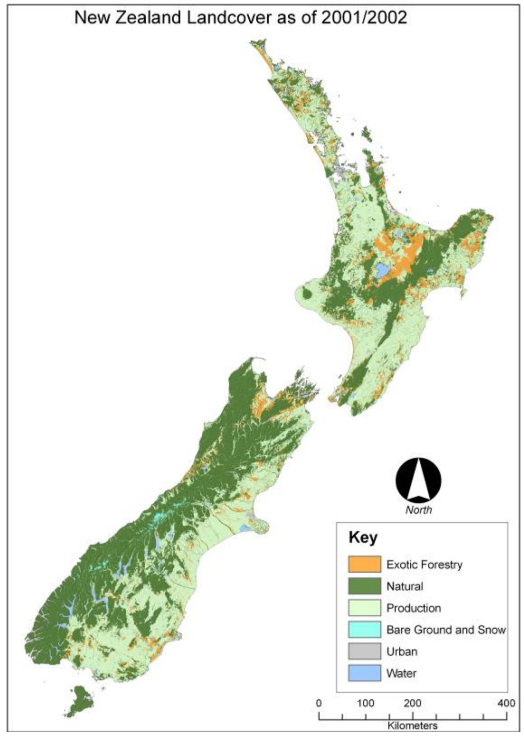

Figure 1. New Zealand land cover at 2001/2002.

Since humans arrived ~1000 years ago, much of the landscape has been altered to provide services desired by people. Approximately half the land supports primary production, including dairying, sheep & beef, cropping, forestry or horticulture [Ministry for the Environment 2007]. Together, these industries generated $25.9 billion worth of exports in 2009 or 14.1% of the NZ economy, of which dairy products alone accounted for $9.6 billion or 5.2% [Statistics New Zealand 2010]. At June 2009, the New Zealand population was 4.3 million [Statistics New Zealand 2009a], and is expected to increase to >5 million by 2050. While urban areas occupy <2% of the landscape [Ministry for the Environment 2007], there is increasing concern over the long-term impacts of urbanization around major urban centres and in coastal zones. Very low density residential developments – or "lifestyle blocks" – encroach on the country's most versatile soils [Statistics New Zealand 2008], thereby impacting future agricultural production, while coastal urban developments can permanently alter the coastline character and associated cultural services.

3. POLICY CONTEXT

Management of New Zealand's natural resources falls primarily under the Resource Management Act (RMA), which is administered by a set of 85 regional, district, and city councils[1] with guidance from targeted national policy statements. The RMA requires councils to manage the resources within their jurisdiction sustainably. Despite that laudable goal, policy, planning, and management under the RMA has typically focused on maximizing individual ecosystem services (ES), such as food or fibre production (e.g., provisioning services). In addition, the governance structures created by the RMA and the associated Local Government Act resulted in a highly devolved resource management system in which most environmental decision-making occurs at regional and city/district levels. This has created a tension in balancing broader scale national outcomes with regional or local outcomes.

While natural resource management in New Zealand has traditionally focused on single services, increasing societal expectations are demanding increased consideration of all ES rather than one particular ES. Examples include meeting international obligations to gain and maintain market access, eco-labeling to satisfy consumer concerns about production impacts, or community efforts to restore urban biodiversity. Integrated management of ES will help safeguard $25.9 billion p.a. of primary production exports that depend directly on

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[1] That number will decrease with the consolidation of the Auckland Regional Council and eight city/district councils into a single Auckland Council by November 2010.

provisioning and regulating ES, help conserve supporting ES (valued at ~$300B p.a. assuming the same ES/GDP ratio given in Costanza et al. [1997]), and maintain cultural ES valued both by New Zealanders and visitors (e.g., $21B p.a. from tourism [Statistics NZ 2009b]). New Zealand faces the challenge of making informed natural resource management decisions that consider both the dependence and impact on the full range of ES. New frameworks, methods, and approaches are required that enable explicit assessment of trade-offs among ES and that assist policy development and planning undertake transparent deliberations to disclose the range of possible consequences associated with different decisions.

4. RESEARCH APPROACH

Using the MEA framework as a foundation [Millennium Ecosystem Assessment 2005], we are taking a three-phase approach. First, we will produce a nationwide assessment of ecosystem services. Second, we will determine how ES are linked to land use and explore future scenarios of land-use change and how they affect the provision of ES. Third, we will develop a framework to help adapt existing policy and planning approaches to ensure national consistency and sustainability across a broader range of ecosystem service outcomes. Specifically, our approach will:

- establish functional relationships, e.g. 'How do bundles of ES behave?'; 'How will the promotion of one ES affect delivery of others?'
- undertake the first comprehensive national scale attempt to characterise current and future ES in New Zealand
- design a unifying framework to maximize the utility of other specific ES research
- develop algorithms, surrogates, proxies, etc., to help overcome gaps in an operating environment of limited data and regular uncertainty
- consolidate and align a range of existing models and 'futuring' tools to assist with the characterization of ES across various scales
- transform a research concept into a policy instrument to enable the integration of ES, and the consideration of multiple ES simultaneously, into planning, policy decisions and reporting protocols.

In addition to the national assessments, we will develop two targeted case studies at catchment scales to demonstrate the utility of a multiple ES approach. The sections below describe each of the three phases of our project.

4.1. Characterising and Mapping Ecosystem Services

The first phase of our research will involve developing a method for nationally characterising and mapping ES. National databases will be used to map ecosystems and their abiotic drivers. Nationally applicable environmental models will be used to evaluate the biophysical condition of ES. New Zealand fortunately has a number of significant national databases on which to base our research including: the Land Resource Inventory [Lynn et al. 2009], National Soils Database [Hewitt et al. 2001], and Land Cover Database [Thompson et al. 2003]. We are employing a tiered approach that permits flexibility in characterization of ES depending on both the available data and knowledge of ecosystem-ecosystem service relationships (Table 1). Tier 1 will include qualitative assessments of ES condition and trends for which data, knowledge or both are limited or lacking. In that case, ecosystem services will be characterized based primarily on expert judgment of conditions (e.g., excellent/good/poor) and trends (e.g., increasing/stable/decreasing). It will also include assessments of what new information and knowledge would be required to increase understanding and characterization of particular services. Tier 2 will include quantitatively estimating and mapping ES relative to broad ecosystem conditions as represented by, for example, land cover [Chen et al. 2009, Troy and Wilson 2006]. Tier 3 will involve the use of biophysical-based process models to evaluate ES. For example, existing NZ-based models can be used to characterise erosion [Dymond et al. 2010] and water supply [Fahey et al. 2004]. The methods will be used to provide a present-day baseline of ES against which national and international comparisons, and future improvements, can be referenced. To characterize recent trends (e.g., past 20 years) in ES, the baseline will be compared with information on land cover from 1990 that has recently been compiled for Kyoto protocol monitoring and reporting [Ministry for the Environment 2009].

Table 1. Preliminary list of ES in New Zealand illustrating the tiered approach to characterisation and mapping. Lower case letters indicate cultural (c), provisioning (p), regulating (r), or supporting (s) services following MEA conventions.

Tier 1	Tier 2	Tier 3
Aesthetic Values (c)	Freshwater (p)	Biological Control (r)
Air Quality Maintenance (r)	Net Primary Production (s)	Climate Regulation (r)
Biochemical, Medicines (p)	Natural Hazard Regulation (r)	Erosion Control (r)
Cultural Heritage (c)	Nutrient & Water Cycling (s)	Fibre & Fuel (p)
Genetic Resources (p)	Recreation & Tourism (c)	Food (p)
Human Disease Regulation (r)	Soil Formation (s)	Habitat Provision (s)
	Tūrangawaewae* (c)	Water Purification (r)
	Waste Treatment (r)	Water Regulation & Irrigation (r)

*Translation: "a place to stand"; a powerful Māori concept representing places where people feel a strong sense of connection and empowerment.

4.2 Exploring Future Scenarios of Multiple Land-use Change and Ecosystem Services

We will explore future changes in land use and their corresponding effects on ES both nationally and in targeted case studies. We will review the range of policies and plans across scales and integrate them with existing national-scale scenario efforts to develop a comprehensive and consistent framework from which we will develop a set of reference national land-use change scenarios. The scenarios will form the basis for analyzing ES trends 100 years in the future. Scenarios being developed for the IPCC 5th assessment report [Moss et al. 2008] will provide the global context needed to develop our scenarios.

In particular we aim to develop a multiple land-use change model that can more comprehensively and accurately model the full range of ES across landscapes and time. Most land-use change models track changes among discrete, categorical classes of land use, land cover, or both [e.g., Claessens et al. 2009, Deal et al. 2004, Defries et al. 2004, Verburg et al. 2006]. Those models often assume a simple functional relationship between a use/cover class and a service or suite of services (Figure 2), with a key drawback being that the same use/cover could produce different services or "land functions" [Verburg et al. 2009]. Our approach aims to model relationships among different ecosystem components, in the broadest sense, and services using a systems approach. The approach theoretically provides several advantages such as 1) characterising broader suites of services, 2) exploring more subtle land-use changes (e.g., intensification), 3) directly linking management activities and service provision, and 4) retaining the ability to generate different classifications or typologies to suit different needs. However, the approach also carries several disadvantages, especially scaling issues and being data hungry.

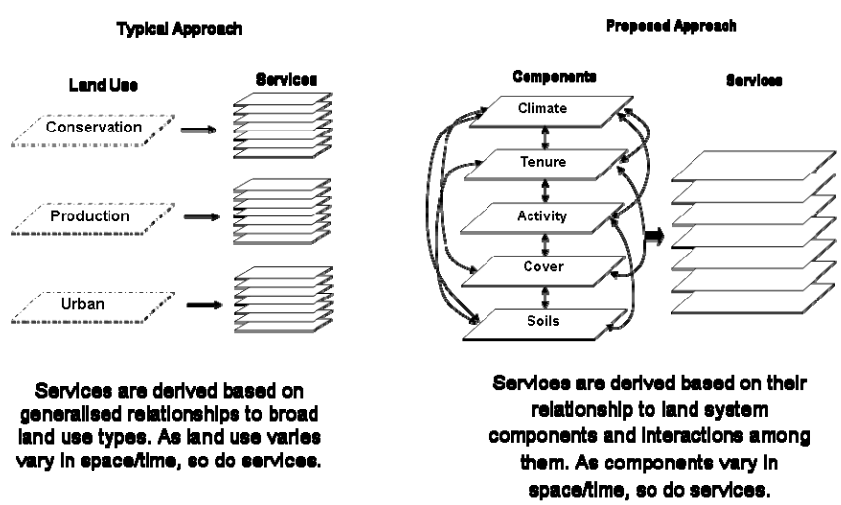

Figure 2: Typical and proposed approached to modeling relationships and changes among land uses and ecosystem services.

4.3 Embedding Ecosystem Services into Natural Resources Policy, Planning and Resource Management

The third phase of our research will develop a working template to enable integration and consideration of multiple ES simultaneously into planning and policy decisions and reporting protocols. We are reviewing the range of available frameworks and tools [e.g., Daily et al. 2009, Haines-Young et al. 2007, Layke 2009, Millennium Ecosystem Assessment 2005] to consider how to integrate multiple-ecosystem services in decision-making. We will select the most appropriate tool/framework and modify it to suit New Zealand conditions and needs. Based on our findings, we will develop recommendations for how to apply an ES approach for New Zealand decision-makers and provide a template outlining a series of steps to take when evaluating projects. A case study approach will be used to demonstrate its applicability to decision-making processes, and will be conducted in close collaboration with relevant decision-makers in each area to understand how the ES framework fits with existing policy frameworks and how these frameworks need to be adapted to support an ES approach. In addition, a science panel comprising representatives from national and regional/local government, industry and other research institutions will provide input into the design of the ES framework.

5. PRELIMINARY EXAMPLE: SOIL, WATER AND CARBON TRADE-OFFS

The following example illustrates the consideration of multiple ecosystem services using at the moment more traditional land use-ES relationships. During the research we intend to adapt these analyses to the land systems approach discussed earlier.

Following European settlement in the mid-1800s, much original indigenous forest in New Zealand was converted to pasture (Figure 1). In hill country, where tree roots are important for slopes stabilisation, deforestation leads to increased erosion, and consequently increased sedimentation in waterways. The increased sediment smothers aquatic habitat and significantly reduces penetration of photo-synthetically active light, thereby reducing the recreational values and flood capacity of the river and stream network.

The remedies for soil erosion in hill country include reforestation or scrub reversion on steep slopes and agro-forestry or soil conservation planting on less steep slopes. Tree planting has the additional benefit of sequestering carbon from the atmosphere and mitigating global warming, and afforestation on marginal land may be justified on the basis of carbon sequestration independent of soil erosion mitigation. Soil conservation plantings such as space-planted poplars on slopes or pair-planted poplars on gullies store little carbon per hectare. However, forestry, especially if permanently maintained, can sequester high rates of carbon – up to 6-7 tonnes of C/ha/yr for *Pinus radiata* forest [Hollinger et al. 1993].

While soil conservation and carbon sinks may be co-benefits of afforestation, water yield is a trade-off [Zhang et al. 2001]. In New Zealand's generally temperate climate, forestry produces less runoff than pasture, typically about 30% less. This is due to much larger interception of rainfall and subsequent evaporation [Fahey 1994]. In catchments of water shortage during summer, reforestation may reduce water yields below the critical levels needed to maintain minimum flow rates, water supply and/or irrigation.

We developed models to assess the trade-offs of soil, water, and carbon associated with forestry using a tier 3 analysis We assessed water yield using WATYIELD [Fahey et al. 2004], erosion using NZeem® [Dymond et al. 2010] and carbon sequestration using regional carbon stock rates [Ministry of Agriculture and Forestry 2009]. Erosion has an estimated marginal cost of $1.50 per cubic metre [Dymond et al. 2010; Krausse et al. 2001], water has an irrigation benefit of $1 per cubic metre [MAF 2004] where there is demand, and sequestered carbon is worth $20 per tone (Figure 3). Considering all three simultaneously, total benefits from afforestation vary highly in space. In the North Island positive benefits occurred on the East Coast and southern coast. In the South Island, only the top east corner (southern Marlborough) and south-east (part of Otago region) showed significant positive benefit, while large areas of dis-benefit occurred in the central portion of the island due to decreases in water yield in more arid environments. The main lesson learned from this preliminary example is that afforestation designed for environmental benefits should consider the consequences for a range of desired ecosystem services.

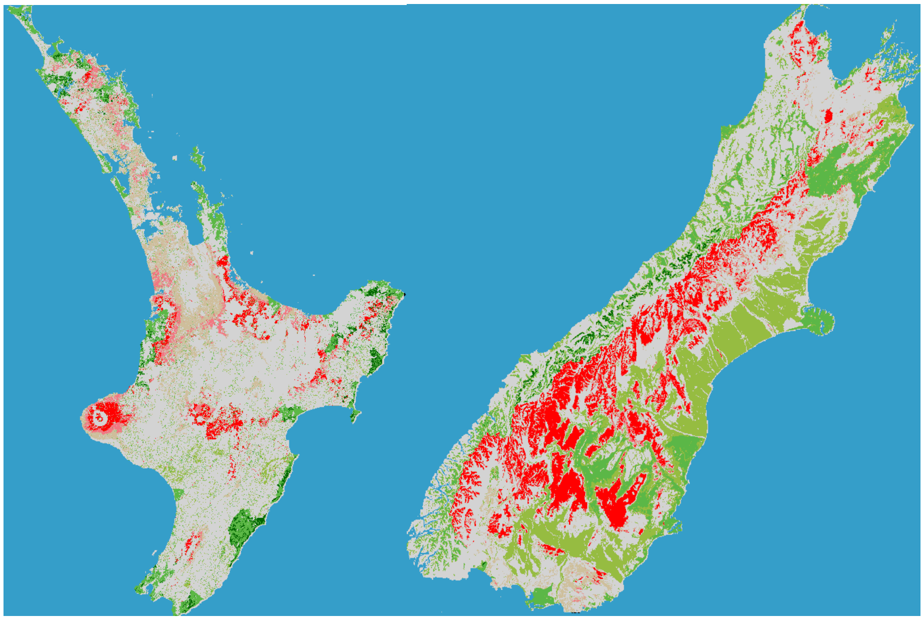

Figure 3. Benefit for soil conservation, carbon sequestration, and water yield of new *Pinus radiata* afforestation in the North Island and South Island. Dark green is greater than $150 /ha/yr. Light green is between $100 and $150 /ha/yr. Red is less than negative $150 /ha/yr. Light red is between negative $100 and negative $50 /ha/yr.

6. DISCUSSION

While our research is just starting, the case study described above illustrates the promise of using an ES approach to ensure the economic viability and sustainable future of New Zealand. New Zealand, like many countries worldwide, needs to maintain its natural resource base in the face of highly complex challenges, e.g., a global economy based on stretched resources, fragile ecosystems, climate change, loss of biodiversity, and the rise of new markets such as carbon trading [Adams 2006]. Responding to these challenges requires a unified management approach that takes account of the broader system-wide and longer timescale impacts – rather than narrower and shorter timescale impacts – as well as the many and varied stakeholders demanding the services that ecosystems provide [Bourgon 2009]. Such a unified management approach necessitates a step-change towards greater shared accountability for results, reduces "thinking in silos" and shifts the role of government from control to coherence and interagency governance [Bourgon, 2009].

Such a step-change is at the heart of the sustainable development debate and requires an integrated research approach that allows:

- Identification of emergent risks and opportunities
- Exploration of the trade-offs between sustainability concepts of viable, equitable and bearable
- Development of sustainable land management frameworks that focus on a "whole-of-catchment" or ecosystem approach
- Consideration of the benefits, both directly and indirectly, of different land use options, over multiple time frames and multiple scales (national, regional, local)
- Transition to markets that enable the economy to tell the economic 'whole truth'
- Exploration of institutions and governance (e.g., land tenure)

- Translation to policy, planning and reporting tools to build national resilience and measure progress towards agreed outcomes.
- Creation of forums for greater collaboration between the research community, industry and policy-makers on natural resource use.

The ES framework that this project seeks to develop will provide the essential integrative approach required to maintain the health of New Zealand's ecosystems and associated goods and services both now and into the future.

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