Evaluation of soil natural capital in two soilscapes

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Abstract
A stock adequacy method is presented for evaluating the soil natural capital in two contrasting soilscapes. The approach is to estimate the adequacy of soil natural capital stocks to support the soil services required by a specified land use. A stock adequacy index is defined to identify whether soil services are limited by soil natural capital stocks or have a stock surplus. Limiting values are derived from a stock quality–quantity curve determined from land evaluation or soil quality literature, or by modelling. The method is applied to eroded soils in a hill country soilscape, and a coastal sands soilscape. The derived stock adequacy index results expressed the principal variations in quality of the soil resources that serve land management in the two locations. The index is capable of being integrated into land resource assessments and provides a basis for economic valuation of soil natural capital.

Key Words
Soil natural capital, soil stocks, land evaluation, soil services.

Introduction
Soil natural capital (SNC) will need to be quantified and mapped at different scales if we are to use the concept to assess and value soil assets and soil services. In this paper we outline a method to quantify SNC in two contrasting soilscapes. We explore the spatial and temporal variation of SNC as a necessary precursor to mapping SNC. We define soil natural capital (adapted from Dominati *et al*. 2009) as the capacity of soil to provide the soil stocks needed to underpin the soil services required by a specified land use. The natural capital of a soil is quantified by a set of morphological, chemical, physical and biological properties that quantify the status of the relevant soil stocks. In this study we have chosen a minimal set of soil services, stocks and associated properties to demonstrate a method to quantify and use that quantification to characterise the variability of SNC in two study areas. The ultimate goal is to quantify the economic value of SNC. The method presented here provides an index of SNC value to which an economic value may be assigned. The index must be capable of being efficiently derived from soil and land resource evaluations.

Methods and materials
The proposed method for evaluating SNC combines the principles used in land evaluation (Rossiter 1996) and soil quality (Sparling *et al*. 2004). It includes the following steps:

- Define the land use type (LUT).
- Define soil services required to support and manage that LUT.
- Define the SNC needed to sustain each soil service in terms of a set of soil stocks.
- Quantify these stocks for each soil type.
- Estimate the quality of each stock to adequately support a specified soil service. The measure of quality is characterised as a stock adequacy index.
- Aggregate stock quality levels across the soil services to derive an aggregated estimate of SNC for the land use. In this study the aggregate is the mean index across all services.

The procedure is outlined in Figure 1.

The method is based on the premise that soil services may be limited by one or more inadequate soil stocks. The stock adequacy index quantifies the quality of a stock to support a soil service. Estimation of the index involves two steps. In step one, a level must be determined for each stock that is adequate for unlimited operation of the chosen soil service. This amount of stock is assigned a quality value of 100%. Values greater than 100% signify a stock surplus and non-limitation of the dependent soil service. The 100% index level is estimated from either (a) land evaluation and soil quality literature recommendations for high class or high quality soils, (b) a site potential value as in the case of soil organic matter where the highest likely level for the site and specified land use is chosen, or (c) a soil process model that represents the soil service that relates stock input to process output. In step two less than adequate stock quality levels are assigned a

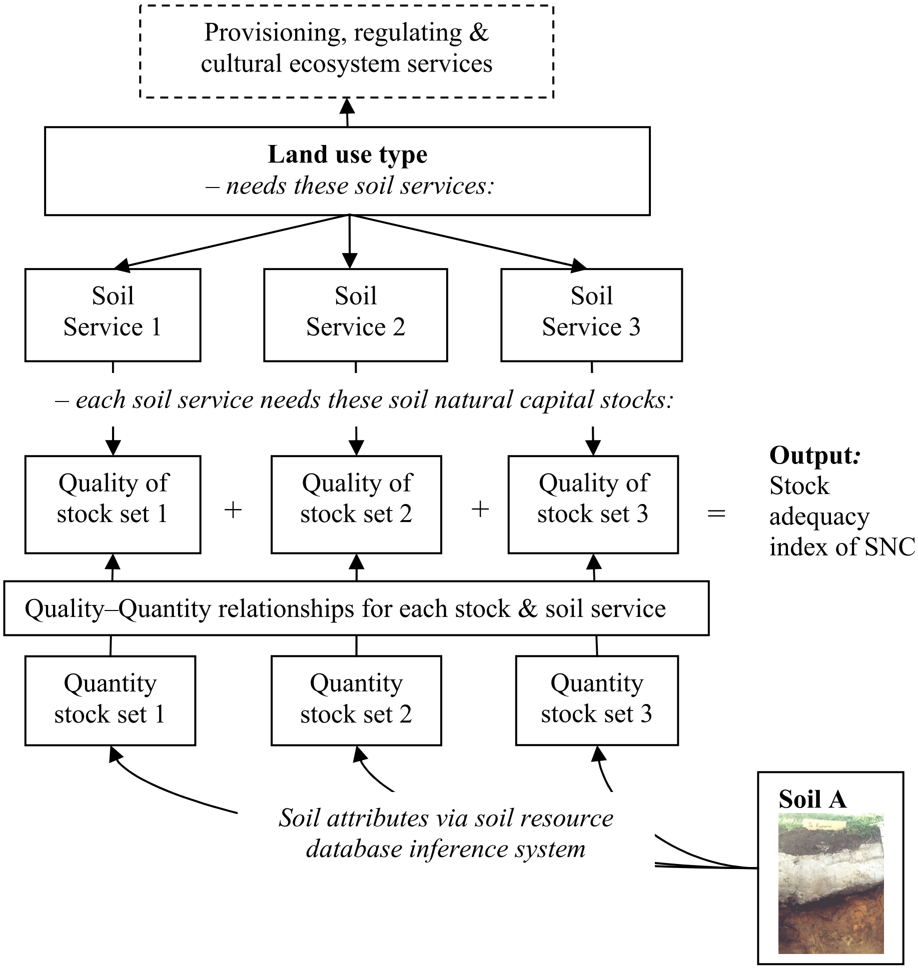

Figure 1. Outline of procedure for evaluating soil natural capital (SNC) for a specified soil and land use type. The stock adequacy indices can be summed over all services to derive an overall SNC index for the soil – land use type combination.

percentage based on a stock quality – stock quantity curve. In this study the 100% stock quality levels were derived from land evaluation "soil qualities" (Webb and Wilson 1995), and soil quality evaluation curves (Sparling *et al*. 2003). Establishing these levels requires further research. SNC stocks are assumed to include soil capacities, such as available water capacity that is dependent on porosity, as well as soil materials such as carbon. There was no distinction made in this study between soil stocks built up by managed SNC and inherent SNC.

Soilscapes

Soil natural capital was estimated in two contrasting soilscapes: soft rock hills and coastal sands. Soils of the soft rock hills are described by Vincent and Milne (1990). The soils are developed in weakly indurated siltstone on step hills with average slopes 28 degrees. The land use is rain-fed pastoral sheep grazing, and the soil mantle is subject to soil slip erosion. The major driver of soil variability is the presence or absence of soil erosion. In uneroded sites the soils are Argillic Pallic Soils (Hewitt 1998) with soil spatial variability related to slope position. Soils on crests are well drained and soils on slopes with redox mottled subsurface horizons. In eroded sites the soils are either Recent Soils or Raw Soils with paralithic contacts at shallow depth. Soil temporal variability is related to time since erosion disturbance. Sites were studied that had been eroded at four periods (Lambert *et al*. 1984). We only included hill slopes in this study and did not consider valley floors or erosion accumulation areas.

Soils of the coastal sands soilscape are described by Cowie *et al*. (1967) on dunes and sand plains along the Manawatu coast. The major driver of soil variability in the undisturbed Sandy Brown Soils and Sandy Gley Soils is the depth to ground-water. The well-drained Foxton soils, imperfectly drained Himatangi soils, and poorly drained Pukepuke soils form a drainage catena. Intensive pastoral and cropping during summer is irrigated, which is supplemented by water via capillary rise from water tables within 1 m of the base of the root zone. Our calculations of water added via capillary rise assumed the water-table height corresponded to the depth to dominant grey soil redox colours. We did not take into account seasonal fluctuations or root depth extension through the growing season. The land use considered in this study was irrigated maize feed cropping.

Soil stocks and services

The soil services and related stocks considered in this study are listed in Table 1. In this paper, only key soil services and stocks were considered in order to illustrate the method.

Table 1. Soil services, the minimum set of supporting soil natural capital stocks studied, and their profile measurement.

Soil services	SNC stocks
Carbon storage	C (t/m^3 to 600 mm depth)
Profile available water storage	Profile available water capacity (mm; within potential rooting depth)
Aeration	Depth to macropores <5%, or depth to dominant grey matrix, whichever is less (mm)
Capillary rise	Capillary rise estimated as water augmentation (Scotter 1989) (mm)
Cation fertility	Sum of bases (exchangeable calcium, potassium, magnesium and sodium) weighted average to 600 mm depth (cmol/kg)

Results

Stock quality estimates are shown in Table 2. The carbon storage service is promoted by soil development as shown by the contrast between non-eroded and eroded soft rock soils. It is limited in eroded soils by shallowness and by immature topsoil development. Lambert et al. (1984) showed that the eroded sites had only recovered 77 % of their pre-eroded pasture productivity in 80 years. After an additional 25 years, no further recovery occurred on the eroded sites (Rosser and Ross 2009).

The PAW service is limited in all the soils. Lower PAW soils in rain-fed pastures on the soft rock soils cause earlier reduction of pasture in summer and consequent reduction in sheep carrying capacity. Soils with relatively low PAW soils in irrigated maize on the coastal sand soils confer relatively higher costs due to higher irrigation water requirements (Hedley and Yule 2009). The aeration service promotes good pasture growth in deep soft rock soils but in shallower soils limitations to the service reduce production. In coastal sand soils aeration promotes deep root growth in well-drained sites but in poorer drained sites maize will suffer root extension limitations. The capillary rise service is active neither in the soft rock soils nor in the well-drained coastal sand soils. It is active in less well drained soils where it reduces irrigation costs for maize production. The cation fertility service is highest in the eroded soft rock soils where the cations are supplied from parent material sources. Lower stocks within the rooting zone in the other soils limit fertility and must be augmented by appropriate fertilisers at a cost that reflects the natural stock limitations.

Table 2. Estimated SNC stock adequacy index ranges (adequate stock = 100%) supporting five soil services in two landscapes.

Soilscapes	Soil services					
And major variations	Carbon storage	Prof. Avail. Water	Aeration	Capillary rise	Cation fertility	Mean
Soft rock						
Non-eroded – spatial variation (aspect, slope length)	56–94	52–76	50–90	-	52–64	51
Eroded – temporal & spatial variation	31–40	36–49	36–52	-	73	31
Coastal sands						
Drainage – spatial variation	71–104	85–190	22–100	0–139	36–40	73

Conclusions

- The method presented provides a quantitative estimate of the quality of SNC to support soil services for any given land use.
- The method provides a quantitative expression of the principal variations in quality of soil resources that serve land management in two study areas.
- The stock adequacy index provides a basis for economic and other measures of SNC value. It has potential for use in quantifying the soil assets of areas of land for incorporation into resource economic analyses.

- The stock adequacy index is standardised and can potentially be used as a basis for comparison across a range of SNC stocks and services.
- The method uses land evaluation and soil quality assessment procedures and is capable of being integrated into land resource assessment, using both traditional soil survey and digital soil mapping approaches.
- The results can be interpreted in terms of the activity of soil services, and the costs of reduced services due to SNC limitations.

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