A Soil Scientist's Perspective on Ecosystem Services and Sustainability

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Sustainability

Sustainability is one of the most widely used terms in environmental science and natural resource management. It is used so frequently, often without being defined, that its implication for various applications is not always clear. How do we know if productivity of a particular ecosystem is sustainable? What does it mean to manage natural resources sustainably? Is sustainability an inherent property of natural systems, or is it based on human values and demands? These Forum articles provide three scientific perspectives that attempt to provide some clarity on the meaning of sustainability for soils, forests, and water in the Pacific Northwest and beyond.

—David L. Peterson

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Introduction

Ecosystem Services

Ecosystem services are defined in the Millennium Ecosystem Assessment (MEA) of 2005 as, "the quantifiable or qualitative benefits of ecosystem functioning to the overall environment, including the products, services and other benefits humans receive from natural, regulated, or otherwise perturbed ecosystems." The MEA classifies benefits from ecosystem services into four categories:

- Supporting services (biogeochemical cycling, production, habitat, biodiversity)
- Regulating services (regulation of water quality, climate, floods, erosion, biological processes such as pollination and diseases)
- Provisioning services (direct or indirect food for humans, fresh water, wood, fiber, and fuel)
- Cultural services (aesthetic, spiritual, educational and recreational)

Sustainability

The U.S. National Environmental Policy Act (NEPA) of 1969 stated the goal of a national policy to, "create and maintain conditions under which [humans] and nature can exist in productive harmony, and fulfill the social, economic and other requirements of present and future generations of Americans." A widely quoted definition of "sustainability" is found in the 1987 Report of the World Commission on Environment and Development: "Meeting the needs of the present without compromising the ability of future generations to meet their own needs" (United Nations 1997).

The Roles of Soils in Ecosystems

The necessity of functioning soils for all four categories of ecosystem services is obvious.

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Less well understood are the magnitudes, kinds, and reasons for soil variability, and the inseparable synergisms among soils, geomorphological processes, climate, and living organisms. Soil-environmental relationships are unique within and among regions (biomes). Generalizations exist across the population of soils, but local variations and processes occur.

All of us have perspectives, conditioned by our education, work and observations, about the patterns and processes which sustain life on Earth. Unfortunately, none of those perspectives can be precise or complete because no one knows everything. Differences in perspectives, beliefs, and knowledge are what create differences in opinion about, "what to do and how to do it," in the context of natural resource management and determining the priorities society sets for development and enforcement of environmental policies and laws.

A pedologist studies soils in their natural settings. Such studies include understanding the accumulations of the (parent) materials from which soils form and the processes which result in soil horizonation – the development of identifiable layers (horizons) within the soil (Simonson 1959). The physical, chemical, mineralogical and biological attributes of horizons determine the classification of the soil in which they reside and how these soils function in nature (Hudson 1992). Collectively, the soil's horizon attributes are the record of the soil's developmental history and the predictor of how that soil contributes to, and responds to, ecological functions and processes. The fundamental, long-standing paradigm of soil genesis is, "The Factors of Formation," popularly attributed to Hans Jenny (1941), but first conceived by V.V. Dokuchaev (1883), a Russian pedologist, in the late 19th Century. The idea behind the, "factors of soil formation" is that soils form as a consequence of the dynamic manifestations of climate and living organisms upon parent materials over time, as modified locally by topography.

The factors of soil formation interact to produce a complex suite of soil-forming processes, all of which are temporally and spatially variable at scales from peds (soil aggregates) to landscapes. Soil-forming processes were categorized broadly by the American pedologist, Roy Simonson (1959), as, "gains, losses, transformations and translocations" *within the soil*. "Gains" include sediments from upslope, organic matter additions, and dissolved constituents in subsurface water movement from other locations. "Losses" include removal of soluble constituents by leaching, plant uptake, and surface erosion. Transformations include *in situ* clay formation, decomposition of organic materials, mineral weathering, and mineral precipitation as different compounds. "Translocations" are material movements within the profile or to other soils, and include clay movement, minerals being dissolved or suspended and relocated by percolating waters and particles from the surface falling into cracks that open when the soil dries and shrinks. These are only a few examples of the soil-forming processes. Dovetailing the factors of soil formation with the concepts of soil-forming processes produces a holistic conceptual model of natural functions that provide ecosystem services (Figure 1).

The oversight most commonly made by non-pedologists when considering soil attributes and

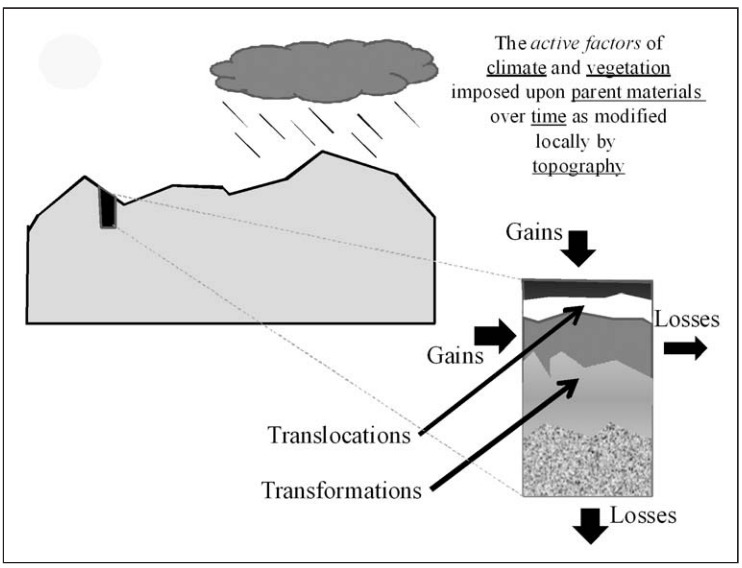

Figure 1. Coupling the conceptual models of "the factors of soil formation" and "the soil-forming processes" results in a holistic model of Earth's soil patterns and processes.

their roles in ecosystem services is not putting a particular soil into its landscape setting in the context of the temporal and spatial processes that weld individual soils into soil-landscape systems (Daniels and Hammer 1992). Not all places in the landscape are the same. Soil systems, like living bodies, are more than the sums of their individually functioning parts in both space and time. Landscapes include erosional and depositional surfaces and places where water enters (recharges) and leaves (discharges) the soil, along with places where water passes through horizontally and/or vertically (throughflow). Water dissolves, transports, and rearranges materials as it moves through the system. The dry slope that is stable after timber harvest in August might be a mudflow during January rains or June snowmelt. Knowing how soils will respond to anthropogenic influences requires an understanding of how soil systems respond to seasonal changes in temperature, water infiltration, and percolation and the biological activities of plants and the other living organisms in the soil.

People generally do not view a watershed or landscape and ask, "Where is the best place to grow plants, build houses that will have dry basements, and place roads that will remain in place during the worst weather of the year, and will cause minimal subsequent maintenance to the ecosystem?" The view site for a "McMansion" might be inherently unstable or might be the habitat of a rare plant species. Landscapes and watersheds historically are altered piecemeal by humans, creating unforeseen environmental consequences. Watershed management activities and "development" generally are not predicated on the pre-change assessments of flows of water, nutrients and energy through the system, but on ownership patterns and owner desires that generally are not predicated on system processes.

The concept of "sustainability" thus becomes complicated when viewed from the perspective of functioning soil systems. One could make the argument that all soil systems and ecosystems have been sustainable in the absence of human influences. When determining if a particular plot of ground is "sustainable," one must ask, "For what purpose, for how long, with what consequences and with what inputs?"

A simple example will be presented of a sustainable system in Whatcom County, Washington. Figure 2 is a photograph of part of the watershed of the Middle Fork of the Nooksack River, with adjacent photographs of two soils in the watershed. Soil temperature regimes range from mesic on the valley floor to cryic on the ridge and shoulders. The Heisler soil (ashy-skeletal over loamy-skeletal, glassy over isotic, mesic Typic Vitrixerands) is a deep soil with a 140 to 220 day growing season. Lateral water flow from upslope (Figure 3) keeps the Heisler subsoil moist throughout the growing season. Crinker soils (medial-skeletal, mixed, Andic Hapolocryods) on the ridge, shoulder and upper backslope are moderately deep and have a 90 to 110 day growing season. A very thick O horizon, densely permeated by tree roots is common on forested, cold, high elevation soils. Under natural conditions, the Crinker soils are wet and cold throughout the year. They are the soils of the headwaters of the watershed and have high soil organic carbon content.

Clear-cutting the forest on this soil results in desiccation and loss of the thick surface organic matter layer, drying and warming of the mineral soil, and drastically alters the soil ecology. The limited growing season and deep annual snowpack greatly hinder post-harvest reforestation. The best use of the Crinker soil is permanent forest vegetation, which allows this soil to function in its most important ecological roles, recharging soil water in the watershed while functioning also as an important carbon sink. The Heisler soil, which is warmer, deeper has a long growing season and receives upslope water, is prime timber growing soil, and with appropriate fertility and management, should be a sustainable source of high quality forest products. This example illustrates how "sustainability" can be practiced in this watershed.

Sustainability, from a soils perspective, is predicated on humans' abilities to understand natural system processes and function, including: how to replace what is removed, respond wisely to what is changed, and predict what will happen "downstream" from anthropogenic influences anywhere in the landscape. Can sustainability happen, "one piece at a time" in the landscape when the system patterns and processes are not understood or are ignored?

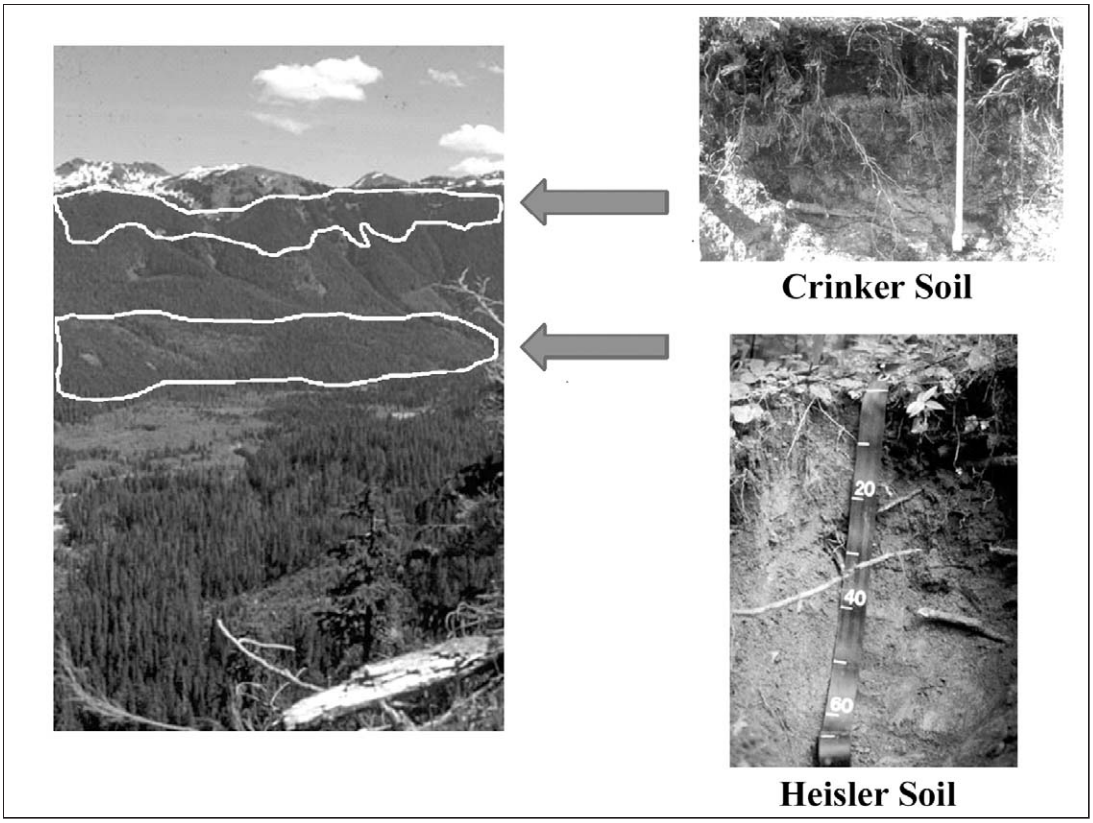

Figure 2. Crinker soils at high elevation, and with a short growing season in the Middle Fork of the Nooksack River in Whatcom County, Washington. The Crinker soil has a thick organic surface, sequesters much soil organic carbon, is the water recharge area for the watershed, and is best managed for permanent forest vegetation. The Heisler soil at lower elevation receives lateral water flow from upslope, has a longer growing season and is excellent timber-producing soil.

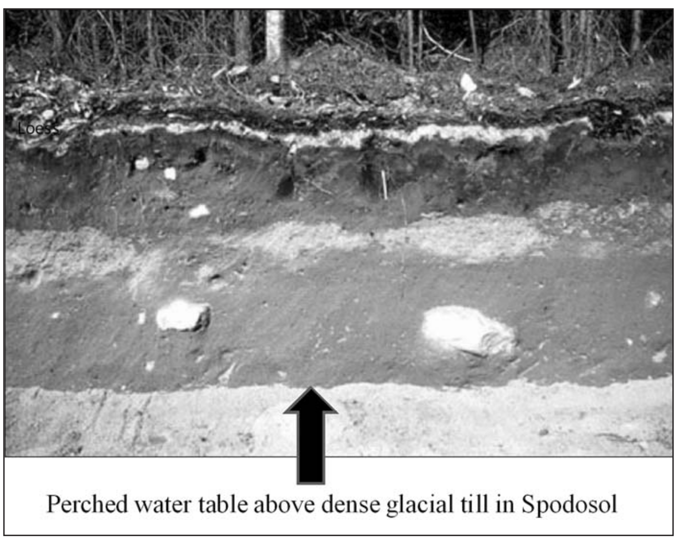

Figure 3. Lateral water movement downslope above dense basal glacial till. This Spodosol is in Skagit County, Washington. Note the thick surface organic layer above the white “E” horizon.

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