SOIL QUALITY AND HEALTH-SOME APPLICATIONS TO FOREST ECOSYSTEMS[1]

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INTRODUCTION

Concerns about sustaining the productivity and health of forest ecosystems have been the subject of much research, debate, and federal actions (Perry, et. al. 1989; Gessel, et. al. 1990; Everett, et. al. 1994.) Forest management practices and their impacts on the environment are scrutinized daily by the media. The National Forests are managed under principles of multiple use and sustained yield "without impairment of the productivity of the land." Soil health and quality are embedded in statute for the National Forests of the United States. Restoration of stressed sites, and processes is an integral component of sustaining forest ecosystem health (Everett, 1994.) Understanding the role of soils is crucial to understanding stress processes within ecosystems and establishment of measurable soil quality standards is a means of expressing desired soil conditions (Meurisse and Geist, 1994.) It is national Forest Service policy to have soil quality standards to ensure sustainability and long-term productivity of forest ecosystems. The several Regions have developed and implemented standards, or measures, of soil quality since the 1970's.

<u>Definitions:</u> The terms, soil quality and soil health, often are used interchangeably. However, there are some subtle differences between them. Soil quality can be defined as: "the <u>capacity</u> of a specific soil <u>to function</u>, within natural or altered land use boundaries, to sustain or improve plant and animal productivity, water, air quality, and human health and habitation." (NCSS SQ Committee, 1995) Health is defined as "freedom from disease or ailment; the general condition of the body or mind with refernce to soundness or vigor (Am. College dictionary). So, I define soil health as "the <u>condition</u> of the soil with reference to its inherent quality and <u>ability to perform vital ecosystem functions</u>." The subtlety is in the capacity to function versus the condition of the soil relative to its inherent qualities.

<u>Vital Soil Functions:</u> Vital soil functions are to: (1) Sustain biological activity, diversity, and productivity; (2) partition water, energy and solute flow; (3) filter, buffer, immobilize, and detoxify organic and inorganic materials; (4)store and cycle nutrients and other materials; and (5)support structures and protect archeological treasures. Therefore, we can say a soil is unhealthy if the soil quality standards are exceeded so that the ability to perform the vital functions is impaired.

WHY ARE WE CONCERNED ABOUT SOIL QUALITY OR SOIL HEALTH?

<u>Soil and Civilizations:</u> Several recent symposia and publications have focused on issues pertinent to soil quality and health. "For humankind, soil is the essence of life and

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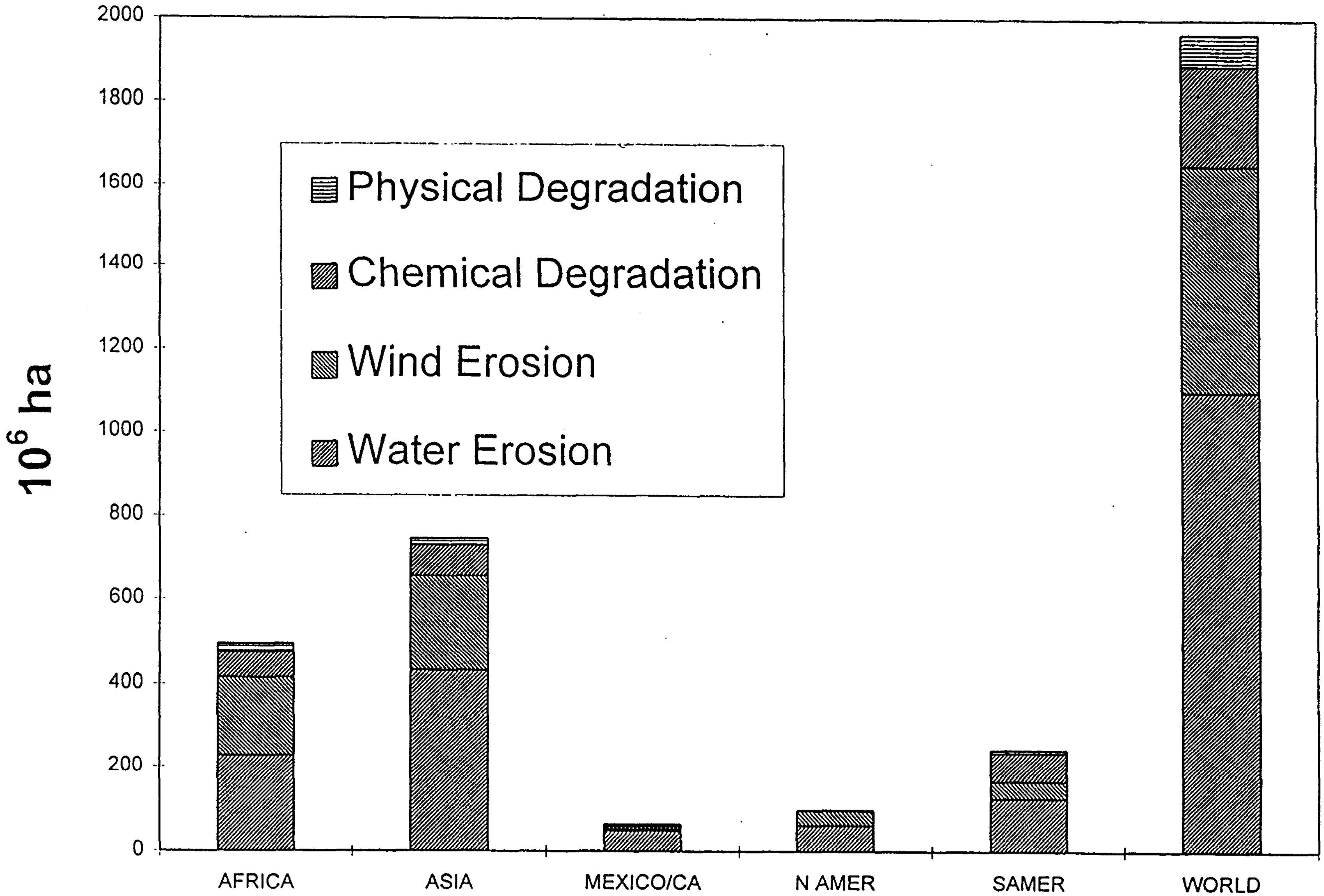
Figure 1.Soil Degradation in Regions of the World
From:Szabolcs,1994



health." This opening sentence of the Preface to the SSSA Publication, Defining Soil Quality for a Sustainable Environment, captures the significance of the soil resource for sustainability of human life and economic well being (Doran, et. al.1994). In the Forward to this same publication, President Darrell Nelson states that for soil quality to become part of the mainstream of soil or environmental science programs, "there must be acceptance of the definition of the term and quantitative indicators must be developed." I concur. Definition is important for communication and establishment of quantitative measures is critical for monitoring conditions. The importance of sound soil and water management in the development and advancement of civilization is further explored in SSSA Publication 41, titled "Soil and Water Science: Key to Understanding our Global Environment." In particular, Hillel (1994), describes the historic relationship between soil, water and civilization. The protection of soil quality through the wise use of soil resources is critical to the sustainability of civilization.

Soil Degradation: Sustainable land use and resilience was the subject of a symposium in Budapest (Greenland and Szabolcs, 1994). Figure 1 illustrates the extent of soil degradation from erosion, and physical and chemical causes from major regions of the world (Szabolcs, 1994). Nearly two billion ha. is degraded worldwide. Most is from erosion. South America, Africa, and Asia have several hundreds of millions of hectares in degraded condition. Most is from water and wind erosion. Although Mexico and Central America and North America are among the least of all Regions, many millions of ha are degraded. In North America, there is no measurable amount shown for physical and chemical degradation. Yet, studies have shown that many areas have reduced productivity and quality largely because of erosion and physical degradation from soil compaction (O'Laughlin and Pearce, 1984; Froehlich and McNabb, 1984; Follett and Stewart, 1985; Sullivan, 1987; Berg, 1988; Geist, et. al. 1991). So, these may be underestimates. Most of the degradation in forest systems is due to physical degradation, namely soil compaction (Sullivan, 1987; Froehlich and McNabb, 1984) and erosion (Megahan, 1981; O'Laughlin and Pearce, 1984; Berg, 1988).

Forest health and productivity: Forest health and ecosystem health have emerged as major concerns in the United States. Usually, the forest health discussion has focused on insects and diseases that have increased mortality in the western and southern parts of the country. These often are only symptoms to more underlying stresses regulated by soil/climate systems. Concerns have been raised about the long-term productivity and sustainability of forest ecosystems. Several symposia and conferences have focused on the multiple facets of this issue (Perry, Meurisse, et. al. 1987; Gasboro and Slaughter, 1987; Gessel, Lacate, Weetman and Powers, 1990; Harvey and Neunschwander, 1991; McFee and Kelly, 1995). Soil quality, health of forest ecosystems, and sustaiability of ecosystem processes, including standards, monitoring methods and management practices have been central to these discussions.

Special Concerns for Mountain Ecosystems: Conserving mountain ecosystems and cultures demands special attention (Denniston, 1995). Mountains span one fifth of the landscape and are home to one tenth of humanity. Mountain cultures and ecosystems face three primary threats from the expanding world economy: land scarcity fueled by inequitable ownership patterns and control of public resources, intensive resource extraction, and mass tourism and recreation. Denniston characterizes mountains as "vertical islands of cultural and biological diversity surrounded by seas of biological impoverishment and cultural homogeneity." Mountain ecosystems are of particular concern because the soils there often are less well developed than on more gentle slopes and are subject to intense storms that can accelerate erosion. Mountain soils also may be less resilient than deeper, better developed soils on lands of low relief and lowlands with older geomorphic surfaces. Mountain ecosystems usually are managed for forestry, range, watershed and recreation activities. More than half of humanity receives its water supply from mountain watersheds. Thus, mantenance of soil quality is particularly important in mountain ecosystems.

Development of quantitative soil quality measures, assessment of soil health conditions and application of sound management practices is essential for sustainable development and survival of civilizations. Mountainous forest and rangeland ecosystems play unique and important roles in the sustainability of civilizations. Soil health is crucial for achieving ecosystem sustainability and soil quality standards must be appropriate for these conditions.

SOIL QUALITY-FOREST HEALTH-ECOSYSTEM HEALTH-WATERSHED HEALTH CONNECTIONS

There is a close relationship between soil quality and health and the quality and health of forests, watersheds and ecosystems (Figure 2). There is much discussion, debate and disagreement about forest and ecosystem health and watershed health. Forest health usually is considered in terms of insects and diseases and their effects on tree mortality. This is particularly a concern in much of the mountain west and in parts of the south. Recent infestations of spruce budworm, mountain beetle, southern pine beetle, and other insects have caused much mortality. Some root diseases are also a major concern. There is increasing evidence that some of this mortality is accelerated by other stresses on the system (Mika, et. al.1992). The stresses may be due to drought and nutrients, but detrimental soil conditions from management activities often are major contributors to the stresses (Everett, et. a,. 1994). For example, soil compaction, displacement and severe burns, result in conditions that reduce available moisture and nutrients for sustained plant growth.

Soil microorganisms play a critical role in the functions of ecosystems. They are particularly important for nutrient cycling, carbon mineralization and energy flow, nitrogen fixation, and nutrient and moisture supply through mychorrizal symbiosis (Richards, 1987; Amaranthus, et. al. 1990; Allen, 1991). Habitat provided by variable soil conditions influences the species and populations of soil biota. Significant changes in the habitat from management practices can greatly alter the species and their abundance.

There is an evolving body of literature defining ecological linkages between soil processes, plant growth, and community dynamics in the rhizosphere (Molina and Amaranthus, 1991). Mychorrizae affect soil structure by producing humic compounds. Interrupting flow of organic materials to mychorrizae can cause a deteriortion in soil structure and aggregate stability, and reduce forest regeneration and root growth (Amaranthus, et. al., 1990). Healthy populations of mychorrizal fungi and other soil microbes are essential for the growth and survival of tree seedlings, particularly on droughty and nutrient-poor sites.

Similarly, watershed health has a direct linkage with soil health. When soil compaction exceeds about 12 percent of a watershed, significant changes in peak flows have been reported in Western Oregon (Harr, 1976). Accelerated erosion from poorly designed or improperly applied practices decreases water quality and productivity (Megahan, 1981; O'Laughlin and pearce, 1984; Berg, 1988). Properly functioning watersheds are dependent on properly functioning, healthy soil systems.

The connections between forests, ecosystems and watersheds are dynamic and complex. They are highly variable in their qualities and in their conditions or health. Fudamentally, all are underlain and regulated largely by the quality and health of the soil ecosystem and its complex, dynamic web of properties, processes and functions. These connections are illustrated by the irregular lines and shapes in Figure 2.

SOIL QUALITY STANDARDS ON NATIONAL FORESTS

Soil quality standards have been established by the Forest Service for the National Forests since the late 1970's. The general concepts and standards are described by (Griffith, Goudey and Poff, 1990). Specific standards vary by region. The Pacific Northwest Region developed the first comprehensive set of quantitative soil quality standards and a procedure for measuring soil physical conditions. These are described by Meurisse (1987) and Geist et. al. (1991). Sullivan (1987) presented some of the most complete data that illustrates the use of the sampling methods and the effects of some management practices on soil conditions.

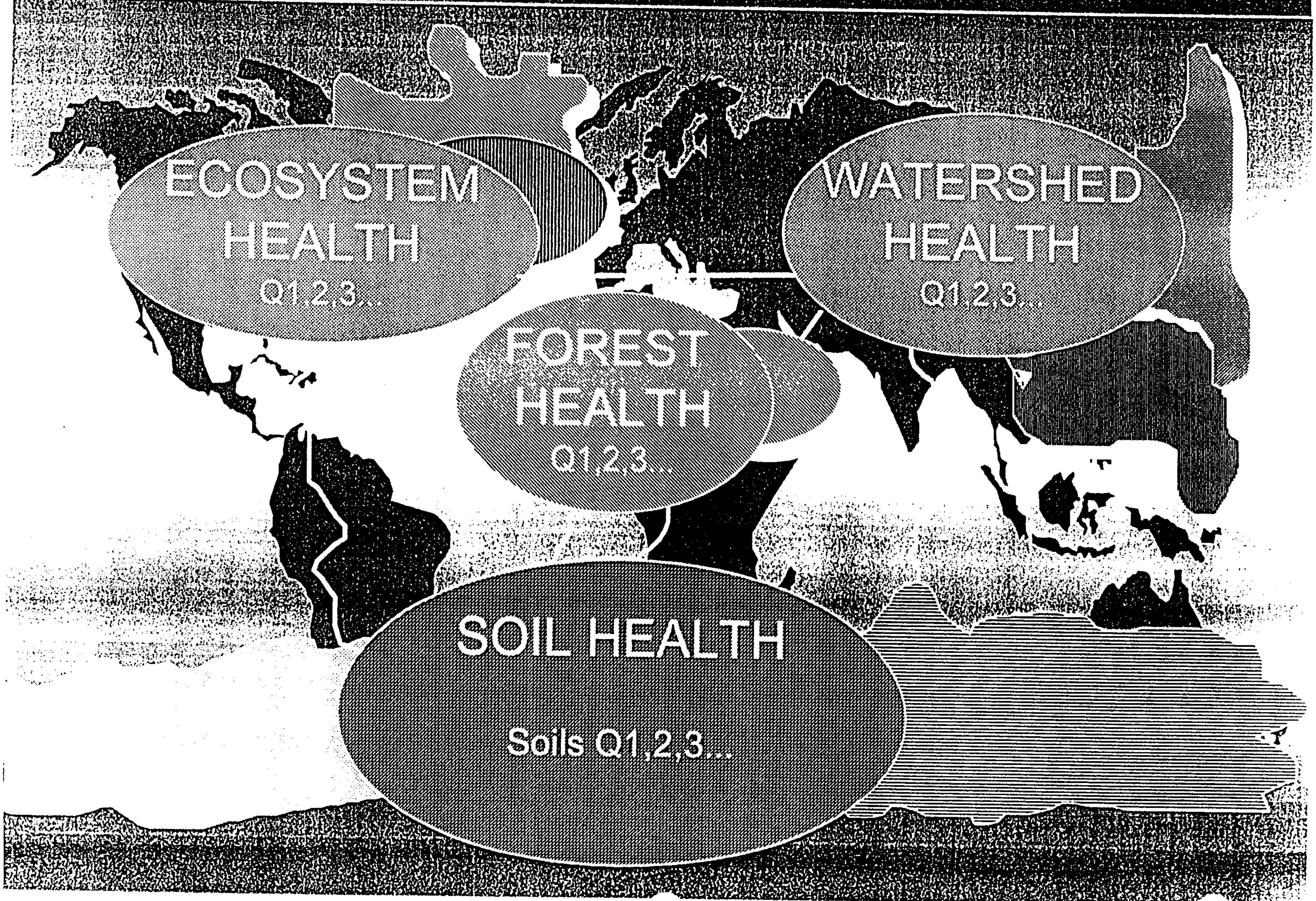
The most common measures of soil quality used on the National Forests are various physical properties. There are others such as erosion, organic matter, and degree of burning. A general description of the common measures follows.

<u>Physical measures</u>: bulk density, porosity, soil displacement, infiltration, rutting and puddling.

<u>Erosion measures:</u> These are more indirect and include soil loss tolerance, some specified percentage of topsoil loss, effective soil cover, and some percent of forest floor removal.

<u>Organic matter measures</u>: X percent loss in surface layers, amount of organic matter less than some specified quantity, amount of large woody debris, and large woody debris sufficiency.

Figure 2. Relationship of soil health to forest, ecosystem and watershed health



<u>Detrimental burning</u> is a measure of loss of O horizons and signs of oxidation, change in soil color at the surface together with the next cm depth blackened.

Specific quantitative standards, or thresholds, determine detrimental conditions. The detrimental conditions are presumed to be "unhealthy" soil conditions because they are impaired in their ability to perform one or more of the vital functions. In most cases, functions of concern are productivity and diversity, water quality and changes in water and energy flows, and effects on nutrient and carbon cycles.

SOME EXAMPLES OF SOIL QUALITY AND HEALTH ISSUES IN FOREST ECOSYSTEMS

A few brief examples of specific relationships between soil quality and productivity, biological diversity, water quality, hydrologic function, and soil borne diseases are described. Also, the concept of soil resiliency and its application to soil health evaluation is discussed.

<u>Productivity and forest health</u>- The effects of soil compaction and related loss of soil structure on tree establishment and growth is well documented (Froehlich and McNabb 1984). The direct effects of displacement and erosion, also are evident. The relationship between nutrient depletion and availability is becoming clearer for many tree species (Weetman, et. al., 1992; Mika, et. al. 1992). There appear to be some direct links between potassium availability and tree mortality from insects and diseases. The ratio of nitrogen to potassium may be significant. Soil organisms are increasingly the subject of study for their effects on forest soils and forest health. Preliminary results from sampling soil arthropods and other mesofauna in compacted soils, reveal some changes in numbers of some species (K. Bennett, personal communication). The significance for tree growth or diseases is not known.

Soils have a high degree of biological diversity (Richards 1987; Allen 1991; Molina and Amaranthus, 1991). A high percentage of all organisms make their home in the soil. Some estimate thst as much as 90 percent of all organims are below ground. Recent studies found 200 mychorrizal types on one study site in southwestern Oregon (M. Amaranthus, personal communication). About 50 truffel species were found at the site. Other studies suggest that sporocarp (mushroom) production may be reduced in compacted soils. Ectomychorrizal fungal types and numbers may be affected by soil compaction and organic matter removal (M. Amaranthus, personal communication).

<u>Hydrologic Function</u>-Hydrologic function and water quality are impaired when soils are compacted and eroded. The literature is replete with studies that document effects from silivicultural practices, land use and fire on soil and water resources (Megahan, 1981; O'Loughlin and Pearce, 1984; Berg, 1988).

<u>Soil Borne Diseases</u>-Soil borne diseases may be increased when soil health is impaired by compaction and changes in soil nutrient supply. Surveys and personal observations have revealed black stain in Douglas-fir and in ponderosa pine in compacted soils. Black stain reduces the quality and comercial value of wood products.

Soil Resilience-The concept of resilience is fundamental to assessing soil quality or soil health. Resilience is defined variously as the ability to rebound or recover from some condition or stress. Szabolcs (1994) defines resilience as follows:

$$SR=BC_{ph} + BC_{ch} + BC_{b} + \int_{t1}^{t2} dPSF/dt + \int_{t1}^{t2} dAF/dt$$

Where: SR =Soil resilience
BC_{ph} =Physical buffering
BC_{ch} =Chemical buffering
Bc_{b} =Biological buffering
PSF =Pedological soil fluxes
AF =Anthropological soil fluxes

Such an approach to resilience can contribute not only to its interpretation, but to its modelling and estimation through further studies. The concept of resilience is crucial to characterization of soil health. Thus, interpretations of soil resilience need to be made. Some of the important dynamic factors that contribute to resilience are organic carbon, soil structure, soil organisms and soil nutrients. Other intrinsic properties include moisture and temperature regimes, depth, partcle size distribution and permeability.

SOME PRESCRIPTIONS FOR SUSTAINING AND IMPROVING SOIL HEALTH DURING FOREST MANAGEMENT OPERATIONS

The discussion about soil health is incomplete in the absence of prescriptions to conserve soil resources while managing forests for a variety purposes. A key to managing the soil resources to sustain their health, is to have knowledge of the soils and their behavior in response to management practices. Clearly defined, quantitative soil quality standards are essential. Then, design practices to meet the standards and implement a sound monitoring program that includes management feedback.

Prevention of damage should be a primary consideration. For harvest and site preparation, the goal is to reduce the amount of area impacted. This can be done by operating when soils are in a favorable moisture state, or when frozen or covered with snow. Use logging methods that minimize ground impacts and minimize the number of entries. Designate skid trails and re-use them in future entries.

Some practices that minimize adverse effects from fire include doing broadcast burning within prescription, selective use of underburning within prescription to reduce fuel loads, crushing residues in lieu of burning, and selectively piling for burning. Improvement of soil conditions where soils have been degraded or where inherent qualitites are low can be accomplished with management practices. Subsoiling is a common practice to restore compacted soils. Winged susbsoilers can be effective. Forest fertilization can be an important practice where response information and soil deficiencies are known. A variety of nitrogen-fixing species are known and can be managed so that soil quality is improved where nitrogen is deficient. Appropriate application of these practices, and others, is fundamental to achieve soil and ecosystem health.

FOREST SOIL AND ECOSYSTEM PROCESSES RESEARCH

There are several significant research projects actively investigating various aspects of soil quality in relation to tree nutrition, productivity and forest ecosystem health. One of the longer running studies is the Stand Management Cooperative and the portion that formerly was the Regional Forest Nutrition Research Project at the University of Washington. It is a cooperative effort with several industry organizations and U.S. Forest Service and Bureau of Land Management. This project has investigated the relationship between soil fertility, tree nutrition and tree growth. Nitrogen is a limiting nutrient in many soils of the Pacific Northwest and significant response to fertilizer additions is experienced (Chappell, et. al. 1992). The Intermountain Forest Tree Nutrition Cooperative, at the University of Idaho, also has studied response of interior species to nitrogen. More recently, the investigations have included the broader aspects of forest health. Results suggest a relationship between soil nitrogen and potassium and tree mortality (Mika, et. al. 1992). Management practices that diminish nutrient supplies from severe burns or from soil displacement, can impact tree growth and mortality from insects and diseases because of increased stress.

The USDA Forest Service is conducting a National Long-term soil productivity study of soil compaction and organic matter removals at three levels each (Powers, Alban, et. al. 1990). Preliminary results seem to confirm previous studies that decreased soil quality from compaction and loss of organic matter impair tree growth.

The Pacific Northwest Research Station and Region are conducting an integrated, long-term ecosystem productivity study. A series of integrated research sites is established in Western Oregon and Washington. This study has some unique and innovative characteristics. This large scale study, of 15 ha. treatments, integrates physical, biological and social sciences. It is designed to provide managers, scientists and the public with a comprehensive and integrated understanding of the ability to manage forests for sustained ecological, social and economic values and is planned to continue for 200 years. The study includes effects of early, mid and late successional stages on productivity and soil processes and properties. It also has three levels of organic matter for each successional treatment. This study will examine fundamental soil and ecosystem processes including carbon sequestration and cycling, soil organisms and net primary productivity.

RESEARCH, DEVELOPMENT AND APPLICATION NEEDS

In order to have a broader understanding of the extent of soil degradation and causes of it, an assessment of soil conditions is needed. While there are individual studies, monitoring projects, and observations, there is not a comprehensive assessment of soil conditions. This is especially true of forest ecosystems.

Measures of soil quality need to be developed and tested for three distinct groups. Land owners and managers need to have general, qualitative and quantitative measures that are easily observed or measured. Technical advisors require somewhat more inclusive, quantitative, measurable standards for monitoring soil conditions. Research scientists need to consider a variety of quantitative measures including physical, chemical and biological properties and processes. Soil organisms, microbila biomass, enzyme studies and other biological measures should be tested to determine effects of management practices on population distributions, numbers, and processes. Much of the research to date has been fragmented and lacks a comprehensive knowledge base for setting policy about soil quality or soil health issues. An integrated and coordinated research, development, monitoring and applications effort is needed to maximize effectiveness of scarce resources. The NRCS Soil Quality Institute is a beginning for this approach.

Sustainable healthy forest ecosystems and watersheds are intricately linked with healthy soil conditions. An understanding of the basic soil ecosystem properties and processes is essential to sustaining soil quality and soil health. Life and civilization depends upon sustaining the quality of soils and their ability to perform their vital functions.

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