



NATIONAL COOPERATIVE SOIL SURVEY

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Plymouth,
Massachusetts



Soil Information for a Changing World

Committee 2: Ecological Interpretations & Principles

This Committee should review classical references and University curricula for ecological principles and associations with soil and natural resource inventories. The Committee should investigate new interpretations and management recommendations associated with state and transition models; ecological frameworks; ecological site inventories and ecological land use inventories and discuss how they may be incorporated into soil survey.

Co-Chairs: Randy Davis, USFS, Washington, DC; Curtis Talbot, NRCS-NSSC, Lincoln, NE

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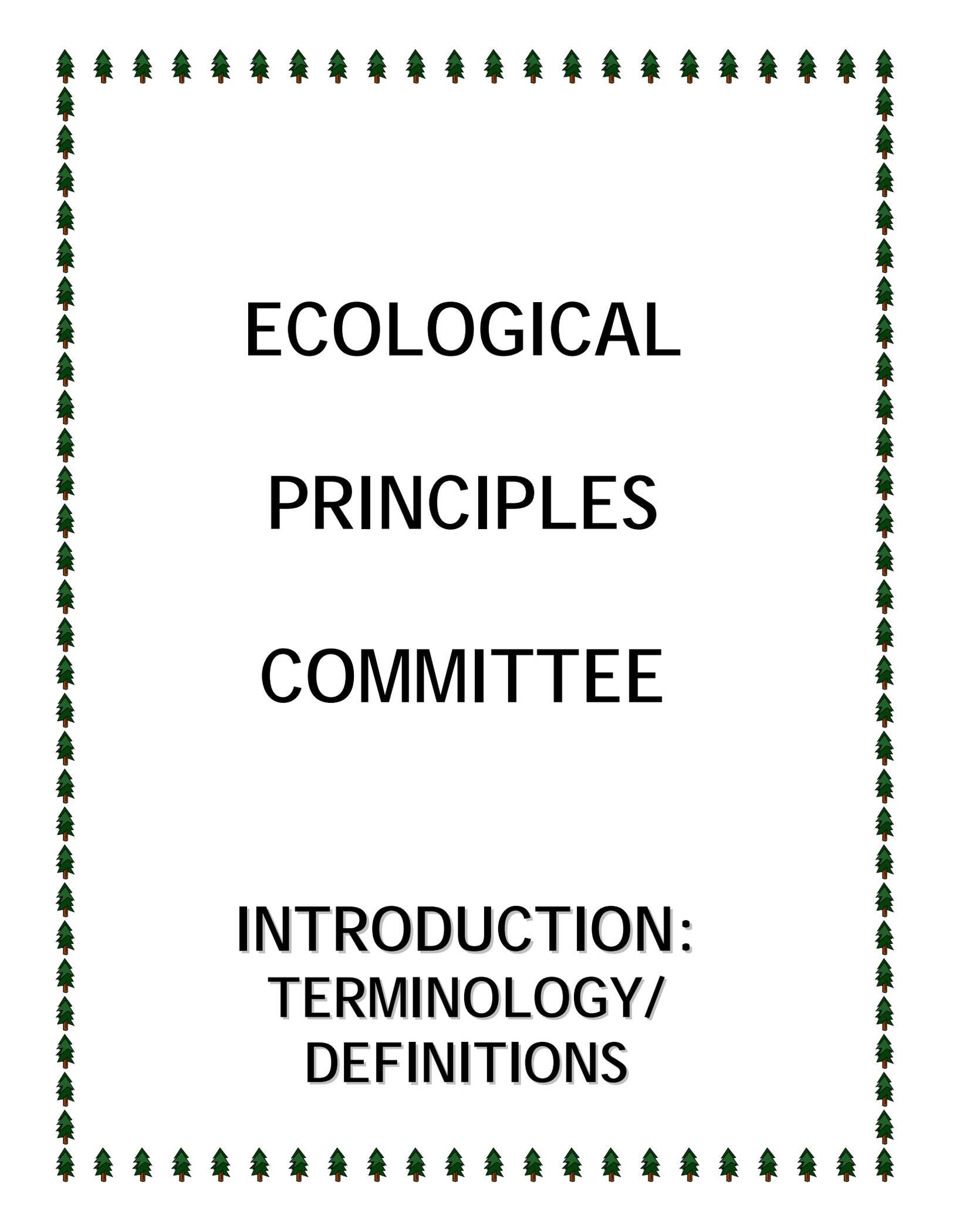
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**ECOLOGICAL
PRINCIPLES
COMMITTEE**

**INTRODUCTION:
TERMINOLOGY/
DEFINITIONS**

TWINS FROM SEPARATE MOTHERS – SOIL SCIENTISTS AND ECOLOGISTS

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August 14, 2003

Two disciplines have been instrumental in the creation and application of ecological classification and mapping (ECOMAP) systems in the United States – soil science and ecology. The U.S. Forest Service has been a leader in developing and testing ECOMAP protocols, culminating in the “National Hierarchical Framework of Ecological Units” (Cleland et al. 1997). Inherent to this framework is that soil scientists and ecologists, along with other disciplines, work cooperatively in its implementation. Although this vision is well intentioned and meaningful (and seemingly achievable!), many efforts to date have been disjunct and fraught with disharmony, oftentimes being directed singly by one of these groups. As a result, controversy arises and paralleling efforts unfold resulting in redundancy, inefficiency, conflicting maps, and confusion. Instead of synergism and greater understanding through interdisciplinary discourse, efforts instead suffer in myopia, entrenchment, and continuing discord.

One of the root causes of this problem is that both consider their discipline fundamental in understanding terrestrial ecosystems. Hans Jenny, soil scientist extraordinaire, clearly illustrated the integrative powers of soils in the function: $S = f(\text{cl}, \text{o}, \text{r}, \text{p}, \text{t})$, where cl = climate, o = organisms, r = topography, p = parent material, and t = time (Jenny 1941). In contrast, ecologists use vegetation as the proxy to distinguish ecosystems, arguing that vegetation is the ultimate environmental integrator. Indeed, vegetation can be substituted for soils in the above function without an apparent loss of meaning (Kruckeberg 2002). In any event, the use of single indicators (soils or vegetation) does not equate to the multiple factor approach envisioned for production of ECOMAP products. Furthermore, the integrative powers of either discipline are substantially diluted when forcing single-resource classifications (which are ridden with quasi-ecological artificial breaks) directly into the ECOMAP process (see companion paper entitled “The limitations of applying single-resource taxonomies to ecological partonomies” for details).

The ultimate goal of ecological mapping and classification is to have these two groups, along with other disciplines, work together productively. Both soil scientists and ecologists are striving for the same thing – the most accurate depiction of terrestrial ecosystems at various spatial scales for the benefit of land management. This can be best accomplished through mutual respect, interaction and resultant synergism, which capture the true meaning of ecological mapping and classification.

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ECOLOGY AND PEDOLOGY
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The “E-word” – Ecology

“It is the mark of an educated mind to entertain a thought without accepting it.” -Aristotle

Recently, a colleague related an exchange that took place at a Land Grant University College of Agriculture. During a research meeting one faculty member suggested using the term “ecology” in a research proposal title. The response from a more senior faculty member was “We don’t use that language in agriculture”.

This simple exchange describes a common response of agriculturists and pedologists when working with scientists who practice the discipline of ecology. A brief examination of the relationship of ecology, specifically the ecosystem concept, to pedology may shed some light on this phenomenon. This review may help those pedologists trained in the traditions of the late 20th century (like myself) better understand the perception that ecologists have of the discipline of pedology today.

The Language of Pedology

The Concise Oxford Dictionary of Ecology (Allaby, 1994) includes entries for all soil order terms such as Mollisols, Spodosols, and Alfisols as well as pedology, pedogenesis, pedocal and many others. Whittaker’s “Communities and Ecosystems”(1975) includes fifteen entries for soils in the index and devotes 25% of Chapter 6 on Nutrient Circulation to soils. In “Pattern and Process in a Forested Ecosystem” Bormann and Likens (1981) provide eight listings for soil in the index. In Bailey’s 2002 publication “Ecoregion-Based Design for Sustainability” he provides twenty-four separate entries for soil related topics in the index.

In comparison, an easy search of the on-line Soil Science Society of America Glossary of Soil Science Terms (Soil Science Society of America, 2003) yielded just (8) entries containing the word “ecosystem” and zero responses for the word “ecology” and two entries for the word “ecological”. The recent “Global Desk Reference for Soil Classification” (Eswaran, et al., 2002) is not indexed to any word containing an “eco” prefix, nor do any chapters reference the word “ecology or ecosystem”. In the “Handbook of Soil Science” (Sumner et al., 2000), the index is also absent any word containing an “eco” prefix, however a single subchapter is titled “The Canadian Soil Database – National Ecological Framework” does appear in the table of contents. Sumner prefaces his publication as “rich in data which will provide professional soil scientists, agronomists, engineers, *ecologists*, biologists, naturalists, and students with their point of first entry into a particular aspect of soil science”(1999). And on page E-41 Oliver Chadwick and Robert Graham discuss “ The concept of soil-forming factors is one of the earliest and most

important of soil science. It defines soil as a component of ecosystems that must be characterized in terms of both geological substrate and biological input” as attributed to Jenny and Amundson in 1941 and 1997.

Steila’s “Geography of Soils” (1976) as well as Birkeland’s “Pedology, Weathering, and Geomorphological Research (1974) are absent e-words in both the table of contents and index. In the 1983 edition of “Pedogenesis and Soil Taxonomy II. The Soil Orders” (Wilding et al, 1983), e-words do not appear in the index. However in Chapter 9 “Oxisols” by Van Wambeke and others, the five soil forming factors section is entitled “Ecological Determinants” whereas the equivalent sections of the remaining Soil Order Chapters are entitled as “Environmental factors” or “Genetic considerations” or handled differently under sections dealing with genesis.

In “The Guy Smith Interviews: Rationale for Concepts in Soil Taxonomy” (1986) there are also no “e-words” used in the table of contents or index. However, subchapter 1.8.1 ‘Fundamental Theses of Dokuchaiev, Glinka and Marbut’ discusses the issues surrounding a classification system that can be used for both large scale soil mapping versus small scale soil mapping that mirrors the discussions in historical ecology of “top-down” (holism) versus “bottom-up” (reductionism) (Golley, 1993). In “Building Soils for Better Crops”, no entries appear for “eco-“ or “ecology” in the index or the table of contents (Magdoff and van Es, 2000). Even in “Defining Soil Quality for a Sustainable Environment” (Doran et al, 1994), no entries for “eco-“ or “ecology” appear in the index, but the final chapter by Bohlen and Edwards references “Agroecosystems”. This sampling of basic soil references indicates that most students or ecological researchers using pedology publications from the last quarter of the 20th century were probably not be exposed to many “e-words” and the concepts they impart.

This simple comparison of reference documents highlights the general lack of inclusive language and terminology on the part of pedologists and hints at the difficulties that arise when attempting to assess the success of communications between ecologists and pedologists and resulting perceptions.

I consider myself a student of the late 20th century training in pedology, principally schooled in the ideas of the five soil forming factors of Jenny (Jenny, 1941). “In the words of Hans Jenny (1980), “pedogenic order in a landscape is unraveled by stratified random sampling along vectors of the state factors” (Chadwick and Graham, 1999). With this model of the soil landscape in my mind, I am left speechless when an ecologist or geographer preparing small scale ecoregion maps suggests that soil maps (and associated data) are developed for agricultural management concerns alone (McMahon et al., 2001) with no consideration for the ecosystem.

One thing is clear, if one cannot express an idea in the accepted language of the discipline one is trying to communicate with, there is no hope for success for the communication of that idea.

My hypothesis is this “Pedologists speak a language that ecologists do not recognize, yet pedologists practice many of the principles of ecology, in particular those related to the ecosystem”.

Definition of Terms

Allaby (1994) describes the prefix “**eco-**” as derived from the Greek *oikos*, meaning ‘house’ or ‘dwelling place’. In addition, Allaby (1994) defines **ecology** as the scientific study of the inter-relationships among organisms and between organisms, and between them and all aspects, living and non-living, of their environment. Ernst Heinrich Haeckel is usually credited with having coined the word “ecology” in 1866.

The Glossary of Soil Science Terms (2003) defines “**pedology**” as the scientific study of soils and their weathering profiles. The Concise Oxford Dictionary of Ecology defines pedology as “the scientific study of the composition, distribution, and formation of soils, as they occur naturally” and also **pedogenesis** as “the natural process of soil formation, including a variety of subsidiary processes such as humification, weathering, leaching, and calcification.”

Webster’s New Collegiate Dictionary (1980) gives two definitions for the word “**pedology**”. The first “the scientific study of the life and development of children and the second, the more familiar, “a science dealing with **soils**.” Webster’s also provides a definition for “**ecology**” as either a branch of science concerned with the interrelationship of organisms and their environments or the totality or pattern of relations between organisms and their environment. Webster’s definition of **ecosystem** is “the complex of a community and its environment functioning as an ecological unit in nature.:

Buol et al (1973) states that “**Ecologists** see the **soil** as part of the environment which is conditioned by organisms, and which in turn influences the organisms.

Possible Synonyms

Soil forming factors, ecological constituents

Pedogenesis, genetic processes, pedological processes, genesis, pedogenic processes, environmental processes, natural processes, ecological processes

Sustainable systems, soil quality, agroecological systems, agroecological processes, anthropogenic processes; anthropogenic systems

History of Ecology and Pedology

Ernst Henrich Philipp August **Haeckel** (1834-1919) was a German anatomist, zoologist, and field naturalist, who was appointed professor of zoology at the Zoological Institute, Jena, in 1865. He was an enthusiastic supporter of the Darwinian theory of evolution and Darwin accredited him with the success that theory enjoyed in Germany. He was an accomplished field naturalist and is usually credited with having coined the word ‘**ecology**’ in his *Generelle Morphologie der Organismen*, published in 1866 (as German word *okologie*, from the Greek *oikos*, meaning ‘house’ and *logos*, meaning ‘discourse’). (Allaby, 1994)

Ellen Swallow **Richards** was the first female at Institute of Technology in Boston (later MIT) in 1870 where she established a women’s chemistry laboratory. There she studied “sanitary chemistry” where food, air and water were analyzed. Her research in the purity of air in school

houses, the cleanliness of water in reservoirs, and the reliability of food sold in markets near the end of the 19th century led to the creation of food safety standards in the Massachusetts Food and Drug Act. In 1892, [twenty-six years after Haeckel], she proposed a new science to be called “**oekology**” after the Greek word for household. Ecology has come to mean the study of the household of the universe, with its beginnings in consumer science in America. With colleagues who shared her interests in scientific home management, she founded the Home Economics Association in 1908. (Roberts, 2000).

Sir Alfred George **Tansley**, a British terrestrial plant ecologist, is credited with developing the concept of the **ecosystem**. In 1935 he published in *Ecology*-

- “But the more fundamental conception is, as it seems to me, the whole system (in the sense of physics), including not only the organism-complex, but also the whole complex of physical factors forming what we call the environment of the biome – the habitat factors in the widest sense. It is the systems so formed which form the point of view of the ecologist, are the basic units of nature on the face of the earth. These ecosystems, as we may call them, are of the most various kinds and sizes. They form one category of the multitudinous physical systems of the universe, which range from the universe as a whole down to the atom.” (Golley, 1993)

Buol et al (1973) describes the origin of **pedology** “In the middle of the 19th century several German scientists, including **Ramann** and **Fallou**, developed **agrogeology** which viewed the soil as weathered, somewhat leached surficial mantle rock. Fallou suggested that “**pedology**,” which signified theoretical geological soil science, be distinguished from “**agrology**” , the practical agronomical soil science.”

Agroecology was proposed by **Bensin** in 1930 “to apply to detailed studies of commercially important crop plants by the use of ecological methods. He proposed a systematic collection of data so that the main agricultural regions (agrochoras) of the world and the characteristics of local cultivated varieties of important crops (chorotypes) may be described and recorded by employment of standard methods and by a prescribed and uniform terminology” (Klages, 1948).

This history and examination of ecology and pedology should be expanded into the 21st century, beyond the space provided for in this short paper.

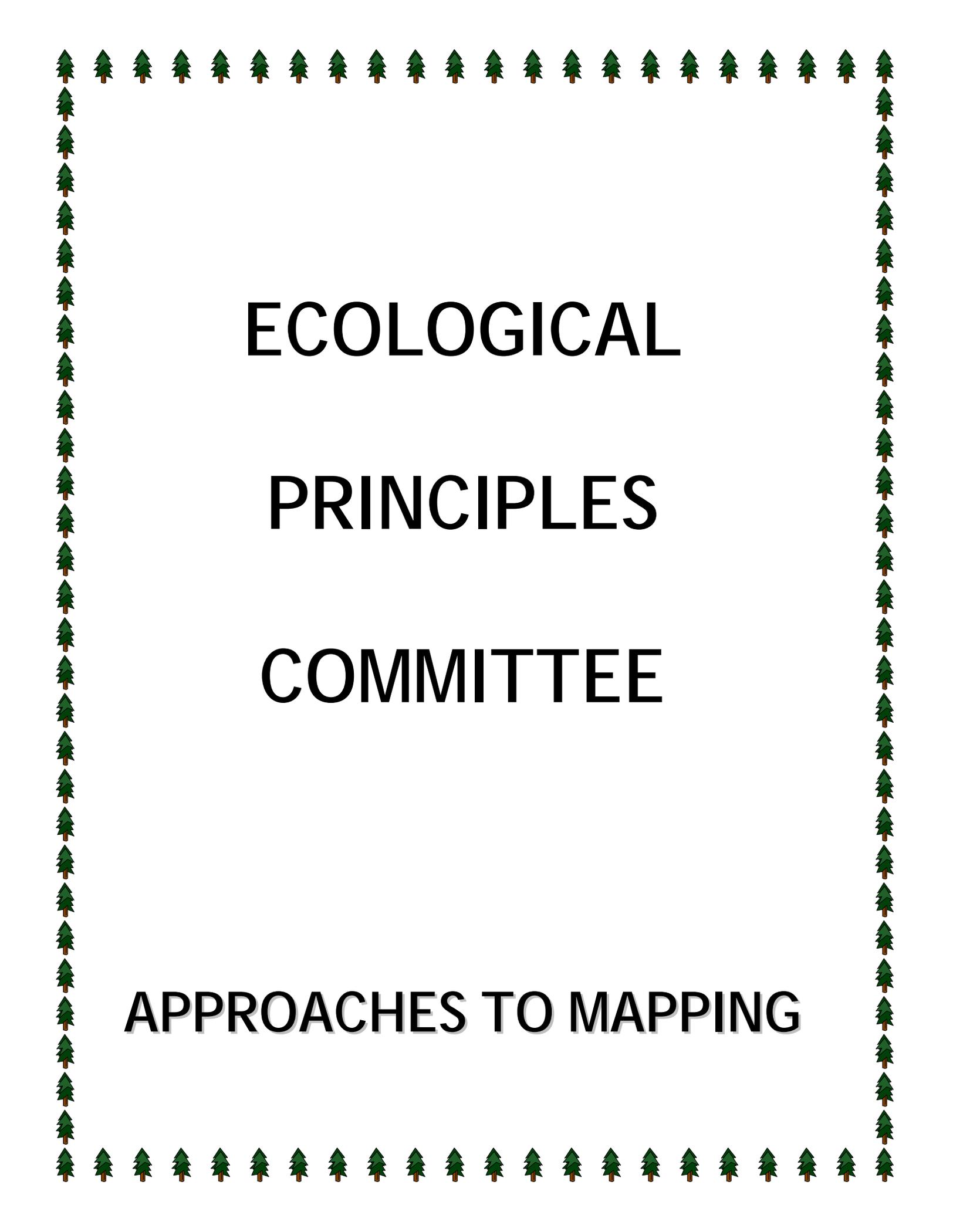
Summary

Recommendation is for pedologists to publish their research and work, translating the language of pedology into more recognizable ecology terms to gain a broader audience for their knowledge and ideas.

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**ECOLOGICAL
PRINCIPLES
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APPROACHES TO MAPPING

EVOLUTION OF THE FOREST SERVICE SOIL SURVEY PROGRAM

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Brief History

When the USDA Forest Service (FS) became involved in soil investigations, it discovered that methods devised for agricultural land were not always appropriate for upland mountain soils. It needed to innovate and it did (Helms, et al., 2002). This said, the FS has always been committed to meeting NCSS correlation standards. In 1957, Chief Richard McArdle sent a memorandum to the National Forests stating “Soil Surveys and mapping of any substantial amount carried out by the FS must be correlated with the NCSS to insure that they fit the National system criteria and nomenclature for classification and make their maximum contribution to the standard soil survey of the nation” (Chief’s Memorandum, 4/29/57). In 1961, the FS signed a Memorandum of Understanding (MOU) with the Soil Conservation Service (NRCS) that formally established compliance with NCSS technical standards. In 1968, the FS replaced the term “Soil Survey” with “Soil Resource Inventory”. This change allowed each Region to develop survey procedures based on Regional needs. Soil Survey, Land Systems Inventory, etc. were grouped as soil resource inventory (USDA Forest Service, 1986, Terrestrial Ecosystem Survey Handbook, USDA FS Southwestern Region).

In 1980, the FS published “Descriptions of the Ecoregions of the United States.” In 1981, the FS signed Amendment Number 1 of the MOU with the Soil Conservation Service (NRCS) providing correlation and update procedures, work plan or MOU requirements, reporting of acreages inventoried, compliance with USDA Soil Taxonomy, allowing for FS to supplement soil survey reports, and agreeing to expedite the resolution of technical and administrative differences between the two agencies. In 1984 the FS published “An Ecological Land Classification Framework for the United States”. In 1992, the FS adopted a policy of ecosystem management that applied to national forests, grasslands, and research stations (USDA Forest Service, WO-WSA-5, Ecological Subregions of the United States: Section Descriptions, 1994). In 1993, the FS formulated the National Framework of Hierarchical Units. In 1994, the FS published “Ecological Subregions of the United States: Subsection Descriptions”. In 1996, nine federal agencies with mandates to inventory and manage the nation’s land, water, and biological resources signed a MOU entitled “Developing a Spatial Framework of Ecological Units of the United States” including the FS and NRCS. In March 2003, the FS adopted the Terrestrial Ecological Unit Inventory (TEUI) as its national protocol for conducting soil resource inventories.

Forest Service Legal Mandates

The FS is responsible for management of approximately 192 million acres of national forests and grasslands. It has always considered sustainable production of natural resources and maintenance of soil productivity a high priority as it has planned and carried out management initiatives and activities. Major legislation such as the Organic Administration Act of 1897,

Multiple-Use and Sustained-Yield Act of 1960, National Environmental Policy Act of 1969, Forest and Rangelands Renewable Resources Planning Act, 1994, and National Forest Management Act of 1976 mandate that we provide high quality water, protection of soil productivity, continuous supplies of timber and forage, improve growth of forest and grassland vegetation and protection of fisheries and wildlife habitats.

Terrestrial Ecological Unit Inventory (TEUI)

One of the most complex challenging aspects to managing the National Forests is to comply with the Multiple-Yield Sustained-Use Act, 1960. Identifying appropriate land management uses on a particular piece of ground whereby the associated resources will be protected for future generations remains the center of many debates and lawsuits. Striking a reasonable balance was never easy and has only gotten more complex with increased human populations and limited natural resources. Increased concern for water quality and quantity, fish and wildlife species along with recreation and commodity demands have combined to exacerbate the need for a better understanding of ecological processes and hydrologic function.

Within climatic-geomorphic regions, water, plants, animals, soils and topography interact to form ecosystems at Land Unit scales. Thus ecological systems exist at many spatial scales from global ecosphere down to regions of microbial activity. The challenge of ecological classification and mapping is to distinguish natural associations of ecological factors at different spatial scales, and to define ecological types and map ecological units that reflect these different levels of organization (Cleland, et al., 1997). To this end, the FS developed the TEUI protocol to capture ecological systems at the finer scale of the FS National Hierarchical Framework of Ecological Units. TEUI complies with NCSS with respect to characterization of soil physical, chemical, and classification procedures and nomenclature. The primary difference in is the realm of vegetation data collection and ecological classification. Several FS Regions (Rocky Mountain Region – Common Land Unit, Southwestern Region – Terrestrial Ecosystem Survey) have adopted similar protocols that largely comply with the TEUI protocol. The other FS Regions will be evaluating their soil resource inventories and integrated resource inventories to develop strategies to come into compliance with the TEUI protocol.

The recent request from Congress concerning “Improving Information on the Nation’s Rangelands” has heightened the need to complete soil surveys establish a standard methodology for ecological classification. The FS has been working with BLM and NRCS to formulate a strategy to comply with Congress’ request. In October 2002, a field trip was made to gain field experiences and assess the situation in Arizona and Oregon. A preliminary report was provided to Congress in early 2003. In March 2003 representatives from FS, BLM, and NRCS met and proposed a framework to develop a strategy for completing an inventory of rangelands.

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ESSENTIAL CHARACTERISTICS OF A SOIL MAP

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When soil mapping is done predominantly for one purpose it is easy to strongly bias the mapping toward that purpose. In many parts of the western U.S., potential native vegetation is the most important attribute feature derived from the soil map. During the field mapping both map unit design and line placement may be strongly influenced by vegetation. To some degree this bias is desirable and enhances the utility of the soil map, but there is a limit to how far this bias can be carried. When carried to the extreme, these maps may no longer be valid soil maps. The following are some observations and principles that characterize a valid soil map, within the context of the National Cooperative Soil Survey.

Of course, a true soil map is based first and foremost on observations of soil. Although biased perhaps by potential land use and management, the nature of the soil is always the primary focus of the mapping. The *Soil Survey Manual* addresses this subject (page 12):

“The different kinds of soil used to name soil map units have sets of interrelated properties that are characteristic of soil as a natural body. This definition is intended to exclude maps showing the distribution of a single soil property such as texture, slope, or depth, alone or in limited combinations; maps that show the distribution of soil qualities such as productivity or erodibility; and maps of soil-forming factors, such as climate, topography, vegetation, or geologic material. A soil map delineates areas occupied by different kinds of soil, each of which has a unique set of interrelated properties characteristic of the material from which it formed, its environment, and its history.”

The soil map is constructed from observations. The soil and its set of interrelated properties are identified first, then its qualities or interpretive groupings, such as vegetation classes or erodibility hazards, are attributed to the soil. Thus the soil is what we map, not the attribute feature. Similarly, soil map units are designed and correlated to a national classification system based on the nature of the soil properties, not based on its attribute features or interpretive groupings.

Because the fundamental basis for a soil map is the soil, there are soil-based standards prescribed for identifying and naming map units and their component soils. Standards also are established for a minimum level of field observations for soil map units. These standards ensure a degree of credibility and a certain level of confidence – that the soil properties accurately and consistently portray the area that has been delineated. Again, these are soil-based confidence limits, and only by association do the standards imply any reliability of the soil attribute features or interpretive groups.

Standards are also established for recognizing the representative soils and classifying them to a national system. This is the process of soil correlation. Through this process the sometimes highly variable composition of soils within a map unit is aggregated into the named soils that will represent the unit. The representative soils are classified into a national system, based on soil properties. A soil map and legend cannot be considered a NCSS soil survey unless it meets the standards for field documentation, map unit purity, and soil correlation.

To illustrate, a map that would not be considered a true soil map is the following: the map delineates landforms; soils information is presented, but it is simply derived from one random soil observation within each landform. One soil observation within each landform is not adequate to determine the representative soils. Although the random soil descriptions may be classified into the national system, such a map would not be fundamentally soil-based, and would not possess a level of confidence that the

soil information is representative and valid. At best, this would be considered a landform map that is attributed with sample soil properties of unknown validity and usefulness.

When mapping is based on soils, it is natural sometimes for several soils to be identified within one attribute class or interpretive group. For example, many soil map units may be attributed with a stream terrace landform, or with a ponderosa pine vegetation class. This may be evidence that the map units are in fact based on soil observations. A legend where each vegetation class is represented by only one map unit suggests it was the vegetation that was the focus of the mapping, and not the soil. This is particularly questionable if soils on such a map are broadly defined and appear to cross significant landscape or geomorphic boundaries (i.e., the map unit likely contains some significantly different soils that should have been recognized). Thus on a true soil map, units are not mapped only to recognize the vegetation class, but rather to recognize different soils.

At times the opposite situation to the above may occur, when there is a need to recognize more than one attribute class for a particular soil. This is when soil phases are used. However, every attempt is made to relate the phase to observed soil characteristics, including less apparent characteristics such as soil temperature or soil moisture. This reinforces the concept that soil is the focus of the mapping.

The placement of soil map unit boundaries can be an indication of a true soil map. When the soil is the primary focus of the mapping, boundaries are drawn where the soil map unit changes, not where the attribute features change. This is not to say that changes in attributes (such as landforms, climate zones, or vegetation classes) are not considered during line placement. Because soils often change gradually on the landscape, the exact boundary cannot always be plotted precisely. In those situations a soil line may be biased toward the attribute. This is done to enhance the utility of the soil map, and to more clearly portray the relationship between the soil and the attribute (such as vegetation or landform). This is valid as long as it does not significantly compromise the integrity of the soil map nor the standards of map unit purity. In general, however, the fundamental principle is that the lines are placed where there is a significant change in soil properties.

The above essential characteristics provide a way to validate a map as a true soil map, as contrasted with a map of another physiographic feature that is merely correlated to soils. A true soil map must be based fundamentally on the set of interrelated properties known collectively as the soil. Soil-based mapping standards must be applied that will ensure a level of map unit purity and predictability, and that also will ensure confidence that the identified soils are representative and meaningful. Soil map units may be biased toward some soil quality or interpretive grouping, but not to the extent that the grouping is the focus of the mapping. In the last analysis, the underlying purpose for all these essential characteristics is to ensure the soil map can be widely and accurately used for varying land use applications.

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AN APPROACH TO SOIL AND PLANT INVENTORY

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With the development of Geographic Information Systems (GIS) the need for standardized, seamless resource inventories for all lands, both public and private, has become very apparent. In order to better manage natural resources and address resource needs it becomes necessary to evaluate those resources across large areas such as watersheds. One watershed may cover several land ownerships such as private, state and federal. The analyses of natural resource issues and needs across all land ownership is much easier for the GIS user if there are seamless inventories based on the same standards, procedures, and classifications. As the needs for this seamless inventory grew in Oregon, Region Six of the US Forest Service (USFS), the Winema National Forest, and the Natural Resources Conservation Service (NRCS) developed and entered into an agreement to produce such an inventory on the Winema National Forest and the private and state land of the northern part of Klamath County, Oregon. Specifically, this project was developed to demonstrate how the Ecological Unit Inventory completed on the Winema National Forest and the standard soil survey completed on the non-USFS lands of the Northern Part of Klamath County could be correlated. The inventory could then be digitized and provided to the public in both an electronic format and as a hard copy publication in the standard soil survey publication series.

The purpose of the project is to provide integrated resource information needed to manage the landscape. This project will provide information of sufficient detail for use in watershed analyses, in implementation of the Forest Plan, conservation planning, and other programs. In the implementation of this project, the USFS has lead responsibility for the inventory on USFS managed lands and the NRCS has lead responsibility for the inventory on non-USFS lands. There will be one common legend for the Inventory/Survey which is here after referred to as the Project Area. The naming conventions for soil survey map units (NRCS) and ecological units (USFS) differ. However, the purpose and design of the units and their representative soil components or ecological types is the same. For the purpose of this project, the terminology used in Forest Service (FS) Ecological Classification and Inventory Handbook (FSH 2090.11) for the conduct of Ecological Unit Inventories (EUI), and in Natural Resources Conservation Service (NRCS) National Soil Survey Handbook (title 430-VI) for the conduct of soil surveys are considered synonymous.

<u>FS</u>	<u>NRCS</u>	<u>Common Term</u>
ecological unit inventory	soil survey	project
ecological unit(s)	map unit(s)	unit(s)
ecological type(s)	map unit component(s)	type(s)/component(s)

The cooperating agencies acknowledge there are no differences in standards, procedures or products recognized by a different term. The units in this project will correspond with the landtype or landtype phase in the National Hierarchical Framework of Ecological Units and with an Order 2 and Order 3 mapping intensity in the National Cooperative Soil Survey.

It was mutually agreed that the soils will be mapped and classified according to the standards and procedures of the National Cooperative Soil Survey (NCSS). The standards and procedures are defined in the National Soil Survey Handbook, Soil Survey Manual, Soil Taxonomy, and the Field Book for Describing and Sampling Soils. The data will be entered into the National Soil Information System (NASIS) so that interpretations can be generated and the data can be used in GISs and downloaded to databases such as Access for use and manipulation. The soils portion of the project will be the same whether the units are part of the Ecological Unit Inventory or the soil survey. Even though the ecological

unit may be named differently than the map units, the units will be the same including the same soil types/components. There will be an exact join of the soil layer along the USFS and non-USFS boundary.

The classification and mapping of the vegetation part of the inventory presented more of a problem. There currently is not an accepted National Standard for naming and mapping vegetation communities as the NCSS provides for the soils. The USFS uses Potential Natural Plant Communities (PNC) and the NRCS uses Historic Climax Plant Communities (HCPC) to classify and map vegetation. PNC determinations exclude disturbances such as fire when correlating a vegetative plot to a plant association. Vegetation descriptions consist of percent cover by species. HCPC determinations include disturbances such as fire when correlating a vegetative plot to an ecological site. It was mutually agreed that PNC would be correlated to all units and associated type(s)/components occurring on USFS lands and that HCPC would be correlated to all units and associated type(s)/components that occur on non-USFS lands. For units and associated types/components that occur on both USFS and non-USFS lands both a PNC and HCPC plant community will be correlated. As can be seen from the description of how the work will be accomplished this provides somewhat of a correlation nightmare. It also is difficult for many users of the information to understand why there are two different plant communities assigned to the same unit and associated type/component. In most cases the plant communities being described are probably the same but are in a different state or in a transition to a state.

It appears that the Ecological Site Description (ESD) with its state and transition model as described in the USDA, NRCS, National Range and Pasture Handbook, September, 1997 and the USDA, NRCS National Forestry Manual, September, 1998 could be modified slightly to encompass the needs of both agencies. For example the ESD now describes percent of species by dry weight. If the ESD could also include percent of species by cover this would encompass at least one of the needs of the USFS. If the ESD could be adapted as a standard for inventory of vegetation on all lands then with the correlation of the ESD to the appropriate type/component a seamless inventory of soils and correlated plant communities could be completed. The next release of NASIS will provide the functionality to handle both weight and cover in the vegetation information.

In the Appropriations Bill for 2002, the Committee on Appropriations directed the Secretary of Agriculture and the Secretary of the Interior to jointly charter an interagency group to address rangeland assessment and monitoring issues. The charge specifically stated that standardized soil surveys and ecological classification will be completed on all rangeland. As mentioned previously, there is a defined set of standards, guidelines, procedures, and classification for the National Cooperative Soil Survey (NCSS).

The NCSS provides the framework to complete the "standardized soil surveys" on all lands in the United States. However, it must be agreed that no matter whether the inventory is called an Ecological Unit Inventory or a soil survey it will meet NCSS standards. The next step is to develop a parallel framework to provide a standardized vegetation classification system. With that established and agreed upon, then seamless inventories may be completed on federal, state, and private land ownerships.

THE LIMITATIONS OF APPLYING SINGLE-RESOURCE TAXONOMIES TO ECOLOGICAL PARTONOMIES

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August 14, 2003

Introduction

Employing a multi-factored approach to delineate and nest ecosystems at various spatial scales is a daunting task. The selection and integration of delineation factors (climate, geology, vegetation, soils, etc.) across hierarchical levels is particularly challenging. To help alleviate this problem, single-resource layers have at times been directly inserted into ecological hierarchies. This approach accomplishes two things: 1) simplifies and expedites an otherwise very complex and drawn-out process and 2) allows for the direct use (and recognition) of important preexisting resource layers. Although appealing, this approach eludes the integrative multifactor intent of ecological mapping and classification (Bailey 1996). Furthermore, a fundamental flaw exists with this approach that few people recognize – that the taxonomic basis of single-resource classifications precludes their direct placement in a spatially based ecological hierarchy (a “partonomy”). Recognizing the existence of and differences between these two concepts has important implications for ecological mapping, classification, and hierarchical arrangement.

Taxonomy vs. Partonomy

Taxonomies divide and organize items into hierarchies using “kind-of” relations. They work well for arranging entities possessing distinct, identifiable characteristics – the Linnaean system of plant and animal classification is one such example. Specific criteria are used to sort things in fixed rigid slots. As such, specific resources (soils, vegetation, etc.) are often portrayed in a linear manner dictated precisely by the type and sequence of criteria. Though attractive for categorizing individual resources for certain applications, this “taxonomic predestination” limits their usefulness in landscape ecology. Indeed, applying taxonomic classifications to characterize ecological patterns and processes that vary continuously over space proves difficult.

Partonomies in contrast reflect “part-of” relations based on space or proximity (Simons 1987, Smith 1996). Examples include the subdivision of a mountain into toe slopes, mid slopes, upper slopes, and ridge top or a catena representing a sequence of soil types connected along a topomosture gradient. Hence, partonomies reflect how elements fit together and interact on the landscape. Recognition of patterns at different spatial resolutions is fundamental to partonomies. Fortunately, there is a natural tendency for humans to perceive and subdivide the environment on the basis of part-whole (partonomic) relationships (Mark et al. 1999). Equally important is that most patterns or structures originate from ecological processes (e.g., erosion and deposition; fire and wind disturbance) that are inherently spatial and thus partonomic in nature.

Partonomies and taxonomies are similar in the sense that both form hierarchies and can be diagrammed as trees. Properties of objects and classes can be inferred through their place within a

taxonomic or partonomic hierarchy. One major difference between the two systems is that taxonomic relations (kind-of, is-a) can occur only between the types of objects. Only “part-of” relations can link particular objects. For instance, we can say that a certain soil type (class) occurs within a particular gully. However, we cannot say that this soil type is a gully per se (or belongs to the class of gullies). The latter relationship can be handled by a partonomy, which reflects spatial relations (part-of) occurring between particular objects.

Dangers mixing taxonomies and partonomies

Taxonomic systems work well to arrange or classify distinct “either-or” items based on specific sets of criteria. By necessity, artificial breaks are used for dividing entities. Because of this, taxonomic classifications have inherent limitations when applied to ecological mapping. For instance, modern soil series classifications and maps are limited in capturing important differences in parent material mineralogy – differences that often have profound effects on ecosystem expression. Another example is age-based divisions in geology. Although it is convenient to break geologic materials based on time, these divisions generally have little meaning in delineating ecological units – in other words, it is the type of geology that influences ecosystem expression, not age! However, taxonomies do have value in attributing ecological units and for pooling data of the same type across discontinuous areas regardless of geographic location (e.g., How much ponderosa pine forest is there in the country?).

Ecological hierarchies are partonomies!

Ecological mapping and classification is partonomy-based where visual cues reflecting organism-environmental relations are used to delineate and hierarchically link ecosystems, resulting in a more natural subdivision of our environment. Ecological “space-based” partonomies require a mix of environmental factors that intergrades along hierarchical tiers for nesting purposes. In turn, single resource layers produced outside of this context and based on taxonomic rules specific to that resource cannot be merely inserted. Ecological partonomies also allow aggregation of units to form larger entities that are not expressible in terms of original taxonomic-based data layers.

Recognition that two systems (taxonomies and partonomies) exist in the world of resource mapping is important, both serving different needs. The nature of rigorous, rules-based taxonomies often limits their use in ecological hierarchies that embody multiple factors. Since ecological mapping is partonomy-driven, caution is needed when integrating taxonomic-based, single-resource layers. Indeed, it is best to network elements of several resource maps to capture important organism-environmental relations rather than hard-wiring a single-resource map that happens to reflect only taxonomically relevant things.

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TERRESTRIAL ECOSYSTEM SURVEY PROVIDES ECOLOGICAL INFORMATION FOR NATURAL RESOURCE MANAGEMENT

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The USDA Forest Service is required to conduct comprehensive ecological surveys, to analyze resource conditions and determine existing and potential productivity of National Forest System lands in the United States. To meet this purpose, Terrestrial Ecosystem Survey (TES) is the approach used to gather information about ecosystems on National Forests in Arizona and New Mexico and to apply this knowledge to ecosystem analysis, planning and decision-making.

Definitions

Naturally occurring terrestrial ecosystems with unique sets of properties can be classified, mapped, and interpreted. The methodologies applied in describing and characterizing a terrestrial ecosystem depends upon the interactions of soil, vegetation and climate.

A *terrestrial ecosystem* is defined as the conceptual representation of the obligatory relationship existing between climate, soil and vegetation. The integrated processes of these complex interactions define a terrestrial ecosystem.

A *terrestrial ecosystem survey* consists of the systematic examination, description, classification (soil, vegetation and climate), and mapping of terrestrial ecosystems. Other ecosystem components that modify soil or vegetation components such as landform, geology and geomorphology are integrated during the mapping process. The unique combination of terrestrial ecosystems and appropriate phase criteria (i.e., slope, surface texture, soil depth, etc.) define and describe an ecological map unit.

Classification

Terrestrial Ecosystem Survey utilizes a component approach for classification of ecosystems (terrestrial and aquatic) and a holistic approach for the integration of components with climate through direct gradient analysis. This approach is hierarchical with respect to classification levels of terrestrial ecosystem components and mapping intensities. These taxonomic systems are important as they incorporate, within class limits, diagnostic physical, chemical and biological properties. Many non-hierarchical classification systems (rock fragment classes, texture classes, runoff classes etc.) are also used in this process.

Direct Gradient Analysis

Direct gradient analysis is used to integrate ecosystem components (soil and vegetation) with climate. Soil moisture and soil temperature regimes provide the initial, quantifiable means of separating a climatic continuum into meaningful segments or life zones.

The correlation of indicator plants with soil moisture/temperature regimes results in further refinement of the zones. This is based on the following two concepts: 1) the lower elevation limit of a given plant species on a moisture-temperature gradient is controlled by deficient moisture, and 2) the upper elevation limit is controlled by deficient heat.

The final phase of direct gradient analysis consists of integrating soil taxonomic categories with plant communities to form individual terrestrial ecosystems. The resultant organized alignment of terrestrial ecosystems is a continuum of climax categories of plant communities and their edaphic environments.

Information Management

Ecological data collected from TES meets the corporate business requirements of the USDA Forest Service's Natural Resources Information System. This corporate information system is an ORACLE database Geographic Information System (GIS) and analytical tool package designed to implement data standards for Terrestrial Ecological Unit Inventory. The Terra module of NRIS stores core terrestrial ecological data elements on climate, soils, geology, geomorphology, and potential plant communities.

The spatial component of TES is processed and edited through ARC/INFO software. This is a polygon layer of ecological map units.

System generated analysis and interpretations are processed by an Etools application. Etools is a nationally accessible, comprehensive set of data analysis and reporting tools that enables one to work efficiently with data contained in a given database. It is specifically designed to assist in analyzing compiled data utilizing a standard set of sampling protocols.

Etools enables specialists to access basic ecological data, create Taxonomic Unit Description and Map Unit Description summaries. It assists in performing analyses and resource characterizations, and facilitates sharing of information about ecological units and interpretations on a National level.

Use and Application of Terrestrial Ecosystem Survey

Terrestrial Ecosystem Survey provides ecological information that assists land managers in determining desired resource conditions and management activities that conform to the physical and biological capabilities of ecosystems. Ecological map units consist of terrestrial ecosystems and phases from which ecological structure, function, capabilities, responses, and management

opportunities and limitations are determined. Ecological information also describes disturbance events both natural and anthropogenic (fire, floods, wind, grazing, Off-Highway-Vehicles etc.).

This information provides vital basic land capability information for environmental analysis (NEPA) and decision-making; habitat data to predict the determination of effects on threatened and endangered species (ESA); soil, climate and landscape information for watershed assessments (CWA) and interpretations for management activities outlined in Forest plans (NFMA).

Protocols

Terrestrial ecosystem surveys are necessary to meet requirements of the Forest and Rangelands Resource Planning Act of 1974 as amended by the National Forest Management Act of 1976 implementing regulations found in 36 CFR Part 219 of the National Environmental Policy Act. The objectives, policy and responsibility for conducting terrestrial ecosystem surveys are contained in FSM 2060 and FSH 2090.

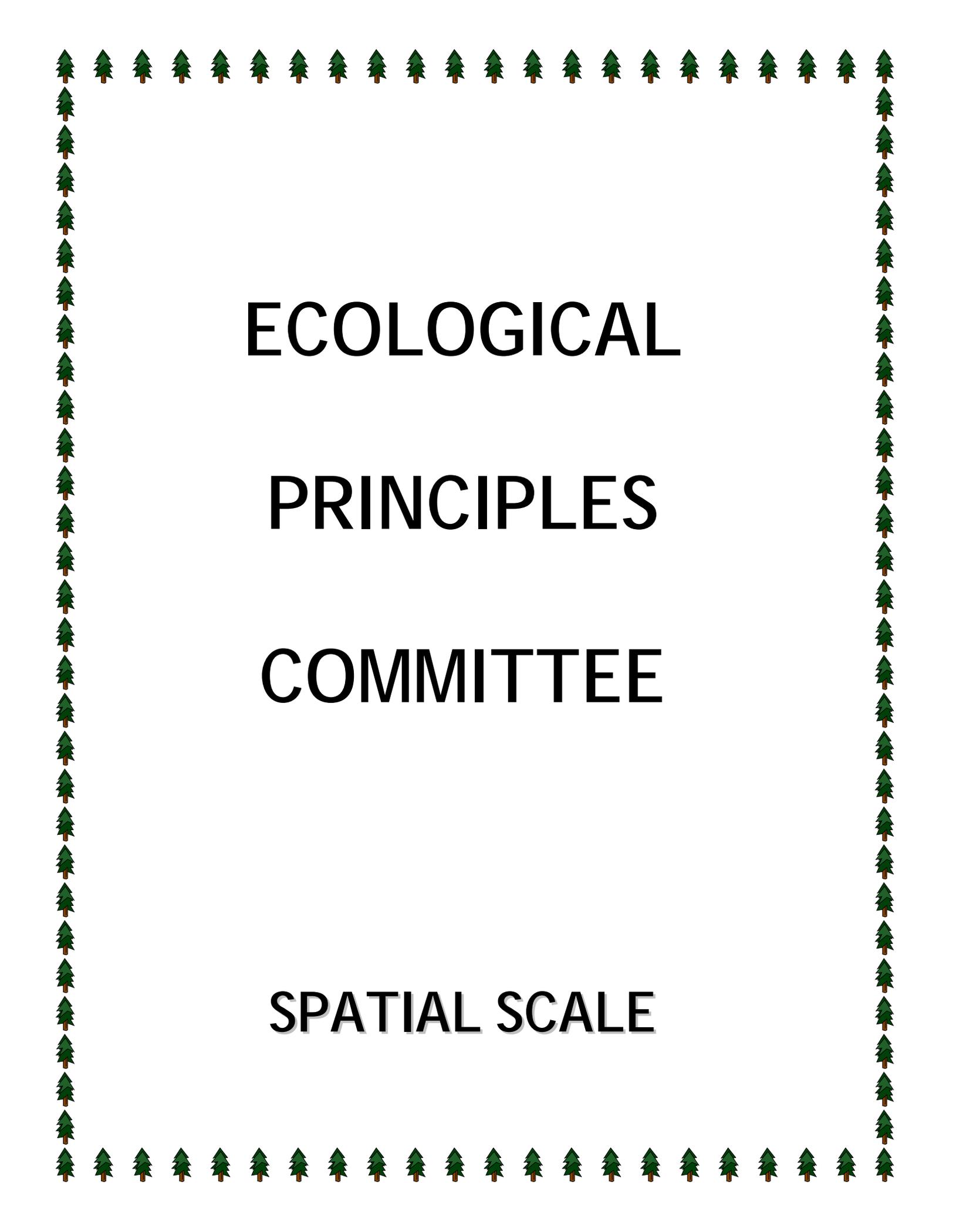
Terrestrial Ecosystem Survey meets the requirements of the National Hierarchical Framework of Ecological Units that is a land classification hierarchy that provides the framework for developing terrestrial ecological units at multi-scales. The Framework is a classification and mapping system for stratifying the Earth into progressively smaller areas of increasingly uniform ecological potentials. Terrestrial Ecosystem Survey provides information useful in landscape ecology analysis at the land type association, land type, land type phase hierarchal levels within the Framework.

Identification of the soil component meets the standards and follows the policies and procedures outlined in the National Cooperative Soil Survey Program. The description and classification of soils meets the criteria established in *Soil Taxonomy, A Basic System of Soil Classification for Making and Interpreting Soil Survey* (2nd edition, 1999), the *Soil Survey Manual* (1993) and the *National Soil Survey Handbook, title 430-VI* (2002).

USDA Forest Service Southwestern Region's *Terrestrial Ecosystem Survey Handbook* contains the basic concepts, standards and procedures for conducting and interpreting terrestrial ecosystem surveys. This handbook requires a systematic (cause/effect) evaluation of the relationship among the components of terrestrial ecosystems.

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ECOLOGICAL

PRINCIPLES

COMMITTEE

SPATIAL SCALE

SYSTEM HIERARCHIES OR ECONOMIES OF SCALE

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Introduction

Across many disciplines, there is recognition that complex spatial and temporal dynamics must be addressed for effective resource assessment and management (e.g., Christensen et al., 1996; Herrick et al., 2002). Systems approaches and hierarchical organizational tools can help scientists and managers deal with complexity in soil ecosystems (Carter et al., 2003). According to Norton (1992), hierarchical environmental management is necessary because, “Processes are not related equally but unfold in systems within systems, which differ mainly regarding the temporal and spatial scale on which they are organized.” Using a hierarchical systems approach may also help soil scientists relate dynamic soil changes to broader system outcomes, such as changes in air or water quality.

All systems exhibit hierarchical organization (Allen & Starr, 1982; O’Neill et al., 1986; Stephens and Hess, 1997). C.R.W. Spedding (1988), one of the earliest adopters of systems thinking in agriculture, offered the following definition:

“A system is a group of interacting components, operating together for a common purpose, capable of reacting as a whole to external stimuli: it is unaffected directly by its own outputs and has a specified boundary based on the inclusion of all significant feedbacks.”

Ellert et al. (1997) and Gliessman (1998) argue that an understanding of these system interactions and properties is prerequisite to effective agroecosystem management. (If you question the validity of this approach for soil science, substitute the word ‘soil’ for ‘system’ in the above definition.)

While there has been much debate about whether hierarchies are a human construct or a true phenomenon (Allen and Starr, 1982), the ability to organize our thinking into spatio-temporal units has clear benefits for research, inventory, and management, including understanding soils, their position in the landscape, and the changes with time under a variety of land use and management practices.

What do hierarchical systems approaches offer?

Hierarchical systems constructs can naturally navigate the complex issues of scale, in large part because temporal and spatial scales usually coincide. Spatially larger processes often require longer time periods compared to spatially smaller ones. Ellert et al. (1997) define the relationships between spatial and temporal scales for a variety of soil systems, subsystems and components, illustrating this proportionality between space and time for soils.

As a result of this relationship, different management approaches or practices may require different levels of systems analysis for assessment of sustainability or quality. For example, soil biophysical processes are often defined at the field level, while rotational cropping might be assessed at a field or farm level using a time scale at least equivalent to the rotation length. Filter strip systems probably need to be assessed at a watershed or regional level at a time scale long enough to allow species establishment and account for precipitation variability. Microeconomics would be properly addressed at the farm level. A watershed or regional level analysis would be appropriate to examine macroeconomic sustainability (Lowrance, 1990).

Hoosbeek and Bouma (1998) emphasized the need for different methodologies for land quality assessment at various scales. As if to demonstrate this need, Wagenet (1998) described unsuccessful attempts at ‘up-scaling’ reductionist research to explain systems behavior and ‘down-scaling’ systems approaches to explain mechanistic questions. Similarly, Karlen et al. (1997) and Seybold et al. (1998) listed various potential soil quality indicators according to spatial scale of interest while describing methods to assess the effects of agricultural management practices on the soil subsystem. These calls for scale-dependent methods underscore the role of system approaches as a necessary component for designing agroecosystem assessment strategies.

Emergent Properties

Overall function and viability of a system emerge from the interactions of systems components (or subsystems) (Bossel, 2001). Therefore, understanding the principle of emergent properties is essential for ecosystem management and assessment (Gliessman, 1998). Emergent properties are unique phenomena occurring at increased scales that are not predictable from observing the individual components or subsystems (Odum, 1953). The phenomenon of ‘overyielding’ seen in many intercropping systems (Vandermeer, 1990) is one example of an emergent property. These properties are the source of the phrase, (systems are) ‘greater than the sum of their parts’ (Ison et al., 1997; Stephens and Hess, 1999; Odum, 1953).

Many believe that these properties ‘emerge’ due to the functional interaction of system components. Others argue that emergent properties not discrete phenomena but rather a function of incomplete understanding of the lower level components (Pomeroy et al., 1988). Nevertheless, interactions within and between subsystems continue to result in properties not predictable from examination of the lower level alone.

Dynamic soil changes, resulting from interactions of land use, management practice, landscape position, and climate (and other factors) are emergent properties of the soil system. As a result of soil changes, the next hierarchical level may exhibit changes. For instance, installation of a riparian buffer may increase filtering and buffering in a soil, which in turn results in improved water quality. Using a hierarchical system approaches may facilitate recognition of emergent properties and other complex properties that describe soil functions in soil survey and other ecosystem monitoring programs.

The Next Step

We recognize sustainable management practices as site- or system-specific. Therefore, conservation alternatives must be compared for each system at a variety of hierarchical levels. Because appropriate scale is essential to assessment, survey, and management of system processes and functions, many authors suggest a systems-based approach to understanding and managing agroecosystems (Hart, 1984; Lowrance et al., 1987) and the soils that comprise their foundation (Carter et al., 2003).

To facilitate management of these complex systems, scientists must develop new ways to evaluate the resource. One way to do this is through the use of an adaptive management framework. In this way, experimentation, survey or assessment, and monitoring in ecosystem management becomes an iterative series of prescribed steps (not unlike the nine steps of conservation planning): 1) identify the problem and its boundaries; 2) define the management goals; 3) formulate management alternatives; 4) determine and implement a management plan; 5) monitor and evaluate management alternatives; and 6) evaluate and identify problems in an iterative fashion (adapted from Moffit, 1995). At small scales, this approach could be applied to the typical pedon or farm field. At larger scales, this entails watershed assessment and multi-objective decision-making.

Ellert et al. (1997) conclude that using a systems approach: 1) places soil within a larger ecosystem; 2) recognizes a broad array of support services or soil functions (beyond crop production); 3) incorporates humans as internal controllers; 4) allows for multiple management goals including production, conservation and aesthetics; and 5) uses integrative science to identify possible pathways to sustainability. It is necessary to utilize these approaches such that each hierarchical level of an agroecosystem, from soil to region, is adaptively managed to meet the multiple goals of conservation ecosystem sustainability.

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FUTURE DIRECTIONS IN SOIL/VEGETATION DESCRIPTIONS

Integrating spatial heterogeneity

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The theoretical basis for describing temporal dynamics of soil/plant associations has recently shifted from a climax-based approach to one based on non-equilibrium dynamics. Site descriptions now include state and transition models as a graphical means of communicating changes over time in response to management and climate. Even though the adoption of non-equilibrium dynamics represents a major change in the way we view temporal dynamics, our concepts and communication tools for spatial dynamics are still confined to the community scale. In essence, site descriptions are community descriptions.

Although we have attempted to measure and manage for different ecosystem services provided by rangelands (for example water, recreation, habitat, open space and forage production) using site-scale information, there is convincing evidence (both experimental and observational) that the accurate prediction of outputs of these important rangeland services cannot be accomplished merely by the linear combination of site scale information. For almost all rangeland values, the transfer of nutrients, energy and information (plant genetic material) among spatially proximate sites governs how products are produced, or more importantly, how we implement management. Understanding the critical interactions among sites and how natural and management stresses and disturbances alter them can only be understood using a multi-scale approach.

Communities (sites) are only one level in the continuum of spatial scale spanning the fine-scale (individual plant/soil unit) to the coarse-scale (landscape) relevant to land management. The value of an attribute at any particular scale is the sum of the values of the individual units at the next finer scale of resolution *plus* interactions. If sites did not interact via ecological processes such as the nutrient or water cycle, it would be relatively easy to calculate the landscape value of an attribute by combining site scale information. However, the interaction(s) among sites is what imparts unique character to landscape; and also the success or failure of management. Determining how site interactions will alter larger scale outputs requires 1) understanding the processes (soil erosion, invasion, nutrient cycling, etc.) occurring within individual sites, 2) knowledge of the landscape (individual site characteristics and arrangement) and 3) accounting for interactions (transfers, flow paths, barriers, positive or negative feedbacks) that link the sites.

ECOLOGICAL SITE DESCRIPTIONS and SOIL MAP UNIT DESCRIPTIONS are the best source of soil/vegetation characteristics at the community scale. Our current approach does a good job of capturing within site dynamics and communicating those dynamics in pictures, text and equations. When knowledge of finer scale processes (plant/soil interactions, population dynamics) are combined in computer models such as PHYGROW, EPIC and CENTURY we can predict relatively well what will happen over time within the community.

Displaying the arrangement of sites within a landscape can be a very powerful visual aid and, in some cases, may actually stimulate insight. However, although interactive Geographic

Information Systems (i.e. ARCINFO etc.) provide a means of spatially positioning sites within a landscape and displaying the information, they lack the ability to account for transfers of energy and matter among sites.

A critical component, process models that recognize spatial interactions (i.e. ECOTONE) in time steps are just beginning to be used experimentally and will soon be available for application. This approach to modeling can actually transfer water, nutrients and plant material among sites and alter within community processes based on those transfers. For instance, early applications of this technology have been helpful in predicting how invasive plant species can move through a landscape in time and space.

Combining these technologies for effective policy and management decisions remains a daunting challenge, but can be implemented via a hypothesis testing framework and continued refinement. Ultimately, these analytical systems will provide guidance for setting objectives, implementing management responses and developing monitoring regimes to determine progress toward land management objectives and warn of impending undesirable change.

A key guiding principle of building integrative systems is insuring that each of the component models or databases is similar in the quality of information they contain. Each of the components must be constructed transparently, maintained to exacting standards and be easily accessible. This will allow each component to evolve independently to improve the overall performance and to allow for critical analysis of system performance.

HOW ENVIRONMENTAL PROCESSES AFFECT SOILS AT MULTIPLE SCALES

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Introduction

Soils provide the critical needs for nearly all terrestrial plant life. Water and nutrients are made available to plants through the soil; plant life is also physically supported by the soil medium. Moreover, by one estimate soils provide 98 percent of the biodiversity in ecosystems. Below-ground bacteria, fungi, nematodes, mites, and other life provide an astounding variety of species when compared with above-ground plants, animals, and fungi. Facilitating decomposition and buffering environmental changes are also vital soil effects on ecosystems (Neher 1999).

In recent years our understanding of the environment has moved beyond a focus on a single environmental factor at a local scale to integrated ecosystems at multiple scales across the landscape. This summary outlines how soil-forming factors change as scale changes.

Soil-Forming Factors

Jenny (1941) outlined five soil-forming factors: climate, living organisms, nature of parent material, topography of area, and time. All of the above can be defined with scale (areal extent), except time, which affects all scales.

Following is a look at how these factors influence soils at each scale of the National Hierarchy of Ecological Units (Cleland et al. 1997). These scales roughly parallel those of other ecological frameworks, as discussed in McMahon et al. 2001. The discussion proceeds from the broadest scale to the most local.

National Hierarchy of Ecological Units

Domain Scale. Over-all, climate is perhaps the most important soil-forming factor, because temperature and precipitation regimes largely determine the rate and nature of weathering, a primary soil-formation process (Lyon et al. 1952). Climate is the key factor in defining domains, the broad climatic zones of our world (Cleland et al. 1997).

Division Scale. At this scale regional climates are elucidated. Resolution is sufficient that broad vegetation types—e.g., forest, grassland, etc. begin to emerge. These living organisms are a soil-forming factor, but less influential on soils at this scale than climate is. Soil orders are a key factor in defining divisions (Cleland et al. 1997).

Province Scale. Broad, regional geomorphology enters as a factor at province scale. The soil-forming factor of topography becomes more important than climate in defining the scale.

Section Scale. Geomorphology increases in importance at this scale, and both bedrock and surficial geology are added in defining the sections. Thus topography and parent material, both soil forming factors, begin to delineate the ecological units. Topography acts to hasten or delay climatic effects by increasing rainfall (orographic effects) or decreasing it (rainshadow effects) (Lyon et al. 1952). Topography also affects soil drainage.

Parent material greatly influences soil development, both by releasing nutrients through the weathering process, and as the primary influence in development of soil texture. Texture in turn determines water and nutrient movement through the soil. At this scale phases of soil orders, suborders, or great groups shape the delineation of sections.

Subsection Scale. Subsections largely operate as a finer resolution of sections. The ecological and soil-forming processes at this scale are essentially the same as for sections.

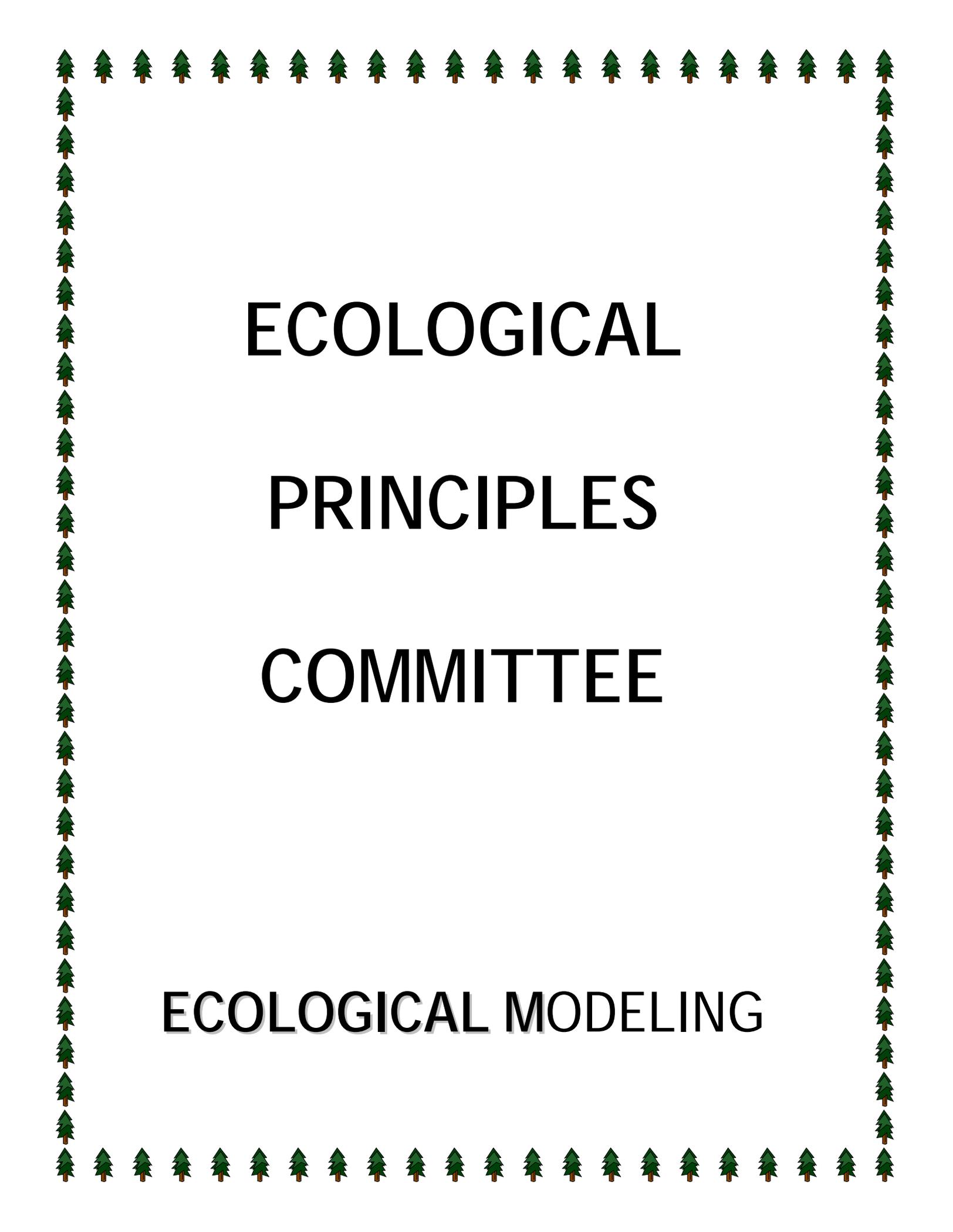
Landtype association (LTA) Scale. Landtype associations are broad enough to be landscapes, but are clearly not regional in scale. They are local enough to cover areas of 1,000 to hundreds of thousands of acres. All the soil-forming factors are important in defining LTAs, but geomorphology and bedrock/surficial geology (think topography and parent material soil-forming factors) are usually the key drivers.

Landtype Scale. Landtypes are local, in the realm of hundreds, not thousands, of acres. Soils at families or series level, along with potential vegetation, are the key drivers of landtype delineation.

Landtype Phase Scale. A finer delineation of landtype scale, with landform slope position, soil series or subseries, and plant associations used to delineate units.

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ECOLOGICAL MODELING

FUTURE DIRECTIONS IN SOIL/VEGETATION DESCRIPTIONS

Systematizing Dynamics

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State-and-transition models are being used to describe the coupled plant - soil dynamics in ecological site descriptions. Major challenges in producing these models include 1) distinguishing transient dynamics from changes persistent (and significant) enough to qualify as “transitions” as recently defined; 2) distinguishing true, self-reinforcing transitions from “pseudo-transitions” caused by persistent perturbation of a system due to continuous heavy grazing, for example, and that will return to the original state once the perturbation ceases; and 3) isolating present-day spatial heterogeneity within ecological sites that is attributable to transient or threshold dynamics from static patterns caused by differences among the soils grouped within ecological sites. If we are to foster a science-based understanding of rangeland ecosystems using ESDs, we must carefully consider how we treat these phenomena in models. We will briefly review the challenges below.

Several authors have treated any statistically-detectable change in plant community composition as a “transition”, irrespective of time scales and mechanisms of change. While this is certainly a valid approach, it is of little use to land managers for two reasons. First, changes in the abundance of some species are cause for management concern and require response, whereas changes in others are not. Certain plants have disproportionate impacts on ecosystem properties of interest (e.g. biomass, nutrient retention, forage value), on soil functioning, and on other species. Dominance by these species (or groups of functionally-similar species) is self-reinforcing and supports the presence of other species. This is not necessarily a recapitulation of the vanquished “Clementsian paradigm”, but an acknowledgment that the abundances of *many* community members are, in fact, tied to one another through a variety of interactions. On the other hand, shifts in the abundance of some species (e.g. within functional groups) have relatively minor impacts on system functioning. Thus, managers tend to focus their attention and efforts on a subset of taxa and certain groupings of them.

Second, once dominant taxa are removed, they often cannot be reestablished without management intervention or infrequent, natural events. Thus, losses of dominant, functionally-important species are often persistent without intervention. Removal of other species does not result in a significant change in environmental conditions so they may recover relatively quickly. In state-and-transition models, then, we feel it is useful to distinguish persistent changes in the presence or abundance of functionally-important taxa or groups (“transitions”), from transient changes in species abundance that do not result in appreciable changes to system functioning (e.g. “community pathways”). The latter type of change characterizes the succession-retrogression model, and both types of behavior are observed in real-world ecosystems. Distinguishing between these behaviors requires attention to mechanisms that cannot be inferred from statistical or temporal patterns alone.

Determining whether observed dynamics conforms to the “transition” or “community pathway” type may be difficult. The observation that a rangeland community has changed significantly in structure and composition from a historical state does not necessarily mean that a transition has occurred. Consider the shift from a grassland to a shrub-dominated state. In some cases, livestock herbivory may continually suppress grass cover. The experiment to determine whether grasses would recover with release from herbivory has thus not been conducted. Such “pseudo-transitions” have been revealed on sites that appear to be degraded beyond self-repair, but where rest from grazing results in rapid and extensive grassland recovery.

The previous scenario highlights two additional, vexing questions in state-and-transition models. First, how long must recovery take to qualify as a transition, rather than a community pathway? In nature, resilience values (i.e. the time it takes for a community to recover a semblance of its pre-disturbance composition, without intervention) vary continuously. Some communities have not yet, and may never, return to a previous state (if ever there was a stable one). Still others may take centuries, decades, or a few years to recover. Generally, infinite to century-long recovery times from previously stable states are associated with transitions, and recovery times or cycles with intervals of several years are associated with community pathways. Decades-long time scales could be associated with transitions or community pathways.

Second, are changes in the relative abundance of functional groups of plants *always* indicative of fundamental changes in system functioning? In some cases, grass and shrub dynamics seem to be largely decoupled from one another, following the “Gleasonian alternative” to Clements. The appearance of shrubs in an ecosystem experiencing grass declines may be a coincidence or opportunism on the part of shrubs. In either case, grass recovery need not require shrub removal and the presence of shrubs may not indicate soil degradation, as is commonly assumed.

Finally, we often do not have information on community dynamics at all. In these cases, we are compelled to assume that existing differences in plant communities occurring on the same ecological site were caused by differences in management: one site underwent a transition, and the other did not. This may or may not be true. Sometimes, both sites may be relatively unchanged due to management but differed initially because of differences in static soil properties not represented in existing ESDs. More likely, both sites have changed in response to management but the trajectory and magnitude of change differs strongly among soils within an ecological site.

Collectively, the issues above suggest an attention to details, mechanisms, and measurements is vital to the production of useful state-and-transition models. We should specify in each model 1) timeframes of recovery, 2) the multiple, potential causes of persistent changes in vegetation, and 3) the influence of relatively subtle soil heterogeneity in determining these features. Above all, we should be up-front about our uncertainties and continue to pursue data that reduce them. Data are simply unavailable in many cases to produce useful models. Expert opinion may provide a temporary fix but it’s not a healthy diet for managers.

STATE AND TRANSITION MODELS: ORGANIZING AND COMMUNICATING VEGETATION DYNAMICS INFORMATION

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Understanding the vegetation dynamics of a site is fundamental for accurate soil/site correlation and development of interpretations for management. The traditional method of describing vegetation dynamics in North America has been centered on climax concepts (Clements 1916). Many ecologists have questioned the application of the climax linear model concept. Vegetation changes in response to disturbances may not always exhibit the expected linear, reversible response. Much of the controversy relates to attempts to define a single method or concept to explain vegetation dynamics in diverse ecosystems.

Westoby, et al (1989) proposed an alternative, the state and transition model, to organize and communicate vegetation dynamics for management purposes. Development of the state and transition model would include a catalog of possible alternative states and transitions from one state to another within a site. Agencies such as the Bureau of Land Management (BLM), Forest Service (FS) and Natural Resources Conservation Service (NRCS) have incorporated the state and transition model concept into their respective ecological descriptions (ecological sites – BLM, NRCS and ecological types – FS) (USDI-BLM 2001, USDA-FS 2003, USDA NRCS 1997).

The state and transition model provides a method to organize and communicate complex information about vegetation response to disturbances (fire, lack of fire, drought, insects, disease, etc.) and management. Components of the model are states, thresholds, transitions, plant community phases, and community pathways (Stringham, et al, 2003).

A state is a recognizable, resistant and resilient complex of 2 components, the soil base and vegetation structure. The soil and vegetative components are inseparably connected through ecological processes that interact to produce a sustained equilibrium that is expressed by a specific suite of plant communities.

States are relatively stable and resistant to change. Disturbances can cause a state to cross a threshold. A threshold is the boundary between two states such that one or more of the ecological processes has changed beyond point of self-repair. These processes must be actively restored before return to previous state is possible.

Transition is the trajectory of change between states triggered by natural events, management actions, or a combination of both. Some transitions may occur very quickly and others over a long period of time. Prior to crossing a threshold, a transition is reversible and represents an opportunity to reverse or arrest the change by eliminating the stress or stresses responsible for triggering the transition. Once a threshold is crossed, the transition is irreversible by removal of the stressors. A new state is formed when the system reestablished equilibrium among its primary ecological processes.

States are not static as they encompass a certain amount of variation because of climatic events, management actions, or both. Retrogression-succession continuum implied with climax concept can be described within the states where plant communities do respond linearly. These dynamics within a state do not represent a state change since a threshold is not breached. These different vegetative assemblages within states are referred to as plant community phases and the change between these communities as community pathways.

The soil resource is a primary component of all terrestrial ecosystems and any disturbance that alters the natural functioning of the soil has the potential to influence the vegetative community. Causes of this vegetative change should be described. The description of the vegetation change should contain information of the impact on primary ecological processes including changes in soil properties. Soil properties may vary within and among states.

Collection of dynamic soil properties and correlating that information to the different states and/or plant community phases will provide a better understanding of the ecology of each site. Information is needed to identify and quantify soil properties that can be used to represent critical threshold conditions. Documentation of the range of values of dynamic soil properties for various states and plant community phases to characterize reference values for ecological descriptions.

Incorporation of the state and transition model concepts for describing vegetation dynamics within the soil survey process will help address and answer many of these questions.

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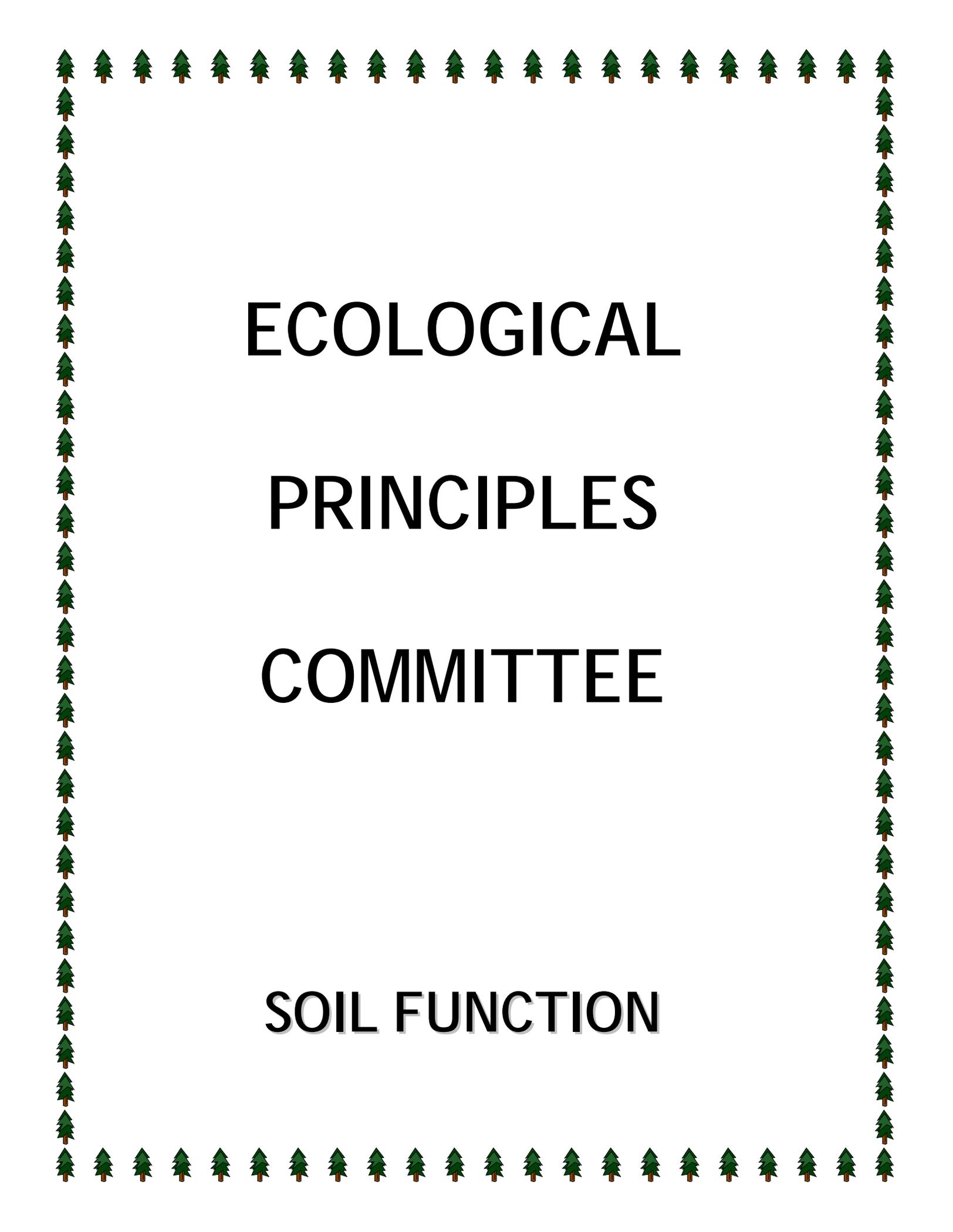
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SOIL FUNCTION

SOIL CHANGE AND FUNCTION

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Introduction

Decision making for soil and resource management requires information about the nature of soil change (Arnold, et. al., 1990). There is increasing demand for information on the management time scale about resource condition and changes in the capacity of the soil to function resulting from disturbances and management. Congress wants to know about the condition of our resources and land managers are being asked to consider resource condition in their management strategies. However, necessary information is not included in soil surveys.

Ecologically based soil change information should be developed to meet current resource and environmental management requirements. Knowledge of how soils change is needed to quantify soil function, detect change in function after a disturbance, to interpret results of assessment and monitoring, and to make predictions of soil response to management and climate change. Specific information includes reference or potential values, rates of change, drivers of change, and resistance and resilience to change in function. Setting productivity and environmental management goals should rely upon knowledge of natural variation, current condition and desired future condition relative to the management action.

Function

For the purposes of this paper, only a few examples of soil and ecosystem functions will be presented. Rangeland health (Pellent, et.al., 2000) assessments evaluate three attributes on the basis of their capacity to function. The attributes are soil and site stability, hydrologic function and biotic integrity. Soil quality assessments identify five functions (Karlen, et. al., 1997): productivity and biodiversity, regulating water, cycling nutrients, filtering and buffering contaminants and providing structural support. The literature includes numerous other similar concepts for function.

Soil change

Soil change through time can be summarized as follows: soil is formed by pedogenesis, affected by historical land-use, and is currently changing in modern ecosystems that have increasing human influence (Richter and Markowitz, 2001). It is important to remember that change is not caused by time. Every change in a system requires time, but change is not caused by the mere passing of time (Nikiforoff, 1959). Change results from variation in physical force or energy, whether the force is climate change on a geologic time scale, absence of fire on a centurial time scale or a plow on the seasonal time scale. Changes from human impacts on soil are more

predictable if our thoughts include an appreciation of energy fluxes or processes (Smeck, et.al., 1983).

Processes

Changes in soil properties result from and produce variation in processes. The primary ecological processes are energy flow, the hydrologic cycle, and nutrient cycling. Processes are the thread that link soil and the other components of an ecosystem to each other. The functional capacity of soil is based on soil processes (Herrick, et. al., 1999) and synergistic or degradational interactions among soils, plants, animals, climate and management. Changes that can be measured, i.e., temporally variable or “dynamic soil properties”, actually reflect the change in process. For example, decreased soil organic matter results in decreased resistance to erosion and infiltration.

Disturbances

A disturbance is a change in force or energy that can modify soil morphology and composition, processes and the capacity to function. A disturbance in the forest ecosystem such as catastrophic fire produces a hydrophobic soil layer that restricts infiltration, increases runoff and can increase erosion. Among other things, the fire changed the capacity of the soil function, e.g., to regulate the flow of water in the system.

Natural and historic variation

Natural and historic variations (Parsons, et. al. 1999) in soil properties over time are caused by a variety of disturbances and stresses to the soil-plant system. A change in the disturbance regime, such as decreased fire interval, can change the natural variation of soil and ecological properties and processes. Causes of historic variation can include climate change, management and land use, hydrologic projects such as dams, diversions and drainage systems, irrigation, recurring fire, and biological agents such as beaver and burrowing animals. It is assumed that the natural range of variation encompasses inherent potential to function, but if irreversible change has occurred, (i.e. soil loss) it may no longer be a possible potential.

The effects of soil change include changes in the condition of soil and other resources and can be desirable or undesirable. For example, altering soil water tables through drainage may be desirable for crop production but not for wetland habitat. Change that alters or disrupts processes in an undesirable and irreversible manner (i.e. some forms of environment degradation) is of primary concern for sustainability. Understanding historic ranges of variation (temporal variability) is essential for interpreting soil change, although it does not necessarily provide all information necessary for predicting future change (Parsons, et.al., 1999).

Future directions:

Soil Survey should include information about soil and ecosystem change on the human time scale resulting from natural and human disturbances, e.g. cultivation, management inputs, irrigation, drought, fire, absence of fire, grazing, invasive weeds, floods, etc. The human time scale includes both decades and centuries (Richter and Markowitz, 2001). The emphasis should be on soil function, such as the effect of decreased organic matter of the mid-grass prairie soil on soil and site stability or production. Ecological principles introduced in this paper are essential ingredients for advancing the knowledge of soil change.

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THE ECOLOGICAL CONCEPTS OF RESISTANCE AND RESILIENCE APPLIED TO SOILS

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Theory and Controversy

While it is well known that ecosystems are dynamic, many ecologists theorize that over time the biological structure and function of a healthy, late successional or sustainably-managed ecosystem should remain relatively stable. This stability is not to be confused with stagnation but rather it is considered an oscillation around a steady-state equilibrium (Ricklefs, 1990). If a stress or disturbance does alter a stable ecosystem, it should be able to bounce back relatively quickly to its original state. For this reason, ecosystem stability, or the recognition of a steady-state, is an important corollary of sustainability or sustainable resource management.

Ecosystem stability has two components: resistance - the ability of the ecosystem to continue to function without change when stressed by disturbance; and resilience – the ability of the ecosystem to recover after disturbance (Pimm, 1984; Holling and Meffe, 1996; Herrick and Wander, 1998; Seybold et al., 1999). An ecosystem disturbance can be a natural or human-induced stress. Natural disturbances include droughts, floods, and other storm events. Human-induced stressors include many of the day-to-day management practices that occur in our food and fiber production systems, such as tillage, pesticide applications, and species introduction or removal.

It is important to note that many publications in the soils literature confuse the terms resistance and resilience, defining soil resilience as the capacity of a soil to resist change (which is the above definition of resistance) (Seybold et al., 1999). Most papers that fail to differentiate these concepts cite Holling (1973) for their definition. Choi and Patten (2001) also claimed that Holling's (1973) definition of resilience is actually the accepted definition for resistance. Rather than citing Holling (1973), soil scientists should refer to Pimm (1984) and Holling and Meffe (1996) for the definitions of these concepts as applied to soil (e.g., Herrick and Wander, 1998; Seybold et al., 1999).

Most ecological publications refer to the resistance and resilience of populations. In soils, the terms usually refer to ecosystem functions such as nutrient cycling, water and solute flow, or physical stability. This adds another layer of complexity to the already much confused terms. Any one soil may display varied levels of resistance or resilience not only depending on the disturbance type but also depending on the soil function of interest (Herrick et al., 2002). Despite the multiplicity of factors affecting a soil's resistance and resilience, there are some basic principles that can be used to guide management and assessment of these important ecosystem properties.

Management Implications

Soils can be managed to maximize their resistance and resilience by addressing three main ecosystem components: diversity, complexity, and disturbance (Carter et al., 2003).

1) Diversity. Plant biodiversity may lead to increased soil nutrient cycling as well as improvements in other soil functions. Madritch and Hunter (2002) found that intraspecies litter diversity, that is within species or phenotypic differences in fallen leaves, led to increased soil nutrient cycling function compared with more genetically similar litter. Although it has yet to be tested for agriculture, this finding is likely to be true for residues from intercropped varieties compared with monocrop residues. These results may stem from having diverse energy sources (resource heterogeneity) to support a diverse soil food web.

Having multiple species in a system infers that each species occupies its own niche space (*sensu* Hutchinson, 1959), this could mean that different system services are performed. However, there can be considerable niche overlap, which could result in functional redundancy. For example, given two species of soil nematodes, one could be a predator and one a fungal feeder, or they could both be fungal feeders. A greater number of functions are being performed in first case but in terms of species richness (a type of biodiversity), the two examples are equal. The diversity of functions is desirable but redundancy may be also. As another example, if there is more than one (redundant) population of microbes that convert ammonium to nitrate and a disturbance alters the system such that one population dies out, that function (nitrification) will continue to be performed by the remaining population. Functional redundancy among diverse populations in an ecosystem may confer stability on a system.

Although diversity is usually defined in terms of species demographics (i.e., species richness or evenness), other kinds of diversity are recognized (Gliessman, 2000). These various diversities are components of system complexity, discussed below. Neher (1999) hypothesized that diversity of ecosystem functions may be more important than species diversity in agricultural ecosystems.

Diversity of below-ground, physical structure has implications not only for species composition (e.g., plant access to nutrients and water or microbial protection from predators) but also for numerous other system functions such as water partitioning and filtering or buffering. The system effects of structure depend on the scale of interest. Many management practices impact soil physical structure such as tillage and organic amendments or field scale structure, like cropping pattern.

2) Complexity. Another source of confusion and controversy is the role played by ecosystem complexity (such as biological diversity, functional redundancy, heterogeneous physical structure or resources, and symbiotic interactions) in system stability. Ecological research has found conflicting results about the relationship between complexity and stability. Pimm (1984) stated that the relationship may depend on what aspect of a system or its complexity is disturbed. Further, disturbances must be defined for various spatio-temporal scales, making generalizations difficult.

Nevertheless, many of the theories and observations described in the agroecology literature support a positive relationship between complexity and system stability. Beare et al. (1995) argued that the spatio-temporal heterogeneity of interactions (creating a hierarchy of scales of controlling factors) in the soil food web leads to increased functioning such as biogeochemical cycling. Under these suppositions, disturbances that create greater homogeneity or less complexity would decrease functioning. In general, reduced function is assumed to lead to lower stability (Gliessman, 2000). Gliessman (2000) further stated that because agroecosystems have reduced structural and functional diversity, they have less resilience than natural systems.

3) Disturbance. Most management practices constitute some form of system disturbance, whether it is physical (e.g. tillage), chemical (e.g. pesticides), biological (e.g. local extinction) or a combination (Table 1). The Intermediate Disturbance Hypothesis, a concept related to ecosystem stability, states that the highest levels of diversity are found at intermediate levels of disturbance (frequency or intensity) (Connell, 1978, Figure 1). In theory, ecosystems experiencing intermediate levels of disturbance, will have the highest biological diversity (i.e. species or genetic diversity), the greatest resource heterogeneity, the most functional redundancy and, therefore, the greatest ecosystem stability (i.e. resistance and resilience). A low-input system using conservation tillage and crop rotations may be an example of an intermediately-disturbed agroecosystem. Management systems and practices might be tailored to use these concepts (Table 1).

Applications for Soil Survey

The ecosystem properties of resistance and resilience are particularly difficult to measure in soils because they can vary within a soil for each soil function as well as for each type of disturbance (or management practice). A soil's resistance and resilience will be affected not only by inherent soil properties but also by dynamic soil properties. For instance, a sandy soil texture (an inherent property) may confer greater resistance to compaction disturbances that impede root growth or water and solute flow than more clayey soils. However, if that same soil is subject to erosion or tillage disturbances that cause it to lose significant amounts of organic matter (a dynamic soil change), it may have reduced resistance or resilience for many functions. Soil change, in general, not only affects but also is affected by these ecosystem properties. For example, if resistance is high, then, by definition, soil change is low or very slow. For these reasons, specific soil properties could be identified as indicators of resistance and resilience in a use-dependent, dynamic, or soil-change database, helping to guide land use and practice decisions and focus future monitoring, validation and assessment efforts.

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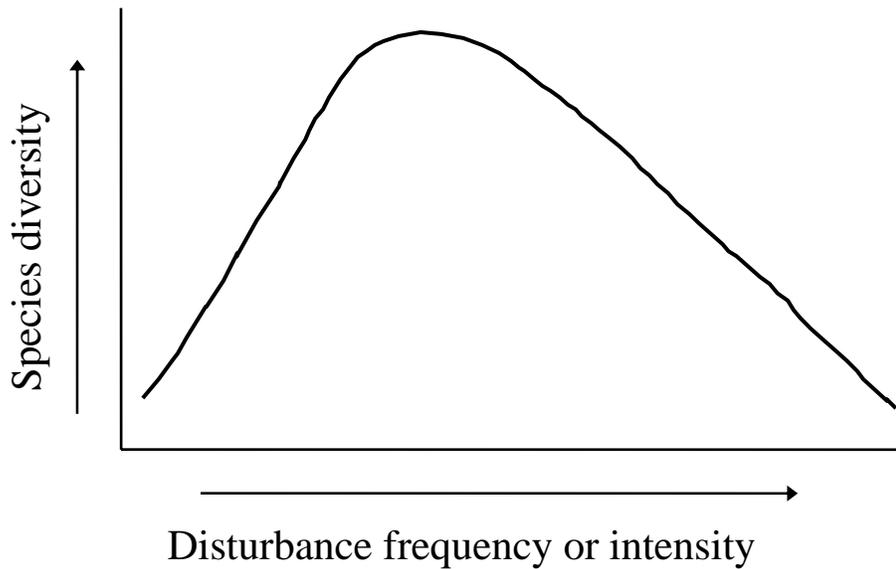


Figure 1. Graphical representation of the Intermediate Disturbance Hypothesis (Connell, 1978). At low levels of disturbance competitive dominants exclude many species; at high levels of disturbance most species are unable to survive. At intermediate disturbance levels the dominants are held in check enough to allow other species some niche space. The y-axis could also represent system function, where the greatest amount of functioning occurs at intermediate levels of disturbance.

Table 1. Factors affecting Agroecosystem Stability and Function

Factor	Disturbance Examples	Suggested Practice
<u>disturbance</u>		
(frequency and intensity)		
chemical	fertilizers and pesticides	account for mineralization of organic amendments, be aware of non-target effects of pesticides
biological	extirpation of native species	intercropping species or varieties, native field borders
physical	frequent tillage, inversion tillage	reduced, minimum or no-till practices
<u>diversity</u>		
species	reduced genetic resources (crop) or competition for water and nutrients (weeds)	intercropping of varieties
structure or habitat	lack of variety in plant heights, root exudates, or rooting depth	intercropping of species (e.g. to increase niche space among insect predators or mutualists)
temporal	lack of variety of plants through time	rotations
<u>complexity</u>		
trophic structure	reduced number of functional groups	practices that improve habitat or increase resources (i.e., create a heterogeneous physical and chemical environment for soil organisms, such as organic matter amendments, intercropping, or no-till
functional redundancy	reduced populations performing the same function(s)	
foodweb structure	reduced interactions within and among functional groups or dominance of a limited number of organisms	
<u>nutrient or energy flux</u>		
	low retention of nutrients or energy	increase OM, increase residues
	low availability of nutrients	increase OM, neutralize pH
	reduced input:output efficiency for energy or nutrients	eliminate over-applications, reduce field passes; all of the above!

FUTURE DIRECTIONS IN SOIL DATA APPLICATIONS: ASSESSMENT AND MONITORING

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Introduction

Assessment and monitoring are two critical functions of successful natural resources management. Over the past decade, a wide variety of tools have been developed and marketed to help land managers evaluate the condition of their land resources. These procedures range from relatively descriptive ecosystem inventories to soil quality and rangeland health protocols that address ecosystem processes. These tools will ultimately help land managers make sound decisions with respect to the long term functioning capacity of the land.

Assessment and monitoring procedures use indicators such as key soil or plant community characteristics that are sensitive to change in the environment. Indicators reflect complex ecosystem processes that are too difficult or expensive to be measured directly. These processes are vital to ecosystem functions including the maintenance of soil and site stability; distributing, storing, and supplying water and plant nutrients; and supporting a healthy plant community. Soil indicators complement vegetation indicators and may be qualitative or quantitative.

Neither assessment nor monitoring should become soil survey activities. However, providing dynamic soil property information to aid in the interpretation of these activities is an important role for the National Cooperative Soil Survey. An understanding of the unique characteristics of these two activities is necessary to develop criteria for selecting soil properties and developing sampling and measurement protocols for soil survey. These two different activities are described below.

Assessment. Assessments are based on estimates or measurements of the functional status of ecological processes. Webster's definition of assessment that most closely defines the concept as used in resource management is "the act of determining the rate or amount of (something)." The definition used in rangeland health (Pellant, et. al., 2000) is: "the process of estimating or judging the value or functional status of ecological processes. The *Internet Glossary of Soil Science Terms* (SSSA, 1997) does not include "assessment".

An assessment must start with an understanding of the standard to be used for comparison. Rangeland health assessments that follow the procedures in "Interpreting Indicators of Rangeland Health" (Pellant, et.al., 2000) use the Ecological Site Description as a standard. No designated standard has been defined for other types of land. Interpretations of assessments on other land uses are often based on a comparison of two or more management systems. Cropland assessments are also based on plant nutrient requirements or toxicity limits (e.g. NPK, pH, salinity) for the productivity function.

Assessments help to identify areas where problems exist and areas of special interest. Land managers can use this information and other inventory and monitoring data to make management decisions, which, in turn, affect soil quality. Potential objectives include:

- selection of sites for monitoring,
- gathering of inventory data,
- identification of areas at risk of degradation, and
- targeting management inputs.

Timing of assessments should consider management objectives and seasonal cycles. Land managers need to know that some soil properties vary on a daily, seasonal, or yearly basis in response to changes in temperature, moisture or management. For example, the total amount of soil organic matter (a surrogate indicator for soil stability) is relatively insensitive to seasonal changes. In contrast, rills (an indicator of erosion) can appear more or less pronounced, depending on the length of time and conditions since the most recent major storm.

Monitoring. The dictionary definition of monitoring that best fits resource monitoring concepts is “keeping track of the operation of (as a machine or process)”. In this sense, the soil is the medium (machine) in which numerous processes are carried out (e.g., nitrogen fixation, immobilization and mineralization; partitioning water; etc.). The Soil Science Society of America does not provide a definition. Therefore, we borrowed from “*A Glossary of Terms Used in Range Management*” (Society for Range Management, 1999). The SRM defines monitoring as, “the orderly collection, analysis and interpretation of resource data to evaluate progress toward meeting management objectives. The process must be conducted over time in order to determine whether or not management objectives are being met.” In summary, monitoring is a procedure to track changes in a system using quantitative data and is used to describe trend. It must be conducted at permanently marked locations and include baseline data if it is to ascertain the trend of the change in the functional status of the resource. Monitoring is often designed so that measurements can be made consistently by more than one observer. Reference data or standards may be used to establish management goals and aid in interpretation of the monitoring results.

Tracking trends in the functional status of the soil-plant system helps to determine the success of the management practices or the need for additional management changes or adjustments. Regular measurement of indicators at the same location can detect changes over seasons or years and provide early warning of future changes. Monitoring objectives include:

- evaluation and documentation of the progress toward management goals,
- detection of changes that may be an early warning of future degradation and
- determination of the trend for areas in desired condition, at risk, or with potential for recovery.

The detected changes must be real and must occur rapidly enough for land managers to correct problems before undesired and perhaps irreversible loss of soil quality occurs. The monitoring plan should include the proper measurement frequency, which either limits or captures seasonal variability, as dictated by the objectives.

Future directions. The NCSS can provide appropriate soil property values to serve as standards or reference values using an objective based approach for selection. The properties/indicators chosen should reflect the processes and functions to be assessed or monitored and the scale (e.g.,

management unit, ranch, watershed, eco-region, national) at which the information is needed. Good indicators are:

- strongly related to the function and scale of interest,
- sensitive to change,
- compatible with time and resource availability and technical expertise, and
- relatively easy to observe or measure in a reliable manner.

Indicators include physical, biological, and chemical soil properties and they may be quantitative or qualitative. Some properties, such as bulk density, reflect limitations to root growth, seedling emergence, and water infiltration. Other properties, such as the diversity and activity of soil biota, reflect the availability of both water and nutrients to plants. Soil organic matter and soil aggregate stability reflect a combination of physical, biological, and chemical processes. Soil surface features are also used as indicators. Pedestals, exposed plant roots, rills, gullies, wind scours, and soil deposition reflect such processes as runoff and erosion.

Conclusions. Evaluations made through assessment and monitoring provide information about the functional status of the soil-plant system. Indicators are properties that change in response to management, climate, or both and reflect current functional status. Assessment procedures use both qualitative and quantitative indicators. Monitoring only uses quantitative indicators. Soil survey can support assessment and monitoring activities of land managers by providing data on dynamic soil properties to aid in interpretation. Such soil data will increase the value and accuracy of assessments and trend analysis.

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ASSESSING AND MONITORING SOIL FUNCTION

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Introduction

The outcomes-based model of performance assessment is upon us. For soils, this means that in addition to collecting information on inherent properties and taxonomy, we need to examine dynamic changes that affect soil function. In terms of Farm Bill programs, soil assessment must answer the question, “what are the quantifiable outcomes of conservation practices for air, water, and soil quality?” Craig Cox, Executive Director of the Soil and Water Conservation Service, has called for tools to do just that: ‘quantify conservation practices’ (Cox, 2002). Assessing soil function is essential for measuring performance outcomes in agroecosystems and other managed ecosystems.

In managed ecosystems there are many properties and processes that could be assessed. The common measures of chemical fertility or slowly changing taxonomic properties each offer only part of the picture. Assessing soil function as a measure of ecosystem performance, integrates biological, chemical, and physical properties and processes that affect soil, water, and air quality. Decision tools that can help organize information as well as interpret how management practices affect soil and ecosystem function will improve the conservation outcomes and sustainability of management inputs (Beinat and Nijkamp, 1998).

The ‘Capacity to Function’ (a.k.a. Soil Quality)

Soil quality is defined as ‘the capacity to function’ (Karlen et al., 1997). Dynamic soil quality refers to the effects of management practices on soil function. Soil or ecosystem function is defined in various ways. Some important soil functions (or services) include: water and solute retention and flow, physical stability and support; retention and cycling of nutrients; buffering and filtering of potentially toxic materials; and maintenance of biodiversity and habitat (Daily, 1997). Although dominated by soil scientists, the study of soil quality is largely an ecological endeavor due to its ultimate concern with ecosystem function.

Historically, productivity is has been used as the only measure functional performance. However, in highly managed systems this function could be subsidized with external resources to the point where it is not actually indicative of the ecosystem’s health. Larson and Pierce (1991) argue that soil quality should no longer be limited to productivity, inferring that emphasizing productivity may have contributed to soil degradation in the past. Soil quality assessment is one area of agricultural research that attempts to estimate performance of multiple essential soil functions (e.g., Larson and Pierce 1991; Doran and Parkin, 1994; Andrews et al., 2002).

Assessment Methods

One way to interpret soil properties as indicators of soil function is through the use of non-linear scoring curves. Non-linear scoring techniques involve the use of curvilinear algorithms with an x-axis representing a site-specific range for the given indicator and a y-axis representing performance of ecosystem function (Karlen and Stott, 1994). This type of scoring is used widely under various guises in economics as utility functions (Norgaard, 1994), multi-objective decision making as decision functions (Yakowitz et al., 1993), and systems engineering as a tool for modeling (Wymore, 1993). The NRCS-NSSC's National Soil Information System (NASIS) also uses a non-linear scoring system as part of its fuzzy logic backbone. This method requires in-depth knowledge of each indicator's behavior and function within the system.

Many researchers have used non-linear scoring to quantify the effects of management on soil function. Andrews and Carroll (2001) used scoring curves to compare alternative poultry litter amendments to fescue pastures. Karlen et al. (1998) used weighted scores to assess land coming out of the Conservation Reserve Program (CRP). Hussain et al. (1999) also used scoring curves to compare tillage systems. Yakowitz et al. (1993) used non-linear scoring to compare the overall effects of alternative farming systems.

Site-specificity or Tool Transferability

Some efforts have been made to assess the site-specificity and transferability of scoring curves. For example, Hussain et al. (1999) and Glover et al. (2000) adjusted the index weighting and indicator threshold values to be applicable to their respective systems. Andrews and Carroll (2001) also shifted the expected ranges for indicators between sites.

A new tool, the Soil Management Assessment Framework, has recently been developed to improve the interpretation ability of scoring curves (Andrews and Karlen, unpublished manuscript). As before, the shape of an indicator's scoring curve (or algorithm) is dictated by the relationship between the indicator and the soil function. However, the expected range for each indicator is determined using site-specific factors, such as crop, climate or soil type. Changes in expected range due to site-specific differences result in automatic parameter shifts in the scoring curve (Figure 1).

Comparisons of scored indicators' ability to explain variation in performance outcomes for four case studies across the U.S. were performed. Results showed good ability of the scored indicators to represent (often difficult to measure) performance outcomes. For example, scored indicator-endpoint regressions for the Iowa case study had R^2 results of 0.99, 0.84, and 0.61 with sedimentation in surface water, atrazine applied, and crop yield, respectively (Andrews and Karlen, manuscript in preparation). This test seemed to confirm that the new scoring method was capturing intended information about the soils' performance of ecosystem functions.

The Soil Management Assessment Framework Highlights:

- Non-linear scoring of soil indicators can accurately quantify or assess the effects of management practices on soil function (Andrews et al., 2002)
- A transferable framework across sites & systems has been developed and is currently being assessed by scientists in the USDA-ARS Soils National Program 202
- Website and Excel format versions for the scoring framework are available for review (contact S. Andrews). Website is still under construction but can be viewed at (temporary URL): <http://129.186.1.36:8080/SoilQualityWebsite/home.htm>

Summary

Quantitative assessments of soil function has potential to be useful in many arenas:

- 1) educators could use it to demonstrate the effects of management on soil function;
- 2) land managers could use it to compare practices or effects over time; and
- 3) program managers could use it as an outcome measure to quantify conservation progress and to justify expenditures.

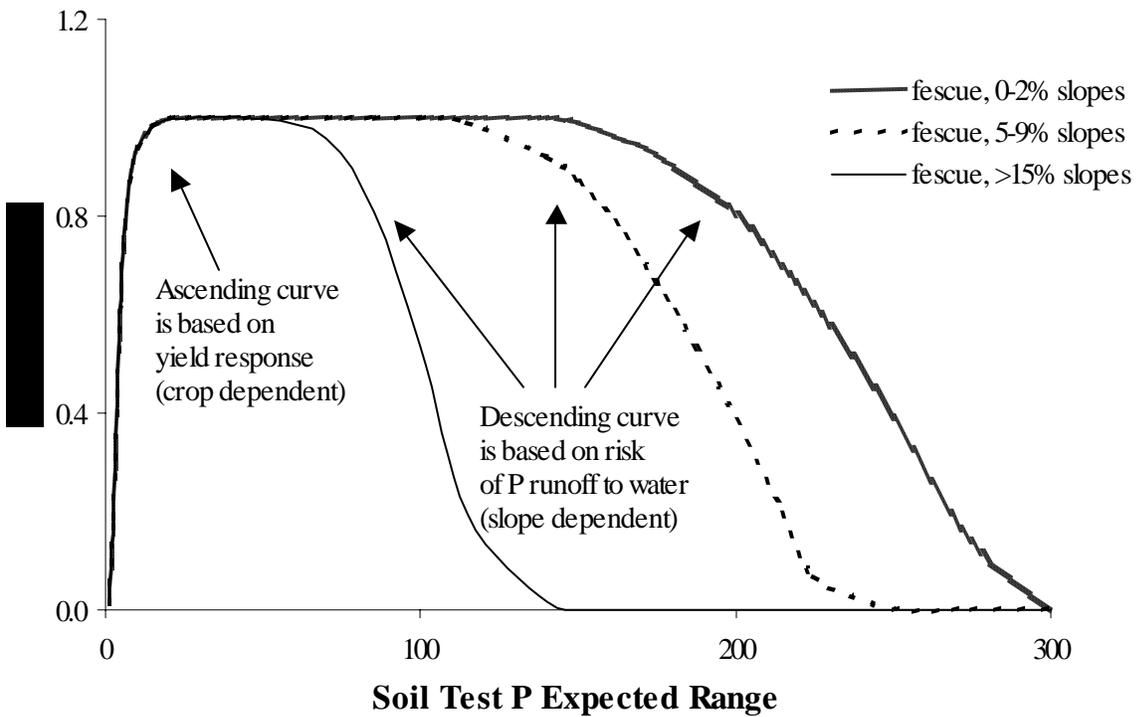
One major difficulty is that soil property interpretations need to change from site to site according to factors such as climate, soil type, and vegetation (Arshad and Martin, 2002). Standard methods for analysis would strengthen comparability between sites, legal defensibility (Maki, 1980), precision and accuracy of interpretation (Nortcliff, 2002). Further, assessment tools that reliably reflect conservation outcomes may significantly improve the sustainability of land management decisions. The framework described here is offered as a method for quantifying soil function toward this end.

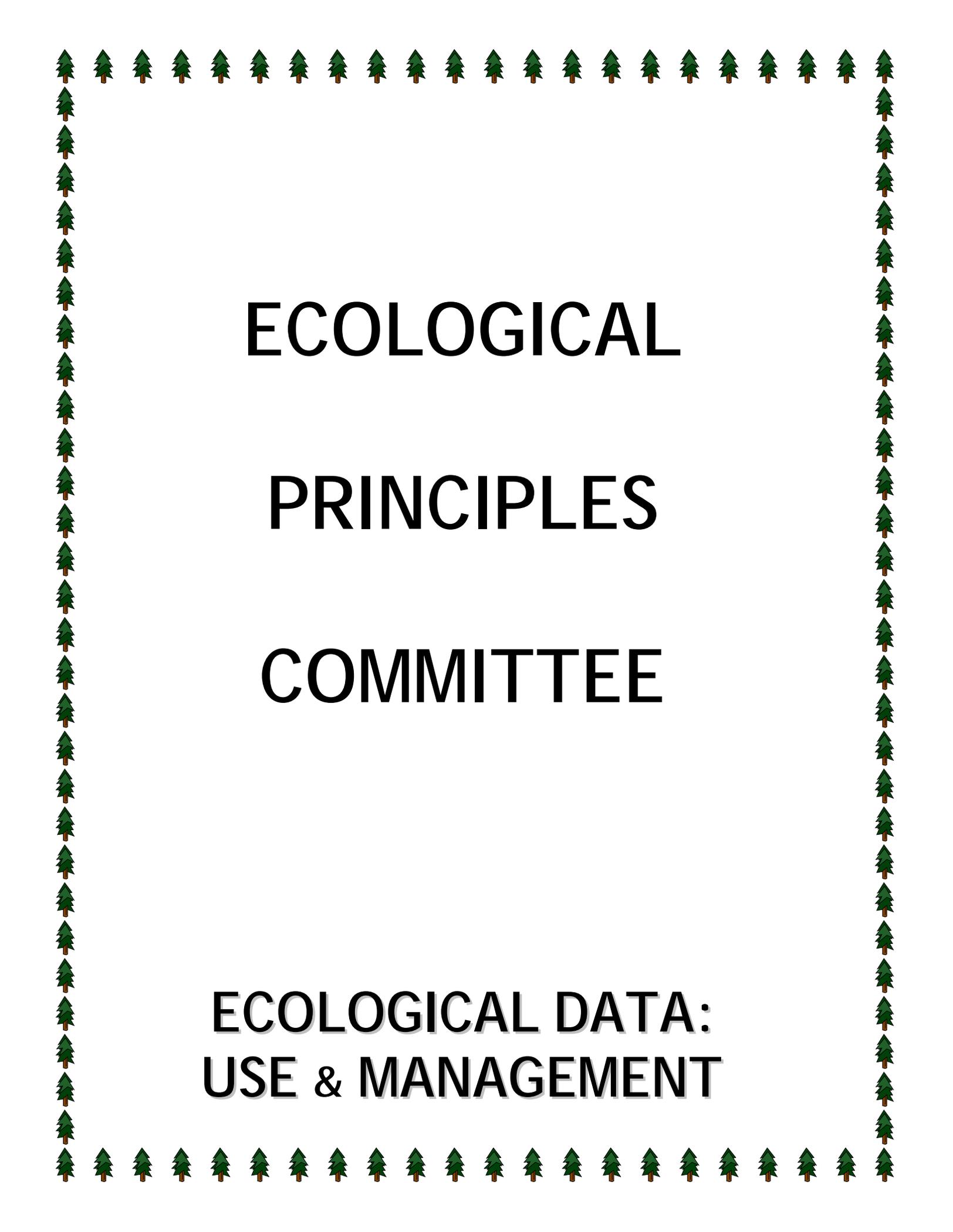
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Figure 1. Scoring curve with site-specific adjustments for soil test P and its relationship to productivity and water quality. The example shows curve shifts based solely on slope: a) for sites with 0-2% slopes, b) for 5-9% slopes, and c) > 15% slopes. Other assumptions made to generate this example were: P was determined using Mehlich III, soils were planted to fescue, and inherent soil characteristics include medium high organic matter (approximately 3.5-5% SOM), silt or silt loam texture, and only slight weathering. In this example, the inflection points for the ascending portion of the curve depend on primarily crop requirements while the descending portion inflection points are largely dictated by slope.





ECOLOGICAL

PRINCIPLES

COMMITTEE

**ECOLOGICAL DATA:
USE & MANAGEMENT**

FUTURE DIRECTIONS IN SOIL/VEGETATION DESCRIPTIONS

Information Needs for Soil Survey and Ecological Site Descriptions

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Resource professionals and the agencies they work for have two kinds of information critical for making good resource management decisions: data and knowledge. Our challenge in the coming decade is to organize these sources of information and put them into a format that is accessible and interactive so that they can be used most effectively. This paper is a description of some of the types of information that will be needed in Ecological Site Descriptions (ESDs) and some suggestions for organizing them to enhance their utility.

Data (Webster's: factual information as measurements and statistics) are important because they are the most unbiased representation of a phenomenon that we can provide. ESD data should include soils, vegetation, climate attributes for a site. Typically, Soil Map Unit and ESD information has included a mean or average value for attributes. Perhaps more important in a world that acknowledges nonequilibrium dynamics in natural systems is the range or variability associated with those attributes as well. In many cases, the variability, in both space and time, gives a much truer picture than the mean. Similarly, the prediction of system behavior requires an estimate of probabilities that also requires both an estimate of a mean and the variability associated with it. In all cases, both the mean and the variability provide insight into function of the site that neither can give alone. Typically, soils data, as recorded in the National Soils Information System (NASIS), does provide reference to the range of many soil properties. However, the degree to which these figures represent measured data vs. estimated numbers is most often unclear. **Any data provided in relation to an ESD must include the methods of collection. In particular, data in tabular form that includes both measured and estimated or modeled numbers must be identified as such.**

Knowledge (Webster's: familiarity gained through experience or association) can also be critical for making good resource management decisions. Knowledge is the translation of data through synthesis into a form that is more relevant to particular applications. We use knowledge to make decisions, including the design of experiments to generate new data. The difficulty comes when we attempt to use knowledge to 'fill in' missing data without the benefit of scientific experiments and fail to identify it as such. We also have to seriously consider how we "package" the knowledge. We often make assumptions, often without good understanding of the end user, who must also perform their own synthesis.

Another element in successful information management is making the information available to users. In the case of ESDs, we have a variety of users ranging from people trying to make decisions about managing a particular piece of land to public interest groups trying to make inferences about the state of the land in general to scientists trying to determine what we know and how to generate new information to expand that understanding. While our information has always been available to anyone interested in it, the internet has dramatically changed

accessibility. Before, people had to know enough to ask for a particular piece of information, now they need only know a few keywords to run a search engine and have the time to stick with it. It is not unusual for people to find information and not know how to use it (data without knowledge). It is also common for people to find opinion (disguised as knowledge) and have no idea of the validity of the data that supports it.

Since we do not have (nor want) the option of restricting access to natural resource information, we need to address the challenges of 1) defining the reliability of the information and 2) constructing a context for use of the information in an environment of unrestricted access. **Any numerical data associated with an ESD should be clearly identified as to how the data was collected and presented with an estimate of the variability (preferably both spatial and temporal) as well as the mean.** This is the best means of communicating the reliability and repeatability of the information. This would include refereed journal publications associated with the site and field investigations reported in a systematic format. If there is not access to the raw data, at least in archived form, we should not include it in the ESD. If the data has been generated with a model, the model and inputs should be identified. Similarly, interpretations of that data should be identified by author(s) and include references upon which the synthesis was based. **Essentially, ESDs and soil survey products should become refereed literature.**

Structural context for information is a field of study in the emerging science of knowledge management that pays particular attention to how information rich institutions organize and distribute their information. Information (and its components) has become a product and the distribution network is just as important as far more tangible products. It makes little sense to have a good product and a poor distribution network and, vice versa, a good distribution network with a poor product is of little benefit. In the case of ESDs, the variety of users has an even wider variety of needs. The information distribution system needs to allow each of the users to access the information (and the metadata) they need without having to pass through every bit of information in the system. There are good examples of this approach on the internet that have many thousands of visitors each day (for example, cars, insurance, medical sites).

ESD information is very complex and, in many cases, difficult to understand. We cannot change that by ‘dumbing it down’. However, using a structured context for accessing that information and clearly defining what the information means and where it came from can increase its utility at all levels. We recommend a thorough, systematic analysis of the structure of the information in ESDs and development of presentation format that will allow users with different needs to selectively access the system.

DYNAMIC SOIL PROPERTIES DATABASE

Soil Biology – A Case Study

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Introduction

Traditionally, soil survey has mainly dealt with soil properties that change slowly with time. After enough change has occurred in land use, or soil science or management practices, a soil survey will be updated. This period of transition time is something on the order of approximately 25 years. In the 'top soil' (A horizon or near surface) change can and does occur much more rapidly. It is more strongly influenced by land use and management practices than the static properties (use-invariant) on which the 25 year updating cycle is based. Soil scientists and others have long been aware that this is the case.

Traditionally, NRCS has pursued the goal of providing soil surveys for the entire country. In the interim many significant new soil (technological advances have occurred that measure new important soil properties or improve upon older measurement methods. Many of these new properties change rapidly with land use and thus they would change during the 25 year of our current surveys. These new soil characteristics, measurable through technological advances, are not limited to, but are most collectively important in the topsoil. Many are as important as or more so to soil survey users than the inherent soil properties we traditionally map, identify and delineate in soil surveys.

We have reached a new era in soil survey where the update and maintenance process is on going but the introduction and application of new information and technology learned in soil science has yet to be effectively introduced into our existing soil survey products. I would suggest that where we provide a traditional soil survey interpretations of use-invariant properties that change little within the 25 year transition period, we have provided only half of the soil information needed by today's more sophisticated users. Soil surveys now have a much broader user base than more traditional agricultural uses such as farming and ranching. Among our non-traditional users we now include cities, counties, other municipalities, businesses, construction and engineering companies to name just a few. It is time to build upon the firm foundation of our traditional soil surveys and create a new product to meet our new customer's broader needs for information and interpretations of dynamic soil properties.

Soil Biology

Soil biological characteristics are inherently dynamic and use-dependent soil properties. Better, more comprehensive information and interpretations of biological properties is paramount to improving management practices, understanding soil carbon dynamics, soil health, rangeland health, wetland function, and understanding nutrient cycling and energy flow throughout the ecosystem. This is particularly important for the surface horizon(s) and rhizosphere; the zones of maximum biological activity and influence.

Typically, NRCS-SSL soil biology data consists of; root biomass microbial biomass/activity, organic C (GC method), total N, particulate organic matter (POM), labile or active organic matter fraction measurements. Ancillary data, not easily captured and stored includes additional dynamic soil properties such as moisture content, bulk density, aggregate stability, crusting, etc. Biological data consists of multiple soil characteristic's measurements, and multiple measurements of a single soil property (replicates). The scale of biological data ranges from

micro-spatial (topographical) to hourly, daily, seasonal or other temporal periods (i.e. it varies with time and space). Samples must be fresh when they arrive at the lab and some must be refrigerated during overnight shipping.

The most common experimental design for Soil Projects that include biological measurements and samples follows:

- Biological samples are collected on Benchmark Sites consisting of both benchmark soils and benchmark plant communities.
- At a minimum, paired sampling is done of two vegetation states occurring on a single phase of a soil series.
- Replication of samples and fields is also required because of the inherent variability of the characteristics being measured.
- Known management history is documented.

Database Needs

Soil Biological data is inherently dynamic and varies with time of day, season of the year, moisture content, management practices and so on. Because of its inherent variable nature soil biological data is measured not estimated. It can be collected in the field and/or through standardized laboratory measurements. Due to the requirement for replication, multiple iterations of values need to be stored in the database at various scales within a site and from different sites in time and space.

Biological Data from Benchmark Sites should be accompanied by:

- The soil must be identified to the map unit component level and include paired sampling with different vegetation states.
- Known management history must be collected, documented, and stored. Complete pedon description (minimum)
- Lab sampling of the pedon and characterization (preferred)
- Plant community (range 417, woodland 5, and soil 1 for crops, etc)
- Date samples and measurements
- Ancillary dynamic soils data is required for interpreting soil biological data; date of sampling (for seasonal variability), moisture content, bulk density, aggregate stability, pore size and distribution and many others.

Summary and Conclusions

A well-documented comprehensive benchmark site is selected and sampled for soil biological characteristics as well as other dynamic physical soil characteristics. Accompanying information must include a complete pedon description (or lab analyses), comprehensive plant community data and documented known management history. Our database system needs to be enhanced to include the new dynamic properties and in a format that is compatible with existing databases such as pedon and lab characterization.

FUTURE DIRECTIONS: USING ESD'S FOR ASSESSMENT, MONITORING AND DECISION-MAKING

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Ecological site descriptions provide the framework for integrating soil, climate, plant community, hydrologic and wildlife information required for the design and implementation of cost-effective rangeland assessment and monitoring programs. Primary sources of information including soil survey data, climatic data and documentation for vegetation descriptions are imported or compiled in ESD's. Hence, ESD's supply the required information to apply assessment and monitoring data to decision-making. Assessment data is generally collected at one point in time to determine current condition. Evaluations are based on comparison to a standard. Monitoring data are used to determine trend. Evaluations are based on the direction, intensity, rate and consistency of the trend.

The need

Assessment and monitoring data are required to evaluate the results of past management actions and to predict the effects of alternative future management scenarios.

An opportunity

Our ability to use assessment and monitoring data is currently limited by four factors. Current and recently updated Ecological Site Descriptions partially address each of these factors. We describe some future enhancements that would increase the value of ESD's for land managers, NRCS personnel, other government agencies, private consultants and scientists.

1. The wrong standard: comparing apples and oranges and circular logic.

Problem: Vegetation data are frequently compared to an inappropriate standard based on existing vegetation (circular logic). Lack of specific knowledge of the soil- and climate-based site potential is often the cause.

Current/updated ESD's: Most ESD's do provide the information on soils and climate required to assist selection of an appropriate standard. This information could significantly improve evaluations if they were more widely applied.

Future versions need to be based on a careful interpretation of the functional edaphic unit to insure valid soil-site correlations. All ESD's need to include soil survey map unit names to document the edaphic unit and to aid in field verification of a site. They also need to define the key soil profile characteristics for each ecological site in order to facilitate correlations with other soil-based surveys, and to help non-soil scientists to select the appropriate ESD.

2. Lack of a standard.

Problem: There is no standard reference for assessment of current condition except for climax plant community-based species lists. These lists provide no information on structure and function. The problem is even more acute for soils. While there is a wealth of information available on the relatively static soil properties (such as soil texture, depth and parent material) that determine site potential, there is no systematic description of

soil dynamics, soil change or the range of variability of dynamic soil properties and processes (e.g. infiltration capacity and runoff, and soil erodibility and erosion) that are used to define the capacity of a site to function relative to its potential range of variability.

3. **Current/updated ESD's:** Updated ESD's will include an "Ecological Reference Sheet" that documents the expected range of variability for 17 function-based rangeland health indicators for undegraded sites. Quantitative data (e.g. 417) are available for some indicators.

4. **Future versions** need to include more quantitative data, particularly for the dynamic soil property-based indicators.

5. **Lost in space (and time), but still making interpretations.**

Problem: An understanding of the spatial and temporal context of historic data is required to interpret them, and to predict the effects of future management throughout the region on the structure and function of a particular site. Most monitoring data are recorded and interpreted without reference to a) potential effects of changes in condition upslope or upwind, b) events that occurred more than one or two years ago, or c) offsite impacts that may result from the monitored trend.

Current/updated ESD's: Ecological sites currently provide the foundation for a spatially-based interpretation of soil and vegetation dynamics because they are defined by soil and climate.

Future versions need to include more information on spatial relationships and process interactions among ecological sites, and on potentially persistent effects of historic events.

6. **Poor site selection.**

Problem: There is no common strategy for determining where on the landscape changes are most likely to occur. Consequently, data are unnecessarily collected across large areas with an extremely low probability of change, or where management is likely to have little or no effect. Conversely, those areas that are changing rapidly may be under documented or ignored.

Current/updated ESD's: Strategies for site selection should include potential management effects as well as the resistance and resilience of the soil-plant system to change. Updated ESD's will include a State and Transition Diagram. This diagram and the associated text can be used together with assessment data to determine (a) where in the landscape management-based changes are most likely to occur and (b) what management options are available. Based on this initial evaluation, monitoring plots can be strategically located in those areas where management intervention may be necessary and in areas in which a management change is planned (e.g. areas with a higher-than-average probability of recovery).

Future versions need to include more information on interacting soil, geomorphic and vegetation processes that determine landscape stability, and on early-warning indicators of change, including changes in site resistance and resilience.

Conclusions

Ecological Site Descriptions provide the best available framework for assessment and monitoring program design and interpretation. As they are updated, they will also include much of the information required. The usefulness of these documents will be increased by (1) improving soil-site correlations, (2) increasing the quantity and quality of quantitative reference data, (3) including more information on spatial and process relationships among ecological sites, and on potentially persistent effects of historic events, and (4) completing and continuing to revise State and Transition Diagrams as our understanding of these dynamic systems continues to increase.