Soil Disturbance Monitoring in the USDA Forest Service, Pacific Northwest Region

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Abstract—*In order to make reasoned decisions, USDA Forest Service managers must understand how changes in specific indicators of soil quality resulting from project implementation affect long-term forest productivity and watershed health. They must also be able to efficiently and economically assess the degree and extent of such changes across specified areas and adjust management activities accordingly. In 1979, the Pacific Northwest Region was the first Forest Service region to develop and implement soil quality standards based on the best research available at the time. Initial monitoring of land management activities for adherence to these standards was uncoordinated and, in many cases, followed protocols that led to questionable results. In partnership with the Pacific Northwest Research Station, a standard soil disturbance assessment protocol was developed in 1983 to provide consistent, comparable, and defensible data across the region. This protocol eventually became a national model for conducting soil disturbance assessments on national forest system lands. Information generated by such monitoring efforts has led to significant changes in techniques used to accomplish land management objectives. Eventually, a need arose for less expensive and time-consuming soil disturbance assessment protocols that still provide reasonably accurate and comparable data. Also needed was a means to improve communication and increase the level of understanding among soil scientists, land managers, operators, and the public. A partnership effort involving research and management personnel from several governmental and large industrial forest land owners in the Northwest is attempting to develop soil quality standards based on visual classifications of disturbance. Land managers and research scientists are also working to develop models that can be used to determine the degree of risk of soil disturbance occurring as a result of equipment operation and burning. These can, in turn, be used to establish site-specific soil management objectives. Continued research and management cooperation is needed to quantify effects of soil disturbance on site productivity and hydrologic response.*

Introduction

The USDA Forest Service considers maintenance of soil and water quality a high priority as it plans and implements management activities. A number of laws regulating activities of the Forest Service (Organic Administration Act of 1897, Multiple Use and Sustained Yield Act of 1960, National Environmental Policy Act of 1969, National Forest Management Act of 1976) all mention providing high quality water, providing sustainable supplies of timber and forage, improving growth of forest and rangeland vegetation, not degrading the productive potential of the national forests, and disclosing to the public impacts of proposed activities on the soil.

Although the laws mentioned above speak to the importance of soils in ecosystems, there are no meaningful standards, procedures, or objectives provided to assess whether the intent of these laws is being met. There are no concise, common definitions of sustainable productivity or watershed condition.

The harvest and removal of forest products, and subsequent land treatment operations such as slash disposal and site preparation, generally result in some degree of soil disturbance. Soil disturbance is not necessarily harmful and, in fact, may often be a management objective, particularly where site preparation and restoration are concerned. However, land managers should be concerned when soils are disturbed to the point where their inherent productive potential is significantly reduced or hydrologic function is impaired. There have been many differences of opinion among soil scientists, foresters, managers, and operators about where this "significant" threshold occurs.

Detrimental soil disturbance commonly is in the form of compaction, displacement, and puddling resulting from the use of ground-based harvesting and slash disposal equipment. It can also be in the form of sheet and rill erosion or charred soil in intensely burned areas. Problems have arisen in operational settings in determining threshold levels for, or defining when, detrimental soil disturbance exists, and in determining how much can be tolerated on a given area of land before unacceptable declines in productive potential or hydrologic function occur.

Soil Quality Standards

The Pacific Northwest Region (R6) first issued a Forest Service Manual supplement dealing with soil productivity protection in 1979. It has been modified a number of times since then (USDA Forest Service, 1998). This direction specified threshold values for determining when detrimental soil disturbance occurs and also set area extent or tolerance limits for detrimental soil disturbance on an activity area basis. Most national forests within R6 incorporated these values as Forest-wide standards as they developed their initial forest land and resource management plans. Other Forest Service Regions subsequently developed similar policy and direction (Powers, Tiarks, and Boyle, 1998). Standards for determining detrimental soil compaction, displacement, puddling, and severely burned soils were developed based on the best research results available at the time. Meurisse (1988) has discussed the history and evolution of the R6 soil quality standards in detail. Howes (1988) has described their application in an operational setting.

Standards emphasize observable and measurable soil characteristics that field personnel can use to monitor effectiveness of activities in meeting soil management objectives. In summary, all forms of detrimental soil disturbance, including permanent features of the transportation system such as roads and landings, are limited in extent to no more than 20 percent of an activity area.

Initial Management/Research Soil Monitoring Partnership

After soil quality standards had been developed and adopted for use, a system of monitoring was needed to ensure that, in fact, they were being met. Initially, no standard monitoring protocol was available. A number of widely disparate sampling procedures were developed; some with questionable scientific basis. This led to inconsistencies in sampling between national forests and often to indefensible results and incomparable data. Results of sampling were frequently challenged by individuals from within the agency, as well as from the public.

The need for a sound soil disturbance monitoring protocol provided the impetus for an informal partnership between R6 and Pacific Northwest Forest and Range Experiment Station. In 1981, a cooperative effort was begun to develop a statistically sound and defensible soil monitoring protocol. Objectives were to:

1. Obtain a representative sample;
2. Control level of precision;
3. Obtain consistent results with repeated sampling; and
4. Sample all types of soil disturbance at one time.

Two years of coordination and field testing resulted in a monitoring protocol that was first described by Howes, Hazard, and Geist (1983) in a field guide prepared for use by R6 soil scientists. Sampling rules and supporting theory were subsequently described by Hazard and Geist (1984).

Briefly, the protocol calls for establishing a systematic sample of grid points, arrayed on a map or aerial photograph of the activity unit to be monitored (fig. 1). The entire grid is randomly located and oriented, and the distance between points is constructed to provide a sample size that meets precision requirements or cost limitations specified in the objectives. Each grid intersection locates a line transect that radiates in a random chosen direction from the grid point.

Soil condition classes (displaced, puddled, eroded, severely burned) are identified using visual surface characteristics and are measured by the proportion of the length of each transect contained in each class. Certain physical soil characteristics may require collection of soil cores or other measurements (porosity, strength) to assess properties along the line transect but within the soil. This is done at fixed intervals. For example, cores

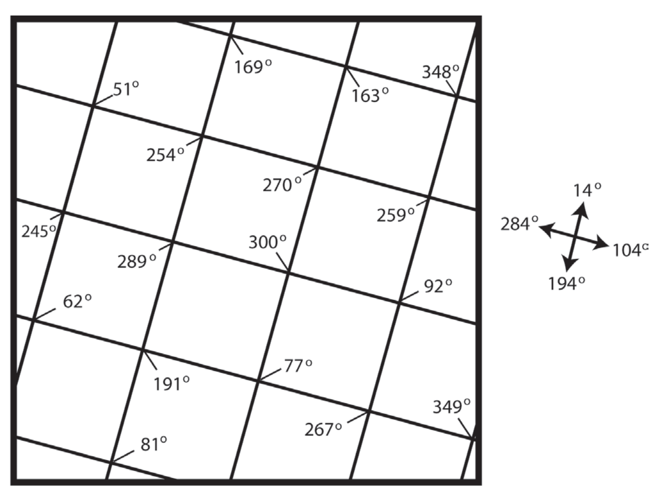

Figure 1. Schematic—R6 Soil Monitoring System.

can be used to assess soil bulk density and partition visual disturbance classes into either compacted or non-compacted categories. Measures of soil strength or porosity can also be used as indices of compaction.

Data collected on all transects provides a representative sample of the activity unit. The percent of the activity unit in each condition class is calculated by determining the proportion of each transect in that class, and averaging the proportions of all transects in the activity area. Reliability is estimated from the variance among estimated transect proportions of each condition class. A computer program was developed by the Pacific Northwest Research Station to assist field soil scientists in processing and summarizing data collected in the field (Hazard, Snellgrove, and Geist. 1985).

Collecting and processing soil core data was the most time consuming segment of the sampling protocol. A computer program to assist in this effort was also developed (Starr and Geist. 1983). Miller, Hazard, and Howes (2001) evaluated the precision, accuracy and efficiency of four tools for measuring soil bulk density and strength to help field soil scientists efficiently plan disturbance assessments.

Development of a simple yet statistically sound soil disturbance assessment protocol may not seem like a significant accomplishment. However, it served a number of purposes. It provided a standard protocol that produces information capable of withstanding legal or other challenges. Field soil scientists and managers began to think about experimental design as they planned soil disturbance monitoring projects. Managers began to understand the complexities involved in making soil disturbance assessments, that sound and defensible surveys took time, and they could involve considerable costs depending on survey objectives. Management needs to be involved in planning soil disturbance assessments. They must consider the kinds of decisions to be made, how information will be used, need for highly precise information (risk), and how much they are willing to spend to collect the data.

The sampling protocol has been used in a number of Forest Service research and operational studies in R6. Cochran and Brock (1985) used it in their study of the effects of soil compaction on initial height growth of ponderosa pine on the Deschutes National Forest in central Oregon. Laing and Howes (1988) used it in their survey of soil disturbance caused by a feller-buncher operation on the Colville National Forest in northeastern Washington. Much of the information generated from these studies has been used to guide soil management efforts within R6.

Sullivan (1987) compiled one of the most complete soil disturbance data sets on the impacts of ground-based harvesting systems on the Malheur National Forest in northeastern Oregon (fig. 2). The sampling protocol was used to monitor impacts of tractor yarding and machine piling on soils in 24 timber sale units. Forest managers were concerned that excessive soil resource damage was occurring where these management activities were being implemented. Detailed information was also collected on soil type, timing of harvest and slash disposal operations, and equipment used. The Forest used information from this monitoring effort to adjust its practices. Fuel management direction was clarified to lessen the extent of slash disposal thus reducing the amount of machine piling. Skidding impacts were reduced by calling for designation of trails prior to felling. Restoration of those units exceeding soil quality standards was called for as soon as practicable.

Such useful monitoring information is not obtained without cost. Sullivan (1987) also collected cost data for 8 of the harvest units he monitored. Cost per acre monitored ranged from $77 to $259. Total cost per unit ranged from $1151 to $2572. Personnel accounted for the majority of costs followed by processing of soil cores. Based on this information, it is easy to see that monitoring can be cost prohibitive when budgets are limited.

Later Partnership Efforts

Beginning in 1990, forest health and wildfire concerns became a major issue in the Blue Mountains of northeastern Oregon. Given the large acreage of overstocked stands requiring treatment, mechanical options, as well as prescribed fire, had to be considered as possible treatment alternatives. Between 1995 and 1997, a cooperative effort was initiated by the Pacific Northwest Research Station, Oregon State University, and the Wallowa-Whitman National Forest to study the economic and environmental impacts of fuel reduction practices used in mixed conifer stands in northeast Oregon (McIver, 1998). A primary objective was to measure effects of harvest activities on soils. The study was conducted on the La Grande Ranger District near Limber Jim Creek. This area of the District contained high fuel loadings, with many stands exhibiting fuel model 10 conditions (high potential for crowning, spotting, and torching during a wildfire). Six of the units consisted of pairs in which one unit of the pair was randomly chosen to be a forwarder unit and the other of the pair was chosen to be a skyline unit. At the request of the Forest, logs in the seventh unit were yarded with a skidder. Soil disturbance results from this unreplicated unit were used only for comparison purposes.

Of the seven experimental units, six had total detrimental disturbance levels under 10 percent (fig. 3).

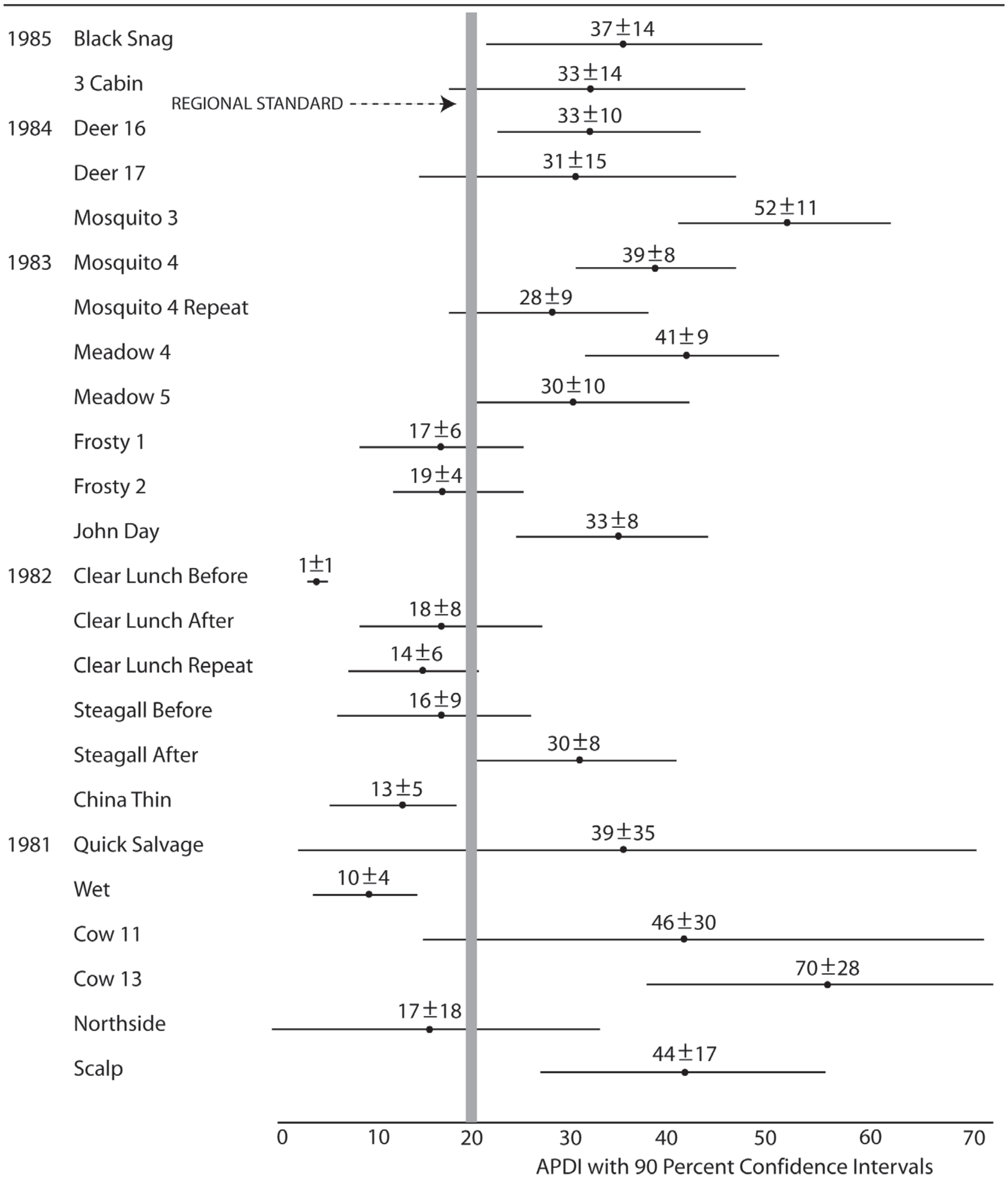

Figure 2. Average Percent Detrimental Impact (APDI) with 90 Percent Confidence Intervals.

Not unexpectedly, the unit harvested by conventional grapple-skidder contained the greatest detrimental soil disturbance. One interesting result was that, in all units, soil displacement (removal of topsoil) was the primary form of detrimental soil disturbance rather than compaction.

Again this may seem like a simple experiment, yet it yielded some very powerful information used locally in planning other fuel reduction projects. It demonstrated that operators at Limber Jim were able to meet Regional soil quality standards by keeping detrimental soil disturbance under 10 percent using cut-to-length timber harvest technology. Information generated as part of this study helped greatly in predicting effects of similar future projects occurring on volcanic ash soils in the Blue Mountains.

Given the costs associated with conducting sound soil disturbance assessments, alternative methods were explored. In 1998, the Wallowa-Whitman National Forest proposed using a modification of a system originally developed by Weyerhaeuser research scientists in 1979 and further described by Miller (1988). The system defines soil disturbance categories or classes based on observable characteristics. It then relates them to soil damage defining criteria and established standards for soil productivity protection. A seven-class system was originally proposed and implemented. Each of the classes could be assessed or measured using a variety of sampling systems.

In 2000, the USDA/USDI Joint Fire Sciences Program initiated a national "fire/fire surrogate" study to evaluate effects of four potential fuel management treatments on

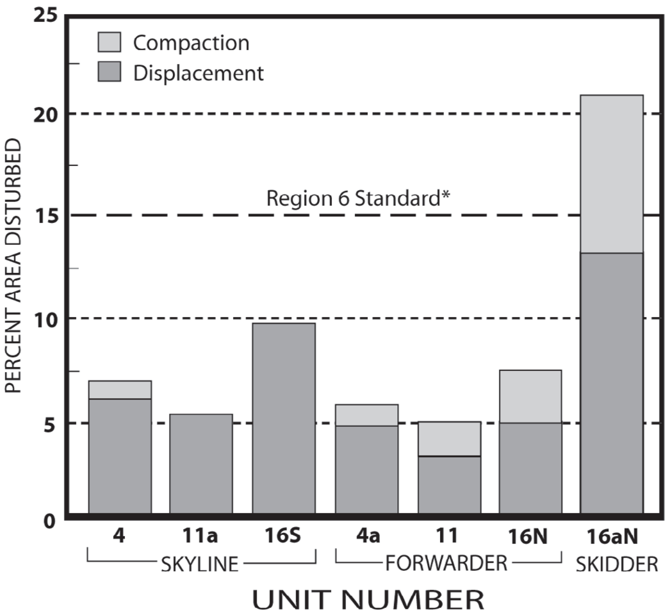

Figure 3. Percentage of soil area detrimentally disturbed among seven experimental units at Limber Jim. *Standard assumes 5 percent roads.

several core response variables including soils. Of particular interest was the amount of soil compaction generated by mechanical treatments. Given time and budget limitations, qualitative soil disturbance categories developed by the Wallowa-Whitman National Forest were used and measured on one of the installations in northeastern Oregon instead of using soil cores for bulk density determinations. During initial sampling, the number of disturbance categories was reduced from seven to four. Questions arose regarding the utility of this method as a research and monitoring tool. Currently, a cooperative study is being carried out by R6 and the Pacific Northwest Research Station to evaluate the precision, accuracy, and repeatability of such qualitative assessments.

Expanding the Soil Disturbance Monitoring Partnership

In the Pacific Northwest, there are a number of large private industrial forest land owners, public land management agencies, and research organizations interested in effects of soil disturbance on the sustainable production of forests and on watershed health. They have been loosely affiliated into a "Soil Disturbance Working Group" under the auspices of the Northwest Forest Soils Council. Scientists from these organizations are working together to develop a strategy for achieving uniformity in monitoring techniques and reporting soil disturbance for operational and research purposes as well as for reporting under international sustainability protocols such as the Montreal Process (Curran et al., 200X). A primary objective of this effort is to provide technical guidance that will facilitate effective communication and comparison of operational and research results.

This strategy contains five major components:

- Uniform terms for describing soil disturbance,
- Cost-effective techniques for monitoring or assessing soil disturbance,
- Reliable methods to rate soils for risk of compaction, rutting, topsoil displacement, and erosion,
- Effective approaches for using operational monitoring to meet a number of objectives including requirements of third-party certification and the Montreal Process,
- Objective comparison of current soil disturbance guidelines.

The importance of monitoring using a reliable process for achieving sustainable soil productivity and watershed health is also recognized.

Some significant progress has been made to date under several components of the strategy. R6 is currently bringing its soil disturbance monitoring methods more in line with the disturbance class approaches used by Weyerhaeuser Company and British Columbia Forest Service. A four-class system is now being tested on two national forests in northeastern Oregon (USDA Forest Service, 2001). R6 is currently cooperating with Weyerhaeuser Company and the Pacific Northwest Research Station to develop standardized models to rate soils for their relative degree of risk of incurring detrimental soil disturbance as a result of ground-based equipment operations. Separate models are being developed for soils east and west of the Cascade crest. Models are being calibrated using actual field monitoring data and professional experience. A model has also been developed to rate soils on the east slope of the Cascade Mountains in Washington State for degree of risk of damage by wildfire (Wenatchee-Okanogan National Forest, 2003). A cooperative effort is currently underway to publish this information and validate it for other geographic areas. These models will be used to adjust management objectives based on local soil conditions and on-site investigations rather than on blanket application of a single standard.

Soil risk ratings will also provide the basis for a standard Region-wide soil quality monitoring program consisting of five major components.

1. Risk assessment using common soil disturbance category definitions,
2. Soil management objectives (prescription),

3. Common monitoring protocols,
4. Maintain common monitoring database, and
5. Validate/adjust risk ratings and prescriptions based on results.

Future Partnership Needs

Although R6 has worked with the Pacific Northwest Research Station to test accuracy, precision, and repeatability of qualitative soil disturbance observations, final versions of category definitions and assessment protocols have yet to be developed. If common disturbance category definitions are the objective, then continued coordination among interested parties is essential.

Once soil disturbance category definitions have been finalized, a training and certification program for those making observations in the field must be developed and implemented. Consistency and accuracy of observations can be gained only through experience and continuous comparison of results collected using more quantitative methods. Development of common training programs among those groups making soil disturbance assessments will also enhance consistency and accuracy; and will encourage information sharing.

Relationships between qualitative definitions of soil disturbance and quantifiable indices of soil quality need to be determined. These indices must reflect physical, chemical, and biological processes important to productivity.

Finally, if sustainable forest productivity and watershed health are the ultimate objectives, then links between soil disturbance and vegetative growth or hydrologic function need to be established. In all probability, these relationships will change between soil type and geographic area. Quantification of these relationships will require continued strong partnerships between researchers and field practitioners in such fields as soil science, hydrology, geomorphology, silviculture, and range management.

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