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# Soil Matters: Improving Forest Landscape Planning and Management for Diverse Objectives with Soils Information and Expertise

**Terry L. Craigg, Paul W. Adams, and Karen A. Bennett**

Most forest managers would agree that soils are a fundamental resource of forestlands, yet many planning and management decisions continue to be made without a detailed and spatially explicit understanding of this unique and vital resource. We discuss the value of soil data and interpretations in forest planning. We emphasize that soil types differ widely in their inherent capacity to perform various ecological functions as well as in their dynamic response to and recovery from disturbances—concepts that can greatly enhance the quality of forest management decisions. We make a case for applying these concepts by introducing an adaptive management model that targets the use of soil information during forest planning and management. Our goal is to help bridge the gap between soil science and decisionmaking by helping forest managers better understand the value of soil information in project planning. A case study highlights applications and potential benefits.

**Keywords:** soil quality, landscape planning, project planning, multiple uses and values, case study

The theme of a recent Society of American Foresters (SAF) National Convention, "Silviculture Matters," seemed to state the obvious about the importance of forest management, but such focused attention can provide valuable reminders, examples, and fresh thinking about the technical underpinnings of well-practiced forestry. Such is the case for soils, which are the most fundamental resource of forestlands, greatly contributing to nearly all other forest resource functions and values. Yet despite a substantial evolution of investigation and expertise in forest soils in the United States (Gessel 1978, Fisher et al. 2005, Binkley and Fisher 2013), the use of soils information and expertise does not seem to have come close to reaching its potential in helping improve current forest planning and management. Here, we discuss the value of soils data and the role of the soil resource in forestry, using some examples from the USDA Forest Service and its Region 6. Although our discussion and the following examples focus on the Forest Service and the Pacific Northwest, we feel this information has comparable value in forest planning and management on other public and private lands, particularly where there are diverse management objectives on larger landscapes.

After several decades of growth in soil science research, education, and professionals, concerns were raised in the 1980s about dropping enrollments in undergraduate soil science degree programs and serious shortages of adequately trained soils professionals (McCracken 1987). More recently, Fisher et al. (2005) noted a significant decline in requirements for a forest soils class in undergraduate forestry curricula and a similar negative trend in forest soils expertise among forestry faculty. These issues appear to have directly or indirectly impacted the Forest Service: Between 1993 and 2012, the number of Region 6 soil scientist positions decreased by 63%, and the national trend in Forest Service soils staffing also has been strongly negative (Zimmerman 2012). In addition, the role of many soil scientists has become focused on monitoring and interpreting soil disturbance from forest operations (USDA Forest Service 2009). This relatively narrow focus stems from the National Environmental Policy Act of 1969 and the National Forest Management Act of 1976 (NFMA) requirements, which shifted

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attention to assessments of potential management impacts and efforts to protect soil and other resources. Specific guidelines to limit soil disturbance from operations were thus developed (e.g., Cornell et al. 1977, Boyer 1979) and added to administrative manuals (e.g., USDA Forest Service 1983). The original Soil Quality Standards (SQS) have been further refined by different Forest Service regions over the past few decades, including the Region 6 supplement to the Forest Service manual (USDA Forest Service 1991).

The overall goal of the Forest Service SQS was to direct national forestland management in ways that would avoid permanent impairment of the land's productivity, consistent with the mandate of the NFMA. The Forest Service SQS greatly increased the awareness of soil disturbance concerns, and more recently, the Forest Service developed national monitoring protocols to quantify soil disturbance within activity areas (Page-Dumroese et al. 2009), with additional soil-based indicators proposed to help identify degraded soil conditions (Burger and Kelting 1998, Powers et al. 1998, Schoenholtz et al. 2000). A notable consequence of this soil disturbance assessment activity has been the citing of Forest Service soil standards in lawsuits and administrative appeals by groups opposed to forest management (e.g., Ecology Center v. Austin in Montana, and League of Wilderness Defenders—Blue Mountains Biodiversity Project v. Bosworth, Civil No. 04–405-AS, in Oregon). This broader issue of legal opposition to Forest Service management activities is well documented (Miner et al. 2014) and helps explain the current level of attention given to the assessment and control of soil disturbance. Although such litigation has often delayed or restricted implementation of Forest Service management projects, it also reflects the high importance of and concern about soils as a fundamental resource in forest ecosystems. Increased attention to the value of soils by the interested public should provide added incentive for engaging soil scientists in management solutions for agency lands.

The need to assess and limit soil impacts cannot be ignored, but its dominance in national forest decisions in recent decades has also led to a diminished awareness of the broader value of soil information in Forest Service planning and management decisions. It is notable that in the 1960s the Forest Service significantly increased its soil and other resource specialist staff to help meet the mandates of the Multiple-Use Sustained Yield Act (MUSYA) of 1960 (Fedkiw 1999, MacCleery 2011). At that time, soil specialists primarily supported timber harvesting, road construction, and subsequent reforestation projects with soil inventories and management interpretations, but soils information also was recognized as valuable in managing for a variety of forest values. For example, Roger Reiske, then a Forest Service regional soil scientist, offered in the *Journal of Forestry* an inspiring and forward-looking discussion of the value and use of soils information in forest management planning, with examples that included wildlife, watershed, and recreation objectives (Reiske 1966).

Although much progress in both forest management and forest soil science has been made over the years, it can be argued that many applications of soils information in forest planning that Reiske proposed decades ago have not been consistently used nor have they been adequately expanded for the diverse management needs of today. Increased emphasis on soil disturbance assessments is likely one of the more important factors contributing to this lack of a proactive approach by soil scientists. Other factors may include the roles and expectations of administrators and the structure and dynamics of interdisciplinary planning teams, most of whom may not recognize the value of soils information in upfront planning. For the soil resource to reach its full potential in forest planning, the soil scientist and other forestry professionals need to carefully think about their concept of soil quality and its applications (Sims et al. 1997). Thus, we offer below an adaptive management approach to the use of soil information in project planning as well as some more contemporary ideas and examples, which we hope will help inspire a renewed interest in the use of soils information and expertise in forest management planning. An initial discussion of current soil quality concepts helps reveal how they can be better integrated into forest planning and management, particularly on national forests and other forestlands with diverse land-use and resource objectives.

## Soil Quality and Diverse Management Objectives

A half-century ago, management of national forests expanded from the basic timber and water supply focus set by the Organic Act of 1897 and the Weeks Act of 1911 to include diverse, compatible values as directed by the MUSYA. Subsequent environmental laws such as the Clean Water Act of 1972 and subsequent amendments and the Endangered Species Act of 1973 (ESA) prompted additional management considerations. Thus, many of today's forest management decisions are not only related to growing trees but also include other resource concerns such as maintaining water quality, unique habitats, and hazardous fuels reduction (Fisher et al. 2005). Similarly, planning and management for national forests now occurs primarily in an interdisciplinary setting with a number of specialists representing different disciplines and forest resource values. The team is challenged to

### Management and Policy Implications

Trends of more generic soils education for foresters and reduced technical staffing in forestry organizations appear to have narrowed or reduced the application of soils knowledge and information in management planning in recent years. However, the careful interpretation and use of soils information, including inherent and dynamic properties, can significantly improve forest planning and management decisions, especially when there are diverse resource objectives on a large land base. The adaptive management model provides a framework for integrating soil quality concepts into the planning, design, implementation, and monitoring of forest projects. This approach helps forest managers recognize the value in using soils information to assure that management objectives are matched to soils that have a high potential for achieving and sustaining those objectives over time. Another benefit is that managers can identify more appropriate and effective project criteria to apply as management activities are implemented, which can avoid overly restrictive criteria that unnecessarily limit operation timing or location, or result in costly mitigations. Although available soils expertise remains a concern, these soil quality and adaptive management concepts provide a foundation that could support effective staff training and certification in forest soils for improved project planning and implementation.

design and implement a management plan for a given planning area that includes multiple and sometimes competing objectives (Noss et al. 2006a, Maron and Cockfield 2008, Rieman et al. 2010). Soil resource information can facilitate this planning and management process by matching the desired objectives to areas of soils that have the best potential to support those objectives over the long term. The expectation is that management actions will be more sustainable and better able to meet the intent of the planners.

Foresters often use potential natural vegetation patterns and estimates of the historic range in variability of vegetation to assess local site characteristics and potentials (Pfister and Arno 1980, Morgan et al. 2008). While valuable in helping to understand the dynamic nature of ecosystems, this approach is sometimes limited by a lack of historical data and or difficulties interpreting the historic record. Land-use history, fire suppression, natural events, and management practices can each alter local vegetation conditions to a degree that masks or distorts true site potentials and limitations, thereby resulting in unreliable assumptions for forest planning and management (Morgan et al. 2008). Soil characteristics can provide much more reliable and stable indicators than vegetation for interpreting site potentials and responses to management prescriptions (Gilliam et al. 1993, Abella et al. 2013).

The concept of soil quality has been used as a tool to improve understanding and assessments for both land-use decisions and the sustainability of different management practices (Doran and Parker 1994, Karlen et al. 2001). To better understand how the soils information can be useful in forest planning and management, it is helpful to further clarify the concept of soil quality by distinguishing two unique and important categories of soil quality, inherent and dynamic soil quality (Karlen et al. 2001), which provide different types of information for planning and decisionmaking.

## Inherent Soil Quality

Inherent soil quality reflects the soil's basic capacity to perform different soil functions that support a variety of land-uses or resource objectives. These inherent soil qualities normally are not significantly altered by management activities and thus can be mapped and described in soil resource inventories. This reflects the fact that a given local soil type is the result of five dominant, soil-forming processes, including climatic influences, soil and surface organisms, local topography/geomorphology, geology/parent materials, and time for soil development (Jenny 1941). The resulting soil characteristics uniquely integrate these local environmental influences and reflect the soil's inherent capacity for performing a variety of soil functions. Examples of inherent soil attributes include soil depth, texture, amounts of rock in the soil, thickness and types of soil horizons, and depth to a water table. Examples of inherent soil quality interpretations are shown in Table 1. In landscape planning, an understanding of the various soil types and how these attributes result in different functional capacities can be used to better design sustainable management actions by matching planned actions to the right soil.

Different soils can vary widely in their inherent capacity to perform various ecological functions. For example, Abella et al. (2014) noted that thinning and grazing treatments applied in a ponderosa pine forest restoration study in northern Arizona showed different responses in species richness and productivity depending on soil type. Other examples include the identification of droughty soil types, which can be helpful in prioritizing stand treatments based on stocking levels, site potentials, and risk of insect and disease problems. Where watershed values are especially important, soils that capture and store large quantities of water can be identified and managed to maintain or enhance their ability to moderate peak flows and water temperatures in nearby streams. By both recognizing different soil types in the local landscape and how those various soils function, managers can better match land management objectives such as timber production, fuels reduction, favorable hydrologic function, and habitat enhancement to soils with a high capacity to meet those objectives.

## Dynamic Soil Quality

Dynamic soil quality, on the other hand, reflects how the functional capacity of soils may be altered in response to natural or human caused disturbances (Seybold et al. 1998). Unlike inherent soil attributes, the dynamic characteristics of the soil are more vulnerable to changes from management actions that disturb soils. Some examples of these disturbances and resulting changes in dynamic soil properties include a reduction in the depth of organic-rich surface horizons resulting from soil displacement, an increase in soil strength or resistance to root penetration as a result of compaction by vehicles, and soil physical and chemical changes due to intense burning. Examples of dynamic soil quality assessments are listed in Table 2. Assessments of changes and trends in dynamic soil quality can provide a valuable tool for directing soil protection, mitigation, or restoration efforts as well as for measuring long-term sustainability of management practices.

Concerns within the Forest Service over changes in dynamic soil quality resulting from forest management prompted national forestland managers and Forest Service research scientists to cooperatively establish the North American Long Term Soil Productivity (LTSP) experiment in the late 1980s (Powers 1991). This effort has since expanded to 62 research sites and numerous additional affiliated sites within the United States and Canada and is now the world's largest organized research network addressing forest management and sustained productivity issues. Treatment design is based on two site properties considered most likely to impact long-term site productivity: soil organic matter and soil porosity (Powers et al. 1990). Study sites cover a broad range of climates, tree species, and soil types and 10- to 15-year results have now become available for some of the older installations (Sanchez et al. 2006, Scott et al. 2014). While initial study results show limited effects to site productivity resulting from core treatments, it is important to note that these are early results of a long-term study, and other measured changes (e.g., soil nutrient status) from the treatments may be revealed as monitoring continues.

Different soils also vary in their immediate and subsequent response to disturbances (Seybold et al. 1999). A soil that is *resistant* to a given disturbance can retain important functional characteristics even when disturbance occurs. A soil that is *resilient* can be altered by disturbance but recover more quickly in its functions, while a soil that is *neither* resistant nor resilient can have long-term impacts to its functions after disturbance. For example, Scott et al. (2014) looked at changes in three ecosystem services: stand volume production, mineral soil C storage, and understory diversity on 13 LTSP study sites located in the southeastern United States. While results showed minor impacts to these ecosystem services at most

**Table 1. Management interpretations for inherent soil qualities in planning for various resource objectives on forestlands in central Oregon.**

| Resource management objectives | | Opportunities and limitations based on inherent soil quality | Applications in planning management actions |
|---|---|---|---|
| Maintain, restore, or improve stand conditions and associated vegetation in native forest types. | Forest health and resilience of drier forest types to insect epidemics and drought. | Inherent water supplying capacity varies among soils and can be estimated using data for mean and extreme precipitation, evapotranspiration, and water infiltration, retention and drainage within the soil profile. | Soil quality information is used to both refine tree stocking prescriptions and prioritize areas for treatment, based on expected drought stress and related increased risk of insect or disease. |
| | Desirable tree mosaic patterns in dry ponderosa pine forest stands. | The volcanic origin of many forests soils and the underlying rocks often results in complex soil patterns, with depths varying from very shallow to very deep. Local tree and stand productivity vary similarly. | Understanding and recognizing these diverse soil areas is used to refine local tree marking and related decisions about appropriate tree densities and design and number of openings. |
| | Desirable types and extent of riparian vegetation. | Soils that historically supported desirable riparian vegetation such as aspen often have thick, dark surface horizons. These soil features persist long after the removal or alteration of the original vegetation. | Identification and qualities of soils that historically supported aspen and other desirable vegetation are used to target locations for restoration projects and refine techniques to enhance success. |
| Maintain, restore, or improve soil water storage, stream flows, and aquatic habitats in local forest watersheds. | | Capture, storage and release of water from rain and snowmelt within a watershed are greatly influenced by soil qualities that can vary widely, including organic and mineral layers, infiltration, permeability, depth, texture, porosity, and landscape position. | Identification of soils with higher and lower capacities for capturing and storing water is used to prioritize areas for vegetation management as well as to refine treatment prescriptions. |
| Maintain, restore, or improve vegetation for local wildlife species. | White headed woodpecker (*Picoides albolarvatus*) habitat. | Soils that historically supported woodpecker habitat (i.e., open stands of widely spaced, large ponderosa pine) often have thick dark surface horizons that developed from heavy understory grass cover. These soil features persist long after the removal or alteration of the original vegetation. | Soil maps and local investigations are used to identify areas of soils with "mollic epipedons," where desirable woodpecker habitat can be effectively developed and maintained. |
| | Mature and old-growth forest habitat. | Soils with higher moisture and nutrient supplying capacities are likely to better develop and maintain mature and old-growth forest vegetation over the long term. | Soil quality information is used to identify locations, including recently disturbed areas, where desirable habitat can be grown and maintained over time. |

study sites, a small number of nutrient-deficient sites did show negative effects resulting from treatments.

A soil's inherent qualities often can also help predict a soil's resistance and resilience to different disturbances. For example, although soil texture or soil rock content may not be changed by management, they sometimes influence a given soil's resistance or resilience to compaction due to variability in inherent load-bearing capacity. By recognizing differences in soils resistance and resilience to disturbance, managers can better design soil protection measures for disturbances that might impact desired soil functions, while also not being overly restrictive.

## Applying Soil Quality to a Forest Planning and Adaptive Management Model

To effectively apply the concept of soil quality and related information in the forest planning and management process, land managers need to identify the management objectives early and have maps and interpretations available for the inherent and dynamic qualities of the soil types within a planning area. The conceptual model in Figure 1 reflects how such soils information is integrated early and the discussion that follows expands on the use and value of soil information.

Integration of soils information into forest planning begins as the interdisciplinary planning team initially identifies the broad *land management objectives* (*A*) for a planning area. For example, the forester may have both ecological and economic targets that require commercial harvest while also promoting desirable stand structure or complexity, whereas the fisheries biologist highlights a need to maintain local cold water habitat for an ESA-listed fish species. The fuels planner seeks to reduce the risk of stand replacement wildfire to protect the urban interface, and the wildlife biologist identifies needs or requirements for minimum canopy cover over a percentage of the landscape, habitat corridors, and forage for an important local species. Understanding the landscape and forest-specific context of these broader objectives is necessary before identifying and refining more specific management actions that are matched to soils that can best sustain such actions.

With soil types identified on the landscape and an understanding of their functions and qualities, managers can next identify *opportunities and limitations based on soil quality* (*B*). Thus, management actions are matched to soils with higher potentials for achieving the objectives and sustaining those actions. The success of this approach requires that local soil types have been well identified and mapped and that interpretations of their potentials and limitations are available for consideration early in the planning process. As this step is completed, potential areas where the desired manage-

**Table 2. Interpretations of dynamic properties of forest soils, including applications to monitoring of soil effects for adaptive management and sustainability.**

| Ecological process | Key soil functions | Dynamic soil quality indicators and common management concerns | Applications in monitoring and adaptive management |
|---|---|---|---|
| Forest vegetation growth and composition | Soil drainage and aeration | Soil porosity, color, and color patterns (mottling). Soil compaction or other disturbance from vehicle traffic may reduce drainage and aeration. | Monitor soil porosity and/or color for changes that reflect significant impacts to soil water and air movement. As needed, modify extent, type or timing of vehicle traffic. |
| | Root growth and plant community composition | Soil resistance to penetration (strength), bulk density, and structure. Soil compaction or other disturbance from vehicle traffic may reduce root growth and/or alter vegetation composition. | Monitor soil strength, density, and/or structure for changes that significantly impact root growth and/or vegetation. Modify extent, type or timing of vehicle traffic; use deep tillage to restore soil penetrability. |
| Hydrologic cycle | Infiltration | Soil infiltration rate. Soil compaction or other disturbance from vehicle traffic may reduce infiltration. | Monitor soil infiltration and runoff for significant changes and effects. Modify extent, type, or timing of vehicle traffic; use surface tillage to restore infiltration. |
| | Water storage and release | Soil porosity and permeability. Soil compaction or other disturbance from vehicle traffic may alter porosity and reduce permeability. | Monitor soil porosity for changes that significantly impact water movement and availability for root uptake. Modify extent, type, or timing of vehicle traffic. |
| Nutrient cycling | Surface woody debris, fine litter, and duff accumulation | Size, amount, and quality of woody material; extent, depth, and quality of surface litter and duff layers. Harvest utilization levels and debris or fuels management (piling and/or burning) may alter amount and quality of surface materials. | Monitor surface woody debris, litter, and duff for characteristics appropriate for vegetation type and successional stage. Modify debris management or other practices that result in undesirable amounts or conditions. |
| | Nutrient availability | Depth and quality of soil A horizon; amounts of plant-available nutrients in rooting zone. Harvest utilization levels and debris or fuels management (piling and/or burning) may alter nutrient availability. | Monitor depth and condition of A horizon and/or soil nutrient levels for changes that significantly impact tree and plant growth. Modify management practices that alter soil nutrient inputs, amounts, and/or availability. |

**Figure 1. A forest planning and adaptive management model that integrates the concepts of inherent and dynamic soil quality.**

ment actions are expected to be more effective and sustainable can be displayed spatially as maps.

These maps provide the basis for the *interdisciplinary planning team (C)* to next work together to strategize and integrate land management objectives and actions. At this stage, the interdisciplinary planning team often must consider tradeoffs and make compromises as management objectives have higher or lower compatibility within the planning area. The understanding of different soil functions and qualities can help staff in various disciplines improve specific resource management decisions and design actions that are both sustainable and effectively integrate diverse and sometimes competing management objectives.

At the *project design and implementation (D)* stage, planners experienced in field operations and project design develop the specifications and schedules for actions in specific locations. Resource specialists also are often involved or provide operating standards or guidelines that will protect or enhance resources of local concern. For example, a ground-based timber harvest plan typically will include directives to use existing or planned skid trails to limit soil disturbance that may impact dynamic soil quality and related functions such as soil drainage. Knowledge of the resistance and resilience of different soil types to disturbances can be applied to project design (Seybold et al. 1999), including the refinement of more general guidelines to target more effective actions and mitigation without being overly restrictive. During project implementation, managers, and sometimes resource specialists, oversee the operation and give the operator feedback to achieve the desired onsite results.

*Ecosystem responses (E)* are revealed through monitoring and more detailed evaluation of resource responses to individual and cumulative project actions. Monitoring of resource conditions and responses to treatments requires data collection, analysis, and interpretation of results. Success requires that monitoring be robust to scrutiny while also meeting the needs of both the resource managers and other stakeholders. To better address this need Larson et al. (2013) suggest an active adaptive management approach to monitoring that includes the use of basic principles of experimental design, thus enabling efficient and confident learning about complex forest responses to management.

Effectiveness monitoring of resource responses occurs after treatments have been implemented; however, important monitoring questions can and should be developed early in the planning process and include input from both the interdisciplinary planning team as well as other stakeholders (Larson et al. 2013). This approach can help build trust both internally and externally for future projects. The ecosystem response can be assessed at both the landscape and local scale (e.g., stand by stand) and also with a temporal context that considers resource responses both immediately following an activity and for some extended period afterward. For example, soil compaction from a ground-based thinning project can result in immediate changes in soil bulk density, but more extended monitoring of tree growth may show an absence of significant impacts when planned skid trails are used to limit the extent of compaction (Miller et al. 2007).

Adaptive management is next used to apply monitoring results and adjust future management activities in ways that incorporate what was learned (Bormann et al. 2007). With local as well as broad-scale monitoring at both short and extended intervals, it is easier to gain useful knowledge and apply adaptive management more effectively. Not only can this knowledge be used in local planning and project design, in some instances, it can also help update agency guidelines for forest resource management.

## A Local Example: Sisters Area Fuels Reduction Planning Area

The forest planning and adaptive management model described above provides a framework for highlighting the value of soils information and expertise in planning and management. However, because the accompanying discussion and examples were relatively general, the following real-world example helps illustrate the added value in using soils information in project planning. The following example and discussion for dry forest management incorporates many of the management strategies and treatment recommendations recently suggested for other federal forestlands in Oregon and Washington, including Forest Service, National Park Service, and Bureau of Land Management lands (Franklin and Johnson 2012).

Sisters Area Fuels Reduction (SAFR) is an approximately 32,000-acre planning area located within lower elevation ponderosa pine (*Pinus ponderosa*) forest of the Deschutes National Forest near the town of Sisters, Oregon (Figure 2). With 72% of the national forestlands within the SAFR planning area identified for treatment, the SAFR project was one of the first large-scale planning projects on the Sisters Ranger District to address the need for accelerated rates of treatment over a broader landscape as suggested by Franklin and Johnson (2012). These predominantly dry ponderosa pine forest ecosystems have been greatly modified over the past 100 years (Hessburg et al. 2005, Noss et al. 2006b). Stand conditions now include young plantations, 60- to 100-year-old stands, and uneven age stands with various tree cohorts. An environmental assessment of the area, which included a variety of restoration treatment prescriptions, was completed in 2008 and many planned activities have been implemented (USDA Forest Service 2008).

### Land Management Objectives

Treatments within the planning area had multiple objectives, including improved forest health and resistance to insect epidemics, drought, and serious wildfires in the wildland–urban interface (US House of Representatives Conference Committee 2003), while also providing quality wildlife habitat and other ecosystem services. Landscape treatments included thinning, shrub mowing, and prescribed burning to restore unique stand-level spatial patterns that serve important ecological functions, such as disturbance, regeneration, and habitat diversity (Hessburg et al. 2005, Johnson et al. 2008, Stephenson et al. 2011). Prescriptions included creating heterogeneous tree spatial patterns while conserving older trees regardless of tree size (Franklin and Johnson 2012). Desired tree spatial patterns and related heterogeneity were planned using a "mosaic thinning" process designed at two distinct scales (Stringer 2008).

Plans included a fuel reduction strategy with treatments to: reduce hazardous fuels, create defensible space adjacent to private lands, and provide safer travel routes should a fire occur. However, the planning area also contains mule deer (*Odocoileus hemionus*) winter range management allocations (USDA Forest Service 1990) where the forest understory often includes antelope bitterbrush (*Purshia tridentata*) that is important for sustaining deer herds during winter (Burrell 1982, Griffith and Peek 1989). This resulted in competing management objectives, i.e., the need to reduce fuels and improve forest health versus retaining or enhancing winter forage and other habitat components.

### Soil Characteristics Reveal Opportunities and Limitations

Reconstructions of presettlement stand patterns can be useful in managing ponderosa pine and mixed conifer forests (Larson and Churchill 2012, Churchill et al. 2013). These authors emphasize, however, that these spatial patterns can vary by soil type. Thus, the Deschutes NF Soil Resource Inventory (Larsen 1976) was used to identify three general soil groups within the SAFR planning area to help assess and match stand-level tree spatial patterns (Figures 3 and 4). One soil group is found on lava plains where soils have developed in shallow to deep pumice or in volcanic ash over an older residual soil on basaltic lavas. General productivity of these soils is reflected in the site index values (100-year base) between 70 and 85 for ponderosa pine (Larsen 1976). A wide range of soil depths, from very shallow to very deep, results in substantial tree spatial heterogeneity from the diverse soil carrying capacities. Linear arrays of larger trees often follow deeper soils formed on the edges of underlying bedrock, and higher stand densities are found where deeper soils are more extensive relative to more shallow soils. Openings occur in areas of shallow soils and the amount, size, and patterns of openings are determined by the extent of shallow soils in a given area.

A second soil group includes soils formed in relatively deep volcanic ash over glacial outwash. Productivity of these soils is somewhat lower than the first group, with site index values (100-year base) between 60 and 75 for ponderosa pine. These soils have relatively high moisture-supplying capacities and the consistent nature of the underlying outwash results in tree patterns that are less variable than with the first soil group. Tree clumps and openings still can occur, but overall the stands have less spatial heterogeneity because soil depth and moisture are less variable.

The third soil group is similar to group 2, with volcanic ash over glacial outwash,

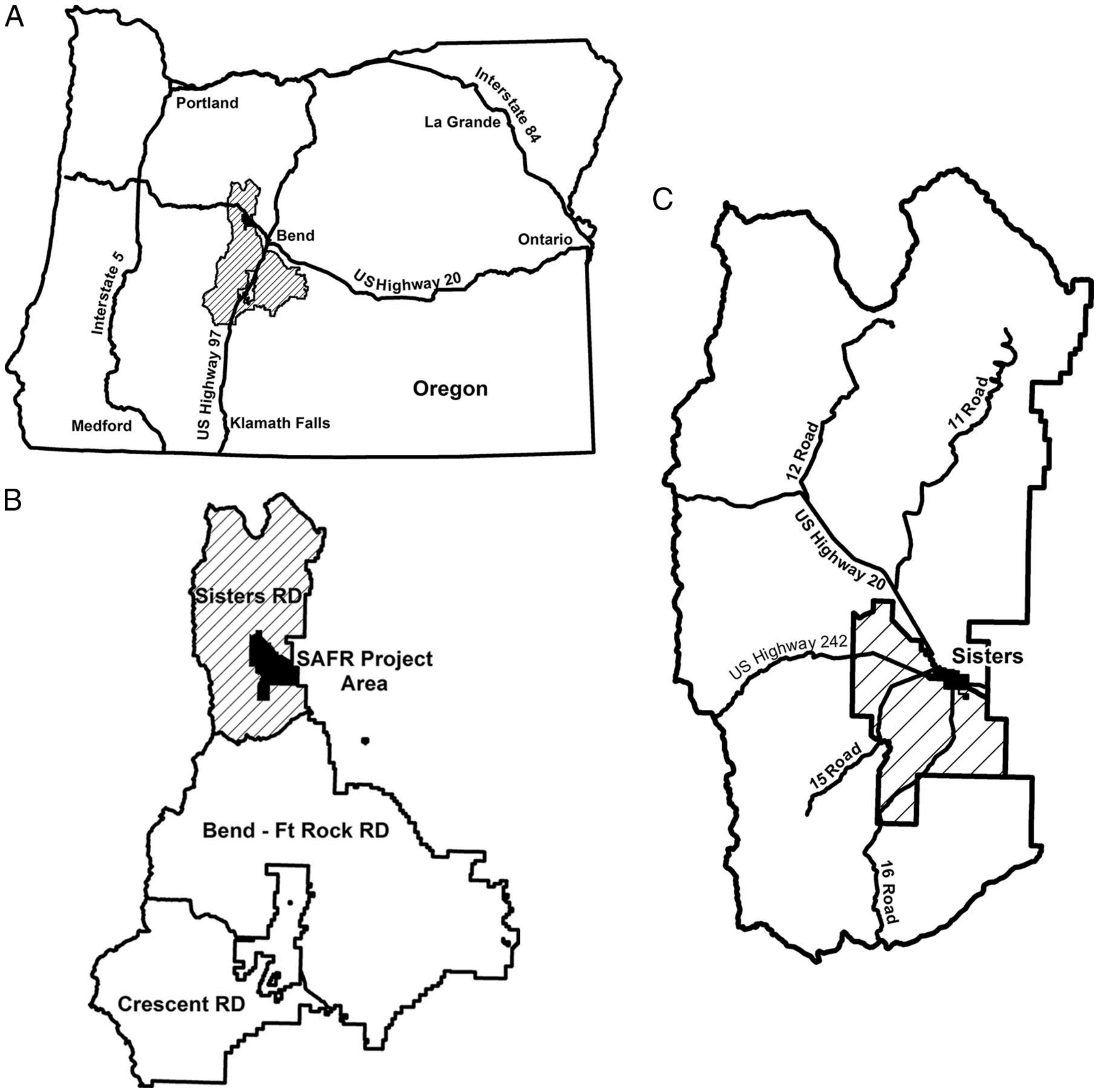

**Figure 2. SAFR project area location: (A) Deschutes National Forest (crosshatch) in Oregon, (B) Sisters Ranger District (crosshatch), and (C) SAFR project (crosshatch) within Sisters District.**

but the ash is thinner and there are more coarse fragments in the surface soil compared to the other soil groups. The result is low moisture availability and a mix of ponderosa pine and western juniper (*Juniperus occidentalis*) with low productivity (Larsen 1976). The droughty soils contribute to lower stand densities and more openings than with group 1 or 2 soils, and removal of competing juniper can strongly alter the spatial patterns of residual trees after treatment. Some of these shallow, rocky soils also provide somewhat fire-resistant areas where scattered, older junipers are well established and other vegetation is limited.

To help plan thinning and fuel reduction treatments that also maintain desirable winter forage, the characteristics of the three soil groups were integrated with local micro- and macro-climate information to refine predictions of amounts and types of understory. The somewhat higher elevation and precipitation of the group 1 soils area result in understory greenleaf manzanita (*Arctostaphylos patula*) and snowbrush (*Ceanothus velutinus*) but little or no bitterbrush. Brush control in these areas requires aggressive treatments and is only maintained when trees reach canopy closure. Group 2 soils are found in a somewhat lower precipitation zone, but their relatively high moisture-supplying capacity can support substantial bitterbrush. Thinning, mowing, and burning treatments on these soils typically result in quick recovery of desirable bitterbrush forage. The droughty soil group 3 supports an understory mixture of sagebrush (*Artemisia tridentata*) and some bitterbrush. In these areas, prescribed fire treatments reduce the shrub component while increasing bunchgrass (*Festuca idahoensis*) in the understory. Thinning the overstory trees on these droughty soils can increase available soil water while promoting bitterbrush in the understory.

## Interdisciplinary Strategy for Land Management Actions

Tree density targets were initially determined from both reference conditions in areas that still had an old-growth tree component and from management tools such as stand density index (Reineke 1933). Recognition and understanding of the three major

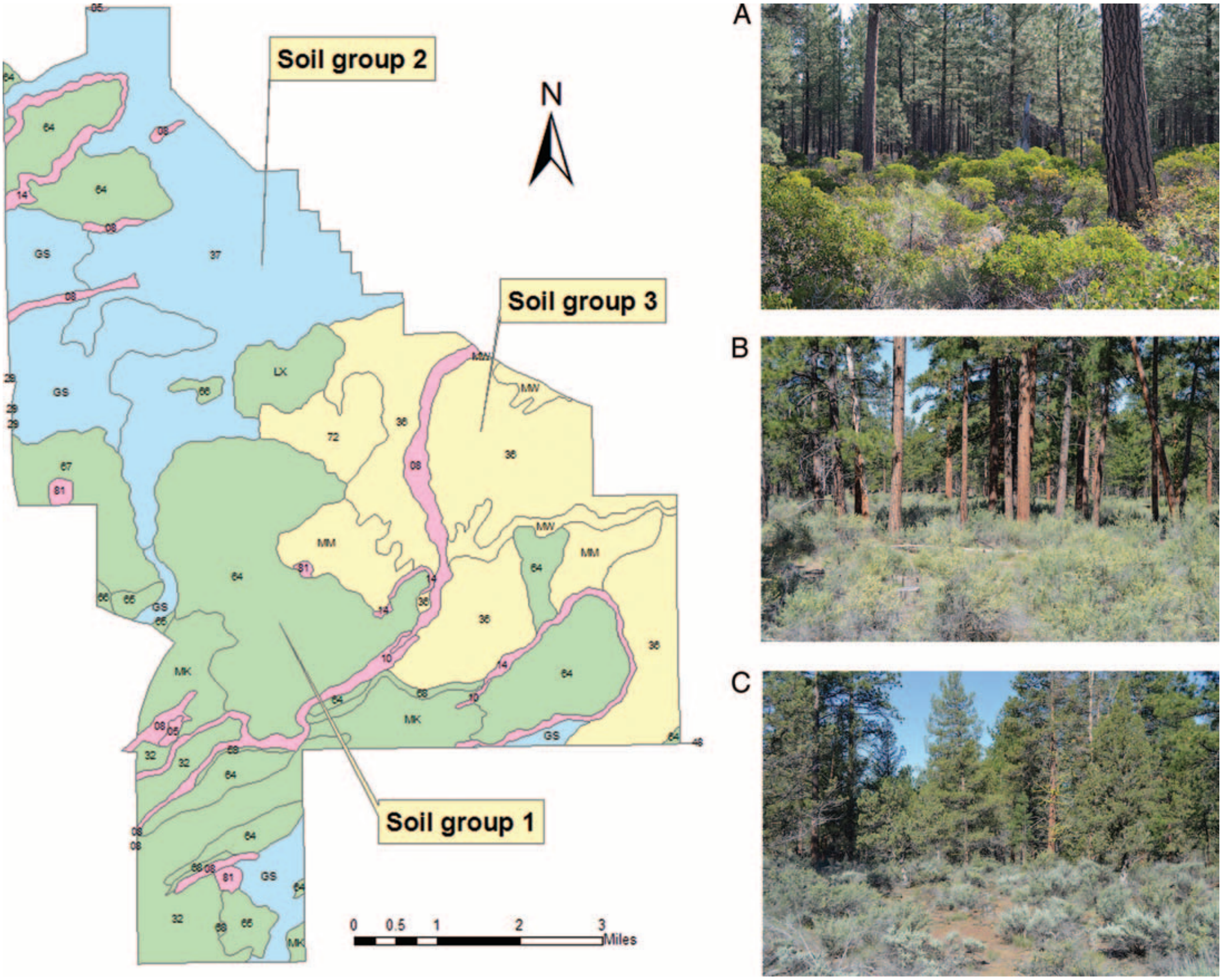

**Figure 3. Major soil types within the SAFR project planning area, with photos of characteristic vegetation for: (A) soil group 1, (B) soil group 2, and (C) soil group 3.**

soil groups were then used to refine treatment prescriptions and implementation guidelines. Thus, in group 1 soil areas, variable soil depths are used to make better choices about retention and removal of trees to achieve the desired landscape heterogeneity. Locations and extent of shallow soils help determine the areas and shapes of openings, whereas identification of deeper soils can help locate areas for retaining wildlife cover where soils are more likely to sustain desirable cover levels.

The relative uniformity of the group 2 soils provides more flexibility for design and placement of tree clumps and openings, whereas management in areas of the droughty group 3 soils provides unique limitations in both carrying capacity and species composition. Targets for residual trees on group 3 soils must consider the related overstory and understory interactions, including the effects of juniper removal. Although juniper control is often desirable, there are areas of old-growth juniper within the planning area that consist of small 1- or 2-acre patches within the larger landscape. These small patches have droughty, rocky, shallow soils that support very little understory vegetation. This makes these areas somewhat fire resistant, allowing juniper to establish and thrive while providing important habitat diversity across the landscape.

Soils information also can be used to strategically plan and focus primary understory fuel treatments on soils less suitable for bitterbrush production and to modify treatments in other areas to retain or promote bitterbrush on soils that can better support the species. Because soil group 1 is less suitable for bitterbrush, these areas are treated more aggressively to reduce brush fuels and encourage residual tree growth. In areas of soil group 2, where a variety of treatments can yield good responses by bitterbrush, treatments are scheduled in a sequence and pattern that allow treated areas to recover before adjacent areas are treated. To maintain a bitterbrush component in areas of soil group 3, stands are thinned to lower densities and prescribed burning sometimes is restricted to avoid converting the understory to bunchgrass.

## Soils Information for Project Design and Implementation

In this step, information about inherent soil qualities and dynamic responses to disturbances can help identify differences in

**Figure 4. From left to right, representative upper soil profiles for Soil group 1, Soil group 2, and Soil group 3, which are shown on the map in Figure 3. The specific soils shown are classified as 1) an Ashy, frigid Humic Vitrixerand, 2) an Ashy over loamy, mixed, frigid Humic Vitrixerand, and 3) an Ashy over loamy skeletal, frigid Typic Vitrixerand. The soils represent a gradient from relatively high to moderate to low soil moisture holding capacity and productivity.**

soil resistance and resilience to disturbances and expected effects on key soil functions (Page-Dumroese et al. 2007). The fine ash soils in the SAFR planning area have inherently high porosity, making them resistant to reduced aeration and infiltration from compaction; however, they can show large reductions in soil penetrability (Craigg and Howes 2007) at levels that can restrict root growth (Siegel-Issem et al. 2005). Operationally, soil monitoring has shown that the added strength of compacted soils can sometimes allow equipment activity to proceed without further disturbance, even when the soils are moist. Again, soils information and expertise help identify such tradeoffs.

### Monitoring Ecosystem Responses and Adaptive Management

Posttreatment monitoring has confirmed expectations of desirable stand patterns and vegetation responses where key soil differences were considered. Treatments in areas of group 1 soils have reduced much of the brush while also retaining habitat in suitable areas. In areas of group 2 soils, bitterbrush responses were positive following thinning, mowing, and burning that reduced stand densities and created both small and large canopy openings. Treatments on these soils also significantly reduced and delayed recovery of less-desirable manzanita that was originally present. Some areas of group 3 soils that were thinned, mowed, and burned were converted largely to a bunchgrass understory, whereas other unburned treatment areas retained a bitterbrush component. Other notable differences and tradeoffs were observed, e.g., bunchgrass-dominated treatment areas contained a variety of understory forbs that provided additional forage value to mule deer when not covered by snow (Monty Gregg, USDA Forest Service, pers. comm., Feb. 10, 2014).

On Sept. 12, 2012, the Pole Creek Fire started about 12 miles southwest of Sisters, Oregon, and after several weeks it eventually burned into the SAFR planning area. Several SAFR treatment units located between the fire and the Sisters community that had been previously thinned, mowed, and burned were successfully back-burned to assist with the suppression efforts (Jinny Reed, USDA Forest Service, pers. comm., Mar. 18, 2014).

## Conclusions and Outlook

With the soil quality concepts, adaptive management model, and real-world example of the SAFR project presented here, we hope that forestry professionals will recognize the value of soils information in planning and management decisions involving diverse resources on a large forestland base. We believe that forest managers can make better planning and management decisions through wider awareness, understanding, and application of local soils information. Our experience suggests that to use soils information to its full potential and assure sustainability, this information should be considered early in the planning process to help match soils to the desired management objectives, related actions, and expected treatment responses. Management planning for diverse benefits also invariably involves some tradeoffs and compromises, and knowledge of soil resources can assist these decisions. By recognizing the wide differences among soils in their capacity for important ecological functions and in their responses to disturbances, managers can help assure adequate measures are being taken to protect soil function while not being overly restrictive. As planned projects are implemented, soils and other resource monitoring can validate expectations or direct effective modifications when planning future management actions.

Although soil science continues to be recognized as an important discipline in natural resource management, more can and should be done to increase the awareness of the soil resource (Drohan et al. 2010). We are also concerned that current and near-future staffing in larger forest management organizations such as the Forest Service do not consistently provide adequate soils expertise and experience for important planning efforts on forestlands (Zimmerman 2012).

Emphasis of the importance of a soils program in forest management decisions starts with leadership at national, regional, and state levels of a public or private organization. Recent administrative direction within public agencies has given more emphasis to growing issues such as ecological restoration and climate change (e.g., Bosworth and Brown 2007, Tidwell and Brown 2011). Increased "executive-level" leadership within important disciplines such as soils could help to communicate the importance of the soil resource and the need for soils staffing comparable to that for other key resources.

Because significant constraints on the number of specialized staff are likely to continue, other approaches may also be helpful in promoting the effective integration of soils information in the planning and design of land management actions. One approach is to provide formal training and certification in forest soils for existing staff, similar to Forest Service programs for silviculture and other key areas (Walker 2014). Staffing of many of the other disciplines within the Forest Service has also declined in recent years (Zimmerman 2012), and this cross training approach suggested for the soil resource may prove useful in other resource areas as well. As with other major resource specializations, training and certification programs cannot serve as a full substitute for staff with professional degrees from university soil science programs. However, soils training and certification can provide valuable awareness and understanding among staff and interdisciplinary planning teams with diverse backgrounds, as well as clarify key concepts and terminology that facilitate effective communication and applications in management planning. The Natural Resource Conservation Service, for example, has soil scientists whose primary responsibility is to develop soil resource inventories, maps and interpretations that can be understood and used by both soil scientists and nonsoil scientists to make informed resource management applications. The agency also has soil conservationists who then use that information to help landowners make appropriate land management decisions. Using a similar approach in forestry organizations, staff certification in forest soils could help create effective teams of "forest soil conservationists," especially if the training targeted a variety of resource disciplines that can benefit from soils information (e.g., hydrology, silviculture, range, wildlife, fisheries, and fuels). The training could include understanding the types of available soil information, how to access and integrate that information with a spatial database, and how various soil interpretations can be further developed and applied in forest planning. The forest planning and adaptive management model presented here could also be used to further organize and refine an effective forest soils training and certification program.

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