Validating Visual Disturbance Types and Classes Used for Forest Soil Monitoring Protocols

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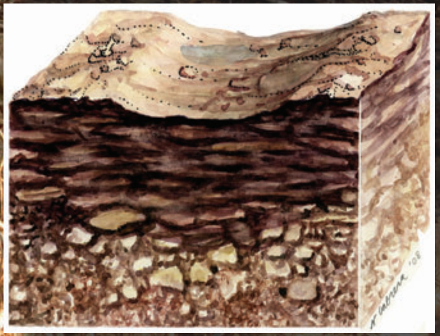

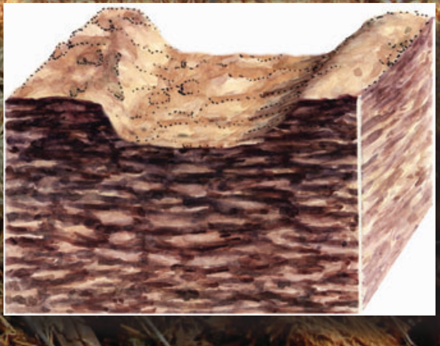

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Abstract

We describe several methods for validating visual soil disturbance classes used during forest soil monitoring after specific management operations. Site-specific vegetative, soil, and hydrologic responses to soil disturbance are needed to identify sensitive and resilient soil properties and processes; therefore, validation of ecosystem responses can provide information for best management practices in selecting appropriate harvest and site preparation techniques that limit long-term degradation and maintain site productivity and hydrologic function. Although research on forest managements affect on soil properties and plant growth responses has been conducted on a few sites, there is a need for additional site-specific validation data of soil visual disturbance attributes across the range of soil and forest conditions.

Keywords: soil productivity, vegetation, hydrologic function, adaptive management, soil disturbance type, soil disturbance severity class

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Research Summary

We describe several validation approaches for developing site-specific relationships among soil disturbance type and severity and vegetative growth, soil properties, and hydrologic response. For example, rutting caused by machine traffic can be classified in various severity classes (based on rut depth) that indicate whether the rutting is a concern for soil quality or hydrologic function and if it "counts" toward soil disturbance limits on a given soil. However, various site attributes, such as soil texture, slope, and soil moisture and/or temperature regime, will determine how plant growth and soil properties (including hydrology) are affected by management activities. Quantifying site-specific changes will provide managers with decisionmaking tools for assessing disturbance and vegetative growth relationships.

Through validation monitoring of actual soil and ecosystem response, resulting databases can be developed to help determine limits for site-specific thresholds when productivity and/or hydrologic function decline beyond acceptable limits. Validation information may be collected from retrospective studies, existing soil disturbance or related research, new experimental plots, or operational trials. Each approach has its own merits and disadvantages. For example, retrospective studies can provide long-term response data in the short term, but give little information on the actual disturbance at the time it was created. Current research studies, such as the North American Long-Term Soil Productivity study, often have a soil disturbance component and can be "data mined" or re-sampled to yield immediately useful, longer-term data on some aspects of soil disturbance response. However, the disturbance types used during study establishment may or may not be entirely compatible with current definitions of disturbance types and severity, or the practices that created the soil disturbance may no longer be used. New studies and operational trials are likely needed for soil disturbance types and soil/site conditions not covered in existing or retrospective studies. Because visual soil disturbance types are the integration of various disturbance processes (e.g., soil compaction and displacement combined), detailed measures of actual soil properties may be less important than monitoring the end-result response variables such as plant productivity and hydrologic function. Ultimately, validation of visual attributes of various disturbance levels will improve understanding of how site, soil, hydrologic function, and vegetation interact. In some cases, it may be desirable to relate vegetation responses to specific soil properties, but such studies will be more intensive and expensive, so they should be limited to a representative subset of study sites (soils and disturbance types).

We will outline a core set of soil properties and vegetation measures that can be used to document site quality changes after land management. Once sites are documented, longer-term monitoring efforts can further refine site-specific best management practices. As long as core soil properties and vegetation measurements are collected and linked to the visual disturbance classes, the adaptive management process can be used to ensure the visual classes are properly associated with changes in hydrologic function and/or above-ground productivity.

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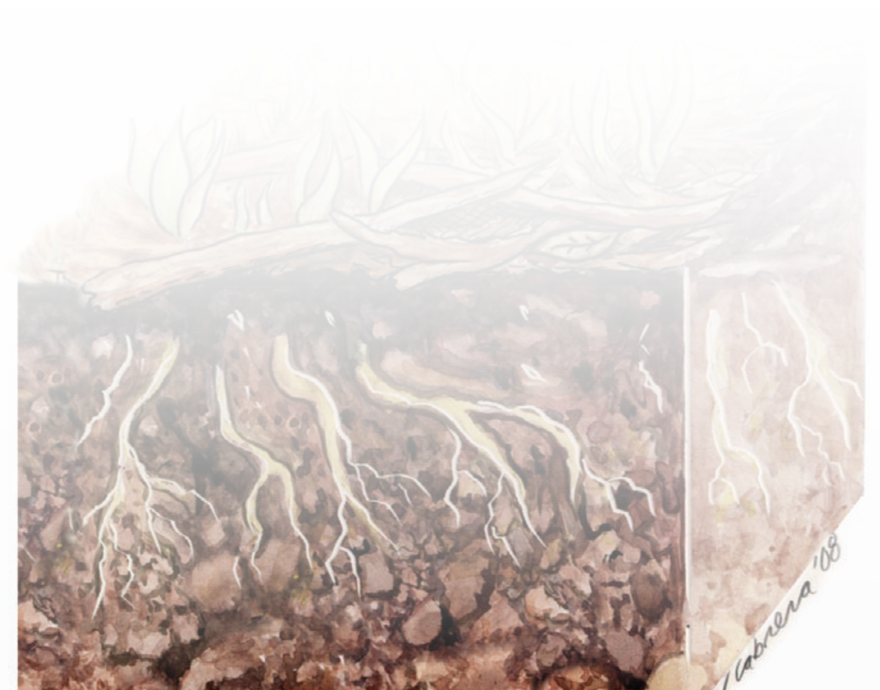
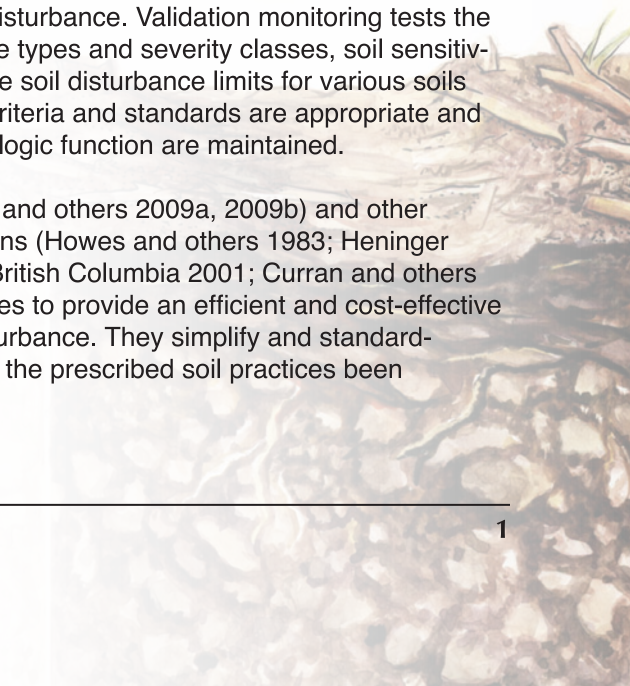


Introduction

There are numerous classification systems for characterizing soil disturbance (e.g., Scott 2000; B.C. Ministry of Forests 2001; Heninger and others 2002). The classification system should include disturbance types and severity classes that are obvious concerns for knowledgeable users (e.g., deeps ruts, excavated/displaced areas, or berms). Other disturbance types may be of concern based on best available information (e.g., shallower or more extensive disturbances) and should be further validated with response variables that are ecologically relevant and that provide direct evidence of a change in a site's capacity to grow vegetation or produce clean water (Curran and others 2005a). In forested ecosystems, soil disturbance is defined in terms of disturbance *type* and *severity*. Soil disturbance types, severity classes, and cumulative limits for disturbance should be related to how sensitive the soil is to long-term damage from the disturbance (Curran and others 2007). For example, ruts are defined disturbance *types*, which are then described under the conditions (dimensions and soil properties) they align with in the various disturbance *severity* classes. Severity classes help to define a disturbance type as being inconsequential, being of concern (and hence counting toward cumulative soil disturbance limits), or being severe enough to require remediation. The visual soil disturbance types, severity classes, and cumulative limits are usually developed within a given jurisdiction, based on best available information. For example, with the recent standardization of U.S. Department of Agriculture, Forest Service Forest Soil Disturbance Monitoring Protocol (FSDMP; Page-Dumroese and others 2009a and 2009b) and the use of other soil disturbance visual classifications systems (Howes and others 1983; Heninger and others 2002; Province of British Columbia 2001; Curran and others 2007) by neighboring jurisdiction (e.g., industry, state lands, and Canadian forest lands), there is a need for site-specific assessments to further characterize forest soil disturbance types and their relationships to soil productivity and hydrologic responses. Although many forest soils are resilient to management activities, such as timber harvesting, thinning, or fire, others can be at risk of losing their productive and/or hydrologic capacity after vegetation management due to a sensitivity or limitation in their inherent soil properties (e.g., more sensitive texture, shallow forest floor, or thin mineral soil mantle; Burger and Kelting 1999). Thus, no set of standards, and thereby no monitoring system, is complete until data are collected that demonstrate the effect of various harvest methods on soil changes, as well as how vegetation growth or hydrologic function is affected on soils of differing sensitivity to disturbance. Validation monitoring tests the assumptions of soil disturbance types and severity classes, soil sensitivity (risk ratings), and cumulative soil disturbance limits for various soils to ensure that the monitoring criteria and standards are appropriate and that soil productivity and hydrologic function are maintained.

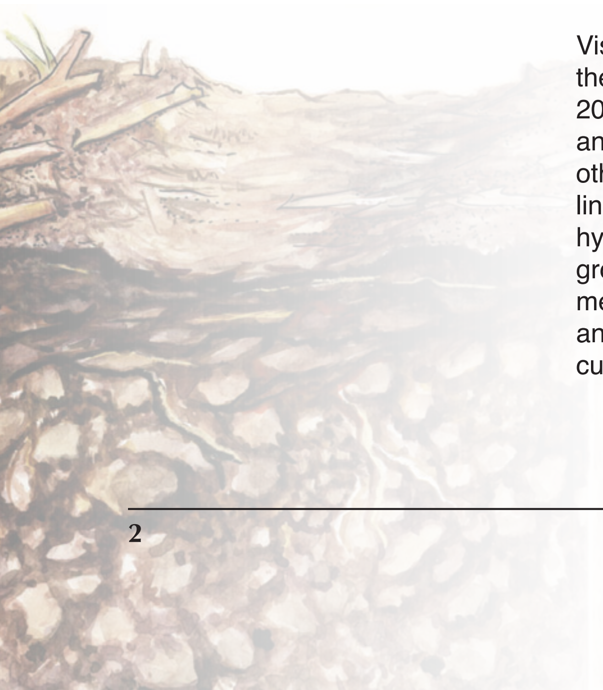
The FSDMP (Page-Dumroese and others 2009a, 2009b) and other visual assessment classifications (Howes and others 1983; Heninger and others 2002; Province of British Columbia 2001; Curran and others 2007) use qualitative procedures to provide an efficient and cost-effective method for measuring soil disturbance. They simplify and standardize implementation (e.g., Have the prescribed soil practices been



implemented?) and effectiveness monitoring (e.g., Was the prescribed soil practice effective in meeting management objectives?). However, more intensive measurements are needed for validation monitoring (e.g., What impact did management have on soil disturbance and/or vegetative growth?). Quantitative measures of soil disturbance include properties related to the degree of soil compaction (e.g., pore size distribution) and displacement, chemical properties, and organic matter content. Quantitative measures of these soil properties are more expensive to collect than qualitative data. However, when coupled with response variables, such as overall soil hydrologic function and/or vegetation productivity, these measures are appropriate for calibration of the qualitative measures through a better understanding of the long-term effects of management activities. Both quantitative and qualitative information can give statistically valid answers to the question of "What does this data mean for site response?" A site's disturbance response depends on many factors (e.g., climate and weather variables, competing vegetation, and pathogens), so it is important to characterize study sites to ensure control of these potentially confounding factors. Therefore, in a previous or retrospective study, it is possible that detrimental soil disturbance may not have resulted in an expected negative growth response due to compensating growth-limiting factors, such as reduced vegetation competition. Lack of a response could also be attributed to a favorable climate during the first 20 years of stand establishment. However, prudence is important because more extreme climatic events are expected in the future, and such disturbance would be expected to have more negative implications for growth and hydrologic function (Westerling and others 2006).

Existing knowledge helps identify soil factors that are expected to influence vegetative responses (and hence form the basis of soil risk ratings for sensitivity to disturbance), including soil texture, soil development (organic matter enrichment, soil depth, and structural integrity), parent material, and topography. Therefore, it is critical to use validation monitoring on select groupings of areas (e.g., an area of similar soil textures with different harvest methods) that also include baseline sampling on a non-harvested control to characterize soil changes that may be occurring due to more variable or changing climate. The first step in a local, regional, or national validation scheme is to develop these site groupings to enable efficient use of available validation resources (Curran and others 2005a).

Visual classification systems define the attributes and severity classes of the disturbance (Heninger and others 1997; Page-Dumroese and others 2009a). Each of these severity classes is designed to ensure consistency and repeatability among classifiers, as recommended in Curran and others (2005b). In order to validate the visual disturbance types that are linked to these classes and to determine site-specific vegetation and/or hydrologic response, direct evidence of a change in the site's capacity to grow vegetation or its hydrologic function is required. Using a consistent method to classify harvest related disturbance across a gradient of soil and climate conditions is the most desirable method to track trends in occurrence and the effect of disturbance on vegetation growth (Curran and



others 2005b). Once validation data have been obtained using a given set of visual criteria, the criteria limits should be reassessed through an adaptive management process so that additional site data can be collected, if needed (Figure 1).

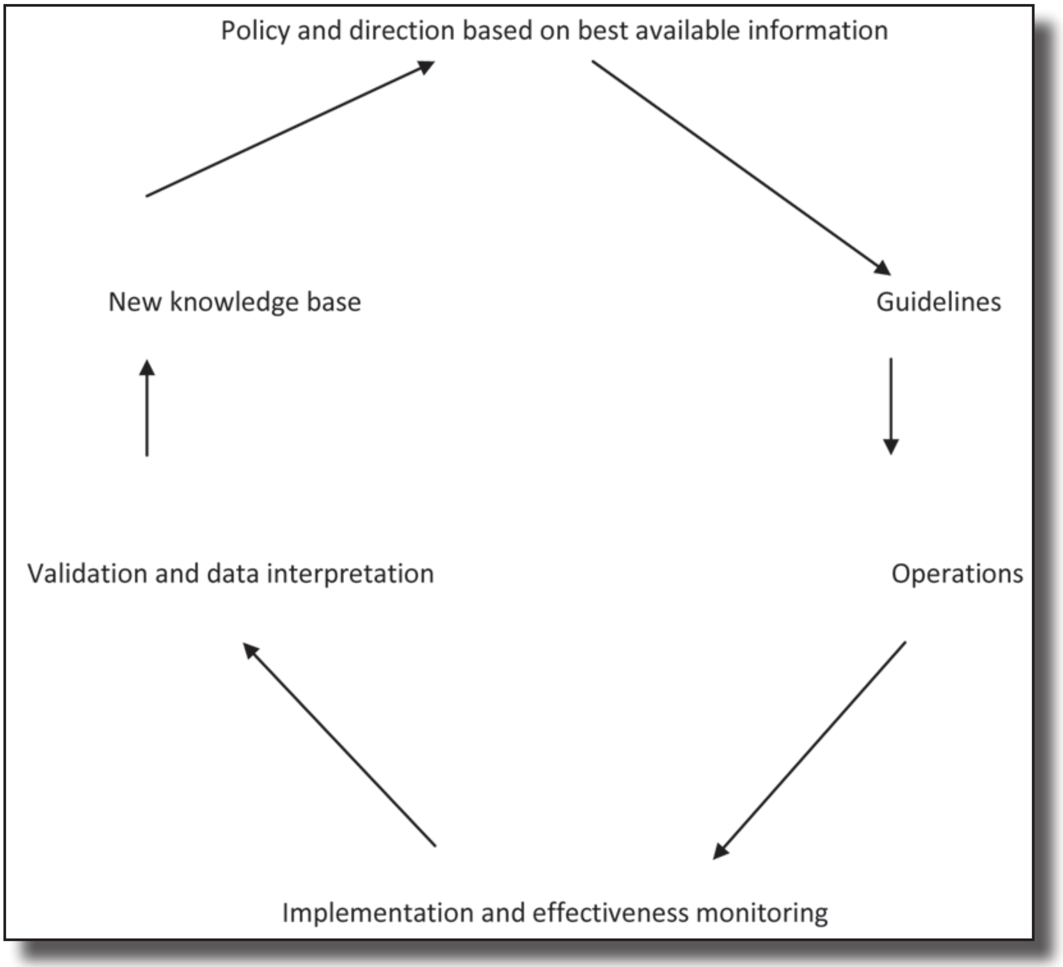


Figure 1. Adaptive management processes for soil monitoring (after Curran and others 2005b; Curran and Maynard 2009).

Validation Approaches

Using existing or retrospective studies

In order to select the right attributes for monitoring and then make the correct management decisions about the results, definitive field experiments are necessary for validating the relationship of the indicators and disturbance classes and management activities to forest productivity or hydrologic function (Burger and Kelting 1999). Results from field experiments will increase the level of confidence in soil quality monitoring by supplementing this implementation and effectiveness monitoring data with more rigorously collected data (validation monitoring).

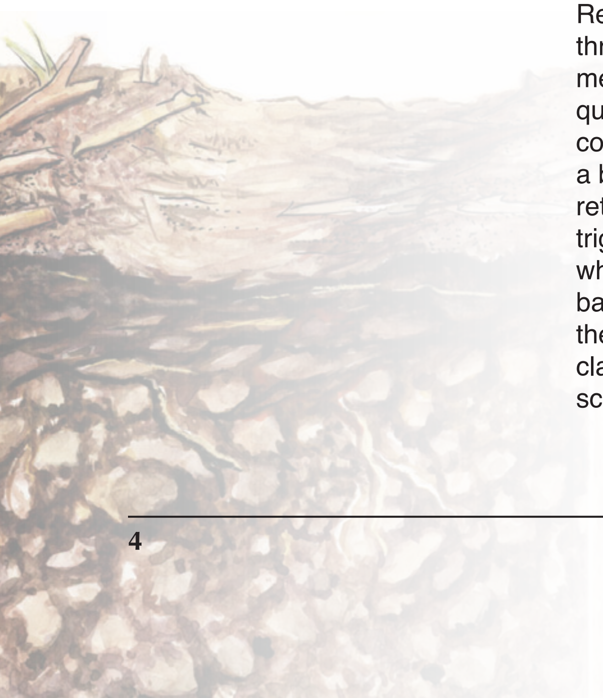
In many areas, a significant number of soil related research projects have been completed by graduate students, local researchers, and forest

Table 1. Examples of the relationship between the North American Long-Term Soil Productivity (LTSP) Study and the visual disturbance classes found in the FSDMP.

LTSP treatment	FSDMP disturbance class
No compaction/bole only harvest (C_0OM_0)	0 – Forest floor intact, no signs of harvest impacts, natural conditions
Moderate compaction/whole tree harvesting (C_1/OM_1)	1 – Dispersed wheel tracks, slight depressions evident, forest floor intact, no displacement
Moderate compaction/bole and forest floor removal (C_1/OM_2)	2 – Faint wheel tracks, forest floor layer missing, change in soil structure <30 cm deep, resistance of surface soil slightly greater than natural conditions
Severe compaction/bole and forest floor removal (C_2/OM_2)	3 – Wheel tracks or depressions highly evident, change in soil structure extends beyond 30 cm deep, increased resistance deep into the soil profile, forest floor layers missing

specialists. If these studies contain sufficient information about soil and vegetative response to forest management activities and can fit into a visual disturbance class system, then these data are appropriate to use for validation efforts. These studies are not likely to contain all the necessary information, but can supplement the information that is needed.

The North American Long-Term Soil Productivity (LTSP) Study (Powers and others 2005) provides one method for validating how changes in soil compaction and organic matter removal may affect vegetation growth. This controlled experiment uses moderately sized (0.4-ha) plots that bracket the extreme ranges of both compaction and organic matter removal, and provide valuable data on soil disturbances that result in a change in vegetative growth or hydrologic function. Although the LTSP study sites are geographically dispersed, they do not cover the full range of soil and vegetation found on National Forest, industry, private, or public lands. However, the LTSP plots can easily be linked to the four disturbance classes in the FSDMP (Table 1), and data from the LTSP network can supply some longer-term data on vegetative response to soil disturbance. Soil properties regularly monitored on LTSP sites (soil physical, chemical, and biological properties and associated vegetation production) can be used to infer some aspects of hydrologic function or site productivity changes.



Retrospective studies can be used to look at the progression of a site through time by looking backward to infer the effects of past treatments. The advantage of such studies is that they produce results much quicker than empirical studies. However, major disadvantages are: no control over the original experimental design, data collection, or use of a baseline (Curran 1988; Dyck and Mees 1990; Table 2). In addition, retrospective studies are more effective if they focus on treatments that trigger large ecosystem responses (Powers and van Cleve 1991), so, while these studies may be helpful for clearly identifiable previous disturbance (e.g., excavated trails), they may not be well suited for evaluating the subtle differences between various severities of soil disturbance classes and their resulting attributes. As with graduate theses, small-scale management, or research studies, the data collected through the

Table 2. Summary of advantages and limitations to re-sampling past research sites (from Curran 1988).

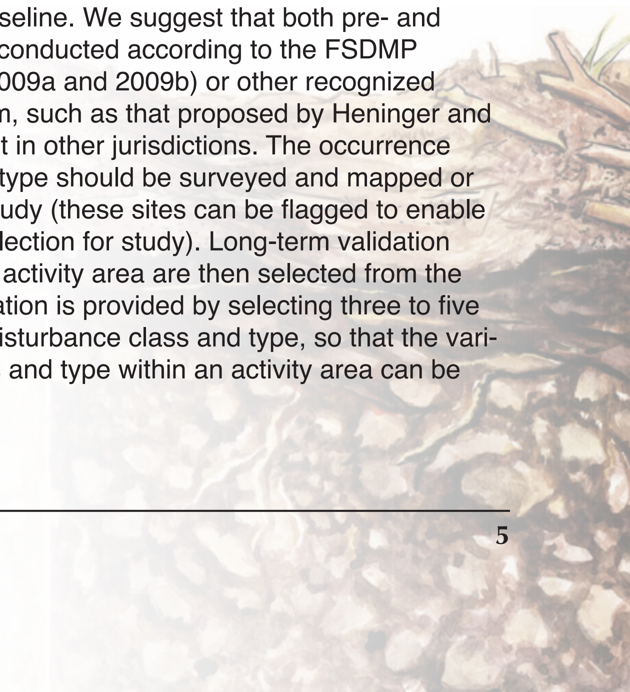
Advantages	Limitations
Feedback provided now for • Current management and policy • Current research efforts	Data set must be questioned • Measurements (before and after?) • Methodology (documented?) • Missing data (for new use)
Capitalize on previous forest study investments	Differing accuracy/precision of sample design
Increases scope of current studies • Elapsed time since treatment • Range of site condition	Controls may be lacking or non-representative

use of retrospective study sites also need to fit into a visual disturbance class system so that inferences about vegetative growth or hydrologic function can be made.

New experimental plots or operational trials

New experimental trials or plots are usually installed to answer a wide array of questions that may or may not be important to land managers, whereas operational trials focus on issues that are of immediate concern and relevancy to management questions (Bulmer and Curran 2000). To begin a new experiment or operational trial, sites should be organized by soil factors that are expected to influence responses (and hence form the basis of soil risk ratings for sensitivity to disturbance). These factors include soil texture, soil development (organic matter enrichment, depth, and structural integrity), parent material, and topography (e.g., slope complexity and position and resulting soil moisture regime). Ideally, validation monitoring sites should be selected to fit into the overall site organizational scheme (sampling hierarchy) and should be selected to capture locally significant soil and site factors so that conclusions can be drawn about how each soil type or climatic regime responds to certain management practices. If possible, these sites should be selected based on the range of soil sensitivities to management impacts.

Once a site is selected, pre-harvest (or unharvested adjacent stands with similar soil, vegetation, slope, aspect, and climate) data should be collected for a reference baseline. We suggest that both pre- and post-harvesting monitoring be conducted according to the FSDMP (Page-Dumroese and others 2009a and 2009b) or other recognized visual disturbance class system, such as that proposed by Heninger and others (2002), or those in effect in other jurisdictions. The occurrence of each disturbance class and type should be surveyed and mapped or otherwise marked for further study (these sites can be flagged to enable relocation following random selection for study). Long-term validation monitoring locations within the activity area are then selected from the monitored sites. On-site replication is provided by selecting three to five (or more) study plots in each disturbance class and type, so that the variability of that disturbance class and type within an activity area can be measured.



Disturbance classes for most visual disturbance monitoring protocols are described based on a range of attributes—forest floor thickness, soil cover, displacement, compaction, erosion, rutting, burning, and soil structure—that need to be considered during validation monitoring. For each disturbance class and type within an activity area, each attribute must be quantified so that long-term recovery can be tracked. For example, these are the types of questions to answer:

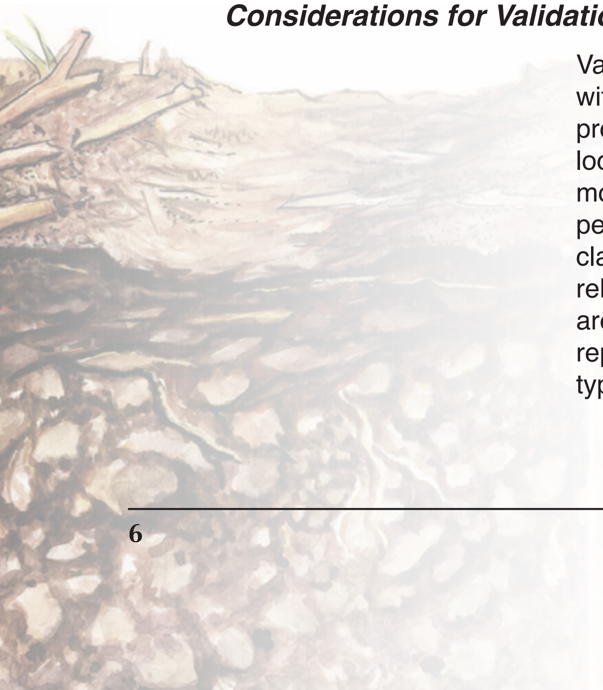
- What is the areal extent of displacement and/or rutting?
    - Record the dimensions of these features:
        - Ruts
        - Scalp or gouge depth and dimensions
        - Remaining forest floor
- What is the level of compaction?
    - Collect bulk density cores down to 30 cm.
- What is the severity of burning?
    - Record the depth of char into the mineral soil or the amount of forest floor consumed in the fire.
- How has soil structure changed?
    - Record the depth and thickness of platy/massive/puddled structure changes.

This is not an inclusive list, and local conditions, such as invasive species or erosion events (e.g., mass-wasting) may dictate other attributes to consider. Study sites can be placed within operational harvests, and if different logging techniques are used on the same soil, similar measurements can be taken in each area.

Below, we outline several methods for validation monitoring. While the actual field plots and layout may be different, a core set of measures needs to be taken on all plots to ensure that validation data are meaningful and useful. Once taken, validation monitoring data can be used to determine on which soil types certain harvest methods are more likely to be detrimental to vegetation growth and/or hydrologic function. This information can then be used to develop or modify best management practices on a given landscape and to develop risk rating systems for various soil and climate conditions. We use the basic concepts of the LTSP study, but provide a method for measuring smaller plots to aid in installation, monumenting, and measurement.

Considerations for Validation Monitoring

Validation monitoring involves establishment of controlled experiments with adequate levels of replication, and it follows an experimental design protocol that enables “roll-up” of data from across a range of sites at the local, regional, and even national level. Before beginning a validation monitoring program, consistent criteria should be established regarding permanent and temporary roads. Will roads be included in the visual class assessment? Will rehabilitated disturbance be assessed to ensure rehabilitation is successful? In addition, locating plots within an activity area should be done with care. To ensure applicability of data, provide replication by selecting at least three plots of the same disturbance type (e.g., ruts) and disturbance class (the categories of ruts in different



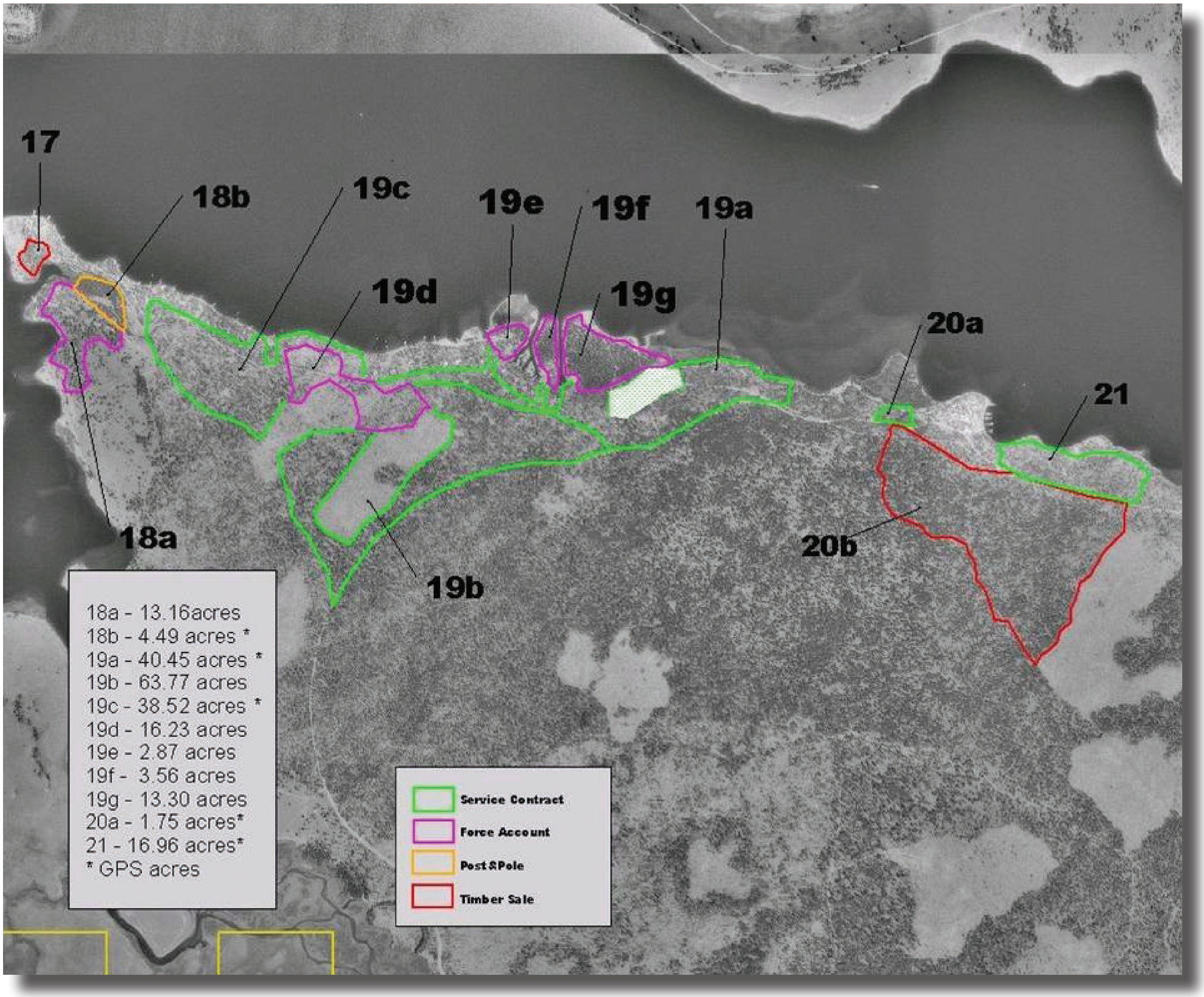


Figure 2. Example of numerous units available for validation monitoring within one area.

disturbance classes) in each activity area. *Site* replication is provided by having several (at least three) sites with similar activity areas, that are located in geographically different areas, but on similar soil, slope, aspect, etc. (Figure 2). *Sample* replication within a site can be achieved by conducting implementation or effectiveness monitoring using a random GPS coordinate (Figure 3a), a random transect (Figure 3b), or other method that does not introduce bias into the sample site selection. Replication is often difficult to achieve in field studies but is essential for validation. Replication refers to the degree of similarity that exists or that can be obtained among experimental units (Hulburt 1984), and some time should be spent selecting adequate replicate sites. A survey may be carried out to identify candidate study plots, and a random subsample of the available plots can be used for studies that enable inferences to be made regarding the entire population of interest. Hence, selection of

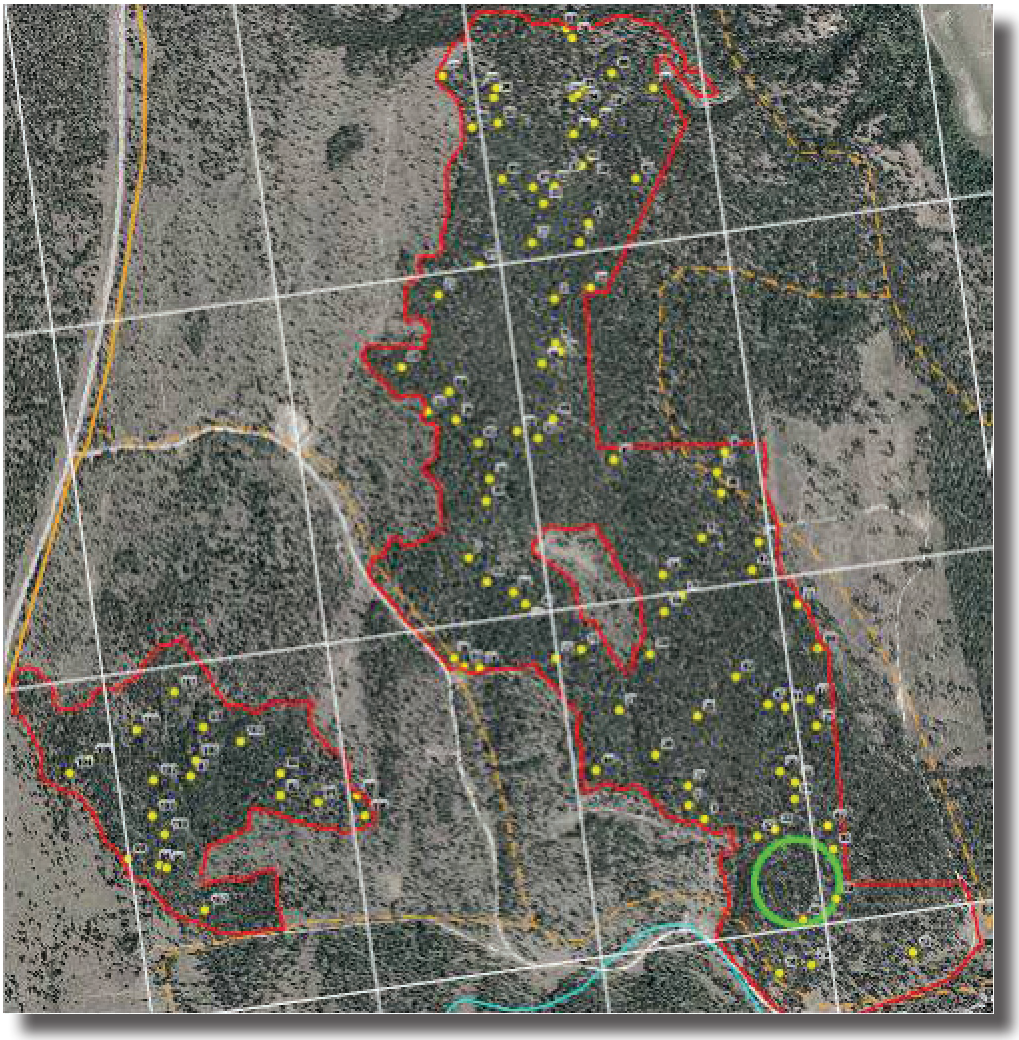


Figure 3a. Example of 110 random GPS points for disturbance monitoring. The green circle is an example of a smaller stratification with other survey points to see if higher disturbance existed around a landing used for in-block chipping.

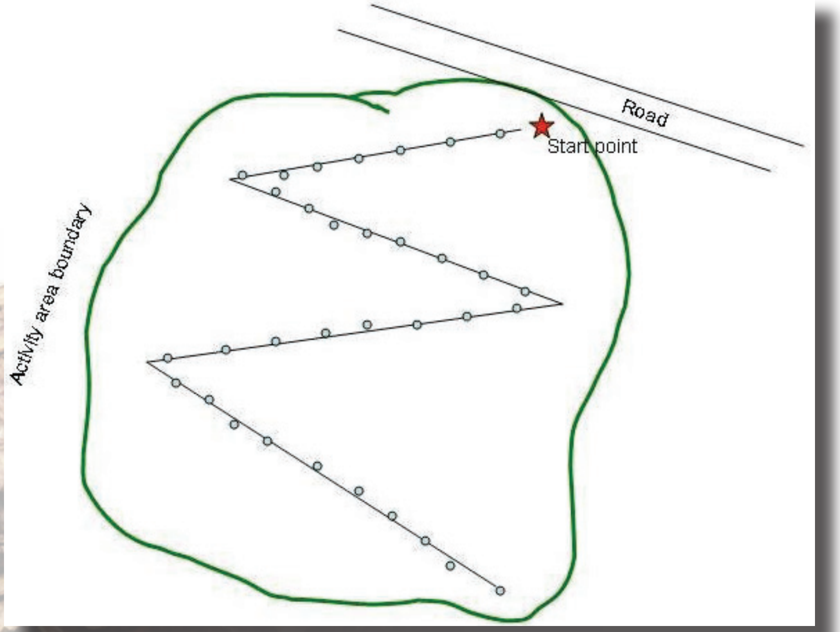


Figure 3b. Selection of soil monitoring points can be on a randomly selected transect within the harvested area.

the appropriate plots should be done with care and objectivity to yield the best possible inferences. Because these validation plots will be used to compare the current estimates of disturbance or productivity with any previous estimate(s), it is also important to ensure that validation plots cover the range of variability within disturbance types (how do the class 2 ruts compare to each other?) and among the different disturbance classes (how do the ruts compare across different disturbance classes?). Large and small plots are possible. For example, if only small disturbances are noted, numerous plots can be installed to determine variability and vegetation response to the soil disturbance. Large areal disturbances, such as skid trails, may have fewer study plots, but will have a larger area for plant growth. Therefore, the final number of plots will likely depend on the size and distribution of the soil disturbance and the presence of target vegetation species. Another consideration is the spatial relationship among smaller disturbances, such as individual ruts, and the response variables, such as a tree that is rooted both in the rut and in the surrounding area.

Sampling numerous small plots within each validation area helps provide a larger data set that can be used to determine within-site variability and to improve understanding of responses, such as plant growth in relation to smaller disturbances. This helps pinpoint the differences in growth-determining factors when forest practices are being monitored for changes in productivity (Curran 1988). Using numerous plots that have the same disturbance types and class will help interpret both short- and long-term validation data. If many small-plot disturbance data are available, vegetation growth is more easily paired with within-site variation, and greater statistical evaluation of the type and class data is possible.

Sampling Design Examples

Fixed plot sampling

Visual disturbance characteristics vary in size depending on the type of equipment used and the amount of disturbance. Either large or small plots can be used along with previous study sites, such as the LTSP installations, rehabilitation studies, graduate student research sites, skid road studies, and retrospective work (see “Using existing or retrospective studies”). Smaller plots and the LTSP study sites offer the advantage of being more uniform, but plot size should be designed to fit the data collected and needs to be related to the disturbances created by the harvest activities of interest. Harvest units should first be monitored for visual disturbance classes. The latitude/longitude of each monitoring point should be recorded and a marker should be placed on the ground so that random selection of a representative sample of each visual class (0-3) can be completed. Prior monitoring of the unit can help define the dimension of the plots. Optimum size of the plots will likely be determined by the attribute(s) of interest, but should be large enough to evaluate vegetative or hydrologic responses over time. Once a disturbance plot is located, it will be useful to designate a measurement plot (a smaller plot within the larger disturbance area) to avoid edge effects.

Regeneration stocking surveys

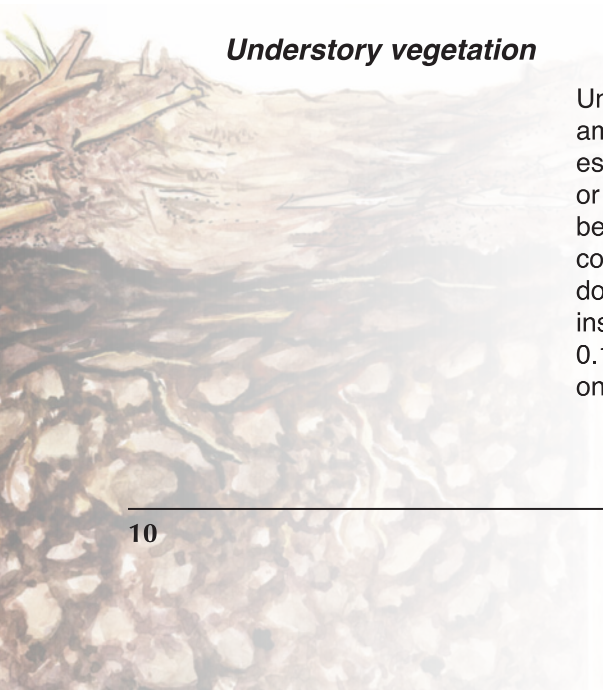
Regeneration surveys are used to track natural reforestation and the progress of any planted or seeded stock. These surveys are often scheduled as part of the stand work plan. This type of survey is easily adaptable to use of soil disturbance visual classifications and validation monitoring. During stocking surveys, visual soil classes can be assessed using a grid or concentric plots, thereby matching soil visual attributes with individual seedling growth. Soil and seedling assessments should be done in the first year or two after disturbance to ensure correct and complete description of both. Once the seedlings are measured and the visual disturbance classes are assessed, a subsample of plots can selected from the range of soil disturbance classes for long-term monitoring. Regeneration plots can be sampled with small (approximately 0.001-ha), circular plots within a larger 0.1-ha plot. This makes it easier to assign only one visual disturbance class, which can be directly linked to one tree seedling and other understory information. Another method is to collect soil disturbance class information in each quadrant around the tree(s) of interest. Since these plots are associated with a seedling, tracking productivity in relation to the soil disturbance classes is relatively easy. Other soil measurements of interest can be obtained at the same time tree measurements are collected.

Core Measurements

Monumenting

Each visual disturbance type and class measurement plot should be mapped and monumented to allow for re-sampling at some interval (one yr, five yrs, etc.). At the very least, each plot should be marked in the field or noted on an air photo, or (preferably) GPS coordinates should be recorded. However, if those methods are not an option, plots can be established by marking one corner with rebar, metal conduit, PVC pipe, “pigtails”, etc., and then providing location surveys from established reference points on landings or road intersections. This method of plot location should be backed up with pin pricks on an air photo, hand-drawn maps, witness trees, or written directions, which will ensure the plots can be re-located. Monumenting plots and tagging trees also ensure that specific trees or vegetation are re-sampled over time (Curran 1988; Scott and others 1998). For specific details on how to establish and measure forestry plots, see Scott (1998).

Understory vegetation



Understory vegetation plots vary in size, but are usually 1-4 m in diameter. Vegetation should be documented by species. Ground cover estimates should be recorded for each species of understory vegetation or height and diameter by species should be measured. These data can be combined into cover classes if needed. Ocular estimates of ground cover can be also used, but consistent categories should be used and documented (Riegel and others 1995; van Hees and Mead 2000). For instance, cover classes use a percentage cover such as: (1) <0.1%, (2) 0.1-1%, (3) 1-2%, (4) 3-5%, (5) 6-10%, (6) 11-20%, (7) 21-30%, and so on.

Overstory vegetation

Taller shrubs, seedlings, and trees need both height and diameter measurements. Height measures are taken with a meter stick or, for larger trees, a laser measuring device. Diameter can be measured with a caliper or diameter tape and should be at breast height once trees are tall enough (basal diameter is done at the start of monitoring). Site index should be determined on dominant tree species before the site is harvested to help document any changes that may occur as a result of the disturbance.

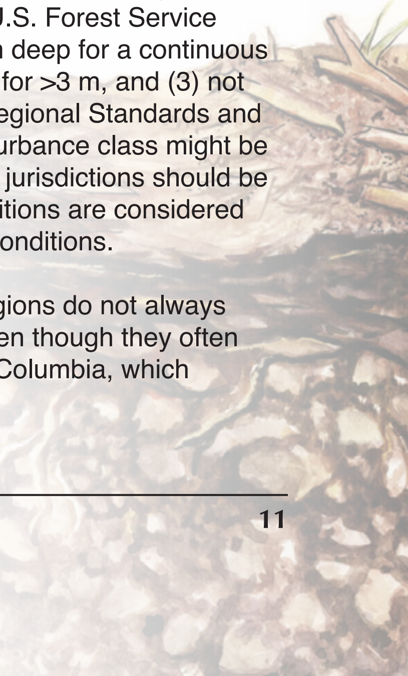
Soil measurements

The most basic soil measurement is the relationship of the visual disturbance class to the change in soil bulk density (Robinson 2011). A slide-hammer core sampler with a known volume is the easiest way to measure this, but rocky soils may require excavating and then filling the hole with foam to determine volume (Page-Dumroese and others 1999) or another standard method. The forest floor (all organic horizons) depth should be measured, if present, as well as the depth of the surface mineral horizon (e.g., A horizon and E horizon). Surface horizon depth is variable, but the entire depth of those horizons should be determined so that changes associated with land management can be documented. Forest floor and surface mineral horizon depths are particularly important if displacement has occurred and can also provide information on the decomposition or accumulation rate of organic matter. If financially possible, the mineral soil and organic matter should be sent to a local laboratory for chemical and physical analyses. Organic carbon should be considered a minimum soil analysis because of its value in interpreting compaction results, but the appropriate analyses will depend on soil type and management concerns. For example, if loss of site potassium is a management concern, then potassium should be analyzed; or if the goal is carbon sequestration, then carbon and organic matter should be analyzed.

Soil Disturbance and Soil Quality Standards

When evaluating the effect of forest harvest disturbance (e.g., ruts, trails, scalps, or gouges) the size of these features can be linked to soil quality standards in place for a given jurisdiction, such as a U.S. Forest Service Region. For example, U.S. Forest Service Region 2 defines displacement as soil loss from a continuous area >9 m^2. U.S. Forest Service Region 8 defines ruts as: (1) not exceeding 15 cm deep for a continuous distance of >15 m, (2) not exceeding 30 cm deep for >3 m, and (3) not exceeding 46 cm deep for any distance. These Regional Standards and Guidelines can help determine when a visual disturbance class might be detrimental, but standards and guidelines from all jurisdictions should be validated to ensure local soil and vegetation conditions are considered when determining alteration in soil or hydrologic conditions.

Interestingly, neighboring U.S. Forest Service Regions do not always have the same soil Standards and Guidelines, even though they often share similar soil types and vegetation. In British Columbia, which



borders the two western-most Forest Service Regions, ruts are “counted” on moderate or higher compaction hazard sites when they exceed 5 cm deep into the mineral soil and are 2 m in length, on all sites when they exceed 15 cm deep from the soil surface, and when any point is gouged deeper than 30 cm into the mineral soil or to bedrock (Curran and others 2007). In contrast, ruts in U.S. Forest Service Region 1 are counted when they are at least 5 cm deep on all sites. Although there are disparities between standards and guidelines, if similar soil attributes are measured during validation monitoring, then data can be more readily used at different scales and across different jurisdictions.

Modeling soil change

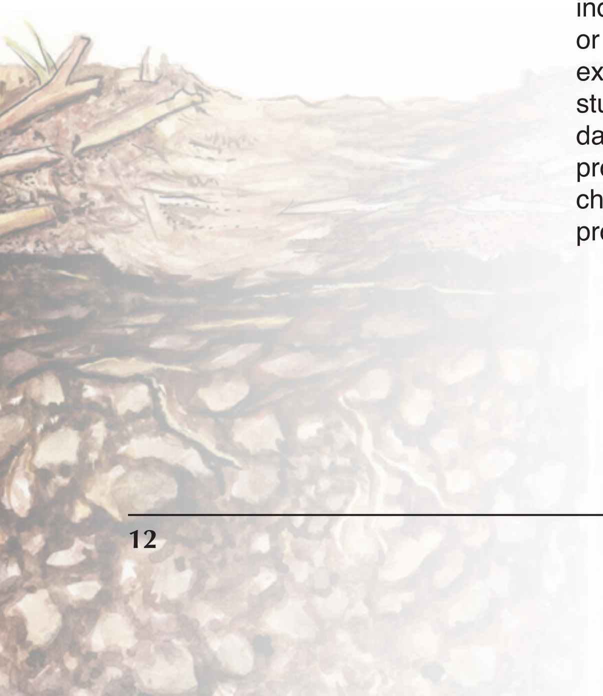
Reeves (2011) developed a method that uses historic soil monitoring data in a decision support tool for ground-based logging operations. It can be used anywhere that soil monitoring and harvest system data are collected. However, the key premise of this tool is that historic soil monitoring data were collected in a consistent manner.

Data storage

Data stored in a database can be used to inform land managers about the impacts of harvest and site preparation systems on changes in the visual disturbance classes and their severity. For the U.S. Forest Service, a national database for soil monitoring and validation data collected on National Forests will be completed by summer 2012. This database will store monitoring data collected pre- and post-harvest. In the future, there will be a place for validation monitoring, but until that is complete, these data must be stored on local computers or a central hard drive. Ultimately, routine soil monitoring and validation data can be used to develop a risk-rating system (Kimsey and others 2011; Reeves 2011; Reynolds and others 2011) that is sensitive to local soil and vegetation conditions.

Conclusions

Sustainable forest operations are a goal for most forestry organizations around the world. However, this goal will likely only be achieved by implementing monitoring and validation processes at the local level. Using a common soil monitoring protocol is one step toward determining the impacts of land management on the soil resource. However, individual attributes and the associated changes in vegetative production or hydrologic function must be validated on a site-specific basis. Using existing data, retrospective studies, regeneration surveys, and long-term studies or developing new studies are some of the ways that validation data can be collected. Identifying soil attributes necessary for maintaining productivity with a set of indicators that measure management-induced change from the desired baseline will help to meet the need for forest products while sustaining forest productivity.



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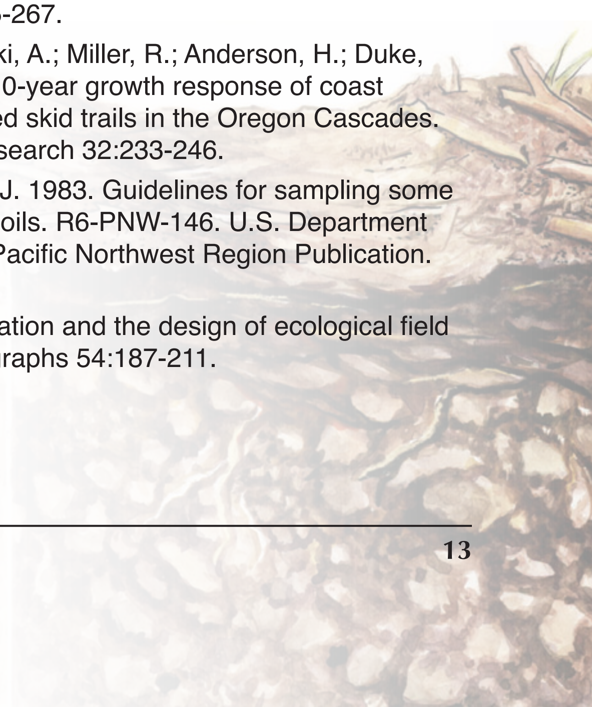

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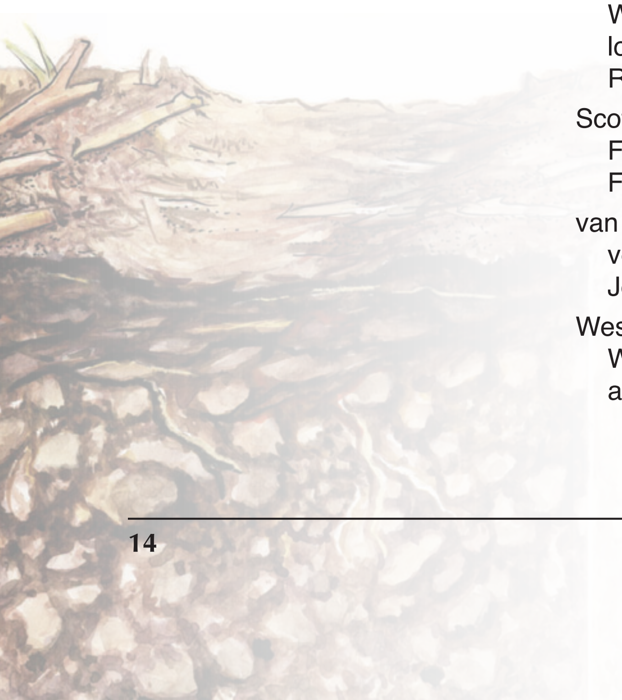

Appendix. See the following resources for further background information on monitoring, validation, statistics, and managing soil effects from land management.

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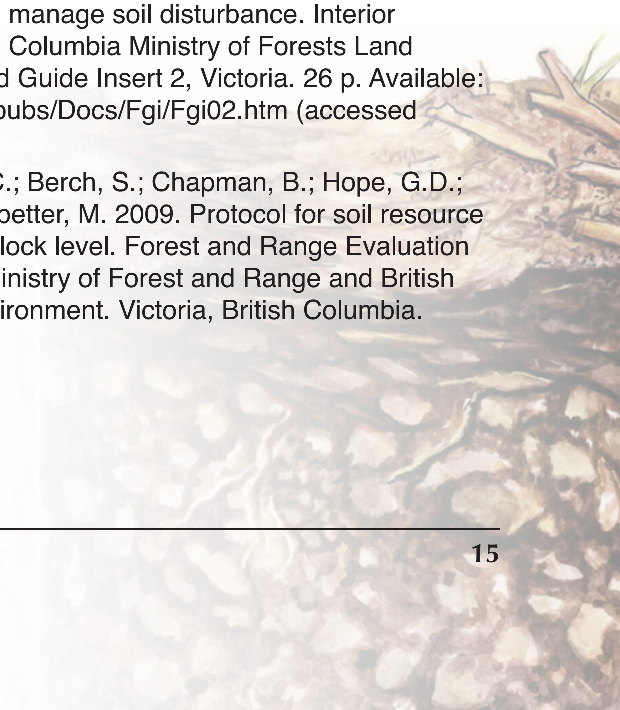

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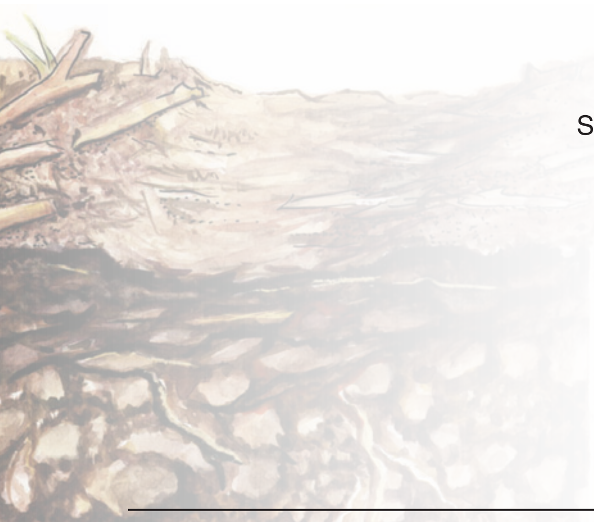

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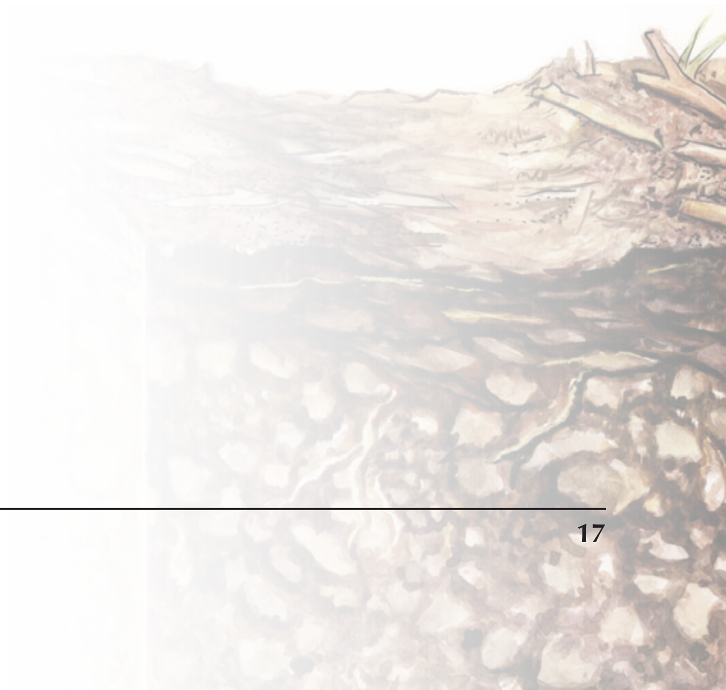

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