Evidence Supporting the Need for a Common Soil Monitoring Protocol

Discussion Paper

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Abstract

Many public land management agencies monitor forest soils for levels of disturbance related to management activities. Although several soil disturbance monitoring protocols based on visual observation have been developed to assess the amount and types of disturbance caused by forest management, no common method is currently used on National Forest lands in the United States. We present data on relative soil disturbance based on harvest system from National Forests throughout Montana and Idaho. Because each National Forest uses its own method for data collection, we developed a common, well-defined visual class system for analyses based on the existing soil monitoring data that accurately normalized disparate classifications. Using this common system, we detected differences in soil disturbance between the ground-based and overhead harvest systems; however, no site attributes (slope, aspect, soil texture, etc.) affected soil disturbance levels. The individual National Forest was the most important factor explaining differences among harvest units. The effect of National Forest may be explained by different forest types, soils, harvest practices, or administrative procedures, but the most likely explanation is differences among the various qualitative classification approaches to soil disturbance monitoring. Although this analysis used a large data set, our inability to correlate disturbance with site characteristics and the differences between monitoring methods points to the need for common terms and comparable guidelines for soil disturbance monitoring.

KEYWORDS: disturbance monitoring; soil disturbance; timber harvest

Introduction

Forest management activities result in rates of soil disturbance that range from minimal to extreme (Grigal 2000). Soil disturbance associated with harvest activities can reduce, increase, or not effect growth rates in future stands, contribute to sediment loading in streams, and give the appearance of poor stewardship (Heninger et al. 2002; Powers et al. 2005). The amount and type of soil disturbance associated with timber harvest activities is of increasing concern to managers and stakeholders alike. On lands managed by the United States Department of Agriculture (USDA) Forest Service, many proposed management projects have been appealed or litigated on the grounds that projects will result in soil degradation (Craigg & Howes 2007), changes in long-term productivity, or alteration of hydrologic function (Curran et al. 2005; Curran & Howes 2011). Nevertheless, effects

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on soil and vegetation can be neutral, negative, or positive, depending on site-specific conditions and sensitivity of the site to disturbance type (Curran et al. 2007; Duckert et al. 2009).

The first soil disturbance monitoring protocols in the world were developed by the USDA Forest Service in response to legislation requiring the maintenance of site productivity. Soil productive capacity on National Forest lands in the United States is governed under numerous laws and acts, including the *Multiple Use and Sustained Yield Act* of 1960, the *National Environmental Policy Act* of 1969, the *Forest and Rangeland Renewable Resources Planning Act* of 1974, and the *National Forest Management Act* of 1976 (Page-Dumroese et al. 2000). Specifically, the *National Forest Management Act* requires that "management systems will not produce substantial and permanent impairment of the productivity of the land."[1] Policies developed for many of the National Forests of the USDA Forest Service require that 85% of a timber harvest unit must be in "satisfactory condition" when timber harvest and site preparation activities are completed (excluding roads). The areal extent of detrimental soil disturbance (i.e., soil disturbance that results in a loss of productivity or a negative change in hydrologic function) existing on the harvest unit must be less than 15% to meet the satisfactory condition requirement.

Current soil quality standards for each USDA Forest Service region were developed in 1983 and refined in 1999 (Page-Dumroese et al. 2000). The USDA Forest Service soil quality standards spell out a systematic process in which data is collected to determine whether soil management objectives to maintain long-term productivity are achieved (Neary et al. 2010). When the soil quality standards were developed, the USDA Forest Service Handbook (Directive Issuance No. 2509.18) gave several examples (i.e., an increase in bulk density of > 15%, a reduction in porosity of > 10%, or forest floor removal along with 25 mm of mineral soil) of what could be used as thresholds. The handbook also indicated that threshold values for areal extent, sample size and variability, and data collection should be addressed through effectiveness and validation monitoring; however, resources and time were not provided to adequately achieve a fully vetted set of soil quality standards (Neary et al. 2010). Therefore, examples from the handbook were used and soil disturbance on greater than 15% of a harvest unit was considered detrimental to soil and vegetation productivity for most of the USDA Forest Service. Additionally, when the handbook came out, detrimental soil disturbance was defined as a combination of compaction, rutting, soil displacement, severely burned areas, surface erosion, and soil mass movement on more than 15% of the harvest unit. In essence, an "example" became the "standard" for most of the United States (Neary et al. 2010).

Although Forest Service regions selected a threshold for detrimental disturbance, it soon became clear that the interactions between forest, equipment, soil physical properties, landform, and environmental conditions altered responses to erosion, growth, and infiltration (Duckert et al. 2009). Different soils range in their ability to withstand and recover from disturbance (Craigg & Howes 2007); consequently, Burger (1997) and Craigg and Howes (2007) suggested that assessments of soil quality indicators should be site specific. Assuming that any soil disturbance causes a reduction in tree growth is unwarranted (Miller et al. 2004). For example, it is generally recognized that compaction can negatively affect tree growth in some settings; however, Gomez et al. (2002) suggested that the correlation between soil disturbance and tree growth is dependent on soil texture and soil water regime, thereby furthering the argument for site-specific assessments relative to soil disturbance and the possible impacts on forest sustainability.

Detrimental soil disturbance thresholds are currently applied uniformly across each USDA Forest Service region. This approach, while administratively convenient, applies an inflexible framework to variable site conditions (DeLuca & Archer 2009) and the correlation between soil monitoring variables and potential productivity is mostly anecdotal or regionally restricted (Powers et al. 2005). Despite the debate over levels of disturbance that degrade productive capacity, maintenance of the soil resource is increasingly recognized as a key to sustainable forest productivity and the basis for the North American Long-Term Soil Productivity (LTSP) study (Powers et al. 2005). The LTSP study was founded to shed light on the productive capacity of forest soils and how this capacity is altered by compaction and organic matter removal, two factors readily altered by land management. The LTSP study was also designed to begin the validation process for soil disturbance thresholds.

Howes et al. (1983) provided initial guidelines for quantitative forest soil monitoring, but an effort to reduce the monitoring burden discouraged quantitative assessment in favour of a qualitative approach to allow more data collection and assessment (Howes 2006). Qualitative, ocular assessments have been used since the 1970s on privately held timber lands in the United States and since the late 1980s on federal lands (Howes 2006). Qualitative classification systems offer economic advantages relative to quantitative assessment. Less labour-intensive qualitative assessments are important in an era of dwindling resources (Curran et al. 2005); however, these assessments are inherently subjective and need to be validated by quantifiable, ecologically relevant variables (Curran et al. 2005; DeLuca & Archer 2009; Page-Dumroese et al. 2012).

Existing evidence demonstrates that timber harvest and subsequent slash disposal operations cause some degree of soil disturbance in forest soils (Xu et al. 2002). Although soil compaction, displacement, and erosion are commonly cited as concerns among foresters (Geist et al. 1989), other concerns include rutting, topsoil mixing, burning, and erosion. Ongoing debate involves how much disturbance causes a substantial and permanent decline in forest productivity, and what are the indicators of detrimental disturbance (Howes 2006; Page-Dumroese et al. 2006; DeLuca & Archer 2009).

Since the first soil quality standards were developed in 1983, considerable data has been collected using methods that employ both quantitative and qualitative measures. Determining a useful way to use this legacy data and convert it to a common database is one key in helping to define site-specific responses to forest management activities. Therefore, we accessed all soil monitoring data collected from 11 National Forests within the Northern Region of the USDA Forest Service from 1999 to present and addressed the following three hypotheses.

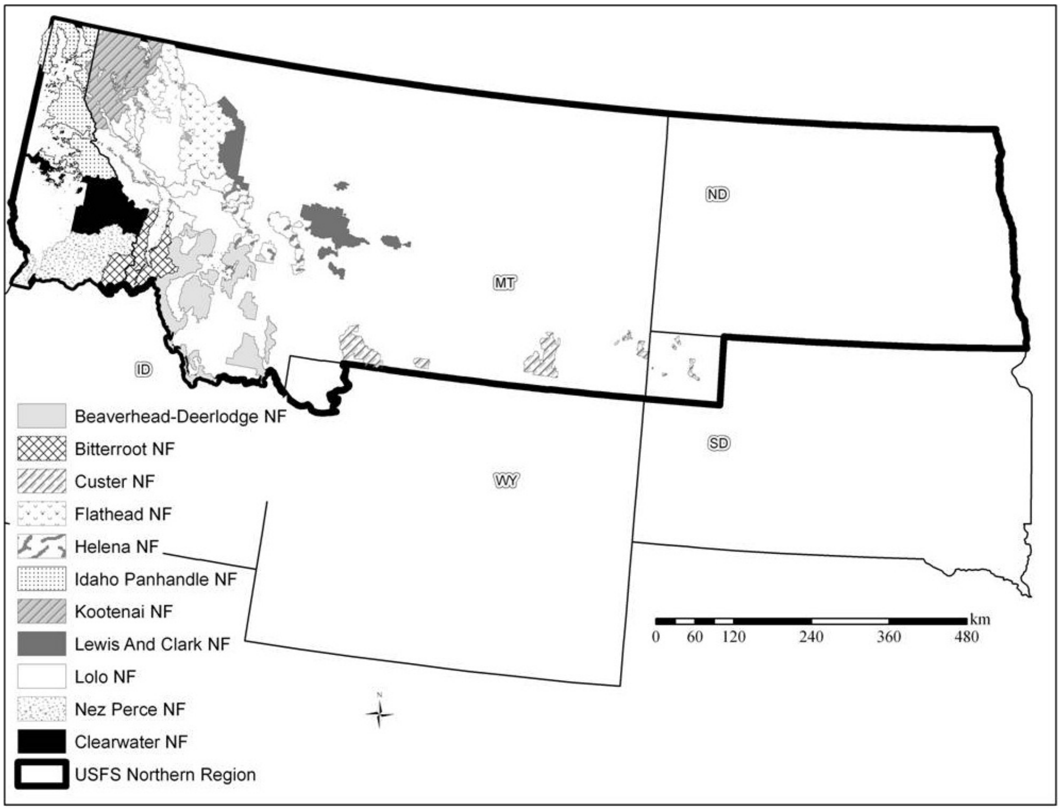
1. Soil disturbance amounts are correlated with timber harvest systems (e.g., helicopter, skyline, ground-based).
2. Soil monitoring protocols employed by various National Forests will not influence the level of soil disturbance observed when similar harvest systems are used during the same harvest season in areas with similar site characteristics.
3. Soil disturbance indicators can be linked to site-specific characteristics (e.g., soil texture, slope, coarse-fragment content).

Methods

Data and harvest systems evaluated

Post-harvest soil monitoring and site characteristic data was collected from within the USDA Forest Service Northern Region (Figure 1) and consisted of data from 157 harvest

Figure 1: National Forests located in the Northern Region of the USDA Forest Service that are represented in this study.



units representing 13 870 individual monitoring points. These units had been harvested between 1993 and 2009. Various ground-based, skyline, and helicopter harvest systems used during four annual seasons are accounted for in the data (Table 1). Harvest season was assigned by the completion date. Spring consists of March, April, and May; summer of June, July, and August; fall of September, October, and November; and winter of December, January, and February.

Tractor harvest system (listed as "tractor" in Table 1) is a combined category for ground-skidded and hand-felled harvest units. This category also includes those units only labelled as "ground-based" since we could not discern specific harvest systems for these units. The number of harvest units included in the data from each National Forest and the number of corresponding monitoring points are listed in Table 2. Using the legacy data sets from each forest meant that monitoring data was collected using disparate methods. Transect length, orientation, number of transects, number of points along each tran-

Table 1: Total number of units surveyed by harvest system and season of harvest

Harvest system	Total units	Spring	Summer	Fall	Winter
Cut-to-length	29	0	16	5	8
Ground/machine-felled	46	6	16	0	24
Helicopter	13	2	5	2	4
Helicopter/machine-piled	7	0	4	3	0
Skyline	21	0	14	4	3
Skyline/machine-felled	4	0	3	0	1
Tractor	37	3	16	2	16
Total all categories	**157**	**11**	**74**	**16**	**56**

Table 2: The number of harvest units for each forest, data points associated with the total number of units, and the percentage of total monitoring points each forest contributed

Forest	Number of harvest units	Number of monitoring points	Total monitoring points (%)
Beaverhead-Deerlodge	2	200	1.4
Bitterroot	10	890	6.4
Clearwater	23	1552	11.2
Custer	1	200	1.4
Flathead	15	1558	11.2
Helena	12	2249	16.2
Idaho Panhandle	23	1743	12.7
Kootenai	25	1808	13.0
Lewis and Clark	7	810	5.8
Lolo	33	2590	18.7
Nez Perce	6	270	2.0
Total	**157**	**13870**	**100**

sect, or other field methods were often not specified. This illustrates one drawback of inconsistent or poorly defined monitoring methods.

Data collection and conversion from disparate databases

Data collection was conducted by individual forest soil scientists or their technicians between 1993 and 2009. The data for 99 of the 157 harvest units were compiled from existing soil monitoring databases and soil monitoring reports produced by individual National Forests. We collected data on the remaining 58 harvest units using the Forest Soil Disturbance Monitoring Protocol (hereafter "the Protocol"; Page-Dumroese et al. 2009). Existing data from the Northern Region had been collected by using several different visual class methods, including the Protocol. Data was not validated against vegetative growth or hydrologic function; however, if data was collected by summer technicians, it was verified by the Forest Soil Scientist. To develop a consistent database across all forests, make relative comparisons of each harvest system, and normalize results among National Forests, we transformed existing data from the class system in which it was originally recorded to the four-class system defined by the Protocol. The majority of transformed data had been collected using the protocol developed by Howes (2006) that included six visual classes; some data had been collected using other methods but resulted in the same six disturbance class soil monitoring structure as Howes (2006). To merge this data with the Protocol, we used the conversion system outlined in Table 3, which keyed on the condition of the forest floor, rutting depth, and evidence of compaction. These keys allowed us to consistently merge disturbance classifications into the Protocol disturbance class best reflecting the original observations.

The primary exception to the soil monitoring efforts that used six visual classes (Howes 2006) was the data collected on the Kootenai National Forest. This National Forest had used a three-class system to evaluate soil disturbance at each step across a transect that spanned the entire length or width of the harvest unit. Soil monitoring data had been entered into the Kootenai National Forest database as class 1, 2, or 3 (i.e., undisturbed, slight disturbance, heavily disturbed). For this analysis, data from the Kootenai National Forest was transcribed using the original written observations recorded on field data sheets provided by the National Forest and data points assigned a Protocol disturbance class (Page-Dumroese et al. 2009).

In addition, the Idaho Panhandle National Forest also had used a three-class system with disturbance levels (Table 3) noted at 50-foot (~15.2 m) intervals across a transect that spanned the entire length or width of the harvest unit. Harvest units had been monitored according to the Protocol, with the exception that disturbance classes 2 and 3 are combined into a single class. As with the Kootenai National Forest, field data sheets provided the necessary information to re-distribute the lumped classes into Protocol visual class 2 or class 3.

Table 3: The four Forest Soil Disturbance Monitoring Protocol disturbance classes and the corresponding Howes (2000) (or other) disturbance classes

Protocol class	Former Howes disturbance class	Former KNF/IPNF disturbance class[a]	Key component
0	0	1	Undisturbed
1	1, 2	1, 2	Forest floor disturbed / remains intact
2	3	2	Forest floor is not intact, ruts go to 10 cm deep
3	≥ 4	3	Forest floor is missing, compaction is evident

Note: [a] Soil disturbance monitoring data was merged from the Kootenai National Forest (KNF) and Idaho Panhandle National Forest (IPNF) into the four-class system defined by the Protocol using written observations recorded on the original soil disturbance monitoring data sheets provided by the forests.

Site physical characteristics

Physical characteristics recorded for each unit include location (latitude, longitude), slope, aspect, and soil texture. Minimum and maximum slope values (%) were recorded for each unit. Where slope values were not given, or recorded by the soil disturbance monitors, they were extracted from a 30-m digital elevation map (DEM) using GIS software. Harvest unit aspect was similarly extracted from a DEM when observed values were unavailable. At the 58 sites we visited, soil texture was recorded in the field using the “feel method” (Brady & Weill 2004:101) from the uppermost *B* horizon. When the soil texture was unavailable in the monitoring reports, the texture was recorded in the data set using the appropriate soil survey manual. To limit the number of soil texture classes, these were grouped according to the USDA Natural Resource Conservation Service soil survey manual (Soil Survey Division Staff 1993; Table 4).

Table 4: Groupings of soil textural classes used in the analysis

Natural Resource Conservation Service soil texture groups	Pooled analysis groups
Coarse sand, sand, fine sand, very fine sand, Loamy coarse sand, loamy sand, loamy fine Sand, loamy very fine sand	Very coarse
Coarse sandy loam, sandy loam, fine sandy loam	Coarse
Very fine sandy loam, loam, silt loam, silt	Medium
Clay loam, sandy clay loam, silty clay loam	Fine
All soils containing a coarse modifier (skeletal, gravelly, etc.), regardless of texture	Skeletal

Analysis

Because of the number of units monitored, the diversity of sites, and different logging systems, we used the Protocol classes to develop a mean soil disturbance (*MSD*) variable for each harvest unit using the equation:

$$MSD = \frac{\sum_{i=0}^{n}(Mc \cdot Ci)}{Mt}$$

where: *MSD* is the mean soil disturbance value ranging from 0 to 4; *i* is the disturbance class; M_c is the number of points in the respective disturbance class; M_t is the total number of data points for the unit; *Ci* is the value of the disturbance class; and *n* is the total number of disturbance classes (i.e., four in this study).

The advantage of this method is that it gives one overall soil disturbance value for each harvest unit and is linked to site attributes (climate, texture, etc.), harvest season, and logging system. However, this method does not identify specific areas where severe soil disturbance is located. It does allow for cross-forest comparison of similar harvest methods or season. A mean soil disturbance provides a large-scale assessment of the impacts of specific logging equipment on overall soil disturbance within any given harvest unit.

We first analyzed the complete data set and then analyzed a subset of the data that included just the ground-based harvest systems. To evaluate the complete data set, slope values were grouped at 10% intervals beginning with 0–9% (slope class 0); slopes in excess of 50% were grouped together as slope class 5. All analyses were conducted using SAS software (SAS Institute 2008). A general linear model was used to generate least-squares means and to test for significant effects (= .05) on mean soil disturbance related to differences in the forest, harvest system, slope class, aspect, soil texture, and season of harvest. All interaction terms were insignificant and subsequently removed from the model.

Results

In the analysis, harvest system and National Forest were the only variables affecting mean soil disturbance ($P < 0.0001$) (Table 5). The analysis considered the effects of the three harvest systems (ground-based, skyline, and helicopter), physical site characteristics, season of harvest, and forest. Ground-based harvesting, using either a feller-buncher, cut-to-length system, or tractor logging, caused greater soil disturbance than did the other harvest methods (Figure 2). Determining mean soil disturbance allows comparison among harvest systems across many site conditions, but it does not pinpoint the specific locations or degree of disturbance within a given site. In this generalized analysis of mean soil disturbance, soil disturbance levels were not large for any harvest system. Mean soil disturbance values for harvest types other than helicopter were usually the equivalent to the Protocol's class 1 disturbance. No differences were evident in mean soil disturbance between ground-based harvest systems (Figure 2); however, calculated *MSD* resulting from ground-based harvest differed among forests ($P < 0.0001$) (Figure 3). As with harvest sys-

Table 5: Model variables and their associated probability values. Variables with significant effect (alpha = .05) are listed in bold.

Variable	*p*-value
National Forest	**< 0.0001**
Slope class	0.6407
Aspect	0.1214
Season	0.5733
Soil texture	0.6388
Harvest system	**< 0.0001**

tem, most forests had a mean soil disturbance class on ground-based units of class 1 or less, with the exception of the Nez Perce National Forest with an *MSD* of 1.7.

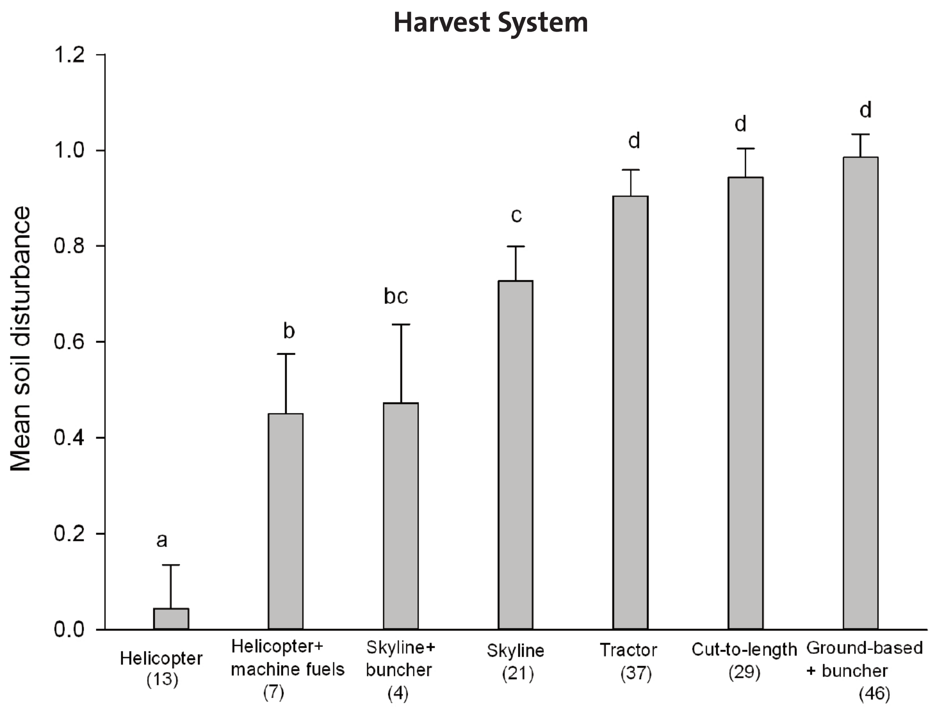


Figure 2: Mean soil disturbance associated with the evaluated timber harvest systems. The number of units associated with each harvest system is indicated in parentheses. Bars with the same letter above are not significantly different (alpha = .05).

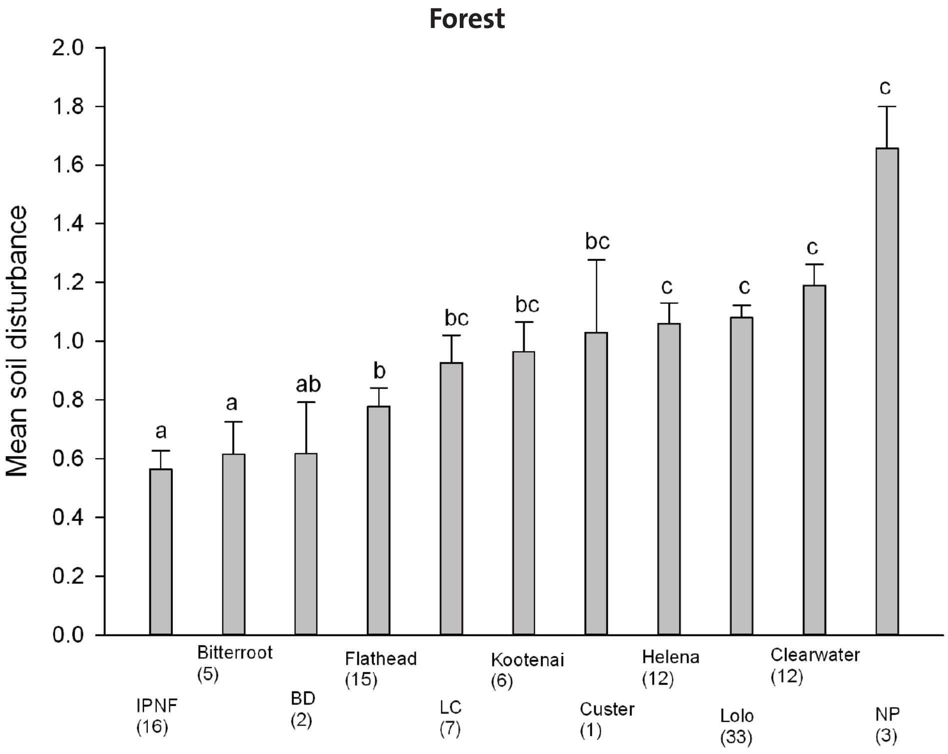


Figure 3: Mean soil disturbance values reported by the individual National Forests for ground-based harvest systems. The number of units represented for each forest is listed following the forest name (“BD” is the Beaverhead-Deerlodge National Forest, “LC” is the Lewis and Clark National Forest, “IP” is Idaho Panhandle National Forest, and “NP” is the Nez Perce National Forest). Bars with the same letter above are not significantly different (alpha = .05).

Discussion

National Forest monitoring

We rejected our hypothesis that the influence of National Forest was not expected to have a significant effect when similar harvest systems were used during similar harvest seasons on sites with similar physical characteristics. This may have resulted from different monitoring protocols, influence of differing landscapes, effect of operator skill and experience, or sale administrator experience and knowledge of local conditions and operator tendencies.

An objective of this project was to find a system that would allow the use of legacy soil monitoring data collected with disparate soil monitoring methods and subsequently to define common soil disturbance classes that correlated soil disturbance to harvest systems and physical site characteristics across a wide geographic range. Combining monitoring data taken by dissimilar methods may have added to the variation we reported among National Forests. Disparate sampling techniques (Curran et al. 2005; Craigg & Howes 2007) and differences in monitor training and experience (Miller et al. 2010) have been linked to results that are incomparable and unreliable in some cases. Significant National Forest differences suggest that the diversity of monitoring methods and (or) protocols employed by the different forests produces results that are too variable to lend themselves to the degree of precision necessary to tie disturbance values to site characteristics across an entire geographic region. Differences among forests that encompass the area from which we obtained samples are not surprising given the amount of variability in site characteristics inherent in the region. What is surprising is that no site physical variables (texture, slope, aspect, etc.) proved to have an effect. Some of this might be explained by the logging harvest machine operators. Logging operator skill has been noted to effect disturbance levels among similar harvest systems (Pinard et al. 2000; Stone 2002). Sale administrator knowledge of local conditions and operator tendencies also play an important role in keeping soil disturbance to acceptable levels (Reeves et al. 2011). Although these factors may have added to the variation in mean soil disturbance among National Forests, it is reasonable to assume operator skill and sale administrator knowledge and competency varies among National Forests as well. The variation in operator skill and sale administrator knowledge and competency should not have produced the differences found between National Forests, if this assumption is true. Differences in mean soil disturbance between Forests are likely explained by the lack of a common disturbance monitoring protocol.

Visual observations of soil disturbance are inherently subjective. Monitoring results may vary with the individual soil disturbance monitors experience, preconceptions, and individual bias (Miller et al. 2010). Our results reflect and highlight this reality. Making the most effective and efficient use of soil monitoring resources should be a paramount objective of public land management agencies. Adopting universal soil disturbance class definitions concurrent with a statistically reliable soil disturbance monitoring protocol is a key process in meeting this objective (Curran et al. 2005).

Harvest systems

We confirmed our hypothesis that harvest systems and forest will have an impact on mean soil disturbance when all harvest systems were evaluated. Not surprisingly, ground-based logging had the greatest effect on mean soil disturbance compared to skyline or helicopter operations. These results suggest that forests relying more heavily on low impact harvest systems can reduce soil disturbance associated with timber harvest operations. An increase in the use of low-impact harvest systems on some forests may have influenced our conclusions regarding the significance of these forests on mean soil disturbance when all harvest systems are considered. These results agree with others finding skyline- and helicopter-based harvest systems produce less soil disturbance than ground-based harvest systems (Bockheim et al. 1975; Miller & Sirois 1986; Laffan et al. 2000; Miller et al. 2004; Page-Dumroese et al. 2006).

We were unable to show differences in mean soil disturbance between ground-based harvest systems. The term "tractor" is sometimes used as a default category when soil monitoring is conducted 1–2 years after an area is harvested because the harvest system is often not detailed in forest records. This renders conclusions about relative levels of soil disturbance between ground-based harvest systems as highly suspect. Mean soil disturbance is a useful tool for describing the relative trends among helicopter, cable-yarding, and ground-based harvesting in the National Forests for which we obtained data. We were able to show differences between helicopter, line, and ground-based harvest systems consistent with published trends, despite the variation in the data and the use of *MSD* values.

Season of harvest

We rejected the hypothesis that season of harvest affects mean soil disturbance (Table 5). Often, ground-based harvests conducted in winter conditions produce less soil disturbance than during other seasons and winter logging is used to mitigate soil disturbance impacts associated with ground-based harvest (Miller et al. 2004; Page-Dumroese et al. 2006; Johnson et al. 2007). Johnson et al. (2007) maintained that low disturbance levels on ash-cap soils common in the inland Northwest associated with winter harvest occur when the soil is frozen to depths of 10–15 cm or has a minimum of 15 cm snow cover. Stone (2002) stated that the depth of frost in the mineral soil that is necessary to reduce compaction depends on the harvest equipment used. Stone (2002) and Kuennen (2007) maintained that soil must be frozen to reduce the susceptibility to disturbance, and made the critical point that snow cover does not achieve the same objective as frozen soils. Moist soils insulated by snow cover will not freeze to levels that reduce soils resistance to compaction by ground-based harvest equipment (Kuennen 2007). After consolidating the data, season of harvest was placed into the category that reflected the month in which harvest operations were completed. Possible explanations for the inconsistency between our findings and those of others involve the following two factors:

1. the variation in local weather patterns produced conditions during the period classified as winter where snowpack was reduced or eliminated and saturated soils thawed to a point conducive to rutting; or
2. a bias exists toward concentrating monitoring resources in areas where there is a concern about site conditions.

The first factor highlights the necessity of removing snow cover from skid trails and allowing these trails to freeze before operating on them and monitoring local soil conditions closely during harvest operations before halting operations when preferential conditions do not exist. If the second factor is true, then winter harvest units more susceptible to disturbance may be monitored preferentially as opposed to a random selection of winter harvest units to monitor for soil disturbance.

Slope

We reject the hypothesis that slope influences mean soil disturbance. The slope class associated with each harvest unit was based on the maximum slope recorded for the unit. We were not surprised that no significant differences were evident in mean soil disturbance between adjacent slope classes; however, we did expect slope to have a significant effect on mean soil disturbance (Table 5). According to Miller et al. (2004), the risk of soil disturbance increases from "low" at slopes of 0–5%, to "very high" at slopes exceeding 30%. Agherkakli et al. (2010) reported increases in compaction and rutting on slopes exceeding 20%. This is partly attributable to the necessity of building skid trails using cut-and-fill construction techniques on steeper slopes. These skid trail construction techniques contribute to increased levels of class 3 disturbance. Possible explanations for the discrepancy between our data and published trends (Miller et al. 2004; Agherkakli et al. 2010) are:

- the degree of error associated with data collected under separate and disparate sampling techniques;
- monitoring points representing cut-and-fill skid trail construction were under-represented in our data set (which seems unlikely given the relative distribution of harvest units in each slope class); or
- (although unlikely) slope does not have the effect on mean soil disturbance previously described within these National Forests.

Soil texture

We expected to see some differences in mean soil disturbance between soil textures. A soil operability risk classification system developed by Weyerhauser Corporation (Heninger et al. 2002) rates soils of sandy texture as "low risk" and soils of clay texture as "very high" risk (Curran et al. 2005). Water-holding capacity is related to soil texture. Soil moisture content has been related directly to the severity of rutting and compaction during ground-based harvest operations (Williamson & Neilsen 2000). Recognizing the role soil moisture content plays in compaction levels, recommendations have been made to limit ground-based harvesting to periods of reduced soil moisture content. Soils with moisture contents less than 15% usually have a greater capacity to support increased ground pressure, which helps limit soil compaction to the surface mineral soil (Johnson et al. 2007). Undisturbed coarse-textured soils will have lower moisture contents than fine-textured soils under similar moisture regimes because of the difference in pore-size distribution among soil textural classes.

Weyerhauser Corporation's soil operability risk rating for five mapped soils in Oregon rates the very gravelly loam as the only soil with a "low" risk rating (Heninger et al. 2002; Curran et al. 2005). In addition, the presence of coarse fragments in a soil can act as a buffer to compaction by ground-skidding machines and can resist reductions in hydraulic conductivity values as compared to fine-textured soils (Williamson & Neilsen 2000).

Surprisingly, our data across 11 National Forests showed no differences in mean soil disturbance between soil textural classes. The soil textural groups we used (Table 4) proportionally under-represented some soil textures. For instance, 28 harvest units had a coarse texture modifier (equivalent to ≥ 15% coarse fragments) and 65 units were in the medium-textured group. This underscores that:

- our textural groupings, combined with the mean soil disturbance groupings, did not capture the heterogeneity of soil texture across the harvest units;
- a degree of error and variability is associated with qualitative data collected using separate and disparate sampling techniques; and
- errors were possible in the description of the soils associated with the harvest units.

When combined, these factors likely contributed to our non-significant soil texture results.

Mean soil disturbance

Calculations of mean soil disturbance can describe overall impacts on individual harvest units, which can then be used to compare numerous sites encompassing a wide variety of geographic areas.

We recognize that mean soil disturbance levels may not adequately illustrate the range of conditions in any given harvest unit. Mean soil disturbance values are likely weighted heavily in units with little or no disturbance in the higher disturbance classes (Figure 2). This is because most harvest units, even those where ground-based logging systems are used, have an overwhelming amount of area in classes 0–1 and relatively few disturbance areas in classes 2–3 (often limited to skid trails and landings). Nevertheless, mean soil disturbance values provide a relative measure for use in evaluations of disturbance levels that result from timber harvest operations across a broad range of site conditions and harvest methods.

Management implications

Because disparate sampling techniques have been used on many National Forests throughout the country, one method for analysis is to convert prior qualitative measurements to a standard method. We take the landscape-scale approach to evaluating the usefulness of this conversion to a common, standardized monitoring method (the Forest Soil Disturbance Monitoring Protocol). Attaining the precision necessary to correlate soil disturbance to site characteristics over landscape scales requires adoption of the standardized monitoring protocol. Our approach (converting legacy data into a common data set) is one method for using disparate data, but the errors associated with this may overshadow the “true” disturbance levels. In addition, using mean soil disturbance as the metric, we were able to demonstrate that significant differences in soil disturbance are associated with different timber harvest systems, despite the variation in the data. This is consistent with current literature on the subject. Reliable monitoring methods and the ability to compare results from one harvest unit, National Forest, or other areas of interest depend on a common language for terminology, a consistent protocol, and an effort to ensure that sampling is unbiased and statistically valid. Concomitant with these criteria should be an effort to ensure training and quality control for those individuals who undertake the monitoring.

The ability to correlate disturbance with site characteristics would be an important tool for managers to utilize in project planning. An analysis of a large soil disturbance monitoring database, for which soil disturbance data has been collected using consistent methods, should be undertaken to determine whether soil disturbance resulting from management activities can be correlated with harvest season and landscape characteristics (Reeves et al. 2012). A standardized approach will also ease communication barriers and raise awareness among resource managers, operators, and the public regarding soil issues.

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Note

National Forest Management Act of 1976, Section 6(g)(3)(C). http://www.fs.fed.us/emc/nfma/includes/NFMA1976.pdf (Accessed June 2013).

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Test Your Knowledge

How well can you recall the main messages in the preceding article? Test your knowledge by answering the following questions.

Evidence Supporting the Need for a Common Soil Monitoring Protocol

1. What harvest systems could be used on sites that are more susceptible to soil disturbance to minimize disturbance levels?
   a. Cut-to-length/forwarder
   b. Helicopter
   c. Skyline

2. How would a standardized soil monitoring protocol aid regional evaluations of forest harvesting impacts?
   a. Would allow researchers to correlate site characteristics with disturbance levels on landscape scales
   b. Would ensure that soil disturbance monitoring is only done in the rain
   c. May highlight the inconsistencies inherent in disparate monitoring regimes

3. Why does this study conclude that site characteristics do not influence soil disturbance levels?
   a. Site characteristics have no bearing on the harvest system used
   b. Microclimates do not impact localized weather patterns
   c. Disturbance monitoring data collected using disparate collection protocols lack the precision necessary to correlate site characteristics with disturbance levels

ANSWERS: 1 = b and c; 2 =a; 3 = c