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A comparison of ground cover and frequency estimation methods for post-harvest soil monitoring

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A COMPARISON OF GROUND COVER AND FREQUENCY ESTIMATION METHODS FOR POST-HARVEST SOIL MONITORING

CURTIS D. KVAMME

A THESIS

Submitted in partial fulfillment of the requirements for a degree of

MASTER OF SCIENCE IN FOREST ECOLOGY AND MANAGEMENT

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This thesis, "A comparison of ground cover and frequency estimation methods for post-harvest soil monitoring," is hereby approved in partial fulfillment of the requirements for the Degree of MASTER OF SCIENCE IN FOREST ECOLOGY AND MANAGEMENT.

SCHOOL OF FOREST RESOURCES AND ENVIRONMENTAL SCIENCE

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Abstract

The amount and type of ground cover is an important characteristic to measure when collecting soil disturbance monitoring data after a timber harvest. Estimates of ground cover and bare soil can be used for tracking changes in invasive species, plant growth and regeneration, woody debris loadings, and the risk of surface water runoff and soil erosion. A new method of assessing ground cover and soil disturbance was recently published by the U.S. Forest Service, the Forest Soil Disturbance Monitoring Protocol (FSDMP). This protocol uses the frequency of cover types in small circular (15cm) plots to compare ground surface in pre- and post-harvest condition. While both frequency and percent cover are common methods of describing vegetation, frequency has rarely been used to measure ground surface cover. In this study, three methods for assessing ground cover percent (step-point, 15cm dia. circular and 1x5m visual plot estimates) were compared to the FSDMP frequency method. Results show that the FSDMP method provides significantly higher estimates of ground surface condition for most soil cover types, except coarse wood. The three cover methods had similar estimates for most cover values. The FSDMP method also produced the highest value when bare soil estimates were used to model erosion risk. In a person-hour analysis, estimating ground cover percent in 15cm dia. plots required the least sampling time, and provided standard errors similar to the other cover estimates even at low sampling intensities (n=18). If ground cover estimates are desired in soil monitoring, then a small plot size (15cm dia. circle), or a step-point method can provide a more accurate estimate in less time than the current FSDMP method.

INTRODUCTION

Many studies have shown that timber harvesting and other forest management activities can have major impacts on physical and chemical soil properties (Powers et al., 1990; Jurgensen et al., 1997; Gomez et al., 2002b). Soil compaction, for example, can change soil porosity and water holding capacity to the benefit or detriment of tree growth, depending on soil and site conditions (Youngberg, 1959; Gomez et al., 2002b; Heninger et al., 2002;). Compaction can also reduce water infiltration, thereby increasing runoff and erosion (Edwards and Burney, 1991). Soil erosion, while often not a significant natural disturbance in forested settings, can be increased by some timber management activities; often forest road networks are the largest sources of sediment (Elliot et al., 1998; Rice et al., 1999). Depending on the level of impact and the extent of soil cover removed, timber harvest areas can also become sources of sediment, especially on skid trails where ground cover can be reduced up to 90%, or on slopes >35% (Packer, 1967; Swanson et al., 1989; Robichaud et al., 1993; Elliot et al., 1998). Because ground cover is an important erosion-controlling factor and is often removed by ground-based timber harvesting equipment, it is important to monitor how it changes after harvesting.

Ground Cover

Ground surface cover components (vegetation litter, woody debris, rocks, living plants, mineral soil) provide information about invasive species, plant growth and regeneration, woody debris loadings, and surface organic layers (Jurgensen et al., 1997; Elzinga et al., 1998; Woldendorp et al., 2004). Detection of ground cover changes after

management activities are important, since exposed soil at some sites has a large role in determining erosion risk (Lang, 1979). Many studies have used simulated rainfall (Simanton et al., 1991), or sediment trap experiments (Larsen et al., 2009) to show that extent of bare soil has a greater influence on erosion than vegetation canopy cover, soil water repellency, and soil sealing. Therefore, it is important to measure bare soil and ground cover after timber management activities to assess erosion risk. While erosion may not occur immediately after a timber harvest even with reduced soil cover, the possibility of increased erosion on a site remains until ground cover and vegetation have reestablished (Packer, 1967; Swanson et al., 1989; Robichaud et al., 1993). However, the amount of ground cover needed to limit erosion risk varies by site and soil type, so regulatory standards are often very broad. For example, some U.S. Forest Service Soil Quality Standards only require that ground cover be sufficient to prevent erosion from exceeding natural rates (Elliot et al., 1998; Page-Dumroese et al., 2000).

Erosion models are commonly used to estimate current or changed erosion rates resulting from timber harvesting (Merritt et al., 2003). Several models available today, such as the U.S. Forest Service Disturbed Water Erosion Prediction Project (FSWEPP), can predict soil erosion based on a set of input variables, which includes an estimate of ground cover (Elliot et al., 2000; Merritt et al., 2003). Consequently, an accurate estimate of ground cover, combined with an erosion model, is one of the most efficient ways to predict the risk of future erosion resulting from management activities.

Soil Monitoring Protocols

Soil disturbance monitoring is one way to estimate bare soil surface and erosion risk, and if pre-harvest baseline data are collected, it is possible to estimate whether increased erosion risk resulted from timber management activities. Soil monitoring is also useful and sometimes required on public lands in the U.S. to show that local and federal regulations for water quality, soil quality, and timber management are being met. Environmental standards used by the U.S. Forest Service are partly defined by the Multiple Use and Sustained Yield Act of 1960, the National Environmental Policy Act of 1969, the National Forest Management Act of 1976, and others. Additionally, each U.S. Forest Service Region has standards dictating the levels of disturbance types thought to influence long-term sustainability or soil quality; this includes a minimum percent ground cover that is acceptable after a harvesting activity (Powers et al., 1998; Page-Dumroese et al., 2000). It is not clear that the broad standards outlined by each U.S. Forest Service region actually relate to severe or detrimental levels of soil disturbance that impair vegetative growth or hydrologic function (Burger and Kelting, 1998; Page-Dumroese et al., 2000). However, as long as quantitative, spatial, or qualitative (*e.g.* erosion presence) requirements are mandated, soil monitoring methods must be capable of consistently detecting differences in soil cover and other disturbances from pre- to post-harvest.

There are at least three methods that can be used to assess soil disturbance after timber harvesting in the western United States. These different methods, discussed by Curran et al. (2007), were developed by the U.S. Forest Service, Weyerhaeuser Timber Company, and the British Columbia Ministry of Forests (respectively: Page-Dumroese et

al., 2009a,b; Scott et al., 1979, as referenced in Heninger et al., 2002; and B.C. Ministry of Forests, 2001). Only the U.S. Forest Service and the B.C. Ministry of Forests methods provide a quantitative measure of ground cover or bare soil, because it is considered important for changes in hydrologic function.

Ground cover is usually recorded as area covered by each cover type (*e.g.* litter, plant, etc.), and is commonly estimated by: 1) visual estimation of percent cover in a plot frame, 2) counting the proportion of points along a transect covered by each type, or 3) by measuring the proportion of distance covered by cover types along a line (Elzinga et al., 1998). Other metrics besides percent cover can be used to describe aboveground vegetation attributes, such as density of plants per unit area, or the frequency of a plant species occurring within a number of plot samples (Greig-Smith, 1983; Elzinga et al., 1998). These other measures are often used to approximate or replace a 'true' cover estimate for vegetation canopies, because they are often faster and easier to collect than percent cover (Elzinga et al., 1998). Frequency, in particular is much faster than visual cover estimates of plant canopy, because only presence or absence of each cover type is recorded. Speed and efficiency of a monitoring method is important for any resource manager, because less sampling time reduces monitoring cost. However, frequency is seldom used for assessing ground surface (Elzinga et al., 1998), and it is not clear if frequency is more efficient than percent cover methods for assessing ground surface condition.

U.S. Forest Service Forest Soil Disturbance Monitoring Protocol

The Forest Soil Disturbance Monitoring Protocol (FSDMP) has become a popular tool among U.S. Forest Service soil scientists to monitor soil disturbance after timber harvesting (Page-Dumroese et al., 2009a, b). It provides a consistent, well-defined tool to collect information about soil in pre- and post-harvest condition. In this protocol, ground cover is assessed by recording the presence or absence of seven ground cover types (bare soil, litter, rock, fine wood, coarse wood, live plant, and invasive plant) in measured plots (15cm diameter circle) along a random transect. These cover-type data are used mostly to determine erosion risk within a sampled area. Since this protocol is being widely used, and data can be shared among National Forests and Regions in the U.S., it is important to ensure that ground cover monitoring objectives can be met, and that methods used in this protocol are supplying useful data.

The FSDMP method uses a measure of frequency, not percent cover, to assess ground surface cover. As mentioned before, frequency data can be collected very quickly, however, the values of these data depend on the plot size used, and the size and shape of measured cover types. With very small plot sizes (3/4 inch diameter), frequency values are generally close to plant canopy cover estimates (Hutchings and Holmgren, 1959). However, larger plot sizes tend to increase the frequency of measured plant canopies (Elzinga et al., 1998). The 15cm diameter circle plot used in the FSDMP is not a common size for measuring vegetation canopies or ground cover (Elzinga et al., 1998). To my knowledge, no assessment has been done to determine if frequency data from this plot size can be used to accurately estimate ground cover in the field.

OBJECTIVES

The objectives of my study are to: 1) compare the FSDMP ground frequency estimation method to three ground cover methods (step-point, 15cm dia. and 1x5m plots), 2) determine the time required by each method to collect data at two levels of sampling intensity, and 3) evaluate the usefulness of each method for modeling erosion risk with FSWEPP.

METHODS

Study Areas

Study sites are located on the Shoshone National Forest in northwestern Wyoming (Figure 1). Three recently active timber sales were selected on the forest; all sites had similar silvicultural prescriptions (sanitation-salvage) resulting from insect infestation or beetle kill. Other site characteristics are given in Table 1. The Carter Mountain site had heavy infestations of spruce beetle and mountain pine beetle, and the Deadman Bench sale had moderate spruce beetle and Douglas-fir beetle infestations. Both sites were treated in 2006-2007 with Leave Tree Mark (LTM) thinning techniques to remove dead and dying timber.

The Purdy Salvage area also had severe mountain pine beetle and spruce beetle infestations, but was also burned by a wildfire in August and September 2006. The applied thinning technique varied, depending on the severity of fire and/or insect damage, thus the cutting units sampled for this study contained multiple harvest treatment types. A majority of the area was either treated with a group selection or clearcut with reserves

in 2008-2009. However, different harvesting treatments on this site resulted in a similar number of equipment passes during harvest operations, and similar overall post-harvest tree density as the other two study areas (personal communication, R. Spiering, 2009).

Engelmann spruce (*Picea engelmannii* Parry ex Engelm. var. *engelmannii*) was one of the dominant overstory trees at all three sites. Lodgepole pine (*Pinus contorta* Douglas ex Louden var. *latifolia* Engelm. ex S. Watson) was codominant on the Purdy and Carter sites, while the Deadman site contained Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco var. *glauca* (Beissn.) Franco) and a minor component of lodgepole pine. Soils at each site were classified using Soil Taxonomy (Soil Survey Staff, 2003): Deadman Bench− loamy skeletal, mixed, superactive, Eutric Haplocryalf; Carter Mountain− loamy-skeletal, mixed, superactive, Typic Eutrocryept; and Purdy− loamy-skeletal, mixed, superactive, Typic Haplocryalf.

Table 1. Physical site characteristics for study areas.

Timber Sale	Slope (%)	Aspect Range	Elevation (m)	Parent Material	Surface Soil Texture	Study Area Size (ha)
Carter Salvage	0 - 30	N - NE	2,600 - 2,800	Mixed Clastic & Volcanic From Landslide	Loam - Sandy Loam	82
Deadman Bench	0 - 35	NE - NW	2,100 - 2,200	Shale, Limestone & Sandstone	Loam - Silt Loam	145
Purdy	0 - 40	N - NW	2,700 - 2,800	Mixed Clastic & Volcanic	Loam	112
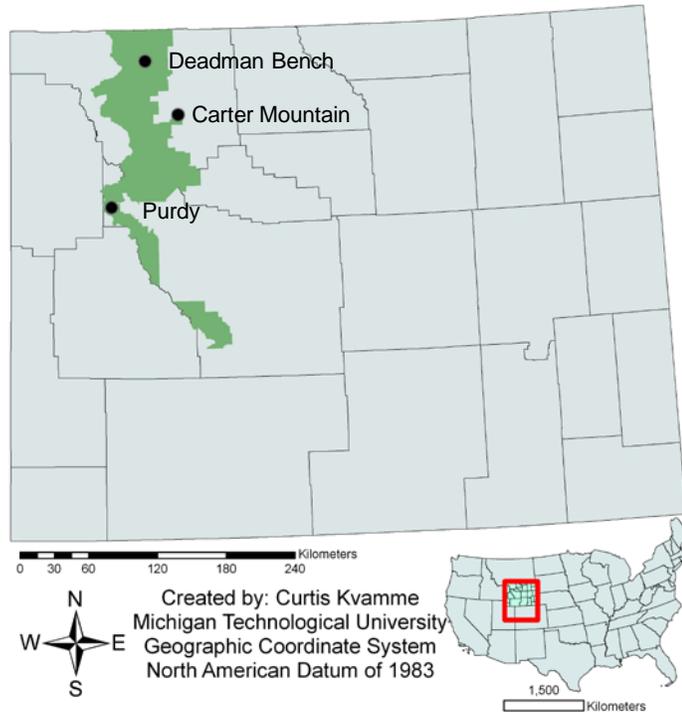
Figure 1. Study site locations, Shoshone National Forest, WY.

Experimental Design

The sample design described in the FSDMP was used in this study (Page-Dumroese et al., 2009a). Field sampling occurred in summer 2009, with pilot sampling in summer 2008. A systematic point-line transect method with random starting location and azimuth was used to assess ground cover within four marked cutting units, or four replicates at each site (Figure 2). The replicates consisted of three post-harvested units and one undisturbed control unit. Points along the transect were spaced according to cutting unit size, with larger units having greater point spacing. At each sample point along the transect, I collected ground cover frequency in a 15cm dia. circle (FSDMP method), and the following cover percent methods: step-point, and ocular estimates in plot sizes of 15cm dia. and 1x5m (Figure 2).
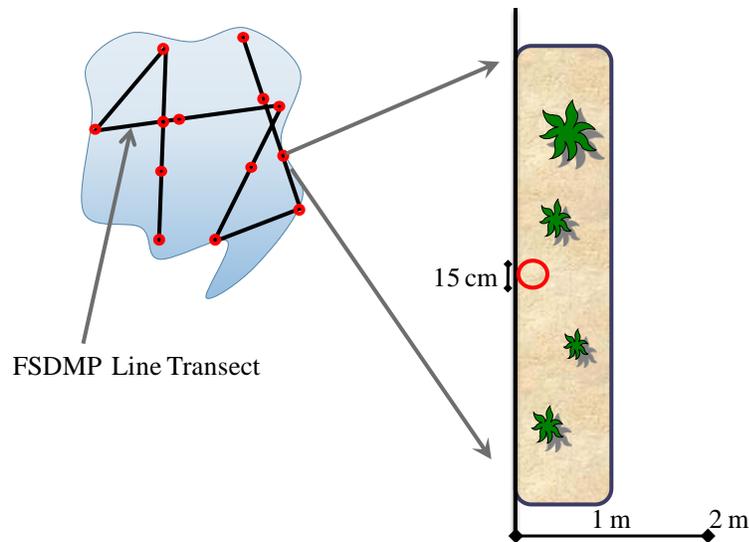
Figure 2. A diagram of the systematic point-line transect used in the FSDMP. The enlarged area shows the 15cm diameter circle, and 1x5m ocular cover estimation plots. The line on the left represents the sampling transect, which defines the left side for both plots.

Ground Cover Estimation

The FSDMP method in this study estimated the presence or absence of six ground cover types, bare soil, rock, fine wood, coarse wood, live plant, and litter as they occurred in a 15cm circular area around the sampling point (Figure 3). Invasive plant coverage, which is normally assessed in the FSDMP, was not measured. This yields binary presence/absence information for each cover type, where a "1" represents any present cover type, and a "0" represents an absent type. Since this method is used in the monitoring protocol, it was the baseline to which the other three ground cover methods were compared.

Unlike the FSDMP, which records all ground cover types, the step-point transect method records a single value for ground cover at each sample point along the transect.

In this method, measurements were taken at a "true" point, indicated by an 'x' in Figure 3, by placing a metal pin flag with a 1.8 mm tip at the front tip of the observer's boot. The appropriate sample size (*n*) for the FSDMP and step-point methods was calculated from 2008 pilot data with the following equation (Triola, 2001):

$$n = \frac{(z_{\alpha/2})^2 * \hat{p} * \hat{q}}{w^2}$$

where $Z_{\alpha/2}$ is the table Z-score value determined by the selected level of confidence (1.282 with 80% CI); $\hat{p}$ is the proportion recorded 'present' for the most variable cover type; $\hat{q}$ is the proportion of points recorded as 'absent' for the determining cover type; and *w* is ½ of the selected margin of error that defines the confidence interval around the mean (*w*=.05).
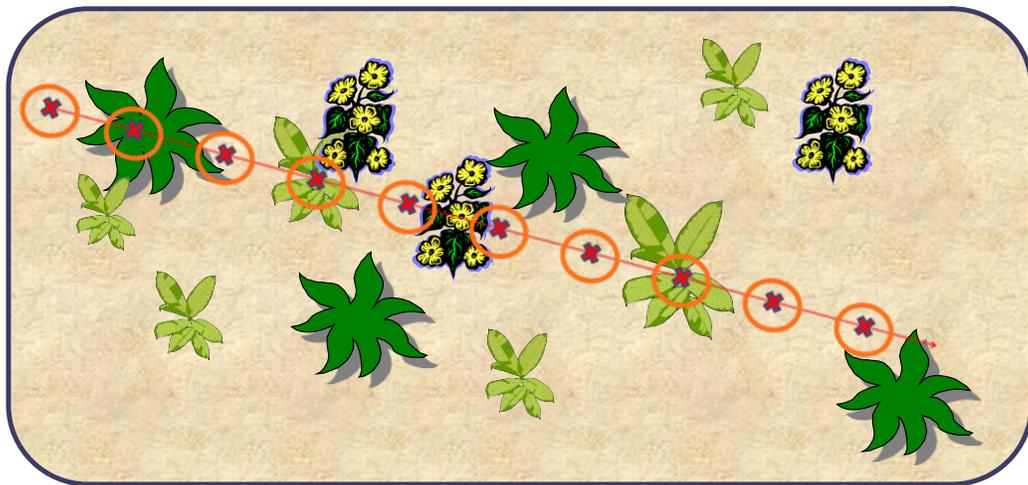
Step-Point Method	1	2	3	4	5	6	7	8	9	10	% Estimate
Cover Type	Soil	Plant	Soil	Plant	Soil	Soil	Soil	Plant	Soil	Soil	30% Live Plant
											70% Bare Soil
FSDMP Method											
Bare Soil?	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	90% Bare Soil
Live Plant?	No	yes	Yes	Yes	Yes	Yes	No	Yes	No	No	60% Live Plant

Figure 3. Example of Step-Point (x) and FSDMP (circle) ground cover assessments. The accompanying data table shows a simplified version of data collected, using only two cover types.

The Daubenmire method (1959) was used to give ocular estimates of percent ground cover on two different plot sizes: a 1x5m rectangle, and a 15cm diameter circle (Figure 2). In each plot size, six ground cover types (bare soil, live plant, litter, fine wood, coarse wood, and rock) were estimated by cover classes (Table 2). The sample size (n) for both plot sizes was also calculated from pilot data from 2008 with the following equation (Scheaffer et al., 2006):

$$n = \frac{N\sigma^2}{(N-1)D + \sigma^2}$$

Where:

$$D = \frac{B^2}{4}$$

N is the potential number of plots in the population, and B is a two standard-deviation bound on the mean percent bare soil cover within a study site. B was calculated from 2008 pilot data, and was not constant at all sites (Purdy, $B \approx 10.6$; Carter Mt., $B \approx 5.5$; Deadman, $B \approx 1.8$). Both plot types were measured at a subset of the total number of points along the transect with a systematic method.

Table 2. Percent classes for plot estimates of ground cover.

Cover Class	% Cover
1	0 - 5
2	6 - 25
3	26 - 50
4	51 - 75
5	76 - 95
6	96 - 100

Sampling Time

In one replicate at each site, the amount of time required to collect data with each of the four methods was recorded in order to perform a person-hour analysis. At every sampling location, a stopwatch was used to record the time spent preparing the site (*i.e.* setting up sampling plot frame), and assessing ground cover. Since all methods were collected along the same paced transect, the time spent walking between the points was not measured, as it was assumed to be the same for each sampling method.

Data Analysis

An analysis of variance (ANOVA) procedure was performed with SAS software (Version 9.2). Proportions of ground cover and frequency were transformed with an arcsin square root function to satisfy the ANOVA assumption of homogeneous variability (Steel et al., 1996). Tests for significant differences in mean ground cover estimates among the four methods were performed with Tukey's studentized range test. Additional analyses were performed when significant differences were found between bare soil frequency and percent cover. Estimates of total ground cover from the four methods were used to model potential water erosion on each site using the Disturbed Water Erosion Prediction Project (Disturbed WEPP Model Version 2008.907). The input variables required by the WEPP model include climate, slope, soil texture, and ground cover, and were selected to match site conditions as closely as possible. The FSWEPP model was selected because it is widely used by U.S. Forest Service mangers, has a simple internet interface, and all input variables except ground cover could be held

constant during model runs. Based on recommendations from the FSWEPP technical

documentation, two different 'treatments' (*i.e.* vegetation or cover types after harvesting)

were selected for each site to show a range of potential erosion rates that would be

produced using estimated bare soil cover from each method.

RESULTS AND DISCUSSION

Ground Cover Sampling Methods

Estimates of cover type by the FSDMP were significantly higher (α=.05) than the

other estimation methods, except for coarse wood (Figure 4). While none of the four

methods can be said to exactly represent 'true' ground cover, the close agreement of the

three cover percent methods for most cover types indicate they provide a consistent and

better estimate of ground cover than the FSDMP method (Floyd and Anderson, 1987).

The 15cm dia. frequency plot used in the FSDMP overestimates percent ground cover,

except for coarse wood. This resulted from measuring overlapping layers of ground

cover in the FSDMP, while the percent cover methods record a single layer at a point or

plot. Frequency methods have also been shown to overestimate plant canopy percent

cover with a ¾ inch plot size (Hutchings and Holmgren, 1959).

In the ANOVA analysis, two significant interactions were found in the FSDMP

frequency data (Figure 5) that highlight a problem of frequency methods that makes them

difficult to interpret biologically. Frequency data, unlike percent cover, cannot

consistently detect seasonal or site changes in cover structural pattern or density (Greig-

Smith, 1983; Elzinga et al., 1998). For example, Figure 5B shows that the low estimates

of bare soil cover at the Deadman site were similar with frequency and cover methods.
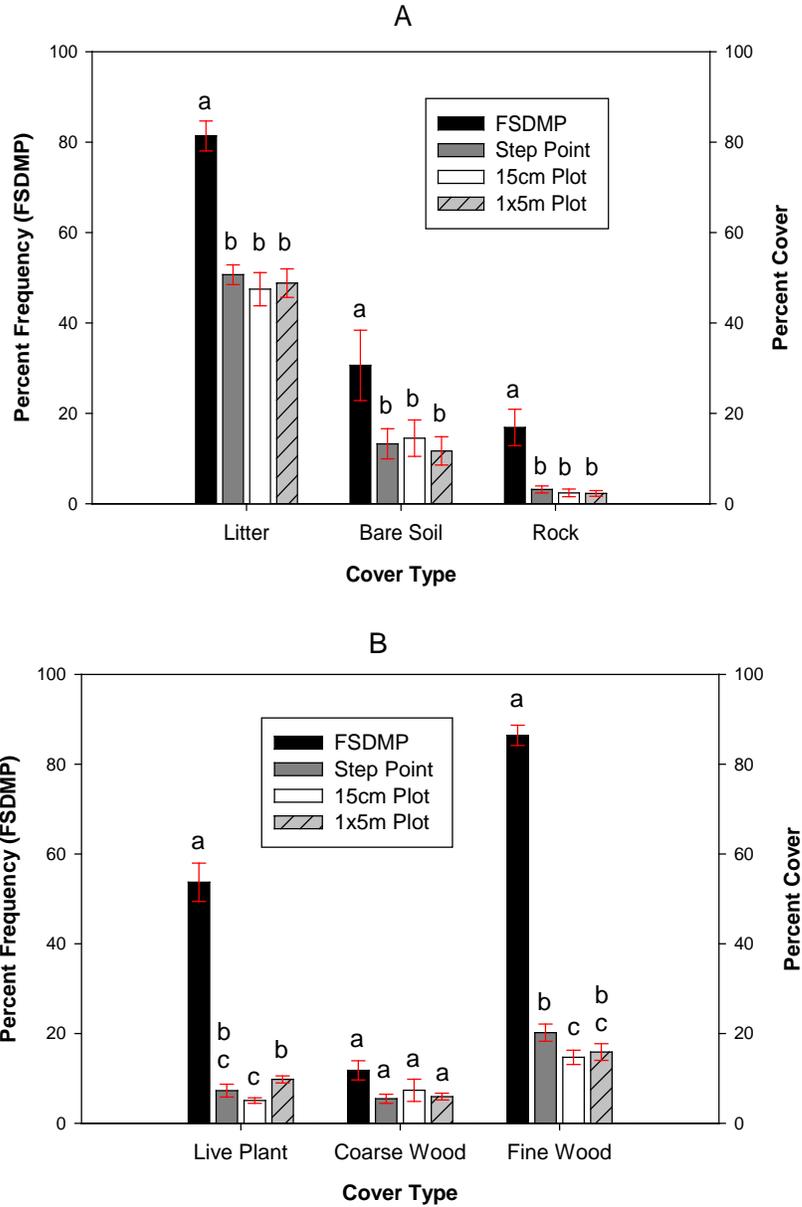
Figure 4. Average estimates of six ground cover types using four sampling methods. Different letters indicate significant differences among sampling methods (α=.05); red bars represent one standard error.

However, as the percent of bare soil increased at Purdy and Carter Mountain, the amount

of overestimation by the FSDMP increased because small patches of bare soil were more

common at these sites. In a frequency plot method, small patches of cover types are

recorded the same as large continuous patches, so the cumulative effect is a large overestimate of percent cover. A different pattern in live plant cover is displayed in figure 5A, with the largest overestimate occurring at the Carter Mt. site. This inconsistent overestimation of ground cover type greatly reduces the utility of the FSDMP in comparing ground cover percentage from different sites.

Ground cover estimates of the two area plot methods and the step-point method were not significantly different, except for fine wood and live plant covers (Figure 4). In all cases, however, differences among these methods were much smaller than the difference between the FSDMP method, and there was no clear trend showing one cover method consistently had higher or lower estimates of cover types. When the FSDMP data were removed from the analysis, there were no significant interactions between sampling method and study site. Since cover estimates are not biased by changes in cover-type structure, percent cover is more useful for comparing ground surface monitoring data among sites than frequency (Greig-Smith, 1983).
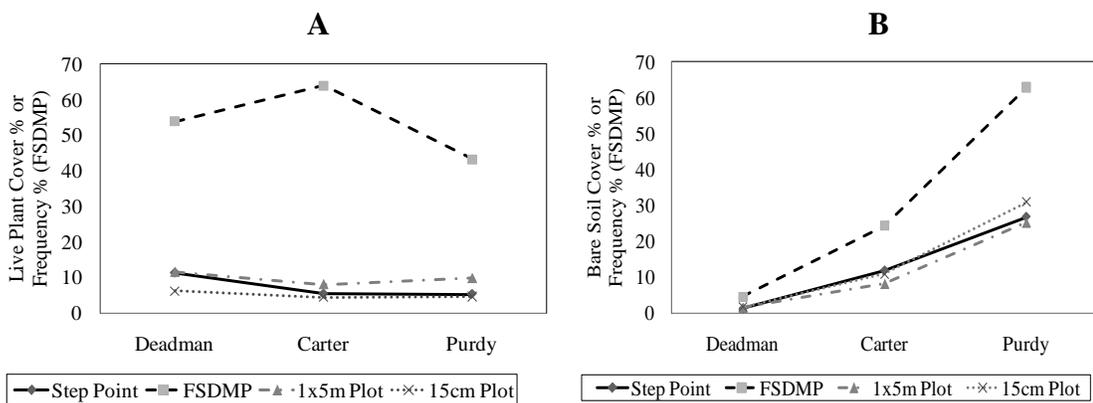

Figure 5. Graphs of significant variable interactions between the FSDMP method and sample site, from ANOVA comparison. A) live plant cover data, B) bare soil data.

There are several important implications for having accurate site-specific estimates of ground cover. For example, pre- and post-harvest surveys are often performed to collect information about the cover and biomass of woody residue of various size and decay conditions, which is important for both nutrient cycling and fire risk management (Laiho and Prescott, 2004 ; Ottmar et al., 2007). While this detailed information is not available from the cover data obtained in this study, percent cover of woody debris and forest floor depth measurements can be used to improve estimates of woody biomass and size classes from woody residue photo series guides (*e.g.* Maxwell and Wayne, 1980). These photo series contain images of forests with known amounts and percent area covered by woody residue that can be used to estimate site conditions. Additionally, the current version of the FSDMP includes 'invasive plant' as a cover type. Though it was not used in this study, managers could use these data to monitor the spread of known populations, or to initially detect isolated occurrences of invasive or non-native plant species. Finally, obtaining accurate bare soil estimates can be important for other management purposes, such as predicting soil erosion.

Erosion Modeling

At the Deadman site, less than 2% difference in predicted erosion was found when FSDMP and percent estimates of bare soil coverage were used as inputs to the Disturbed FSWEPP model. Summarized results for predicted erosion at the other two sites are shown in Figure 6. The control site at Carter Mountain (Figure 6A) also showed no difference in modeled predictions of erosion risk, as the estimates of low bare soil coverage by FSDMP frequency and percent cover methods were very similar. These

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sites generally had low slope steepness, so were not likely to have significant predictions of erosion in FSWEPP.

Since the remaining sites at Purdy and Carter Mountain had higher bare soil coverage, the FSDMP produced higher levels of predicted soil erosion than the percent cover methods (Figure 6). The vegetation conditions shown in the figure are model input parameters (called 'treatment' in FSWEPP) that theoretically represent the conditions at different points of time after harvest; two are shown for each study area to show a likely range of possible model outputs (Elliot, 2000). In Figure 6, the treatments on the right side best represent the conditions at Carter and Purdy (tall grass, and low-severity fire, respectively) in the year each area was sampled. The left side of each figure theoretically represents better established vegetation (shrub and short grass) at each site at least one year after the sampling date. Erosion rates for the control replicate at Purdy (Figure 6B) are likely higher because the treatment units received woody material additions from the timber harvest, which slightly decreased percent exposed bare soil estimates with all methods. The trend of higher erosion predictions with FSDMP data holds for all of the displayed FSWEPP scenarios, but the difference is less in the shrub (Carter Mt.) and short grass (Purdy) treatments.

Overall, differences in erosion prediction only occurred at sites where the natural risk of erosion was high (due to exposed soil and steep slopes), and differences in bare soil estimates between FSDMP and the three percent cover methods was more than 10%. Thus, it seems that the use of either cover or FSDMP frequency data is only important for predicting erosion on sites that have a relatively high natural risk of erosion.
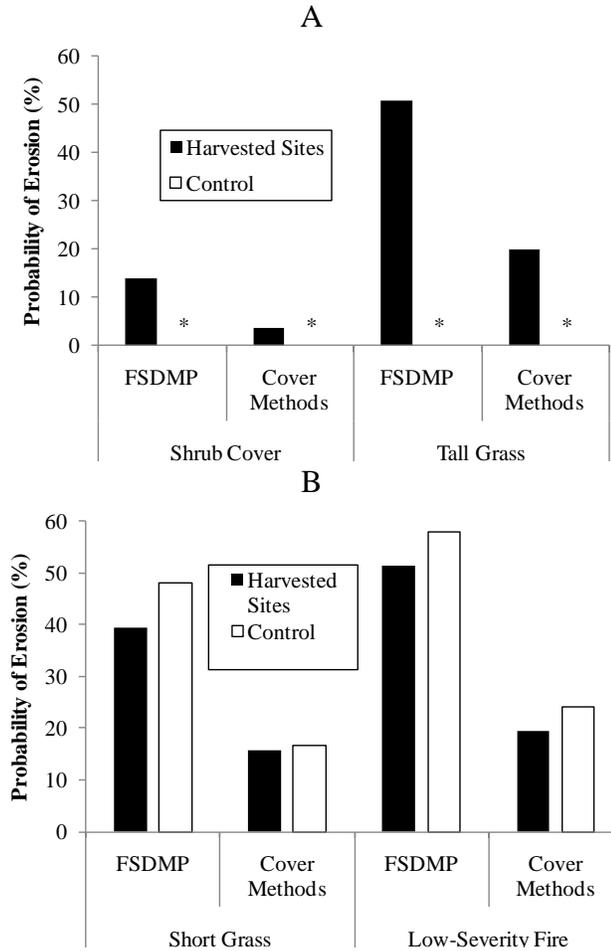
A

Probability of Erosion (%)

60
50
40
30
20
10
0

■ Harvested Sites
□ Control

*   *   *   *

FSDMP   Cover Methods   FSDMP   Cover Methods

Shrub Cover   Tall Grass

B

Probability of Erosion (%)

60
50
40
30
20
10
0

■ Harvested Sites
□ Control

FSDMP   Cover Methods   FSDMP   Cover Methods

Short Grass   Low-Severity Fire

Figure 6. Predicted probability of erosion from FSWEPP Results. For the Carter Mountain site (A), two vegetation condition (treatment) types are shown: Shrub and Tall Grass. *Predicted erosion at the Carter control sites was 0%. Treatment types for the Purdy site (B) are Short Grass, and Low-Severity Fire. Outputs for the three cover methods were nearly identical and are combined.

Ultimately, the decision of how to use bare soil estimates in the FSWEPP model should be left to individual forest managers. Using accurate inputs into all erosion models is important, but prediction errors associated with the model itself are always high (Elliot, 2000). For example, the FSWEPP erosion predictions were exceptionally low for the Carter Mt. site when data from the cover methods was used with the shrub model treatment (Figure 6A). However, clear evidence of surface erosion, such as rills,

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pedestals, and areas of soil deposition, existed at these sites, possibly indicating field

erosion exceeded modeled predictions (Kvamme, unpublished data). Lastly, it should

also be noted that FSWEPP only provides predictions for water erosion; wind erosion can

also be important when bare soil is exposed, and may be an overriding concern in some

areas.

Person-Hour Analysis

In the FSDMP, there are generally two sampling approaches that result in

different time input needs and sample sizes (Page-Dumroese et al., 2009a). If time

constraints exist, or if only basic monitoring data are required, a 'Rapid Assessment' can

be performed by collecting 30 data points in a timber harvest unit. If more detailed,

statistically-backed results are needed, a fixed confidence level (*e.g.* 80%) is selected, and

an appropriate sample size calculated; this is called the 'Full Assessment' (Page-

Dumroese et al., 2009b). Sampling efficiency data for ground cover variables are

presented for both sampling scenarios.

The amount of time needed to collect enough ground cover sample data for the

full sampling assessment (at 80% confidence level) is shown in Figure 7. The 15cm plot

method was the most efficient, followed by the step-point method. It is surprising that

that one of the cover plot methods was more efficient than the FSDMP, because plant

canopy studies have shown that frequency estimates are much more efficient than cover

percentage (Elzinga et al., 1998). However, many more cover types (plant species) are

usually measured in canopy studies than in my ground cover study, which would increase
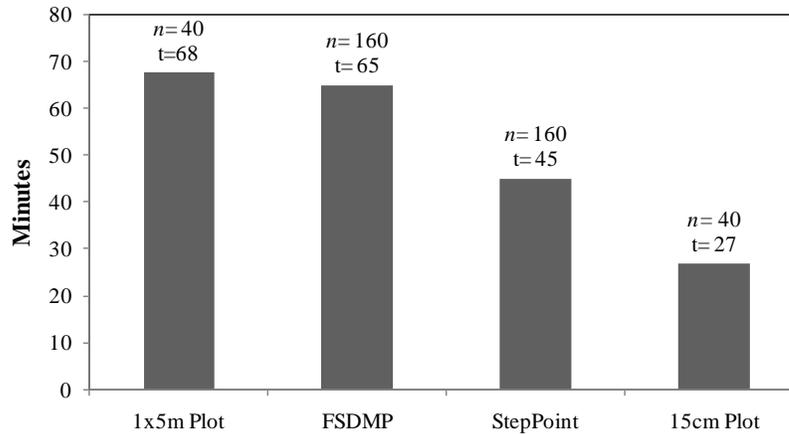
the time required at each plot.

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Figure 7. Average sampling time, in minutes, required to meet an 80% confidence level. *n* values indicate the average number of samples required per replicate cutting unit. The t values represent the approximate number of minutes required.

Floyd and Anderson (1987) showed that plot-based methods can be the most efficient method when sampling only a single cover type (*e.g.* shrub canopy), but point-based methods are the most efficient when multiple cover types are needed, especially at lower sampling intensities. These results agree with my findings for the step-point and large 1x5m plot, but not for the small 15 cm dia. plot. However, most other efficiency analyses have been performed on $0.1m^2$ or $1m^2$ cover plots. In my study, the much smaller 15cm diameter circle ($\approx.02$ m^2) was considerably more efficient than the large $5m^2$ plot, because it required essentially no set-up time, and assessment was more rapid. When compared to the FSDMP frequency method, the 15cm cover plot is more efficient simply based on the smaller sample size required to meet the selected confidence level.

To compare the variability of ground cover estimates at the reduced sample size used in the 'Rapid Assessment' approach, subsamples of the following sizes were taken from the original field data to calculate standard errors (Figure 8). In this approach, it
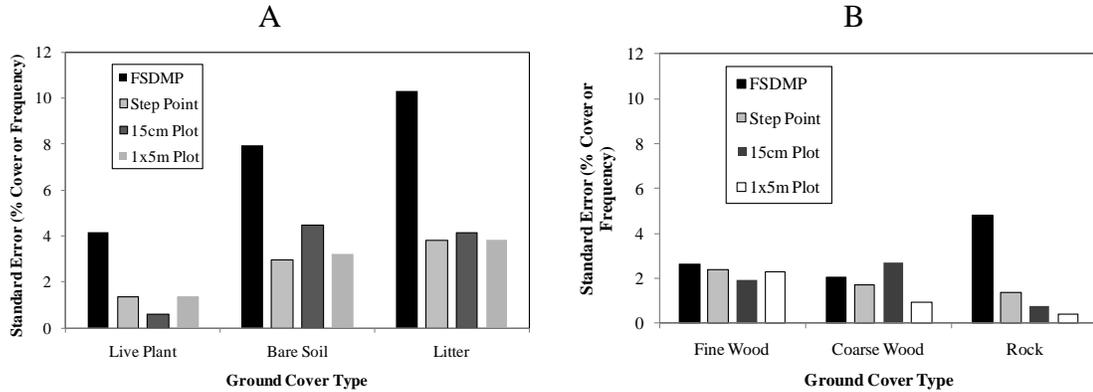
Figure 8. Estimated standard errors of percent cover (or frequency for the FSDMP method) for the 'Rapid Assessment' sampling technique. Sample sizes are: n=30 for FSDMP, n=43 for step-point, n=18 for 15cm plot, and n=7 for the 1x5m plot.

takes approximately 12 minutes to collect 30 ground frequency points with the FSDMP method. In this same amount of time, 43 step-point measurements could be collected, 18 plots of 15cm, or 7 1x5m plots.

The rapid assessment FSDMP method has a high standard error for most cover types except fine woody debris, which was surprisingly low. Among the three cover estimate methods, none stands out as having the highest standard error with reduced sample sizes. The step-point method has the lowest bare soil standard error (2.9%), indicating it may be the most reliable for small sample sizes; however, the differences between the other methods are also small (<2%). In addition, when using the step-point method in the Rapid Assessment, the larger sample size will collect information from a greater area (largest spread) within a harvested unit, assuming a line transect is used for all methods.

My results are similar to that of Murphy and Lodge (2002), who found a 4-5 standard error range in visual ground cover estimates when using a 40 x 40cm plot

(n=60). I could not find a similar field comparison for point-based estimates; however, it is not surprising to see similar variability in estimates, since several studies have shown canopy cover predictions between point and visual plot methods to be similar under controlled laboratory settings (Murphy and Lodge, 2002; Booth et al., 2006).

Sampling Implications for Soil Disturbance Monitoring

The Forest Soil Disturbance Monitoring Protocol uses the same frequency technique to assess other soil disturbance variables (*e.g.* soil compaction, rutting, etc.). Since I did not compare methods for estimating soil disturbances, it is important to know the potential implications for using FSDMP frequency data to assess these variables. One important difference between the soil disturbance variables in the FSDMP and ground cover is the size of soil disturbances are usually larger than the 15cm circle plot area, due to the activity of large mechanical equipment. As seen in Figure 4, frequency values for relatively large objects, like coarse wood, approached values for the cover estimation methods. This was likely caused by large pieces of coarse wood often completely covering the FSDMP plot, so that it was identical to the step-point method. When this occurred, there was no partial coverage or double counting of cover types (counting multiple occurrences as one), making the FSDMP and step-point estimates similar (Greig-Smith, 1983). If the FSDMP plot was not completely covered by a ground cover type or soil disturbance, it overestimated percent cover (Goodall, 1952; Warren-Wilson, 1959; Booth et al., 2006). However, since disturbances, such as soil compaction, are frequently as large or larger in scale than coarse wood, it is possible that the FSDMP

method provides estimates of disturbance similar to percent cover methods. Further investigation is needed to determine how accurately FSDMP measures soil disturbance.

Another important distinction between ground cover and soil disturbance occurrence is that soil disturbances can be layered, like plant canopy cover, at any given point in space. For example, soil compaction and rutting often occur concurrently. In contrast, ground cover is not layered, and if the primary interest is erosion risk, then soil is either covered or it is not. This layering effect means that sum total of all soil disturbance 'cover' values can exceed 100%, just as with plant canopy cover (Greig-Smith, 1983). Thus, each layer of disturbance cover percent should be interpreted independently, and the total disturbed area can only be obtained by subtracting the percent of undisturbed sample points from 100% (ITT, 1999). Consequently, managers should not simply report the sum of all soil disturbance types, as may be the tendency, if the total sum of disturbed areas is less than 100%.

Finally, in my study the step-point method only recorded a single ground cover type at each point. To collect soil disturbance data, the step-point method would need to be modified to record all disturbance types present at the sampling point to obtain layered cover estimates.

Plot-Based Techniques

Most of the problems with the step-point and FSDMP methods discussed above do not apply to visual plot estimates of cover, since the relative amount of each cover type is recorded directly. These methods also have other traits worth discussing. Plot techniques can have large perimeters that increase edge decision error when determining

whether to include or exclude a disturbance type. Generally, long narrow plots, such as the 1x5m plot, have increased edge decision error compared to circular plots (Elzinga et al., 1998). Therefore, I assume the 1x5m plot has the most edge decision error of all the methods tested, however it was not quantified in this study.

Plot based techniques do offer one notable benefit over frequency and step-point methods in soil disturbance monitoring. Large plot sizes, such as the 1x5m plot are much more likely to detect relatively rare objects on a site than are points or smaller plots (Elzinga et al., 1998). This could be potentially beneficial for managers interested in tracking the spread of rare or isolated invasive species after a timber harvest or prescribed fire.

CONCLUSION

The FSDMP method provides frequency data for estimating ground surface cover. While frequency data do detect differences in ground cover that result from timber management, they only give the presence or absence of cover types, not percent ground cover. Ground cover percentage is more frequently used to describe ground surface condition, and is more intuitive. The three methods used for estimating ground cover percentage differed significantly from the FSDMP method for all cover types except coarse wood. Coarse wood estimates did not differ among methods because large pieces of wood often completely covered the FSDMP plot, creating a similar assessment to the step-point method. Accurate monitoring predictions of ground cover are important for meeting soil quality standards in the U.S. Forest Service, and are also useful for

understanding and predicting soil erosion processes. Since frequency estimates from the FSDMP overestimated the occurrence of bare soil cover, much larger predictions of water erosion were produced with the Disturbed FSWEPP model.

The 15cm dia. plot technique was the most efficient method for sampling ground cover at an 80% confidence level, and could reduce sampling time from the FSDMP method by approximately 38 minutes per sampled site. When using a low sample size Rapid Assessment, the step-point method produced the lowest standard error of bare soil with a sample size of 43. Overall, however, no cover estimation method showed a clear advantage with reduced sample sizes.

My study indicates that managers should use a percent ground cover assessment technique, rather than the FSDMP for bare soil and erosion prediction modeling. For estimates of other soil disturbances, such as soil compaction and disturbance classes, the FSDMP method may provide a reasonable estimate of percent disturbance cover, as it did for coarse wood. However, additional research is needed to assess this relationship.

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