GALLATIN NATIONAL FOREST

1991 SOIL MONITORING PROGRAM

SUMMARY REPORT

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04/10/92

SUMMARY OF FOREST PLAN DIRECTION

Soil and site productivity issues relate to the Gallatin National Forest Management Plan as follows:

Soil and Water Quality Maintenance: All practices will be designed or modified as necessary to maintain land productivity (pg. II-24).

Timber production: We will provide a sustained yield of timber products and improve the productivity of timber growing lands (pg. II-1). Site prep. and debris disposal methods will be prescribed which ... maintain an adequate nutrient pool for long-term site productivity through the retention of topsoil and soil organisms.

Finally, maintaining the productivity of the land is central to the Forest Service philosophy of sustained yield.

INTRODUCTION

Soils are a vital component of the natural ecosystem. This is especially true in semi-arid mountainous areas such as the greater Yellowstone area where surface soils are typically thin and are slow to develop. Much scientific work has shown the critical importance of the surface layer, or A horizon, in maintaining healthy ecosystems and site productivity (Harvey and Neuenschwander, 1990; Perry, et. al., 1989). In mountain environments this surface layer is where most biological activity takes place, and cannot be replaced or even approximated by deeper layers. This layer is also most easily damaged by equipment used in logging operations. Topsoil removal, compaction, smearing or sealing, and charring are the most common types of disturbance.

Research Background

Current research shows that increases in soil bulk density (compaction) are only slowly reversible. Measurements made by Froehlich, et al. (1985) showed that bulk densities on former skid trails were still higher than undisturbed areas 23 years after logging. Also, Vora (1988) reported that surface soil compaction from tractor skidding may last 40 years or more. One process of recovery is by the freezing and thawing of the ground surface. This does occur in the northern Rockies before snowfall. Unfortunately, its effectiveness is probably limited. Data gathered on the Gallatin National Forest shows that during most the winter the soils are insulated from the cold by a blanket of snow and remain unfrozen for the winter at a temperature of about 0^{0} C (K. Birkeland, Avalanche Forecasting Center, personal communication).

Research has correlated increases in bulk density to decreases in forest productivity in many areas (Clayton, et al., 1987; Eramian and Neuenschwander, 1989; Froehlich, 1979; Froehlich and McNabb, 1984; Froehlich, et al., 1986; Wert and Thomas, 1981), but no specific scientific studies linking forest productivity to soil disturbance have been conducted on the Gallatin National Forest. This lack of data for our particular locale makes any site specific conclusions impractical; however, existing research in similar ecosystems strongly support the conclusion that increases in soil bulk density may decrease the productivity of the forests in our region. Analysis of long-term productivity become complicated if one considers possible warming/drying trends in our regional climate; these changes are manifested in the rapid retreat of glaciers both in the southern Canadian rockies (Lageson, pers. comm., 1991) and in the Wind River range in Wyoming (Marston, 1991). It is indisputable, however, that soil disturbance does affect soil productivity on non-forested lands, and likely does in forested lands.

Soil disturbance and monitoring studies on Region 1 forests

Personnel on the Idaho Panhandle National Forest have been conducting soil monitoring studies since 1985. Their results have repeatedly shown which specific management activities produce excessive soil disturbance. These activities include: 1) tractor logging and tractor piling, 2) tractor logging using logger's choice skid trails, and 3) burning under dry soil moisture conditions (Ford, 1990). When the Idaho Panhandle National Forests began monitoring soils in 1985, most operations on gently to moderately sloping land were done by tractor yarding and piling, much as it is on the Gallatin National Forest today. On the Idaho Panhandle National Forests such practices resulted in 70 to 90 percent detrimental disturbance (Ford, 1990). New management techniques have since lowered these levels.

Results of soil monitoring work done in the summer of 1990 on the Gallatin National Forest also show a high level of disturbance (Shovic and Widner, 1991). Of the six units sampled, three were shown to be detrimentally damaged in excess of regional guidelines, while the other three were slightly below the critical level.

Purpose and Objectives of this Study

The purpose of this study is to implement Northern Region guidelines to evaluate soil damage on cutting units. In 1990, "detrimentally compacted" areas were evaluated using a rapid method that was used as a surrogate to the lengthy one described in the guidelines. The actual bulk density of those soils was measured this year to verify the accuracy of that rapid method. Specific objectives are:

- Determine soil compaction and other disturbance for soils in recently harvested areas.
- Place the current and 1990 study in a research context.
- Test correlation between the rapid "surrogate" method of measuring bulk density and the "standard" method used in the Regional guidelines.
- Expand the test area to include effects of tractor site preparation and skyline systems.

The assumptions given below are based on research literature and are not part of this study:

- Soil productivity is a component of site productivity.
- Site productivity is altered by alterations in soil productivity.
- Surface soil is important to site productivity.
- Certain kinds soil disturbance probably measurably affect long term site productivity.

METHODS

Study Area

Two timber sale areas were chosen for this project. Unit #3 of the Portal Salvage timber sale was selected for a pilot study. This unit was used in the 1990 monitoring project and was chosen to test the methodology and estimate sample size. It is located in the Gallatin Range approximately 30 miles south of Bozeman, Montana.

The main timber sale designated for study was the Moonlight timber sale, located southwest of Hebgen Lake, approximately 18 miles northwest of West Yellowstone, Montana (Figure 1). Units #2, #4, #13, and #16 were used from this sale (Table 1). This site was selected because first, it offered a variety of logging techniques within one sale, allowing the comparison of a "clearcut unit" that was "tractor yarded" (#4) to "leave tree marked" units that were either "tractor yarded" (#16) or "skyline yarded" (#2 and #13). "Clearcut" units have had all the trees removed from them, while "leave tree marked units" have a few trees marked within the unit left uncut. "Tractor yarding" is the use of bulldozers to pull logs from the site to areas where they can be loaded on trucks. "Skyline yarding" is usually done on steeper slopes, where a cable strung over the unit is used to drag the logs across the site. Either one or both ends of the log is suspended above the ground for most of its travel.

The second reason for this choice is that the area was being harvested at the time of the study. Except unit #4 (logged in 1989), the units studied were sampled within weeks of harvest. This assured the study used the most current harvest techniques on the Gallatin National Forest. Also, characteristics of the site represent current or recent sales on the Gallatin (Table 1).

Finally a current sale allowed an analysis of the effects of site preparation techniques (the preparation of a site for natural regeneration or planting after harvest) on soil disturbance at one site. Site preparation involves "scarification" or the clearing of all materials from the soil surface. This is usually accomplished with tractors having front mounted blades. Site #16 was sampled for soil disturbance both before and after site preparation.

Soil Disturbance

Methods for determining soils disturbance were adapted from Howes, et al. (1983), and were equivalent to those used for last year's soil monitoring project (Shovic and Widner, 1991). In short, a grid (with an interval such that 15 to 17 transects would be included in each unit) was randomly placed over the timber sale map of the unit. Intersections of the grid determined origin points for each transect. Transect origins were located in the field by taking compass bearings and pacing. To insure random orientation of transects, random numbers between 0 and 360 were generated by computer in the office for use as transect azimuths.

Transects were 100 feet long. Soil surface conditions along each transect were evaluated to the nearest foot, and were placed into one of the following categories:

- Undisturbed (UN) - Surface and subsurface horizons of the soil are in their natural, undisturbed state; or have not been disturbed if equipment has been on the site. The litter layer may have been disturbed, but there is no evidence of soil compaction, or other disturbance.
- Deposited (DE) - soil has been moved away from its original location either by equipment or erosion and deposited here. Deposits can be on native, undisturbed soil ; or on previously disturbed soil.
- Compaction Observed (CO) - soil is observed to be compacted, but is otherwise undisturbed and the organic (or "litter") layer is intact.
- Displaced (DI) - soil has been removed from the profile by equipment or logs to another relatively horizontal location.
- Eroded (ER) - soil has been removed (detached and transported) by wind, water, ice or gravity.
- Burned (BU) - soil has been charred.
- Puddled (PU) - soil structure has been destroyed and the soil surface has been "smeared" and sealed. This is usually caused by equipment or log movement. Puddled soils are also usually displaced, compacted, or deposited.

Vertical displacement of each category was also measured and recorded to the nearest inch. Average displacement along the transect was measured for a continuous length for a given category of relatively similar appearance. No vertical displacement was used for soils in the "burned" class.

In the 1990 study all areas underneath slash piles were assumed to be undisturbed. However, this was modified for 1991 because it was felt that this biased the data in favor of the undisturbed class. Since, realistically nothing is known about the soils under slash piles, the transect distance underneath slash piles was not evaluated, and a distance equivalent to that transect length was added to the end of that transect. Temporary roads in cutting units were evaluated, as in 1990.

Detrimental and Severe Disturbance

Classification of a soil as "detrimentally" or "severely" disturbed is determined by the disturbance category and the magnitude of that disturbance. The Forest Service Soil Management Handbook (FSH 2509.18), outlines Regional criteria for "detrimental" changes in soil properties and is used here. Specifically the handbook states that:

"A minimum of 70 percent of an activity area must retain soil properties favorable for plant growth. No more than 30 percent of an activity area can be detrimentally compacted, puddled or displaced [detrimentally disturbed]. Within the 30 percent detrimentally compacted, puddled, or displaced no more than 15 percent of an area can be severely affected. Most heavily used skid trails, landings, temporary roads or similar disturbances are severely affected."

These guidelines were developed with research and field experience, and represent levels of disturbance above which long term productivity is probably affected. Soils which fall into the undisturbed or the deposited categories are considered to be undamaged. Soils in the CO class are considered "damaged" if bulk density increases by 15% or more. A surrogate assessment of the CO class is made in both the 1990 and the present 1991 study. This method replaces the actual physical measurement of bulk density. It correlates highly with actual bulk density measurements (see below), and is used for all sites in the 1991 study. The assessment is based on vertical displacement of soil without significant horizontal movement. If vertical displacement exceeds one inch, then the soil is considered damaged. This threshold was developed assuming a 6 inch depth affected layer and a 15% allowable decrease in soil volume.

Displaced (DI) and eroded (ER) soils are considered damaged if a vertical depth of 3 inches or more of topsoil is removed. Burned (BU) soils are considered damaged if charring occurs at depths greater than 2 inches. Finally, all soils that are puddled (PU) are considered damaged.

Total "detrimental" disturbance is calculated as the sum of the damaged soils in each surface condition class and expressed as a proportion of the total. Total "severe" disturbance was limited to the sum of the damaged soils within the DI category.

Bulk Densities

Bulk density measurements were made using methods recommended in the Regional Guidelines. These are correlated to the surrogate method described above to verify its accuracy for the CO class.

Regional guidelines suggest that bulk density measurements be taken every five feet along each transect. Such high-density sampling results in an unrealistically large number of bulk density measurements. For example, a typical unit has about 16 transects. Taking bulk density measurements every five feet on each transect results in 20 measurements per transect, or a total of 400 bulk density measurements per unit. The average time to take one of these measurements using the recommended method for stony soils, including lab time, is about 1.5 hours. Thus, sampling one unit would take 600 person-hours, or would take one person 15 weeks, not including travel time! These guidelines may have been developed in areas without stony soils, where techniques for faster measurement of bulk densities are available.

In other studies, many samples were needed to estimate variability. Seven studies used an average of 71 samples to obtain adequate reliability (Clayton, et. al. 1987; Eramian and Neuenschwander, 1989; Froehlich, et. al., 1985; Froehlich and McNabb, 1984; Froehlich, 1979; Wert and Thomas, 1981). Because of time constraints on this study, a method was needed to reduce the required number of measurements. Stratified sampling has been recently suggested by others as a sampling technique for these kinds of data (Geist, et al., 1990). Therefore, measurement locations were stratified to maximize sampling efficiency.

Strata were based on the following parameters. Since areas that were either puddled or displaced 3 inches or more were already considered "damaged" under current guidelines, bulk density measurements were not taken in these areas. Likewise, measurements in areas evaluated as undisturbed would not be a good use of time. The areas sampled for bulk density fell into two categories: 1) areas displaced less than 3 inches in the DI class, and 2) areas in the CO, ER, or BU class. Most the measurements taken fell into the CO class. Sample size was incremented until an adequate reliability was reached.

Bulk density is difficult to measure in the stony soils of the Gallatin National Forest. The sand excavation method of measuring bulk density (McLintock, 1959), which was recommended by the Region, was used. This method has been successfully used by others in the greater Yellowstone area (Lane, 1990), and has been called the "standard of precision" for bulk density measurements (Cassidy, 1981). As mentioned above, however, this method is time consuming. A brief explanation of the method follows:

1) Special 30 grit silica sand was purchased. This sand has been washed and sieved to achieve a uniform particle size. It is particularly good for this kind of work because it has consistent packing characteristics.

2) The packing characteristics of the sand (bulk density) and the weight of sand held above the plexiglass baseplate were determined. One kilogram bags of sand were pre-weighed to be taken into the field.

3) At each sample site in the field, a 30 cm by 30 cm (approximately one square foot) area was carefully flattened out. The duff and approximately the first inch of topsoil were removed, and the plexiglass baseplate was placed on the site.

4) The baseplate has a 15 cm diameter hole in it. The soil was carefully excavated through this hole with a large spoon and placed in a sample bag.

5) A funnel attached to a buret stand was placed on the baseplate and sand was poured through the apparatus into the excavated hole until the hole was full.

6) The sand was then tamped by pushing the handle of a spoon into it 50 to 60 times. This insured uniform packing of the sand as well as making sure that the sand worked its way into any small unconformities in the excavated hole.

7) Excess sand was struck off with a ruler, and was returned to the bag it came from so it could be returned to the lab for weighing. The weight of the sand left (from the initial one kilogram that was pre-weighed), combined with the bulk density of the sand allowed calculation of the excavated hole volume.

8) Soils were taken to the lab and dried in an oven at 105^0 C for at least 48 hours. Roots were separated from the sample and a sieve was used to separate the fines (less than 2 mm in diameter) from the coarse fragments. Peds were broken up with a mortar and pestle. All three fractions of the soil (roots, coarse fragments, and fines) were weighed, allowing total bulk density to be calculated. Using assumed bulk densities of 0.5 gm/cc for roots and 2.65 gm/cc for coarse fragments (Cassidy, 1981) the volume of the fines could be determined, by that allowing the bulk density of the fines to be calculated. Besides these data, a complete soil profile description was taken in an undisturbed area next to units that were evaluated for increases in bulk density.

Analysis

Statistics for Disturbance Measurements

From 15 to 17 transects were used in each sample unit. Grid spacing was calculated using the following formula (from Howes, et al., 1983):

$I = (A/n)^0.5$, where:
A = area in square feet
n = sample size
I = spacing interval

A standard single-tailed t-test was used to test if the mean value for detrimental damage for a particular site was greater than 30%(FSH 2509.18). The single-tailed test was used since the test was only applied to see if the transect damage was greater than the regional standard (Barber, 1988). The same test was used to see if the mean value for severe damage was greater than the 15% level mandated by the Region. P-values were computed instead of using set alpha levels. A "P-value" is the probability of observing a test statistic ($t_c$alc in our examples below) as extreme as we actually calculated. P-values are determined by computing $t_c$alc, and looking at the minimum possible value for alpha for which the relationship would still be valid in a t-table. Thus, the lower the p-value, the more statistically valid the result. The t-test is performed as follows:

$t_c\text{alc} = (MTD - RS)/(s^2(1/n)^0.5)$
p-value = minimum value for alpha for which t_{calc}
$> t_{table}$ with degrees of freedom = n-1
where:
MTD = mean transect damage (detrimental or severe, depending on the test)
RS = regional standard (30% for detrimental damage, 15% for severe damage)
s^2 = sample variance for the transects
n = sample size

Statistics for Bulk Density Measurements

For bulk densities a one-tailed two-sample t-test was used to test the relationship between disturbed and undisturbed sites (Barber, 1988). The two sample test is quite similar to the one sample test described above, and is performed as follows:

$t_{calc} = ((BD_DIS - BD_UN) - RS)/(s_p2(1/m + 1/n)^0.5)$
p-value = minimum value for alpha for which t_{calc}
$> t_{table}$ with degrees of freedom = m+n-2
where:
BD_DIS = mean bulk density of the disturbed sites
BD_UN = mean bulk density of the undisturbed sites
RS = regional standard for the difference between disturbed and undisturbed soils (15%)
m = number of disturbed samples
n = number of undisturbed samples
s_p2 = pooled variance = $((m-1)s_12 + (n-1)s_22)/(m+n-2)$
s_12 = sample variance of the disturbed samples
s_22 = sample variance of the undisturbed samples

The two sample test discussed above assumes the population variances for the two samples are equal. Complications arise when population variances are not equal. According to Devore and Peck (1986), "there are several possible inferential procédures [to deal with these problems], but there is still controversy among statisticians about which one should be used."

We used an F-distribution to test whether the populations' variances were "statistically equal" given the available data. This test is done as follows (values of s_12, s_22, m, n are already defined above):

s_12/s_22 is the test statistic and is applied to an F distribution with n-1 and m-1 degrees of freedom. From this an alpha level is computed. If the computed alpha level is less than or equal to 0.1 (our chosen alpha level), then the population variances are considered to be equal.

This test is not very "powerful" i.e., it is not very sensitive in detecting differences between variances. but it is the only test available (Munholland, P. 1989. Personal communication. Department of Mathematics and Statistics, Montana State University, Bozeman, MT.). Results did not show any differences between the sample variances of our populations of interest, so it was unnecessary to find a test for the difference of means of two populations with unequal variances.

Computation of Results

Data were analyzed on a Dell 310 Personal Computer using a Quattro Pro 3.0 spreadsheet program. Spreadsheets were designed to automatically calculate tallies and statistics for both transect and bulk density data, and required the user merely to input data. Not only did this minimize the potential for calculation errors, but it was fast, allowing all the transect data for a particular unit to be entered and analyzed in about an hour, and all the bulk density data for a unit to be entered and analyzed in less than 15 minutes. Over 2600 data points were required for this study. Hand or manual calculations would have been ineffective.

RESULTS AND DISCUSSION

Bulk Densities and the CO Category

The soil monitoring study conducted last year (Shovic and Widner, 1991) used modifications of standard methods for analyzing soil disturbance. Specifically, a "compaction observed (CO)" class of soil disturbance was used in the analysis, with a surrogate method for measuring bulk density (See Methods). One of the primary goals of this year's monitoring study was to identify and quantify changes in bulk density in areas that were classified as "CO" to verify the usefulness of the rapid method. Recall that random bulk density measurements in disturbed areas were stratified so that all measurements were taken in areas classified as CO or DI (less than 3 inches). By chance, only two out of 36 bulk density measurements were taken in the DI class, and 34 in the CO class. Those in the DI class were both in areas that were displaced 2 inches. Twelve bulk density measurements were taken in each cutting unit. These twelve measurements were compared with 8 bulk densities from undisturbed sites around the unit. It was found that this number of samples was sufficient to keep sample variance between other bulk density measurements reported in the literature (Table 2); (Clayton, 1990), and allowed a comparison of disturbed and undisturbed areas. Undisturbed sites were selected in the field by locating representative sites around the unit that had similar soil, landform, and vegetation.

Bulk densities in two of the units evaluated (Moonlight #4 and Moonlight #16) were much greater in areas in the CO class than in undisturbed areas around the perimeter of the units (Table 2; Figure 2). The p-values for these units (for a 15% increase in bulk density) are equal to or less than 0.001, or statistically highly significant. At an alpha confidence level of 0.05, disturbed areas of Moonlight units #4 and #16 had, respectively 30% and 34% greater bulk densities than undisturbed areas around the perimeters of the units. **The data at these two sample sites strongly indicate that areas that were classified as "compacted observed (CO)" have been compacted more than the threshold level of 15% set by the region. It is likely that long term productivity has been affected.**

All sample areas on these two sites were carefully evaluated to assure that soils and landscapes were similar both within cutting units and on the sampled borders. This is critical to study success as showed by the high variability on the Portal Creek site. There was only weak statistical evidence (p-value = 0.2) of a 15% difference between the disturbed and undisturbed bulk densities (Table 2). A reasonable explanation for this lies in the geomorphology of the site. At the Moonlight units surficial material is primarily glacial till, and the slopes next to the site are of similar slope, aspect, and parent material to those within the site. This made it probable that undisturbed samples were representative of samples within the unit before disturbance. The Portal Creek unit, on the other hand, was on an old landslide. The boundaries of the cutting unit were coincidental with the boundaries of the landslide. Few appropriate sites existed to take undisturbed measurements on the steep slopes adjacent to the unit. The soils on those steep adjacent slopes probably did not have the same parent material as areas within the unit and thus variability was too high for a valid comparison. This knowledge was used in selecting the Moonlight units.

Bulk density measurements appear to validate the results and methods of the 1991 soil monitoring report, and the use of the controversial CO class. Soils in that class were found to have increases in bulk densities well in excess of the 15% level used by the region to determine detrimental compaction. It appears that the surrogate method used for evaluating soil disturbance is adequate and statistically valid. Additional work on this is recommended. This method could be used to evaluate the effects of different management strategies on long term productivity for the Gallatin Forest. Extrapolation to other areas is not recommended without further study.

One additional note is of interest here to the scientific community. Bulk densities measured here were relatively low when compared to other studies. To test whether the low measurements were due to the procedure used, comparisons were made with a soil core sampler (the other bulk density test recommended by FSH 2509.18) in non-stony soils. Using the soil core method resulted in bulk density measurements that averaged 18% greater than bulk density measurements made with the sand displacement method (Table 3). This is significant at an alpha confidence level of 0.05. Thus, actual measurements made in this study may be underestimated by as much as 18%. Still, long term changes in soil productivity and regional guidelines are based on **changes** in bulk density and not on absolute values. Therefore this anomaly, though interesting, is not relevant to conclusions made in this study.

Soil Disturbance with Transect Measurements

Tractor logged units sampled have detrimental damage well in excess of the regional standard of 30% (Table 4; Figure 3). Results were shown to be statistically significant with p-values less than 0.005. These data are consistent with data gathered last year (Shovic and Widner, 1991), and with soil monitoring results on other Region 1 forests. As on the Idaho Panhandle National Forest (Ford, 1990), the tractors in these units caused different kinds of soil damage, including compaction, displacement, puddling, and erosion (Figure 4). One type of common damage was not mentioned in the regional guidelines. Some areas had a mixture of soil and woody debris, sometimes relatively loose, but usually over a highly compacted, puddled layer. It would have been advantageous to have another class, possibly called "churned". For this study, "churned" areas were put into most closely fitting standard classifications. The amount of disturbed and "churned" area is not surprising when one watches a tractor logging operation. Tractors are driven around the unit to pick up trees, and as they move and turn the soil surface layers are disturbed.

In contrast, the two units that were skyline logged had little detrimental or severe soil disturbance, and were well below regional standards (Table 4, Figure 3). Soil disturbance was primarily displacement (Figure 4), probably from the scraping of logs across the soil surface. Skyline techniques have an average of over 8 times less disturbance than tractor methods (Table 4).

Comparisons of transect data from unit #16 before and after site preparation show that site preparation with tractors has an impact on detrimental soil disturbance (Table 4, Figure 3). Because of the large amount of variability between transects, this relationship is not statistically significant. Still, detrimental disturbance increased from 40.8% to 55.4% due to site preparation, while the percentage of undisturbed areas dropped from 52.5% to 20.4% (Table 3). Site preparation approximately doubled the proportion of puddled and displaced soils (Table 4, Figure 4). Apparently site preparation techniques redisturbed areas already disturbed, and therefore the cumulative disturbed area is not much greater than pre-preparation. However, the kinds of disturbance change to more detrimental categories.

These results are not unexpected since this type of site preparation entails driving a tractor over the unit to attain 30 to 50% scarification. Indeed, there may be a conflict in relation to soils disturbance and site preparation. Silvicultural standards currently call for 30 to 50% scarification of sites during site preparation, and this is primarily done by tractor. In contrast, 30% has been set as the allowable level for soils disturbance. Site preparation with a tractor will cause some sort of detrimental soil disturbance; therefore, with current site preparation techniques it is unlikely that long term site productivity can be preserved.

A different perspective on the transect data can be attained by looking at the amount of soil removal or deposition. The data show that approximately 3 to 3 1/2 inches of topsoil have been either removed or compacted from disturbed areas, while between 4 and 7 inches of soil has been deposited in areas classified as "deposited" (Table 5). Therefore, there is relatively more soil deposited in areas classified as "deposited" than there is soil removed or compacted in the other areas of disturbance. However, there is a much larger area in the former class than in that of the latter class. Thus, when soil removal and deposition is calculated over the whole unit area, between 0.2 and 2 inches are either removed or compacted, and approximately 0.15 to 0.8 inches are deposited, making for a net negative surface change. A marked difference exists between tractor and skyline logged units when removal and deposition are calculated over the entire unit area. Skyline logging shows a loss or compaction of 0.24 inches and a gain of 0.25 inches for a net surface change of approximately 0 inches. Conversely, on the tractor units there is a loss or compaction of 1.88 inches and a gain of 1.00 inches for a net surface change of approximately -0.88 inches. This much soil loss may be detrimental for these types of areas where soil formation may take 1000's of years.

EVALUATION AND RECOMMENDATIONS

- We are exceeding guidelines for detrimental and severe soil disturbance in our tractor harvest units. Our judgement is that site productivity probably is being affected. We have implemented modified timber harvest and site preparation practices to decrease soil disturbance on tractor units. Skyline logging is effective at cutting down soil losses and compaction associated with tractor units. Additional soil-protecting practices have been in use on other forests for several years. The Idaho Panhandle National Forests currently use techniques such as winter logging and designated skid trails to reduce soil compaction during logging operations. For site preparation, broadcast burning and grapple piling are suggested. Care has to be taken when burning because a severe burn can inhibit soil productivity; therefore, the Idaho Panhandle National Forests burn only when soil moisture levels are above 25%. Such practices as winter logging, use of designated skid trails, broadcast burning, and grapple piling could be implemented on the Gallatin National Forest to protect the long-term productivity of the soils.

The following specific recommendations are suggested:

- Logging practices should be modified to reduce disturbed area or to reduce the severity of the disturbance. The former could be accomplished by using designated skid trails or skyline logging (where appropriate), while the latter could be accomplished with winter logging over snow or using low ground pressure vehicles.

- Site preparation methods should be modified to lessen their effects on the soils. Wherever possible, broadcast burning should be used to eliminate excess fuel and achieve site scarification instead of dozer piling. Grapple piling may also be an acceptable alternative to dozer piling for excess fuel elimination. It may be necessary to hand scalp and plant more sites to get adequate regeneration. Use of different kinds of dozer attachments should be evaluated, as well as new technology in low ground pressure vehicles. Education of contractors and contract administrators should be emphasized.

- The rapid bulk density measurement methods proposed and verified in this study should be used in future projects to more effectively and efficiently monitor soil disturbance.

- Additional soil monitoring studies should be conducted on units where new techniques for minimizing soil disturbance are being used. These studies should not only help us to insure that regional guidelines are being met, but also should identify the best and most economical techniques for keeping soil disturbance below detrimental levels.

The application of regional guidelines for soil disturbance are designed to act as a "barometer" of forest practice effectiveness, and a tool for better management decisions. Based on the results of the 1990 and 1991 studies, forest management personnel have made changes in harvest methods. All new timber sale proposals include mitigation measures designed to reduce soil disturbance levels during harvest. These method changes included designating skid trails at set spacings, restricting use off trails to low ground pressure vehicles, alternate site preparation techniques, increased administration, and continued soil monitoring of new applications.

While many of these new techniques and practices may seem complicated and difficult at first, carefully protecting the soils in our region is the most cost-effective alternative. Semi-arid mountain soils develop slowly, and detrimental impacts will last for generations. Protecting the soils will insure that productivity is maintained, allowing cut areas to recover as quickly as possible, and thereby preserving sustainable forestry in our region.

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Gallatin National Forest

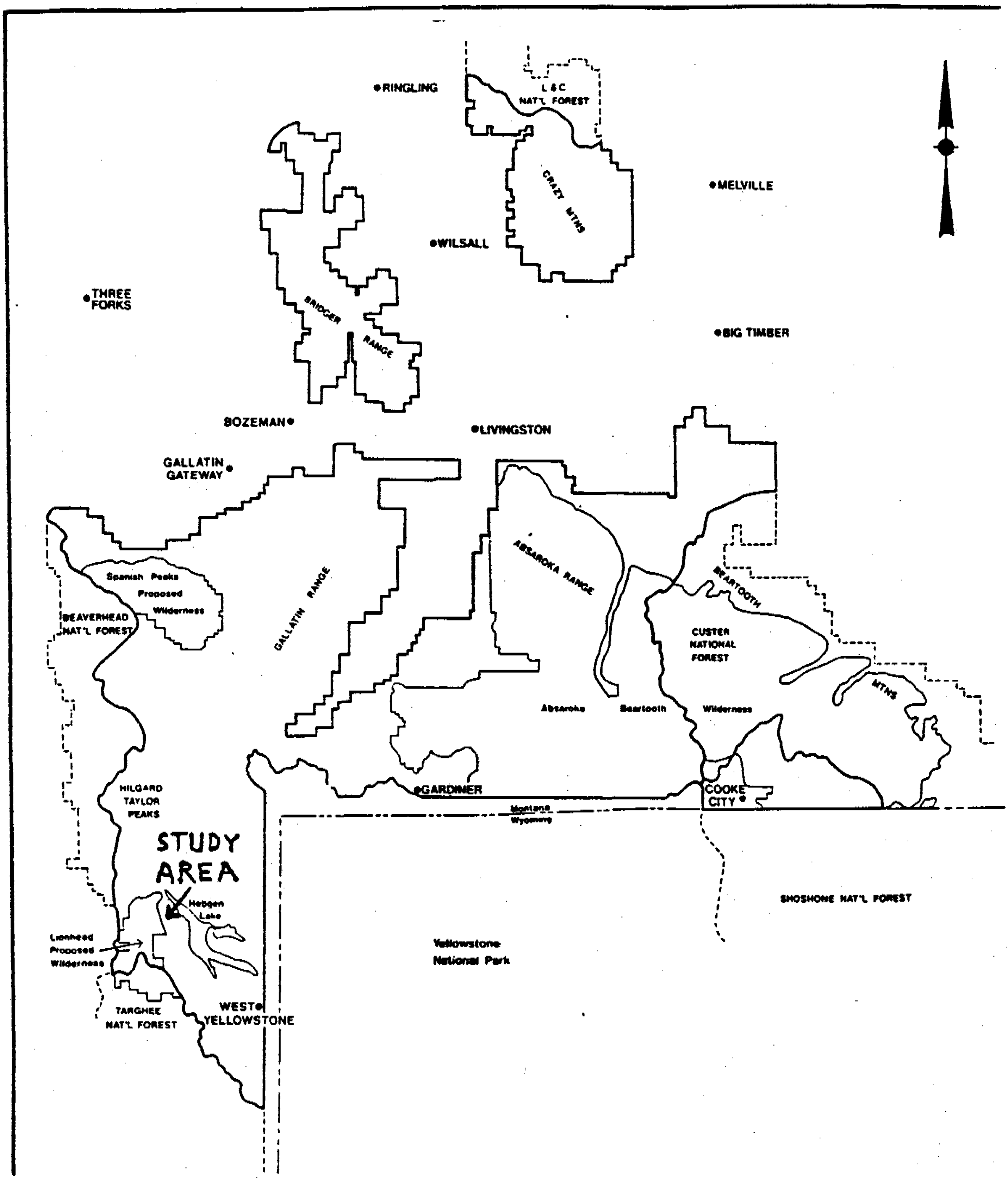

Figure 1. Study Area Location

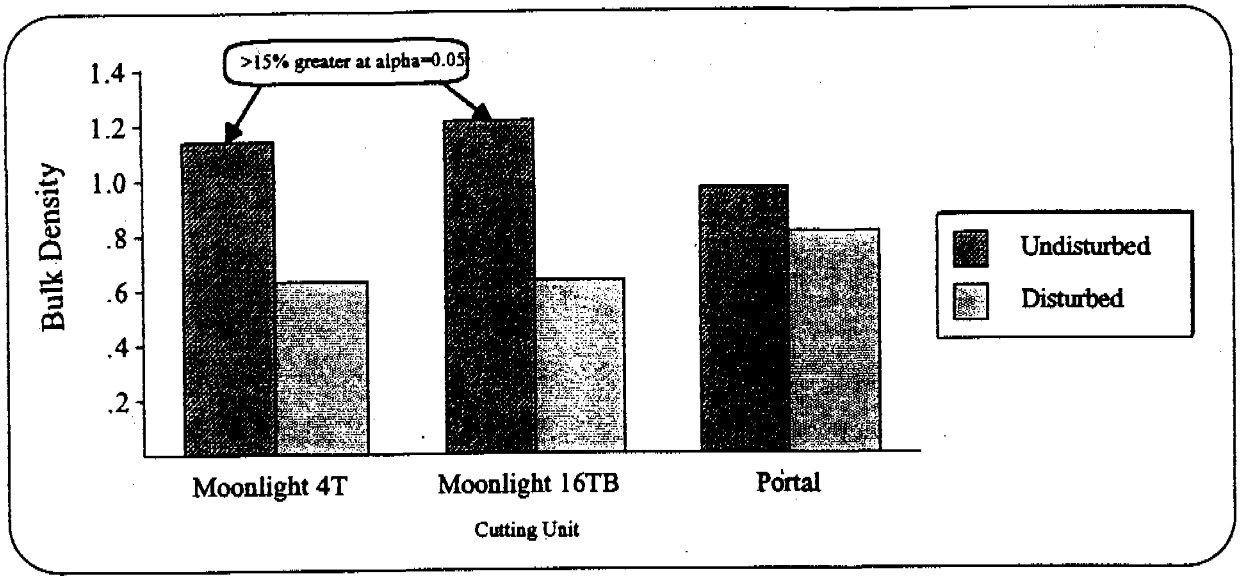

Figure 2. Average Bulk Density of the Fine Soil Fraction for Undisturbed and Disturbed Areas

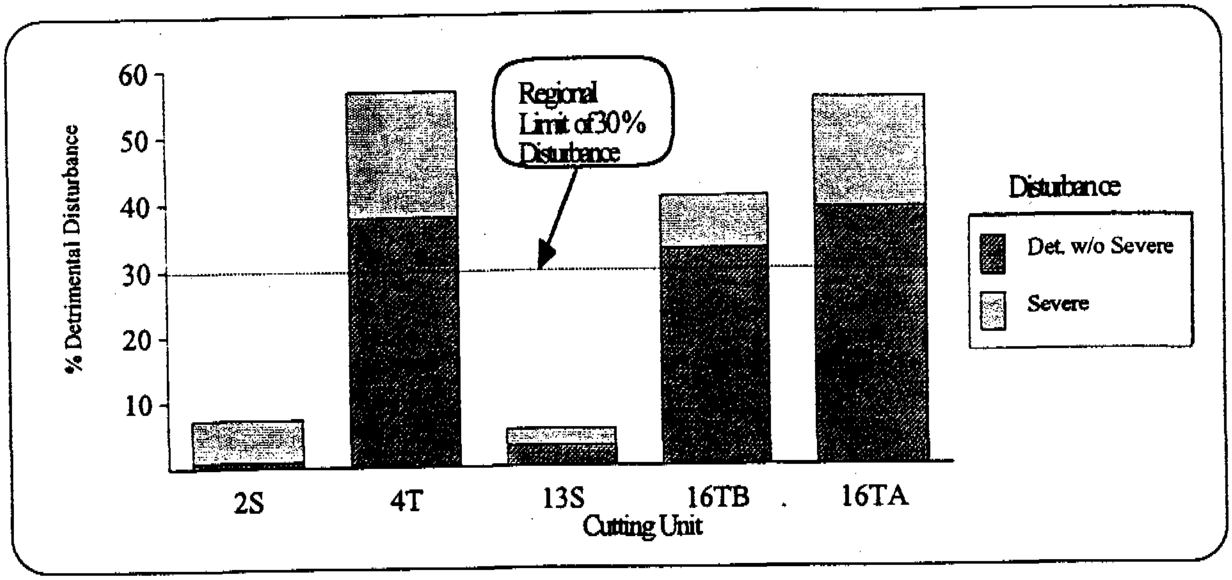

Figure 3. Detrimental Disturbance by Cutting Unit (T=tractor; S=skyline; TA=tractor, before site prep.; TA= tractor, after site prep.)

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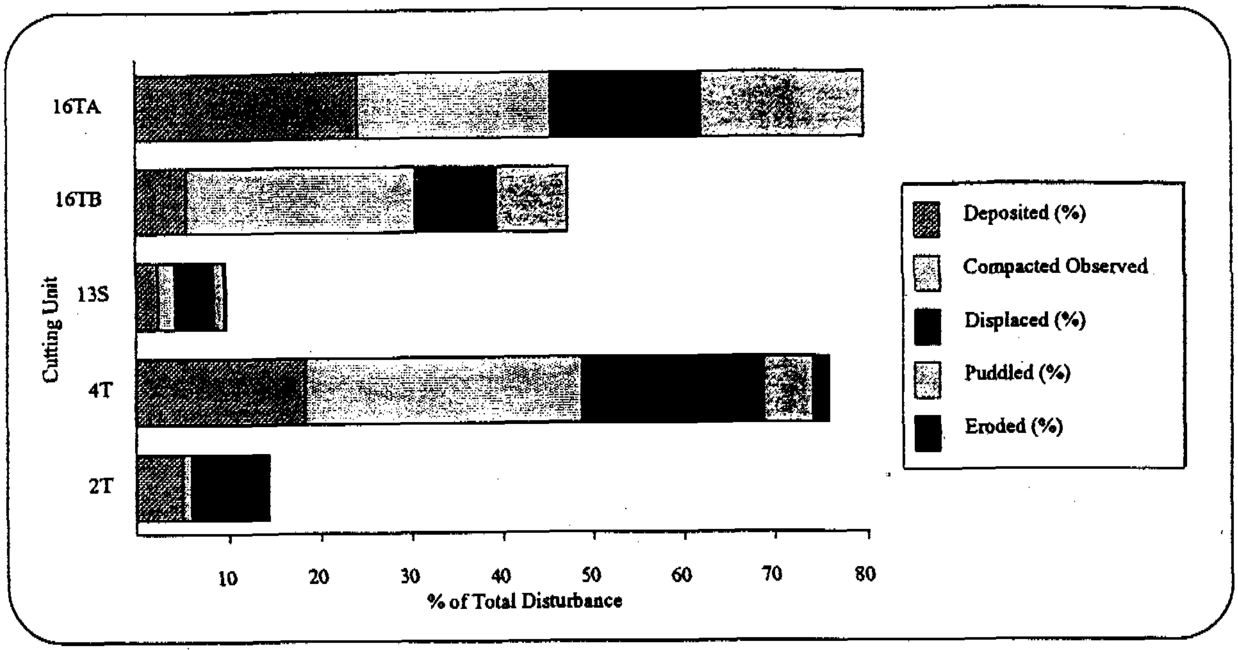

Figure 4. Detrimental Disturbance Types by Cutting Unit (T=tractor; S=skyline; TA=tractor, before site prep.; TA= tractor, after site prep.)

Table 1. Characteristics of Monitored Sale Areas (Moonlight Units used in 1991 are in bold cells).

Sale	District	Area (ac)	Elevation	Slope	Dates	Soils (texture, coarse frag.)
Bear Chestnut	Bozeman	18	6800'	10-30%	87-91	mod. fine; few c. f.
Cooke City	Gardiner	35	8400'	10-25%	89-91	med. - mod. fine; many c. f.
East Boulder	Big Timber	133	7500'	15-25%	85-90	mod. coarse; many c. f.
Iron Mountain	Big Timber	42	6600'	10-30%	88-90	medium; few - many c. f.
Portal Salvage	Bozeman	25	7300'	10-25%	86-90	mod. fine; few c. f.
West Hebgen	Hebgen Lake	33	7600'	0-25%	86-89	mod coarse; few - many c. f.
Moonlight #2 (Skyline)	Hebgen Lake	23	7400'	40-50%	91	mod coarse; many c. f.
Moonlight #4 (Tractor)	Hebgen Lake	34	7600'	0-25%	89	mod. coarse, many c. f.
Moonlight #13 (Skyline)	Hebgen Lake	34	7400'	35-45%	91	mod. coarse, many c. f.
Moonlight #16 (Tractor)	Hebgen Lake	28	7200'	5-25%	91	medium, few c. f.

Table 2. Soil bulk densities of the fine fraction (< 2mm) and the total soil in disturbed and undisturbed areas

Unit	Disturbed or Undisturbed?	< 2mm Soil Bulk Density (gm/cc)	Standard Deviation	Coeff. of Variation	n	15% Different (at alpha = 0.05)?	p-value	(Total Soil Bulk Density (gm/cc))
Moonlight #4	Disturbed	0.99	0.19	0.19	12	YES	0	1.14
	Undisturbed	0.56	0.11	0.2	8			0.63
Moonlight #16	Disturbed	1.05	0.2	0.19	12	YES	< 0.001	1.21
	Undisturbed	0.54	0.09	0.17	7			0.63
Portal Creek	Disturbed	0.69	0.12	0.17	12	NO	0.2	0.97
	Undisturbed	0.56	0.2	0.36	12			0.81

Table 3. Soil Core Method vs. Sand Cone method for bulk density measurements

Sample	Core Bulk Density	Cone Bulk Density	Difference	
1	1.05	0.86	0.19	
2	1.02	0.93	0.09	
3	1.02	0.86	0.16	
4	1.06	0.95	0.11	
5	1.1	0.83	0.27	
Average	1.05	0.89	0.16	% difference = 18

Table 4. Transect disturbance on selected harvest units (p values given for significant differences only).

Unit #	Type of Logging	Detri-mental Dist. (%)	Exceeds Regional Std.?	Severe Dist. (%)	Undis-turbed (%)	Deposited (%)	Compacted Observed (%)	Displaced (%)	Puddled (%)	Erod-ed (%)
2	Skyline	7.3	NO	6.3	85.7	5	1	8.3	0	0
4	Tractor	56.6	YES p <0.001	18.8	24.2	18.3	30.4	20.1	5.4	1.7
13	Skyline	5.7	NO	2.6	90.3	2.4	1.8	4.1	1.2	0.2
16	Tractor (before site prep.)	40.8	YES p <0.005	7.9	52.5	5.5	24.9	8.8	8	0
16	Tractor (after site prep.)	55.4	YES p <0.001	16.4	20.4	24	21.3	16.6	17.7	0

Table 5. Average vertical displacement by harvest unit.

Unit	Type of Logging	As Proportion of Each Disturbed Area		As Proportion of Entire Disturbed Area		As Proportion of Entire Unit Area	
		Soil removal or compaction (in)	Soil deposition (in)	Soil removal or compaction (in)	Soil deposition (in)	Soil removal or compaction (in)	Soil deposition (in)
Moonlight #2	Skyline	-3.02	7.28	-1.97	2.54	-0.28	0.36
Moonlight #4	Tractor	-3.05	4.63	-2.33	1.1	-1.76	0.83
Moonlight #13	Skyline	-3.09	5.53	-2.23	1.54	-0.2	0.14
Moonlight #16 (before prep.)	Tractor	-3.67	6.1	-3.22	0.76	-1.56	0.36
Moonlight #16 (after prep.)	Tractor	-3.62	4.86	-2.53	1.46	-2.01	1.17
Average for Skyline Units..						-0.24	0.25
Average for Tractor Units (After Site Preparation)............................						-1.88	1.00