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Soil Compaction Monitoring of the Pool Timber Sale, Rio Grande National Forest, Colorado, 16 Years After Logging

John J. Rawinski and Deborah S. Page-Dumroese

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Abstract

We conducted a soil monitoring project in 1992 after a shelterwood harvest. One year after harvesting, we determined that 21.32 percent of the area in Unit 5 of the Pool Timber Sale was considered to have detrimental soil compaction. In 2007, we conducted another monitoring project on the same stand by the same person to determine the degree of soil compaction recovery on skid trails. Results from the 2007 monitoring showed that detrimental soil compaction still existed in the stand and that there was no significant difference between the 1992 and the 2007 skid trail bulk densities. Monitoring the occurrence of platy structure on these sites was not an accurate predictor of detrimental soil compaction.

Keywords: compaction, soil monitoring, skid trails, soil recovery, harvesting

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Introduction

In southwest Colorado, recent insect outbreaks have resulted in some forested stands being re-entered after a 10 to 20 year absence of logging activity. Assessing the existing soil impacts within a stand is necessary to meet the intent of the National Environmental Policy Act to describe the existing conditions as well as to estimate cumulative effects. In addition, because of the National Forest Management Act of 1976 and related legislation, management of public lands must maintain the productive potential of National Forest lands. With the enactment of the Healthy Forest Restoration Act in 2003, forest management decisions increasingly rely on repeated entries to conduct partial cuts for the removal of small-diameter trees from forest stands. However, these multiple entries by mechanical equipment to reduce potential wildfire risk and severity may impact ecosystem processes and site sustainability. As described in Curran and others (2005), multiple stand entries can increase soil impacts so that cumulative effects at the stand and watershed scale become significant.

In USFS Region 2, managers often question the longevity of soil compaction and the rate of soil recovery following harvest activities. Numerous studies have shown that once compacted, forest soils are often slow to recover and may require decades to return to pre-disturbance levels (Froehlich and others 1985; Sands and others 1979; Tiarks and Haywood 1996). However, recovery rates are dependent on many factors, but chief among them is repeated harvest cycles, soil moisture conditions at the time of harvest, soil texture, and rock-fragment content (Liechty and others 2002). The extent and depth of impact, initial bulk density, and the recovery rate are all factors that determine the consequences of timber harvesting on site sustainability.

Soil standards and guidelines in USFS Region 2 require that no more than 15 percent of an activity area have "detrimental" soil impacts (areal extent) and the Supplement defines detrimental soil compaction as an increase in soil bulk density of >15 percent over natural conditions (USDA Forest Service FSH 2509.18 1992; USDA Forest Service 1996). Exceeding the standards prior to another harvest cycle could indicate the need for some form of site amelioration. However, data is scarce on the long-term recovery of compaction on high-elevation sites in Colorado. Consequently, the objective of this study was to re-monitor a site that had been previously logged and monitored to determine if soil compaction levels had recovered to pre-disturbance levels.

Methods and Materials

Site Description

The harvest unit is located in the NW ¼ of the NE ¼ of section 23, T 41 N, R 2 E. Elevation is 3352 m (11,000 ft) and the mean annual precipitation is 63.5 cm (25 in). The Ecological Unit for this site is MU 165 (subalpine fir (*Abies lasiocarpa* [Hook.] Nutt) and Engelmann spruce (*Picea engelmannii* Parry ex Engelm.)) on Seitz soils, moist phase. Sietz soils are very deep, well-drained clayey-skeletal, smectitic Ustic Glossocryalfs (Soil Survey Staff 1999). In the surface 25 cm (10 in), gravelly loam was the dominant texture and fine gravel was the predominant coarse-fragment size class, comprising an average of 20 percent by volume.

Harvest Methods

The most recent timber harvest occurred in June 1991 (Unit 5 Pool Timber Sale) using a Timbco whole-tree harvester, which is a tracked implement. Once the harvester cut the timber, it was stacked near a series of skid trails for removal by a grapple (wheeled) skidder.

Paul Hancock, Kirby Self and Holly Boaz collect core samples in June 2007.

At the landing area, trees were delimbed and bucked to length. Additionally, records indicated that there was a timber harvest on this site prior to 1962, but details on the type of equipment used and the amount of timber extracted were unavailable.

Soil Monitoring Methods

Soil monitoring was done in June 1992 using the soil monitoring protocol established by Howes and others (1983). Soil bulk density cores (core volume was 90.38 cm^3) were collected to estimate soil compaction levels within the stand. The protocol outlined in Howes and others (1983) defines three visual classes: (1) the *skid trail* visual class occurs only on defined skid trails, (2) the *miscellaneous* visual class can be found in areas where equipment has disturbed the surface soil layer, but not in a defined skid trail, and (3) the *undisturbed* visual class occurs when no trafficking can be noted on the soil surface. While all three of these visual classes were used for sample collection in 1992, only the skid trail visual class was used in 2007. A complete re-sampling of this unit using all three visual classes in the protocol was not possible due to funding constraints. No GPS coordinates were taken 15 years ago during the initial sampling, and therefore exact transects points could not be re-located. Instead, we re-established the stand boundary using air photos, established GPS coordination, and identified the main skid trails within the unit. We chose to stratify our sampling and confine it to the skid trails since they were still recognizable after 16 years.

A random number generator was used to establish sampling distances on each of the four main skid trails. Teams of two to four individuals collected the soil core samples on June 21, 2007. This date approximated the date of the 1992 sampling (June 17, 1992). Each soil sampling point was alternately directed toward left wheel rut, center, and right wheel rut. We used the same core sampler tools (90.38 cm^3), sampling depth in the mineral soil (10 to 15 cm; 4 to 6 in), and laboratory protocols of the 1992 project. A total of 32 soil samples were collected. Samples were oven-dried (105 ºC until they reached a constant weight) and weighed. Bulk density is based on the fine earth fraction of the soil (in other words, coarse-fragments were removed) and fine-fraction bulk density calculated using the equations in Page-Dumroese and others (1999).

We compared the 2007 soil density values to the same reference samples (undisturbed) we used for the 1992 sampling. Using the same reference samples was necessary since it was difficult to find an undisturbed area where no previous impacts existed. There was no reason that the original reference values of 0.93 Mg m^{-3} would not still be applicable (based on 30 core samples). Using the current Region 2 soil quality standards, a 15 percent increase from the reference stand bulk density yields a value of 1.07 Mg m^{-3} as the threshold value of compaction considered detrimental to stand productivity on this soil type.

In addition to collecting bulk density cores to estimate compaction levels, visual observations were made on soil structure. Of particular interest was the occurrence of platy soil structure and its possible use as an indicator of detrimental site impacts. Platy structure is defined as the arrangement of soil particles into aggregates that are flat horizontally (Schoeneberger and others 1998). Platy structure can be natural or it can be caused by excess trafficking.

Results and Discussion

1992 Pool Monitoring Project Summary

In 1992, a total of 233 soil samples were collected along 24 randomly selected transect points and azimuths (table 1). Transect Number 1 was disqualified since it fell on a designated road.

In Unit 5, 17.3 percent of the area was skid trails. This is generally higher than desirable on these sites. Usually, a total skid trail area of 6 percent to 10 percent in each harvest unit is preferred in ground-based logging to keep soil impacts within acceptable limits (<15 percent of the area capable of growing trees). Table 2 shows the summary of the areal extent of detrimental compaction by visual class. However, it is likely that some compaction existed in the stand prior to the 1991 logging. We based this on the fact that even the undisturbed visual class had 2.31 percent (areal extent) of detrimental compaction. This could be the result of past logging that occurred in this area pre-1962. After years of inactivity, the forest floor may appear undisturbed but may mask underlying soil compaction.

Table 1. Areal extent (in percent) of each visual disturbance class for Unit 5 in 1992. Values are an average of 233 sample points.

Transect numbers	Undisturbed	Miscellaneous	Skid trails
	------------------percent------------------		
2 through 25	11.4	71.1	17.3

A separate comparison (table 3) of the 1992 undisturbed bulk densities and the 1992 skid trail bulk densities yielded an average mean difference in bulk density between undisturbed sites and skid trails of 0.09 Mg m^{-3} and is a change of 9 percent (standard error of 0.043). This amount of difference in mean bulk density is detectable from zero ($p = 0.046$). This means that there is significant difference between the 1992 undisturbed bulk densities and the skid trail bulk densities.

2007 Monitoring Project Summary

Raw data and statistical analyses are contained in Appendix A. The two sample periods (1992 and 2007) cannot be compared in all aspects since the 2007 sampling focused solely on the skid trail class. No conclusions could be drawn regarding the miscellaneous areas or undisturbed areas since we did not investigate these components. However, this re-sampling can set the stage for future monitoring investigations.

In 1992, the average bulk density of the skid trails was 1.02 Mg m^{-3} and was slightly less than that (1.01 Mg m^{-3}) in 2007 (table 4). Although the average values were less than the 1.07 Mg m^{-3} bulk density threshold (a 15 percent increase in bulk density), skid trails accounted for >6 percent of the area classed as detrimental compaction (table 2). The average difference in skid trail bulk density between 1992 and 2007 was 0.012 with a standard error of 0.043. This amount of difference in mean bulk density is not detectable from zero ($p = 0.73$) so it would be inappropriate to interpret this result in a way that indicates that recovery on skid trails was detectable after 15 years.

Table 2. Summary of detrimental compaction (in percent) by visual class.

Visual class	Undisturbed	Miscellaneous	Skid trails	Total
	---------------------------percent---------------------------			
	2.31	12.12	6.89	21.32

Table 3. Comparison of 1992 undisturbed and skid trail bulk densities. Forty-three samples were collected in the skid trail and 30 were collected from the undisturbed areas.

Variable	Lower CL Mean	Mean	Upper CL mean	Lower CL standard deviation	Standard deviation	Upper CL standard deviation	Standard error	Min	Max
Skid trail 1992	0.958	1.0173	1.0737	0.1589	0.1927	0.2449	0.0294	0.59	1.34
Undisturbed 1992	0.8717	0.9317	0.9916	0.1279	0.1606	0.2159	0.0293	0.72	1.21
Difference (1-2)	0.0002	0.0857	0.1712	0.1549	0.1803	0.2157	0.0429		

Table 4. Average bulk density in the undisturbed and skid trail visual classes. Samples taken in 1992 and 2007.

	1992 Undisturbed	1992 Skid trails	2007 Skid trails
	--------------------------------Mg m^3-------------------------------		
Bulk density	0.93	1.02	1.01
Number of samples	30	43	32
Standard deviation	0.145	0.194	0.171

Table 5. Comparison of bulk density in 2007 with the undisturbed bulk densities from 1992. Thirty two samples were collected in 2007 and 30 samples were collected in 1992 from the undisturbed areas.

Variable	Lower CL Mean	Mean	Upper CL mean	Lower CL standard deviation	Standard deviation	Upper CL standard deviation	Standard error	Min	Max
Skid trail 2007	0.9439	1.0054	1.0669	0.1367	0.1705	0.2267	0.0301	0.717	1.368
Undisturbed 1992	0.8717	0.9317	0.9916	0.1279	0.1606	0.2159	0.0293	0.720	1.210
Difference (1-2)	-0.011	0.0737	0.1580	0.1407	0.1658	0.2019	0.0421		

The comparison between the 1992 undisturbed and the 2007 skid trail bulk densities (table 5) illustrates a small numerical reduction in skid trail bulk density between 1992 and 2007, but the reduction is too small relative to sampling variability to provide a definitive interpretation that recovery is occurring. The average difference between the bulk densities of the undisturbed sites in 1992 and skid trails in 2007 was 0.07, with a standard error of 0.042. This amount of difference in mean bulk density is weakly detectable from zero ($p = 0.089$).

The analyses above compare skid trail bulk densities within their respective populations. In USFS Region 2, compaction that exceeds the 1.07 Mg m^{-3} on this soil type is considered detrimental to vegetative growth. Based on 32 core samples collected in 2007, 11 samples (34 percent) had detrimental compaction. This compares with the 1992 project that found 18 of 42 samples (43 percent) of the skid trails to have detrimental compaction. Because of the differences in sample size and not having exact GPS coordinates from the original sample date, it is difficult to interpret whether the detrimental compaction is showing slight recovery from 1992 to 2007 or if the values are reflecting normal site variability.

Variability in Unit 5

For Unit 5, we assessed the distribution of bulk density cores in the undisturbed after sampling in 1992 and in 2007. Figure 1 illustrates how the bulk density values shift to the right hand portion of the graph. This Figure shows that compaction does not occur uniformly (all one value). Rather, bulk density values shift from low to high as trafficking increases. This is similar to the shift in bulk densities noted on the LTSP sites (Page-Dumroese and others 2006). Since harvest activity ended, there is no evidence of skid trail use (legally or illegally) by vehicles for firewood gathering or other uses. The soil seems to reflect the original conditions left after the timber harvest.

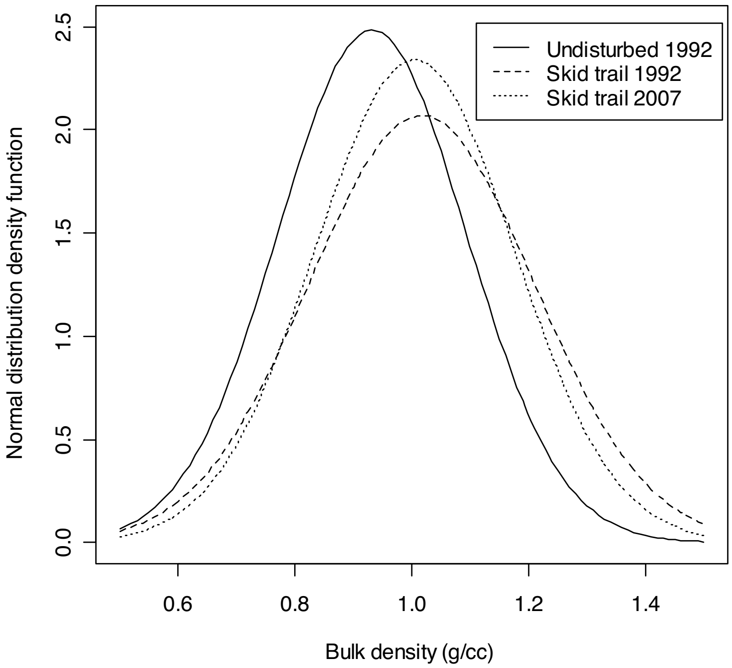

Figure 1. Distribution of bulk density cores taken from undisturbed areas and the skid trails (both samples dates).

In an effort to determine where detrimental compaction might be more prevalent, we looked within the skid trails to see if the location of the most compaction was in the left rut (three samples exceeded standards), right rut (four samples exceeded standards) or the center of the skid trail (four samples exceeded standards). However, samples that exceeded the standards occurred equally across the skid trail.

Analysis of Platy Structure

Of the 32 samples collected in 2007, 22 exhibited platy structure. Of the 22 samples exhibiting platy structure, only six had detrimental compaction. Only one in three samples showed platy structure associated with detrimental compaction. On the other hand, in five samples, no platy structure was observed yet detrimental compaction was evident. The findings demonstrate that it is a complex challenge to evaluate detrimental soil compaction using observable platy structure. Other assessment tools would be necessary.

Growth-Limiting Bulk Density Analysis

None of the 32 samples collected in 2007 in Unit 5 exceeded growth-limiting bulk density values (Daddow and Warrington 1983) or the values defined in the R2 Supplement (USDA Forest Service FSH 2509.18 1992) for a loam (1.40 Mg m^{-3}). Soil texture is one of the most important properties which govern the growth-limiting bulk density because of overall mechanical resistance and pore-size distribution. In addition, key assumptions of growth-limiting bulk density are that (1) the soil has less than 10 percent coarse-fragment content (Unit 5 had ~20 percent), (2) <3 percent organic matter, and (3) the relationship

Visual observations of platy structure were documented.

between root growth and bulk density were developed at or near field capacity (Daddow and Warrington 1983). In addition, most of the data points used to develop the growth-limiting bulk density curves were from agricultural situations and may not be applicable to many forest sites. Over the past 16 years, more than 350 individual core samples have been collected on the Rio Grande National Forest for range, recreation, and timber projects. None of the samples exceeded growth-limiting bulk density values for a loam, which is the dominant surface texture on the Rio Grande National Forest. The assumptions listed above may be key reasons why growth-limiting bulk densities are rarely detected.

Miscellaneous Areas

Areas that were identified as "miscellaneous areas" in the 1992 project were not sampled in the 2007 project. This is because surface conditions in miscellaneous areas (places where the whole-tree harvester tracked into the stand) have either started to ameliorate over time or could not be observed on the ground (now covered with forest floor material). Miscellaneous areas actually accounted for most of the compaction in the entire stand by contributing 12.12 percent of the area impact. It is unknown as to how well this compaction recovered over time.

Summary

The results show that little to no recovery has taken place over 15 years since the 1992 sampling (or over 16 years since the timber harvest occurred) based on bulk density samples. In addition, compaction considered detrimental to vegetation growth persists in 2007, 16 years after logging. Our findings are consistent with the findings of LTSP study (Powers and others 2005). The LTSP study indicated that sites with low rates of recovery from extreme compaction were those in Idaho, Michigan, and Minnesota—all sites with frigid soil temperature regimes. It concluded that perhaps freeze and thaw cycles in cool, temperate, and boreal life zones are not particularly effective for ameliorating the impacts of soil compaction below 10 cm. The Seitz soil series, on which harvest Unit 5 occurs, is in the cryic temperature regime, which is colder than frigid and found in a boreal life zone. This temperature regime may also be ineffective at altering soil compaction.

Prevention of soil impacts is generally preferred over restoration measures. Careful design and spacing of skid trails can keep soil impacts within soil standards. Winter logging on snow or frozen conditions can also minimize soil impacts. Alternatively, operating on dry soil conditions can be useful in managing soil impacts. Although rehabilitation of compaction impacts was not studied, use of a winged subsoiler has been successfully used to ameliorate soil compaction concerns on this and other Forests in USFS Region 2. Subsoiling or other rehabilitation efforts can bring areas considered detrimentally disturbed below the threshold levels for both areal extent and compaction.

Curt Calkins prepares a site for soil sampling, June 1992.

Management Implications

It is important for land managers to know if soil quality standards for their respective USFS Regions are being met prior to decisions to conduct salvage logging, thinning, or other timber harvest operations. On-site investigations and evaluations are essential and should be performed by qualified soil scientists or others trained in soil monitoring methods and protocols to assess the degree of soil impacts. Soil impact evaluations also provide analysis of potential cumulative effects to soils from project activities and whether projects would meet soil protection standards and design criteria in order to comply with the National Environmental Policy Act and National Forest Management Act requirements.

In Unit 5, observations of platy structure were of limited value in assessing soil impacts on an areal basis. Soil assessments should employ a variety of tools that work for a given ecological area. The soil monitoring approach used for Unit 5 provides information regarding recovery of compaction in natural conditions of this boreal forest stand. This is one of a few assessments that evaluate longer-term recovery of soil compaction after harvest operations. However, it is not being advocated as a "rapid" field methodology because of the number of bulk density cores taken and site variability.

Growth-limiting bulk density values were never exceeded in Unit 5 or on other monitoring studies on the Rio Grande National Forest (Rawinski 2008). Growth-limiting bulk densities were also difficult to induce during plot compaction in the LTSP studies. Using growth-limiting bulk density or platy structure may not be effective monitoring tools for forest sites and other methods may be necessary to assess the impacts of forest harvest operations on soil conditions.

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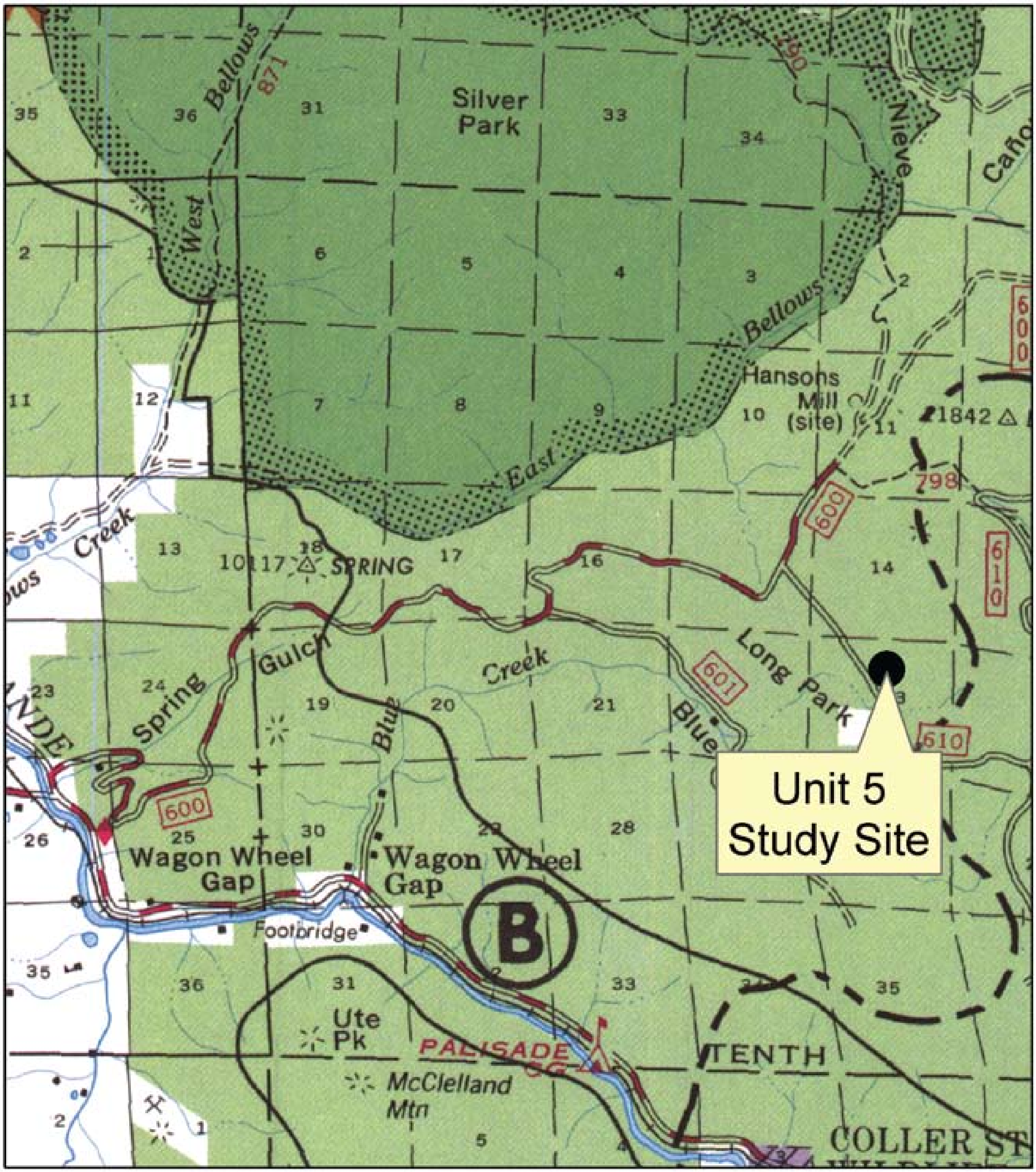
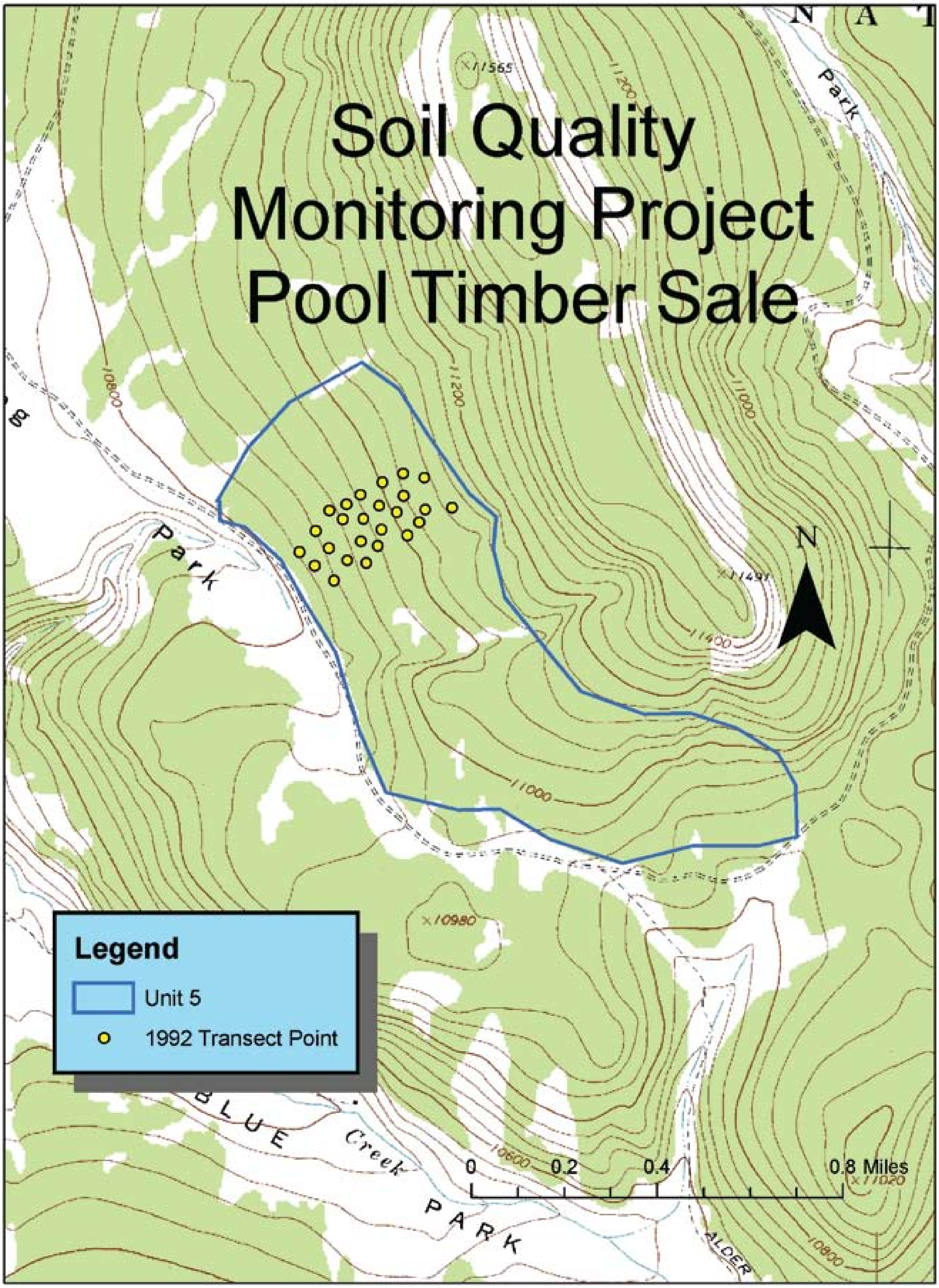
APPENDIX A. Field Data and Statistical Analysis.

	1992 Undisturbed bulk density (Mg/m³)	1992 Skid trail bulk density (Mg/m³)	2007 Skid trail bulk density (Mg/m³)
	0.72	0.59	0.72
	0.72	0.61	0.72
	0.72	0.68	0.74
	0.73	0.73	0.76
	0.74	0.73	0.80
	0.75	0.76	0.84
	0.76	0.79	0.85
	0.79	0.80	0.86
	0.80	0.86	0.87
	0.84	0.89	0.88
	0.85	0.89	0.89
	0.86	0.91	0.95
	0.87	0.92	0.98
	0.87	0.92	1.01
	0.92	0.96	1.02
	0.92	0.97	1.02
	0.94	0.98	1.03
	0.96	1.00	1.03
	0.96	1.03	1.05
	1.00	1.04	1.05
	1.03	1.05	1.05
	1.03	1.05	1.07
	1.10	1.05	1.09
	1.10	1.05	1.11
	1.11	1.07	1.16
	1.13	1.07	1.19
	1.15	1.10	1.19
	1.16	1.10	1.21
	1.21	1.11	1.21
	1.21	1.12	1.22
		1.12	1.25
		1.13	1.37
		1.13	
		1.16	
		1.19	
		1.21	
	1.22		
	1.23		
	1.27		
	1.29		
	1.30		
	1.33		
	1.34		
Mean	**0.93**	**1.02**	**1.01**
Number samples	**30**	**43**	**32**
Standard deviation	**0.161**	**0.193**	**0.171**

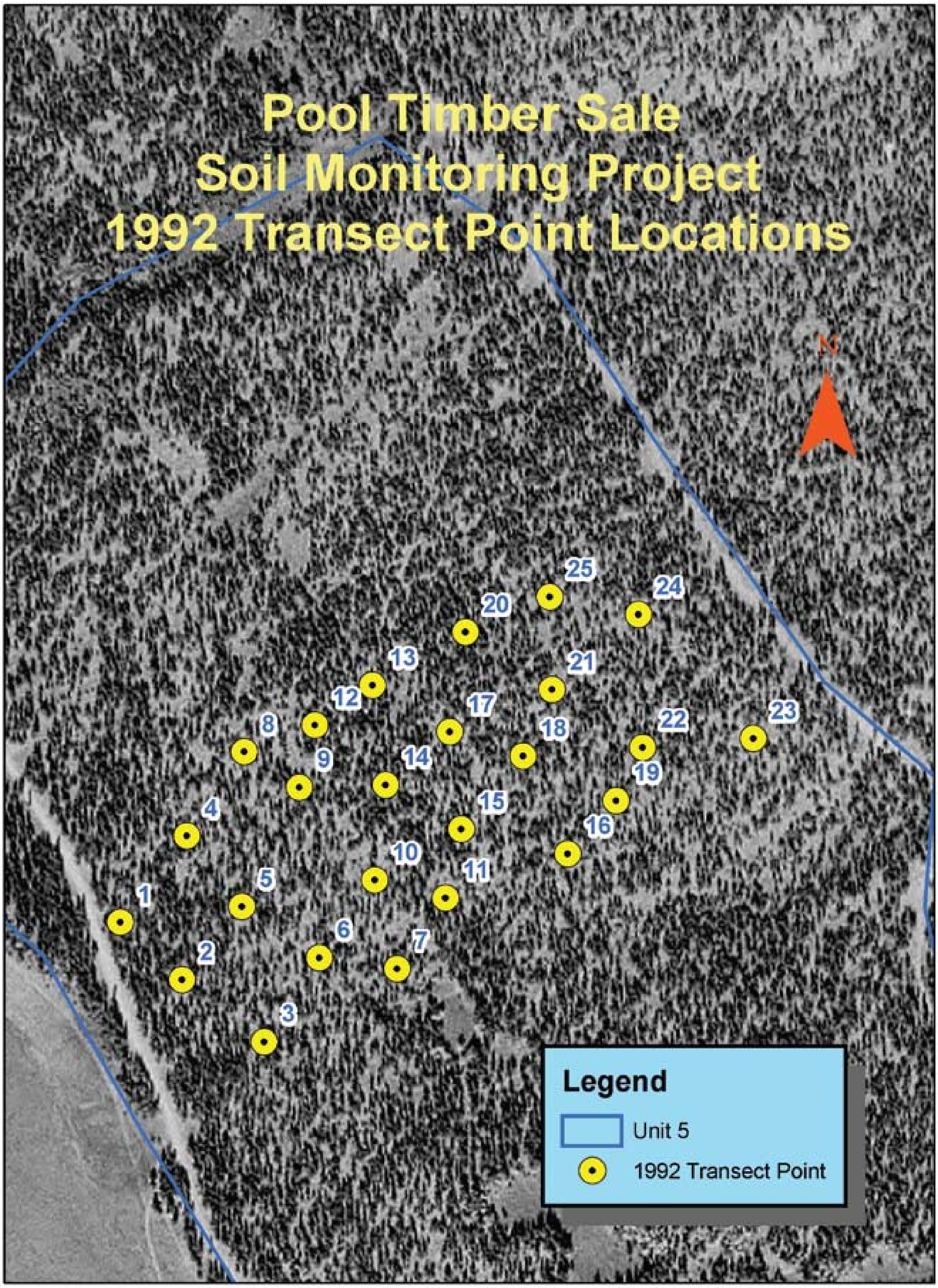
APPENDIX B. Pool Timber Sale Monitoring Site Rio Grande National Forest, Colorado.



Map 1. Pool monitoring site location.



Map 2. Diagrams of Unit 5 showing the portion of the Unit where the 1992 soil sampling occurred



Map 3. Close-up of the layout of sample point distribution and numbering system

Map 4. Distribution of skid trails within unit 5.

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