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How Much Soil Disturbance Can Be Expected as a Result of Southern Pine Beetle Suppression Activities?

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Abstract

Land managers have long recognized the importance of maintaining soil productivity in the context of sustainable forest management. Soil disturbance that results in impaired hydrologic function and changes in certain soil properties (e.g., structure, organic matter) may be detrimental to soil productivity. Little is known about the degree of soil disturbance that results from salvage logging implemented in response to large-scale disturbances in the Southern Region of the Forest Service, U.S. Department of Agriculture. We assess the degree of soil disturbance following harvest operations after an outbreak of southern pine beetle on the Bienville and Homochitto National Forests in Mississippi. Post-implementation monitoring was carried out on 37 cutting units using methods consistent with the Forest Soils Disturbance Monitoring Protocol. Soil disturbance was detected on approximately 52 percent of the cutting units; the majority of soil disturbance was class 1 and 2. High levels of soil disturbance were avoided in part by effective communication between soil scientists, timber sale administrators, and equipment operators. High levels of detrimental soil disturbance were from excessive rutting when logging operations occurred during high soil moisture conditions, which are suboptimal for soil strength. These data provide a baseline for evaluating soil disturbance recovery in the Southern Region and indicate the magnitude of soil disturbance to be expected during salvage logging activities.

Keywords: Southern pine beetle, salvage logging, soil monitoring, soil disturbance, FSDMP

Cover: Top, Woody residues resulting from harvest operations (photo: R.M. Bergstrom, USDA Forest Service); center, Skid trail through a harvest unit (photo: R.M. Bergstrom, USDA Forest Service); bottom, Log landing during harvest operations to remove southern pine beetle-killed trees (photo: R.M. Bergstrom, USDA Forest Service).

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Introduction

Soil quality is both a driver and an indicator of forest ecosystem health. The health of forest ecosystems is largely dependent on hydrologic function and soil organic matter dynamics. Hydrologic function has long been recognized to be influenced by various soil properties such as bulk density, structure, and porosity (Amacher et al. 2007; Schoenholtz et al. 2000). Management-induced changes in soil properties have the potential to impact soil quality, and in turn, impair long-term soil productivity (Burger et al. 2010). The North American Long-Term Soil Productivity (LTSP) study began in 1989 in an effort to understand the connection between soil disturbance and forest productivity. This research was undertaken at least partially in response to the mandate in the National Forest Management Act of 1976 that forest management not permanently impair land productivity (Powers 2006). However, because of the diversity of sites, harvest methods, soil, and disturbance regime, additional data are needed to quantify the types of soil disturbance. Understanding the role of disturbance in maintaining or improving long-term soil productivity (and associated hydrologic function) remains a management goal within the Forest Service, U.S. Department of Agriculture (USDA FS 2010).

The awareness that forest management operations have the potential to impair long-term soil productivity has led private and public landholders to recognize the need for both maintaining soil productivity and developing soil monitoring guidelines and soil quality standards (Neary et al. 2010). Without standardized monitoring protocols, the potential exists for the evolution of soil monitoring methods that are self-suiting, but produce data not necessarily comparable with data gathered by other methods. Sharing questions about soil monitoring and coordinating across sites with common protocols allow for cross-site analysis and increase the capacity to understand key drivers of long-term soil productivity.

The Forest Soil Disturbance Monitoring Protocol (FSDMP) was developed to provide a common protocol for the monitoring of soil quality, using visual soil disturbance indicators that indicate potential decreases in soil productivity or hydrologic function (Page-Dumroese et al. 2009). It is also an integral part of the adaptive management process (Curran et al. 2005) and develops a common language for reporting soil disturbance (Curran et al. 2007). The FSDMP is used extensively by forest specialists conducting soil monitoring and assessment surveys before and after land management activities. The protocol provides a rapid tool for estimating the amount and types of disturbances caused by land management activities. Disturbances include compaction, rutting, displacement, severe burning, and loss of soil cover.

Moderate amounts of soil disturbance on the Coastal Plain of South Carolina have been associated with high site productivity 5 years after stand replacement (Eisenbies et al. 2005), and the authors provide evidence that trees on disturbed sites performed as well or better than trees on minimally disturbed sites. Furthermore, severely compacted sites on the DeSoto National Forest in Mississippi had significantly greater loblolly pine (*Pinus taeda* L.) volume as compared to sites with lower amounts of soil compaction after 5 years of growth (Scott et al. 2004). Stagg and Scott (2006) indicate that planted pine biomass was unaffected by soil compaction 5 and 10 years post-treatment. However, data from a long-term study site in a loblolly pine plantation in North Carolina showed that organic matter removal reduced species diversity more than soil compaction did 14 years post-treatment (Vierra and Blank 2010).

Although the relationship between soil compaction and productivity loss is not always evident, this kind of soil disturbance should not be dismissed as inconsequential. Severe and moderate soil compaction have been shown to hinder succession and reduce woody understory biomass (Stagg and Scott 2006). A study from 2010 on the Croatan National Forest in North Carolina found that trees which would normally be measured for site index curve development had significantly reduced height growth 14 years after organic matter removal and soil compaction (Eaton et al. 2010). However, the effects of soil compaction cannot be broadly applied to other soil types without considering their inherent physical properties. For example, seeding survival is more affected by soil compaction in fine-textured soils than in sandy soils (Miwa et al. 2004). Furthermore, soil compaction or soil erosion or both are often the consequence of excessive soil rutting. Generally, soil rutting is most evident on sites with high soil moisture content during logging operations. High soil moisture content makes soil more susceptible to puddling (smearing of surface pores), decreased resistance to mechanical stresses, soil mixing, and displacement. Vidrine et al. (1999) noted that the average rut depth was 13.0 inches (33 cm) in the most severely disturbed areas on a sandy loam soil in Louisiana.

Generally, soil recovery (or formation) in the Forest Service's Southern Region (Region 8: the 13 southeastern States, as well as Puerto Rico) occurs more quickly than in colder and drier regions of the United States following disturbance, due to the pace of weathering induced by the climate in the Southeast. Even in areas that exhibit high areal extent and severity of soil disturbance, soils are expected to naturally recover from disturbance impacts relatively quickly. Dickerson (1976) estimated that complete recovery of soil bulk density may occur in 8 to 12 years on the northern Mississippi Coastal Plain. Similarly, soil bulk density increases induced by compacting the soil were shown to have recovered by 5 percent between 1 and 5 years post-treatment (Scott et al. 2004). Even after severe compaction on southern LTSP sites with a fine sandy loam soil, recovery to predisturbance bulk density occurred in less than 5 years (Page-Dumroese et al. 2006). Deeply rutted soils in the South Carolina Coastal Plain had partial recovery within 2 years of disturbance due to the positive effects of clays, which have high shrink-swell properties (Miwa et al. 1999).

Monitoring soil quality is a major task associated with watershed management programs and restoration activities within the Forest Service. As such, it is important that soil quality responses to land management activities are measured and understood within the context of maintaining long-term soil health and site productivity. The majority of widely available data regarding the effects of land management activities on soil productivity or quality, using soil disturbance as a proxy, is concentrated in the Forest Service's Northern Region (Region 1: northern Idaho, Montana, North Dakota, and part of South Dakota) and Pacific Northwest Region (Region 6: Oregon and Washington). However, additional data are needed from other Forest Service regions to expand the applicability of the FSDMP. With the potential for forest disturbances related to forest health and wildfire, salvage logging operations may temporarily take priority over a national forest's normal plan of work related to vegetation management. Studies have not begun to link soil disturbance indicators to soil quality in the South, especially as related to salvage logging operations.

The objective of this study was to assess the degree of soil disturbance associated with salvage logging operations in two national forests in the South, in part to establish a baseline for expected impacts of this type of management activity, and to evaluate the long-term recovery of soil disturbance in these ecosystems.

Methods

Managers treated almost 6,300 acres (2,600 ha) on the Bienville and Homochitto National Forests in Mississippi (fig. 1) during the southern pine beetle (SPB; *Dendroctonus frontalis*) suppression effort in 2017. Approximately 5,200 acres (2,100 ha) of cut and leave were accomplished between March and November 2017; 1,100 acres (445 ha) of cut and remove were accomplished between March 2017 and January 2018. Approximately 400 to 500 trees/acre (990 to 1,200 trees/ha) were cut during this effort, depending on the age class of treated timber stands. Residual material from cut and leave operations included "jackstraw" trees with logging slash distributed across the cutting units. In addition, logging slash was distributed across cutting units in cut and remove operations. Both types of operations left standing dead timber in the center of the cutting units. Mechanical equipment and hand operations (chainsaw) were used to implement treatments in varying ground and weather conditions. The soil monitoring

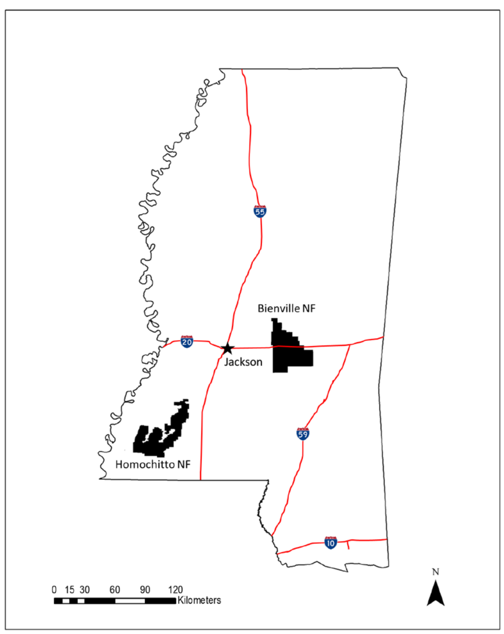

Figure 1—Location of the Bienville and Homochitto National Forests in Mississippi.

data in this paper include only harvest units that were completed using mechanical equipment.

The soil texture of the dominant soil map component for 62 percent of cutting units was either silty clay loam or silt loam. Thirty-two percent of dominant soil map units within cutting units were sandy loam. The remainder of cutting units were mapped as loamy soils. The majority of slopes ranged between 2 and 8 percent (Soil Survey Staff 2017).

During the 2017 SPB suppression efforts, operators used ground-based feller-buncher cutting machines, rubber-tired skidders, and knuckle boom loaders. The feller buncher was used to cut and group stems so that the skidder could move bundles of wood to the knuckle boom loader. Bundles were placed so that the skidder stayed on or close to the main skid trail in order to decrease the amount of soil disturbance throughout a cutting unit. In some instances slash was placed on the main skid trail to mitigate soil rutting or soil displacement. Soil moisture conditions, at the surface or at depth (or both), were assessed daily to safeguard against excessive ground disturbance. Soil interpretations derived from Web Soil Survey (Soil Survey Staff 2017) were used to establish a strategy for timing logging operations during wet ground conditions.

Thirty-seven cutting units were evaluated using the soil disturbance classification scheme described in the FSDMP (Page-Dumroese et al. 2009). Random transects were oriented within each cutting unit and monitoring points were established every 50 feet (15 m). Soil disturbance was assessed at each monitoring point for degree of compaction, rut depth, displacement, burn severity, and soil cover. After data on these attributes were collected, each monitoring point was assigned a soil disturbance class that also evaluated the point within the context of the landscape. Because there are few data on the relationship of disturbance class to the potential loss in long-term productivity (validation data), assignment of “detrimental soil disturbance” (DSD) based on visual observations was made after discussions with other Forest Service soil scientists. For these cutting units and soil types detrimental disturbance was noted when the soil disturbance class was class 3. Cutting units were evaluated 1 to 3 months after logging was completed.

Results and Discussion

Over 2,400 soil disturbance monitoring points were gathered in 37 harvest units, each with an average of 66 monitoring points. Monitored units had an average of 45 percent (areal extent) of land with class 0 soil disturbance (fig. 2). Approximately 52 percent of the cutting units had soil disturbance in some combination of soil disturbance classes 1, 2, and 3. Approximately 5 percent of the cutting units showed class 3 soil disturbance (fig. 2). The amount of undisturbed land in these cutting units was higher than reported by two studies in central and southern Alabama using similar harvest methods. These studies found that only 25 percent of land area within cutting units was left in an undisturbed condition (Carter and Grace 2012; McDonald et al. 1998). Our results suggest that current ground-based harvest methods (e.g., feller buncher) when used during a similar time of year can limit the amount of soil disturbance that may

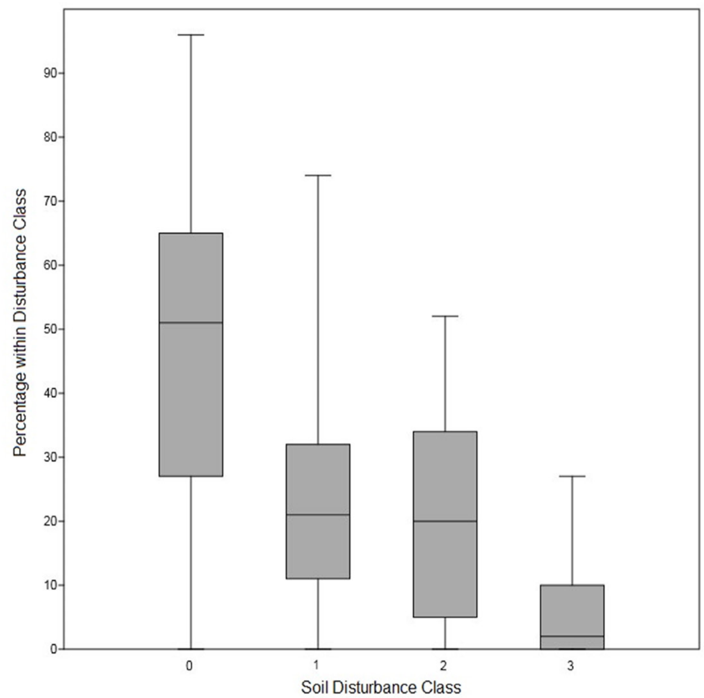

Figure 2—Overall soil disturbance in each Forest Soil Disturbance Monitoring Protocol class for 2017 southern pine beetle suppression treatment units (n = 37). Box plots show median soil disturbance class (horizontal line), middle 50 percent (box), and upper and lower 25 percent (bars).

impact site productivity and soil health. The lack of disturbance in surface organic matter and mineral soil also indicates that these sites are likely to be more resilient to future stressors (e.g., climate change, drought, and insect or disease outbreaks).

Management Implications

National forest units (forests and regions) in the western and northwestern United States have linked current soil quality standards and guidelines for long-term productivity on some soils (Page-Dumroese et al. 2000). The concepts of soil or site productivity, as they relate to sustainable forest management, can be linked to thresholds derived from FSDMP data. For instance, in the Northern Region (Region 1) adherence to soil quality guidelines means that DSD is limited to 15 percent of an activity area. Another example of DSD in Region 1 is the removal of 1 or more inches (2.5 cm) of any surface soil horizon from a continuous area greater than 100 ft^2 (9 m^2). It has been difficult to demonstrate the link between sustainable forest management and soil property changes observed using the FSDMP in the Southern Region (Region 8). In general, soils in the Southeast are more resilient and recover relatively quickly after management activities. However, findings from the LTSP installations across North America have pointed out that loss of the forest floor leads to declines in soil carbon content, which can also lead to reduced nutrient availability (Powers et al. 2005).

Although there are no common soil standards that are correlated to soil disturbance data across Region 8, there is utility in monitoring activity units using the FSDMP as it provides a consistent language and approach to assessing soil disturbance. This monitoring will also prove useful in assessing the degree of disturbance expected with different land management, restoration activities, and long-term productivity.

While acknowledging the difficulty of drawing generalizations between management-induced changes in soil properties and soil or site productivity in the context of sustainable forest management in the Southeast, we can present these data in the context of the Regional Soil Standards from Region 1. These standards state that no more than 15 percent of an activity area can exhibit DSD. As mentioned earlier, we assumed classification of a sample location as disturbance class 3 indicated that the disturbance was detrimental to long-term soil hydrologic function or site productivity. When using the Region 1 guidelines about the areal extent of DSD to compare to the SPB suppression effort, we found that DSD was exceeded in 4 of the 53 harvest units. One of these units had an unusually high proportion of log landings and skid trails for the size of the unit. Excessive rutting in the other three units contributed to exceeding the DSD threshold. Soil gilgai (small depressions holding water), microknolls, and microdepressions were observed on one of these units, making it difficult to determine a baseline for accurate rutting depth measurements. Generally, the severely rutted areas were observed in lower slopes and drainages. Logging under drier soil moisture conditions will reduce the likelihood of severe rutting. It will be beneficial to revisit the units with the highest disturbance and evaluate their rates of natural recovery or the need for restoration before the next harvest cycle. Soil property changes evaluated with the FSDMP that are most likely to affect soil or site productivity include the loss of porosity and an increase in bulk density associated with compaction, rutting, and organic matter removal. However, these changes in soil properties do not always correspond to losses in soil productivity.

Rutting is visually distinct and usually occurs on wet sites or sites with a seasonal high water table that coincides with harvesting (Aust et al. 1995; Burger et al. 1989). Rutting can also occur on uplands under certain soil conditions and after numerous passes. Rutting increases bulk density and reduces macropore space and saturated hydraulic conductivity. In the SPB suppression harvest units, the rutting hazard for most of the soils is listed as “severe” (fig. 3), meaning that ruts have the potential to form readily, based on soil characteristics (i.e., depth to water table, rock fragments, soil classification). However, the overall low percentage of class 3 (rut depth >4 inches [10 cm]) soil disturbance indicates that the degree of rutting observed in the 2017 SPB treatment units was lower than in the harvest operations described by Vidrine et al. (1999) and Aust et al. (1995). The difference between these older studies and our current monitoring effort could be attributed to a change in logging equipment. The use of rubber-tired skidders operating on larger and higher pressure tires results in less

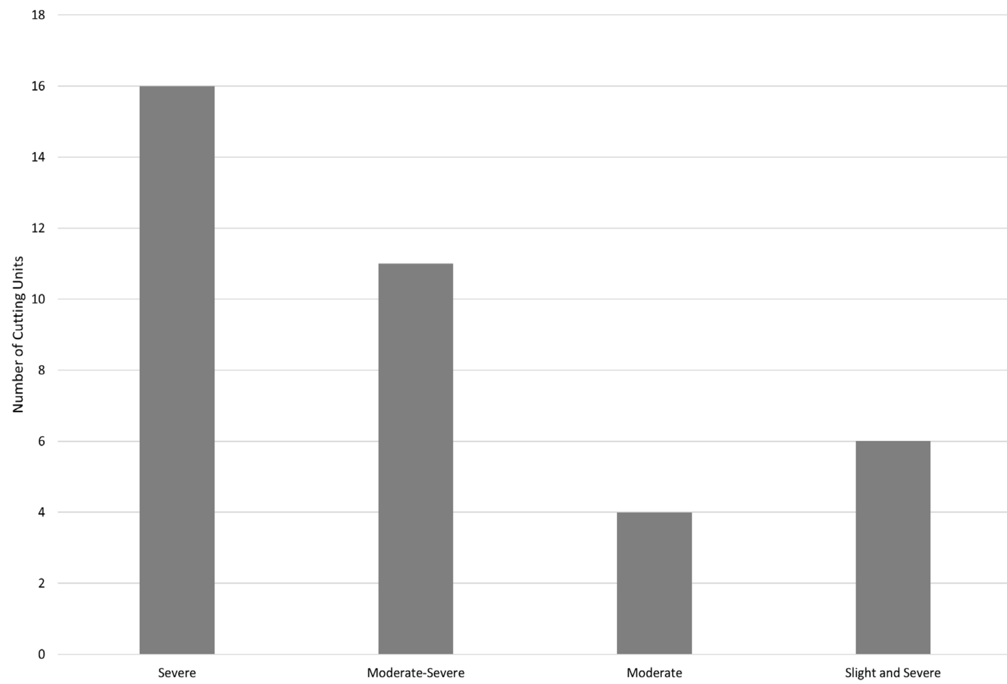

Figure 3—Soil rutting hazard rating for cutting units. Ratings indicate the hazard of surface rut formation through the operation of harvest equipment. A rating of "slight" indicates that the soil is susceptible to little or no rutting, "moderate" indicates that rutting is likely, and "severe" indicates that ruts form easily. Ratings are based on soil characteristics; interpretations were obtained from Web Soil Survey (Soil Survey Staff 2017).

change in soil bulk density and porosity and shallower ruts (Carter 2011). A broad-scale look at the soil disturbance monitoring data suggests that ground-disturbing activities from the 2017 efforts did not result in soil disturbance outside the range of what is currently known. This is a tribute to the local timber sale staff and operators, who were experienced and worked closely together throughout the logging season. Reduced soil disturbance is also linked to effective communications among loggers, timber sale administrators, and soil scientists.

There are no Region 8 Forest Plan or Regional Soil Standards to compare the efficacy of these operations with respect to soil disturbance. Nor was it possible to determine which soil property changes justified a particular soil disturbance class. These data do provide a baseline for estimating the degree of soil disturbance to anticipate when similar harvest unit operation methods are used under similar soil conditions. A missing component from the overall Region 8 soil quality strategy is to monitor the effectiveness of best management practices applied to salvage logging and disturbance classes to validate changes in particular soil properties (e.g., soil organic matter, respiration, porosity) that are key to sustainable forest management and site productivity. Monitoring efforts must move past considering soil disturbance data in a vacuum. Data gathered in Region 8 should be linked to ecosystem health indicators such as forest understory characteristics or soil microbial diversity. This information, combined with specific soil property data gathered using the FSDMP, will prove valuable for estimating the effects of land management activities on the soil resource and its recovery.

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