UNDERSTORY PLANT COMMUNITY RESPONSE TO COMPACTION AND HARVEST REMOVAL IN A LOBLOLLY PINE PLANTATION

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Abstract—In 1992 the Southern Research Station, U.S. Forest Service, constructed three Long-Term Soil Productivity (LTSP) installations in a loblolly pine (Pinus taeda L.) plantation on the Croatan National Forest in Craven County, NC. The LTSP study consists of a nationwide network of experiment sites designed to examine the long-term effects of soil disturbance on forest productivity, one aspect of which is the growth of understory vegetation. Each installation features three levels of soil compaction crossed with three levels of organic matter removal imposed on a harvested site prior to planting. Intensive surveys of the understory vegetation were carried out on the Croatan LTSP site prior to and two years after treatment installation, focusing on the extremes of the soil compaction (no compaction, severe compaction) and organic matter removal treatments (bole only, whole tree + forest floor). We collected plant community data in the summer of 2006 to address the following objectives: (1) to characterize the current standing understory vegetation, (2) to determine the interaction of organic matter removal and compaction treatments fourteen years post-treatment, and (3) to compare current vegetation patterns with the pre-treatment and two years post-treatment vegetation. Preliminary results of an analysis of variance of 2006 vascular plant richness data, as well as a description of changes in species composition over time, are presented here.

INTRODUCTION
The Long-Term Soil Productivity (LTSP) study was established by the U.S. Forest Service (USFS) in response to concerns about declining productivity in managed forests (Powers and others 1989, 2004). The first LTSP experimental site was installed in 1990 in LA. With the construction of additional experimental sites by the USFS in major forest regions across the United States, as well as the formation of partnerships within both the United States and Canada, the LTSP network has grown to include over 100 installations (Powers and others 2004).

The LTSP study focuses on two pulse disturbances associated with forest management activities that are likely to affect site productivity: reduction of soil porosity (through compaction) and removal of organic matter (Powers and others 1989, 2004). Soil compaction may hinder root growth as well as reduce the availability of oxygen, while organic matter removal is a concern because of the removal of nutrients from a site.

While the LTSP experiment was designed as a productivity study, the experimental framework provides an opportunity for studying the long-term effects of anthropogenic pulse disturbances on forest plant communities. The development of understory plant communities has implications for wildlife habitat, biodiversity, conservation of rare species, recreation, and non-timber forest products.

Studies of the long-term effects of organic matter removal set in North Carolina are particularly relevant as the woody biomass in the state’s forests is being considered as a fuel source. As an example, North Carolina State University recently hosted a conference titled “Energy from Wood: Exploring the Issues and Impacts for North Carolina” (Raleigh, NC: March 13-14, 2006), to serve as a forum to discuss the issue. What are the long-term effects of removing more biomass during timber harvest on the development of forest plant communities? How would non-timber forest values and uses, such as biodiversity and wildlife habitat, be impacted by such a shift in harvest practices?

Objectives
This paper is a progress report on a study of the forest plant communities on an LTSP experiment site located on the Croatan National Forest in North Carolina. The objectives of the study are (1) to characterize the current standing understory vegetation at the Croatan National Forest LTSP site, (2) to determine the interaction of organic matter removal and soil compaction 14 years post-treatment, and (3) to compare current vegetation patterns with the pre-treatment and two years post-treatment vegetation. In other words, what vegetation patterns currently exist on the site? What patterns of changes have occurred over the years since timber harvest? Finally, are these patterns linked to the experimental treatment factors of soil compaction and organic matter removal?

METHODS
Study Site Description
The study area is an LTSP site located on the Croatan National Forest in Craven County, in the coastal plain of NC. The site lies in the extreme southeast portion of the county, near the intersection of State Highway 306 and Forest Route 132, roughly 2 km from the Neuse River. Goodwin (1989) characterizes the area’s climate and soils; summers in Craven County are hot and humid while winters are cool with brief cold spells. July and August are the hottest months of the year, with average daily maximum temperatures approaching 32 °C; annual average temperature is 17 °C. Total annual precipitation is 138.4 cm, mostly falling from April through September. Ninety-nine percent of the land is nearly level or gently sloping to the southeast. Much of the county is poorly drained. Soils on the site are mapped as the Lynchburg series (fine-loamy, siliceous, semiactive, thermic Aeric Paleaquults) and Goldsboro series (fine-loamy, siliceous, subactive, thermic Aquic Paleudults).

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Lankford (1995) reports that prior to timber harvest and the installation of the LTSP treatments the site supported a 65 year old loblolly pine (*Pinus taeda* L.) plantation with a component of mixed hardwoods in the mid and upper canopies. Woody shrubs were common in the understory. However, due to incomplete crown closure, a discontinuous herbaceous layer occurred throughout the site.

**Experiment Design and Implementation**

The LTSP experiment features a two-factorial randomized complete block design, with three levels of organic matter removal (bole only, whole tree, whole tree + forest floor) crossed with three levels of soil compaction (none, intermediate, severe) for nine total treatment combinations (Powers and others 1989). At the Croatan LTSP installations, each plot is further split into herbicide and non-herbicide treatments. Blocking is based on soil series. Block 1 is located on the Goldsboro series soil, while Blocks 2 and 3 are mapped as the Lynchburg series. Figure 1 contains a map of plot locations.

The existing timber on the site was harvested from July to September of 1991. Additional organic matter removal was carried out from October of 1991 through January 1992. Soil compaction treatments were implemented in December 1991 and March to April 1992. Loblolly pine seedlings were planted in April 1992 using 3 by 3 m spacing.

This study is restricted to a subset of the non-herbicide treatment plots, including two levels of compaction (none and severe) and two levels of organic matter removal (bole only and whole tree + forest floor). This gives four treatment combinations for a total of twelve plots. The narrow focus was necessitated by budget and time constraints. However, the selection still allows for comparisons between the most extreme treatment levels and also preserves continuity with earlier vegetation surveys on the site, which focused on the same four treatment combinations.

**Vegetation Survey**

The plant communities on the site were surveyed from June through July of 2006 (14 years post-treatment) using the methodology developed by the Carolina Vegetation Survey (CVS) (Peet and others 1998). The preliminary results presented below are based on complete vascular plant species lists developed for the 20 by 50 m CVS sample unit nestled within each LTSP plot. Nomenclature follows Weakley (2006).

Previous vegetation surveys carried out on the Croatan LTSP site in 1991 (Lankford 1995) and 1993 (Mellin 1995) also followed the CVS protocol. The USFS Southern Research Station RWU-4154 (Forestry Sciences Laboratory, 3041 Cornwallis Road, Research Triangle Park, NC) shared the original data produced by these earlier vegetation surveys.

**Initial Analyses**

**Vascular plant richness in 2006**—Species richness, the number of species present in a given area, is a straightforward measurement of species diversity. Total vascular plant richness was determined for each plot and subjected to an analysis of variance (ANOVA) to test whether species diversity differed between plots based on the two treatment factors. The ANOVA was carried out using SAS software (SAS Institute 2001).

**Changes in species composition**—A descriptive approach was used initially to identify patterns of changes in species composition between study years (1991 to 1993 and 1993 to 2006) by treatment combination. The number of species gained and lost between study years on at least two of the three replications of each treatment combination was identified. These species were then grouped by growth form to identify patterns across categories of plants. Species were assigned to growth forms following the classifications used by the PLANTS Database (USDA Natural Resources Conservation Service [n.d.]).

Due to the use of different taxonomic authorities, some plant species in the genera *Dichanthelium*, *Andropogon*, and *Rubus* were treated inconsistently between vegetation surveys. Species from these genera were abundant on the site during all three study years. Whenever necessary, species within these genera were lumped into broader groups to improve comparability between study years.
PRELIMINARY RESULTS

Vascular Plant Richness
In 2006 the Croatan LTSP site was a 14-year-old loblolly pine plantation that had experienced crown closure on all plots, with only infrequent small gaps in the canopy. 121 species of vascular plant were found there. The overall average vascular plant richness was 55.3 per plot. Adjusted for differences in the treatment of the genera *Dichanthelium*, *Andropogon*, and *Rubus*, the overall average richness in 2006 was 53.4 per plot, a slight decrease from 56.3 in 1991 (preharvest) and 56.8 in 1993 (two years post-harvest).

By treatment combination, average 2006 richness per plot was 51.3 for bole only organic matter removal without compaction, 52.3 for bole only organic matter removal with severe compaction, 57.7 for whole tree + forest floor organic matter removal without compaction, and 59.7 for whole tree + forest floor with severe compaction (fig 2). ANOVA revealed that the differences between the bole only and the whole tree + forest floor organic matter removal treatments were significant at \( \alpha = 0.10 \) level (table 1).

Changes in Species Composition
1991 to 1993—Between 1991 and 1993 the Croatan LTSP site was transformed from an established loblolly pine plantation with mixed hardwoods present in the mid- and upper-canopies (Lankford 1995) to an early-successional loblolly plantation. Figure 3a shows the species gained and lost between the two earlier vegetation surveys by growth form. Some of the patterns shown there simply reflect expected successional trends following removal of overstory plants; there was an influx of ruderal forbs/herbs and graminoids that commonly colonize disturbed areas. For example, the genera *Eupatorium*, *Solidago*, *Dichanthelium*, and *Rhynchospora* were represented by at least two species each. For each treatment combination the number of species gained was greater than the number lost, due to this influx of ruderal species.

One pattern may be linked to the intensity of the organic matter removal and soil compaction treatments; changes in species composition were most dramatic on the most intensive treatment combination (whole tree + forest floor and severe compaction), which at the same time gained the most (15) and lost the most (13) species. Also, the only losses of tree species—flowering dogwood (*Cornus florida* L.) and American holly (*Ilex opaca* Ait.)—occurred on this treatment combination.

1993 to 2006—Figure 3b shows species gained and lost from 1993 to 2006 by growth form. During this longer time period, the loblolly pine plantation on the study site experienced crown closure and the loss of many of the early-successional species gained between 1991 and 1993.

There is evidence for a soil compaction treatment effect: The severe compaction treatment combinations each lost more species than they gained, whereas the no compaction treatments gained roughly the same number of species as they lost. Curiously, the recruitment of vine species was particularly affected by compaction level. The two severe compaction treatments gained one species of vine each. In contrast, the no compaction treatments each gained four vine species, two of which—cross-vine (*Bignonia capreolata* L.) and Virginia creeper (*Parthenocissus quinquefolia* (L.)

Table 1—Results for ANOVA (\( \alpha = 0.10 \)) performed on 2006 vascular plant richness data

<table>
<thead>
<tr>
<th>Effects</th>
<th>P</th>
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<tbody>
<tr>
<td>Organic matter removal</td>
<td>0.063</td>
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<tr>
<td>Compaction</td>
<td>0.635</td>
</tr>
<tr>
<td>Interaction</td>
<td>0.873</td>
</tr>
<tr>
<td>Block</td>
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</tr>
<tr>
<td>C.V. (%)</td>
<td>9.410</td>
</tr>
<tr>
<td>R²</td>
<td>0.612</td>
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</table>
Planchon)—were gained on both of the no compaction treatments and neither of the severe compaction treatments. Coral honeysuckle (*Lonicera sempervirens* L.) was gained on both of the no compaction treatments, as well as the bole only organic matter removal and severe compaction treatment.

**DISCUSSION**

**Initial Findings**

The results presented here provide a partial account of the influence of organic matter removal and soil compaction on the development of plant communities on the Croatan LTSP site. In the short span of time from preharvest to early-successional conditions (1991 to 1993) the most intensive treatment combination (whole tree + forest floor and severe compaction) experienced the greatest changes in species composition; other treatment effects are unclear. From early-successional conditions to a few years after canopy closure (1993 to 2006) there is evidence that the soil compaction treatments influenced species compositional change, most notably that of vines. However, ANOVA of 2006 species richness revealed an organic matter removal effect, not a soil compaction effect, 14 years post-treatment. This potential disparity may simply reflect that ANOVA was only performed on the total number of species and not on differences by growth form. Alternatively, the changes in diversity due to soil compaction may have occurred outside of the 1993 to 2006 time frame.
Next Steps
The analyses presented here do not take full advantage of the rich dataset provided by the use of the CVS protocol (Peet and others 1998). In addition to the presence and richness data used above, the abundance of each species was recorded in terms of percent cover. Stems were tallied by species and by diameter class, providing both another measure of abundance and a means of evaluating the structural composition of the plant communities on the site.

Data analysis will be refined and continued through the use of multivariate techniques such as cluster analysis or indirect ordination, which can be used to evaluate the abundance data collected. The ANOVA of vascular plant richness will be expanded to include richness by growth form, in order to evaluate the effects of the experimental treatments on specific categories of plants. An ANOVA will also be performed on the stem count data to evaluate treatment effects on the density of stems. The descriptive evaluation of changes in species composition will be expanded to include the 1991 to 2006 time period, which would allow comparisons between current and preharvest species composition.

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LITERATURE CITED