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Growth responses of mature loblolly pine to dead wood manipulations

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ABSTRACT

Large-scale manipulations of dead wood in mature *Pinus taeda* L. stands in the southeastern United States included a major one-time input of logs (fivefold increase in log volume) created by felling trees onsite, annual removals of all dead wood above ⩾10 cm in diameter and ⩾60 cm in length, and a reference in which no manipulations took place. We returned over a decade later to determine how these treatments affected tree growth using increment cores. There were no significant differences in tree density, basal area or tree diameters among treatments at the time of sampling. Although tree growth was consistently higher in the log-input plots and lower in the removal plots, this was true even during the 5 year period before the experiment began. When growth data from this initial period were included in the model as a covariate, no differences in post-treatment tree growth were detected. It is possible that treatment effects will become apparent after more time has passed, however.

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1. Introduction

With a growing interest in biofuel production, it is now more important than ever to understand how manipulations of dead wood affect forest biodiversity, productivity and long-term sustainability (Tilman et al., 2009). Numerous relatively short-term studies (~5–30 years) have explored the effects of dead wood removals on productivity in managed forests. Although the results are somewhat mixed depending on treatment, tree species, location, site quality and timing (see Thiffault et al., 2011), many have shown a significant relationship between dead wood retention and tree growth. Some of the strongest negative effects have been shown following whole-tree harvests (in which all above-ground biomass including the nutrient-rich twigs and foliage is removed from a site) after clearcutting (Mann et al., 1988; Proe and Dutch, 1994; Proe et al., 1996; Egnell and Leijon, 1999; Johnson et al., 2002; Egnell and Valinger, 2003; Scott and Dean, 2006; Ares et al., 2007; Walmsley et al., 2009; Egnell, 2011; Mason et al., 2012) or thinning (Brantseg, 1962; Sterba, 1988; Jacobson et al., 2000; Nord-Larsen, 2002; Helmisaari et al., 2011). Other studies involving whole-tree harvests have failed to document significant effects, however (Egnell and Leijon, 1997; Johnson et al., 2002; Powers et al., 2005; Sanchez et al., 2006; Busse, 2010; Saarsalmi et al., 2010; Voldseth et al., 2011). Although some studies suggest that stem-only harvests, which do not include the removal of twigs and branches, also negatively affect tree growth (Sterba, 1988) others do not (Busse, 2010) and some have argued that reductions in stand productivity can be greatly lessened by simply leaving branches and foliage behind (e.g., Hopmans and Elms, 2009). Support for this view comes from the fact that removing such debris results in disproportionately large nutrient losses relative to biomass gains (Mälkönen, 1976; Freedman et al., 1981; Hendrickson et al., 1987). Attributing the negative effect of woody debris removal on tree growth to nutrient loss is consistent with the views of people over 500 years ago in Europe Eschenlohr (1921), as translated by Sterba (1988)), is strongly supported by evidence that compensatory fertilization can counteract the effect (Jacobson et al., 1996, 2000; Helmisaari et al., 2011; Mason et al., 2012) and compares well with evidence from agricultural systems (Vance, 2000).

Based on fertilization experiments, Miller (1981) suggested that forests are likely to respond most strongly to nutrient inputs during periods of crown development (i.e., immobilization of nutrients in foliage biomass) such as before canopy closure in young stands and after thinning operations. Manipulations of dead wood during these periods may therefore be more likely to influence tree growth than at other times. Several additional benefits of dead wood suggest that young trees may respond most strongly to woody debris manipulations. These include reduced competition from other plants (Cox and Van Lear, 1985; Stevens and Hornung, 1990; Fahey et al., 1991; Proe and Dutch, 1994; Harrington and Schoenholtz, 2010), shelter from wind (Proe et al., 1994; Proe and Dutch, 1994) and protection from herbivory (de Chantal and Granström, 2007, but see Pellerin et al., 2010). More research is needed from a wide range of stand ages, especially in mature

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forests, to better understand how the effects of dead wood manipulations change throughout the forest cycle.

The forests of the southeastern United States are among the most productive in North America, with loblolly pine (*Pinus taeda* L.) being the most widely planted and intensively managed species. Interest in biofuels is growing in the region as are concerns about how intensive harvesting of woody debris will affect biodiversity (Riffell et al., 2011) and stand productivity (Phillips and Van Lear, 1984; Mayfield et al., 2007; Eisenbies et al., 2009). Several early studies from the region suggest that whole-tree harvests may reduce loblolly pine seedling growth as compared to stem-only harvests (Cox and Van Lear, 1985; Mann et al., 1988; Johnson et al., 2002). More recently, two studies addressing this question have been published from the Long-Term Soil Productivity (LTSP) program, a national research network aimed at examining long-term effects of various interventions on forest productivity. Whereas Scott and Dean (2006) found whole-tree harvests reduced loblolly seedling growth at most study locations after 7–10 years, Sanchez et al. (2006) did not detect a significant effect within the same time period. No efforts, to our knowledge, have been made to determine the effects of dead wood manipulations on loblolly pine growth in mature stands.

In 1996, a multidisciplinary study was initiated on the Savannah River Site in South Carolina to investigate the effects of large-scale manipulations of dead wood on animal communities. Although not the original focus of the study, the existence of the plots provides a special opportunity to examine how tree growth was affected by the manipulations.

2. Methods

2.1. Study site and design

This research was carried out on the 80,267-ha Savannah River Site (SRS) in South Carolina, USA. The forests used in the study are loblolly pine plantations planted in 1950 and 1953 on former agricultural land. They are situated on the Aiken Plateau of the Sandhills physiographic province and have highly weathered, nutrient poor soils consisting of a sandy surface layer of variable thickness over a loamy to clayey subsoil (Kolka et al., 2005). The experiment, initiated in 1996, followed a randomized complete block design. There were four blocks (timber compartments), each containing four square 9.3-ha plots (see map in Ulyshen and Hanula, 2009). Each plot consisted of a 6-ha core surrounded by a 3.3-ha buffer zone. All blocks were thinned between 1991 and 1996 (all plots within each block were thinned the same year) to achieve a standing basal area of 13.8–20.8m^2/ha (Howard, 1997). Although most plots were burned between 1990 and 1994, others had not been burned since 1983 or as early as 1972 (Howard, 1997). Thus, to help control for differences in fire history, prescribed fires were administered in all plots between February 2000 and March 2001. The experiment consisted of two phases based on treatment changes with phases I and II beginning in 1996 and 2001, respectively. The three treatments used in this study are as follows:

(1) *Removal.* Removal of all dead woody material, including snags, ⩾10 cm in diameter and ⩾60 cm in length. This began in 1996 and was repeated yearly until the study ended in 2008. The removals were carried out using chainsaws and small vehicles and caused little noticeable damage to the litter or soil (Hanula et al., 2006). All removed material was discarded in designated piles outside the plots. These plots were thinned in 2001 to match the change in basal area experienced in the log input plots (see below).
(2) *Log input.* A fivefold increase in log volume over average background levels was attained in 2001 by felling trees within the plots. This marked a major treatment change. Prior to this, in phase I of the experiment, all downed woody debris was removed from these plots (snags, however, were not removed).
(3) *Reference.* Aside from being thinned between 1991 and 1996 and again in 2001 (i.e., to match the change in basal area experienced in the log input plots, see above), the reference stands were not manipulated and were comparable to the forest matrix surrounding the plots.

At the time of sampling for the current study (November 2011), one of the blocks had been harvested following a severe burn, leaving just three replicates intact (i.e., nine plots in total). In the 6-ha core of each of these plots, sampling took place in two circular subplots (20 m radius). One subplot was positioned at the center whereas the other was 50 m from the center in a randomly selected cardinal direction.

2.2. Measurements

The diameters of all loblolly pine trees ⩾10 cm in diameter at 1.5 m were measured in the two subplots to estimate stand basal areas (i.e., to confirm that basal area did not vary significantly among treatments). Tree cores were also collected from each tree at 1.5 m, deeply enough to provide tree ring data back to 1991 (5 years before any dead wood manipulations were made) using techniques described by Phipps (1985). The cores were individually placed in paper straws for storage and later carefully sanded and photographed using a digital camera attached to a dissecting microscope. Tree ring widths were measured to the nearest 0.01 mm using Image-Pro® Plus Version 6.3. In order to avoid suppressed trees, only trees ⩾20 cm in diameter were included. Cankerous trees were also excluded as were broken or otherwise damaged cores from which it was not possible to date rings with certainty. With respect to crossdating, several rings were particularly good reference points. Most notably, 2003 was a very wet year (Kabela, 2010) represented by a distinctly wide growth ring (see Fig. 1). Similarly, 2000 was a dry year with a narrow band of late wood present in the corresponding growth ring.

2.3. Statistical analysis

All data collected from the two subplots in each plot were pooled prior to analysis. Analysis of variance was used to compare number of trees, basal areas and average tree diameter among treatments (timber compartment was included in the model as a blocking variable). After excluding small or cankerous trees as specified above, tree ring growth data were collected from and averaged across 25 ± 2 (range 18–35) trees per plot. Due to treatment changes that took place over the sampling period (see above), annual growth data from the following four 5-year periods were summed: 1991–1995 (before any dead wood manipulations were made), 1996–2000 (phase I, described above), 2001–2005 (first 5 years of phase II), 2006–2010 (second 5 years of phase II). Data were also summed for the entire 10-year period (i.e., 2001–2010) after phase II was initiated. Separate analyses of variance were conducted for each time period with data from the first 5-year period included in the model as a covariate (i.e., to control for inherent differences among plots). Standard errors are presented with means throughout this paper.

3. Results

Tree number ($F_{2,4}$ = 0.5, P = 0.6), basal area ($F_{2,4}$ = 0.9, P = 0.5) and tree diameter ($F_{2,4}$ = 0.1, P = 0.9) were similar among treatments

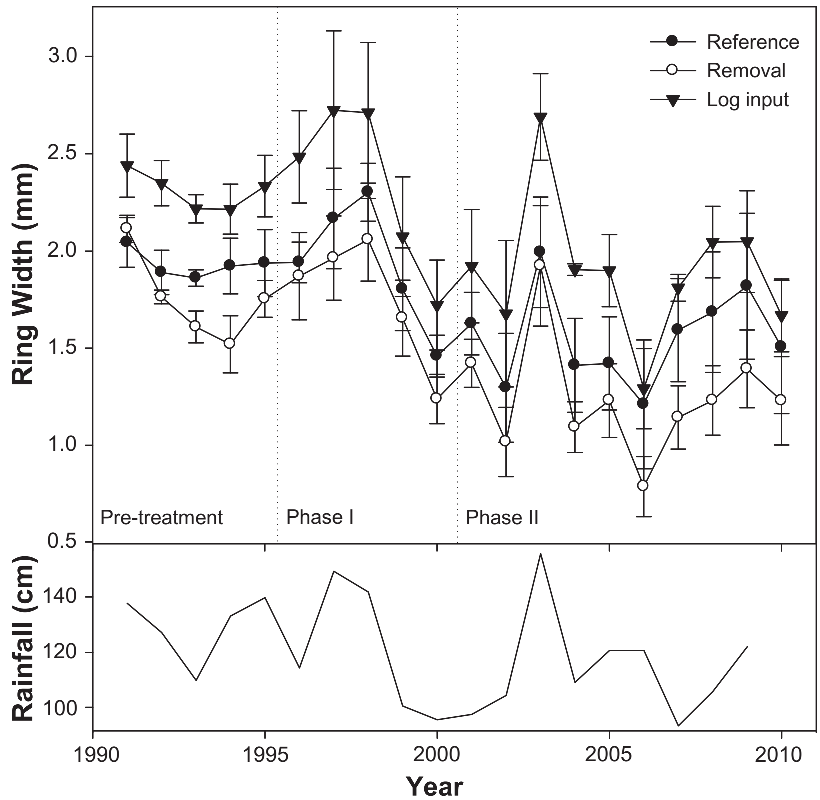

Fig. 1. Mean ± SE (n = 3) growth ring widths by year and treatment (above) and yearly rainfall (below). See text for description of phases I and II.

(Table 1). Measurements from a total of 223 tree cores showed tree growth was consistently higher in the log-input plots and lower in the removal plots, even during the 5 year period before manipulations of dead wood were made (Fig. 1). When growth data from this pre-treatment period were included in the model as a covariate, no differences in post-treatment tree growth were detected. ANOVA results for the different time periods were as follows: 1996–2000 ($F_{2,3}$ = 0.0, P = 1.0); 2001–2005 ($F_{2,3}$ = 0.3, P = 0.8); 2006–2010 ($F_{2,3}$ = 3.1, P = 0.2) and 2001–2010 ($F_{2,3}$ = 1.2, P = 0.4).

4. Discussion

After canopy closure, forest trees are thought to switch largely from a pattern of nutrient immobilization (i.e., primarily in foliage biomass) to a pattern of nutrient cycling (Miller, 1981). Closed-canopy forests are also at their most efficient with respect to capturing and retaining atmospheric nutrients (Miller, 1981). Because mature trees demand less from the soil nutrient capital (Miller, 1981), they are likely less sensitive to manipulations of woody debris than young trees. The results from this study are consistent with this expectation. It is nevertheless interesting that annual removals of dead wood from the removal plots failed to register an effect. This may be attributable, in part, to the fact that these removals were limited to woody debris ⩾10 cm in diameter and ⩾60 cm in length. In addition, the removals took place just once a year and probably included few needles. Thus most twigs and foliage, which contain much higher nutrient concentrations than stem wood (Eisenbies et al., 2009), remained onsite.

Only about 15 and 10 years have passed since the removals and input of wood began. Although we are currently unable to detect treatment responses, it is important to keep in mind that effects may become apparent after more time has passed. Helmisaari et al. (2011), for instance, detected stronger effects of whole-tree harvests on tree growth in thinned Norway spruce (*Picea abies* (L.) Karst.) and Scots pine (*Pinus sylvestris* L.) forests during the second 10-year period in northern Europe. This is reasonable considering how slowly nutrients are released from woody debris. In Swedish spruce and pine forests, for example, Hyvönen et al. (2000) measured no net release of N from branches within the first 8 years. Although rates of decay and nutrient release are no doubt much higher for the forests of the southeastern United States (Eisenbies et al., 2009), it would nevertheless be informative to resample the plots after another decade or more has passed, if possible. It is worth mentioning here that the results from ANOVA for the different time periods (see above) indicate the separation between the growth trend for the removal treatment and the other treatments may be widening with time (also see Fig. 1), suggesting the effects may be delayed and that differences may occur after longer time periods.

Thiffault et al. (2011) point out that the negative effects of whole-tree removals have been more commonly found in European than in North American studies. One possible explanation

Table 1
Mean ± SE (n = 3) basal area, mature tree diameter, number of trees and number of cores analyzed by treatment. All trees in the sampled subplots with diameters at 1.5 m ⩾ 10 cm are included in the basal area, number of trees and average dbh calculations. Tree cores were only analyzed from trees with diameters ⩾20 cm.

	No. trees	Basal area (m^2/ha)	Average tree diameter at 1.5 m (cm)	Number of cores analyzed per plot
Reference	35.3 ± 5.5	15.7 ± 1.7	36.6 ± 1.8	22–32
Removal	30.7 ± 4.3	14.0 ± 0.8	37.1 ± 2.3	18–22
Log input	38.3 ± 4.4	17.0 ± 1.5	35.4 ± 1.6	21–35

for this posited by the authors is that European forests have a longer history of intensive management. Thus, repeated removals of woody debris from forests over multiple rotations may increasingly reduce the soil nutrient capital and reduce stand productivity. The results from the current short-term study should not, therefore, be used to reach long-term conclusions regarding the effects of woody biomass removal until more information becomes available.

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