ABOVEGROUND CARBON STOCK AND DISTRIBUTION IN MANAGED AND UNMANAGED MATURE, NATURAL-ORIGIN, PINE-HARDWOOD FOREST STANDS

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Abstract—Carbon storage and maintaining forest complexity have been important objectives in developing forest management strategies to address global climate change. Although maintaining complexity and carbon stores are inherently interrelated, the effect of management strategies on these objectives have generally been examined independently. Moreover, little is known about the effect of management on carbon stock and distribution in structurally and compositionally complex forests. This study examines the effect of selective, partial harvests on carbon stock and distribution in natural-origin, 80- to 120-year-old, pine (*Pinus* spp.)-hardwood stands of southeastern Arkansas. Carbon pool estimates were derived for all aboveground pools. Harvests resulted in slightly more uniform stand structure and reduced aboveground carbon stores by 8 tons per acre. Post-harvest large tree residuals maintained carbon stock at relatively high-levels with greater potential for live tree carbon increment. Carefully planned partial harvests in complex stands may allow for greater flexibility in balancing maintenance of carbon stock and fostering structural and compositional complexity.

INTRODUCTION

Area of natural-origin pine (*Pinus* spp.) forest in the Southeastern United States declined dramatically between 1950 and 2010 (Hartsell and Conner 2013). This decline was associated with an increase in pine plantation dominance over the landscape (Zhang and Polyakov 2010), as landowner's preference shifted toward short-rotation, high-yielding systems. Similar but less drastic declines were also reported for oak (*Quercus* spp.)-pine forest (Hartsell and Conner 2013), highlighting the increased homogenization of the southern landscape. In Arkansas, declines in natural-origin pine and oak-pine forest amounted to 2 million acres since 1978, while planted pine acreage increased by 3 million acres (USDA FIA 2019). Area changes in natural-origin pine were accompanied by increased structural uniformity. For example, 70 percent of the remaining natural-origin pine in Arkansas is currently under 40 years old and natural-origin stands greater than 80 years account for only 3 percent of the area (USDA FIA 2019).

In light of these trends, it is becoming more important to quantify and document the current conditions of mature, unmanaged, natural-origin pine, pine-hardwood, and upland hardwood stands. These stands represent a legacy of natural disturbance and stand dynamics and may serve as reference conditions (Bragg 2013, Bragg and Shelton 2011) and analogs in establishing, converting to, restoring, or maintaining structurally and compositionally complex forests that may have higher adaptive capacity than their counterparts. Although current management strategies to address global climate change stress enhancing carbon stores and fostering forest adaptive capacity through maintenance of structural and compositional complexity, there is clearly a trade-off between storing carbon on site using highly stocked stands and promoting stand-level complexity (D'Amato and others 2011). Moreover, little is known about the effect of management on carbon stock and distribution in structurally and compositionally complex forests, such as mature, natural-origin pine-hardwood forests of the Upper West Gulf Coastal Plain (UWGCP).

Although pine-hardwood stands of the UWGCP were described as transient in successional development in the absence of disturbance (Bragg and Shelton 2011, Hartsell and Conner 2013), these stands provide potential for the establishment and maintenance of mixed-species, multi-cohort/stratified stands that provide for enhanced carbon stores while simultaneously maintaining and enhancing complexity. The objective of this study was to examine the effect of selective, partial harvests on carbon stock and distribution in natural-origin, 80- to 120-year-old, mature pine-hardwood stands of southeastern Arkansas.

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MATERIALS AND METHODS

Study Area

The study area is within the UWGCP, which is described as rolling plains punctuated with fluvial terraces, bottomlands, and low cuestas. Forests dominate the landscape with loblolly pine (*Pinus taeda*), shortleaf pine (*P. echinata*), sweetgum (*Liquidambar styraciflua*), oak (*Quercus* spp.), gum (*Nyssa* spp.), and hickory (*Carya* spp.) as main species (Woods and others 2004). Elevation is 430 feet above sea level. The climate is characterized by warm summers and mild winters with mean annual precipitation of 53 inches, 70 percent of which falls in November through May, and an annual frost-free period of 236 days (Larance and others 1968). Mean annual temperature is 62.8 °F. Soils series of the study area include Savannah (siliceous, semiactive, thermic Typic Fragiudults), which are described as very deep, moderately well-drained, and slowly permeable on uplands and terraces; Wehadkee (mixed, active, nonacid, thermic Fluvaquentic Endoaquepts), which are very deep, poorly to very poorly drained along streams and on floodplains in bottomlands; Boswell (mixed, active, thermic Vertic Paleudalfs), which are very deep, moderately well-drained, and very slowly permeable fine sandy loams on uplands; Caddo (siliceous, active, thermic Typic Glossaqualfs), which are described as very deep, poorly drained, acidic soils, with little organic matter in upland locations; and Stough (siliceous, semiactive, thermic Fragiaquic Paleudults), which are poorly drained, acidic, of low fertility, coarse loams along stream terraces (Larance and others 1968).

Study Design and Treatments

Four mature (80-120 years old), natural-origin, pine-hardwood stands were selected in Cleveland County, Arkansas. The four stands had a similar disturbance history with a harvest in the late 19th century followed by no management intervention until the partial harvest treatments in 2013. Stand overstories were composed of a mixture of pine-hardwood with shortleaf pine, loblolly pine, southern red oak (*Q. falcata*), cherrybark oak (*Q. pagoda*), post oak (*Q. stellata*), and white oak (*Q. alba*) as main components. Dense hardwood dominated understories were present with an abundance of shrubs and vines. Stands were 4 to 9 miles apart.

In fall 2013, two stands were harvested (i.e., East and Northeast stands) and two were left unharvested (i.e., North and West stands). The harvest was a selective, partial cut that removed a quarter to a third of the standing overstory basal area. Removals included the midstory layer. The management objective was to increase the growth of residual overstory trees while also stimulating regeneration of pine and oak species. No pre-harvest data were available.

Measurements

In fall 2015, the four stands were selected for sampling. Within each stand, 10 permanent 0.2-acre plots were established to measure overstory trees (≥5 inches in diameter at breast height (d.b.h.)). Using the same plot centers, snags (standing dead trees with ≥5 inches d.b.h.) were measured within 10 0.5-acre plots extending beyond the perimeter of overstory tree plots (fig. 1). Three nested 0.02-acre subplots were used for sapling (<5 inches in d.b.h. and ≥4.5 feet in height) measurements. Three 6.8-foot-radius microplots were established for measurements of tree seedlings (1 foot < height < 4.5 feet). Ground vegetation was measured within each of three 10.7-square-foot quadrats centered at each microplot. Coarse (≥3 inches diameter at intersection) and fine (<3 inches diameter at intersection) downed woody material (DWM) were quantified using three line transects along the same azimuth used for establishing the three microplots. DWM transects were 52.7 feet in length and the whole length was used in sampling coarse DWM while a 22-foot transect section was used for fine DWM. None of the plots fell in riparian areas.

Within each permanent plot and subplot, all overstory trees and saplings were identified, tagged, and d.b.h. measured. Snag d.b.h. and total height were measured and snags were assigned one of five decay classes following Chojnacky and others (2004). Tree seedlings were harvested within each microplot and ground vegetation by growth habit were also clipped to estimate biomass. Samples were dried to a constant mass at 212 °F then weighed. DWM was counted or diameter measured along corresponding transect lengths then converted to biomass estimates using Brown's (1974) established methodology. DWM was assigned to one of five decay classes following Chojnacky and others (2004). Snags and DWM were identified to species when unique features were still present and lumped into either pine or hardwood groups when no identifiable species features were present. Specific gravity of DWM species were determined using Miles and Smith (2009).

Analytical Approach

The updated generalized national biomass equations were used to calculate biomass for overstory trees, saplings, and snags (Chojnacky and others 2014). Snags biomass were reduced based on decay status following Harmon and others (2011). Individual tree estimates were pooled for each sampling plot and biomass estimates were converted into carbon using a 0.5 ratio. Seedlings and ground vegetation biomass were determined using dry weights then converted to carbon estimates. Ground vegetation was pooled by growth habit within each quadrat. DWM weights were adjusted based on decay following Chojnacky and others (2004). DWM mass

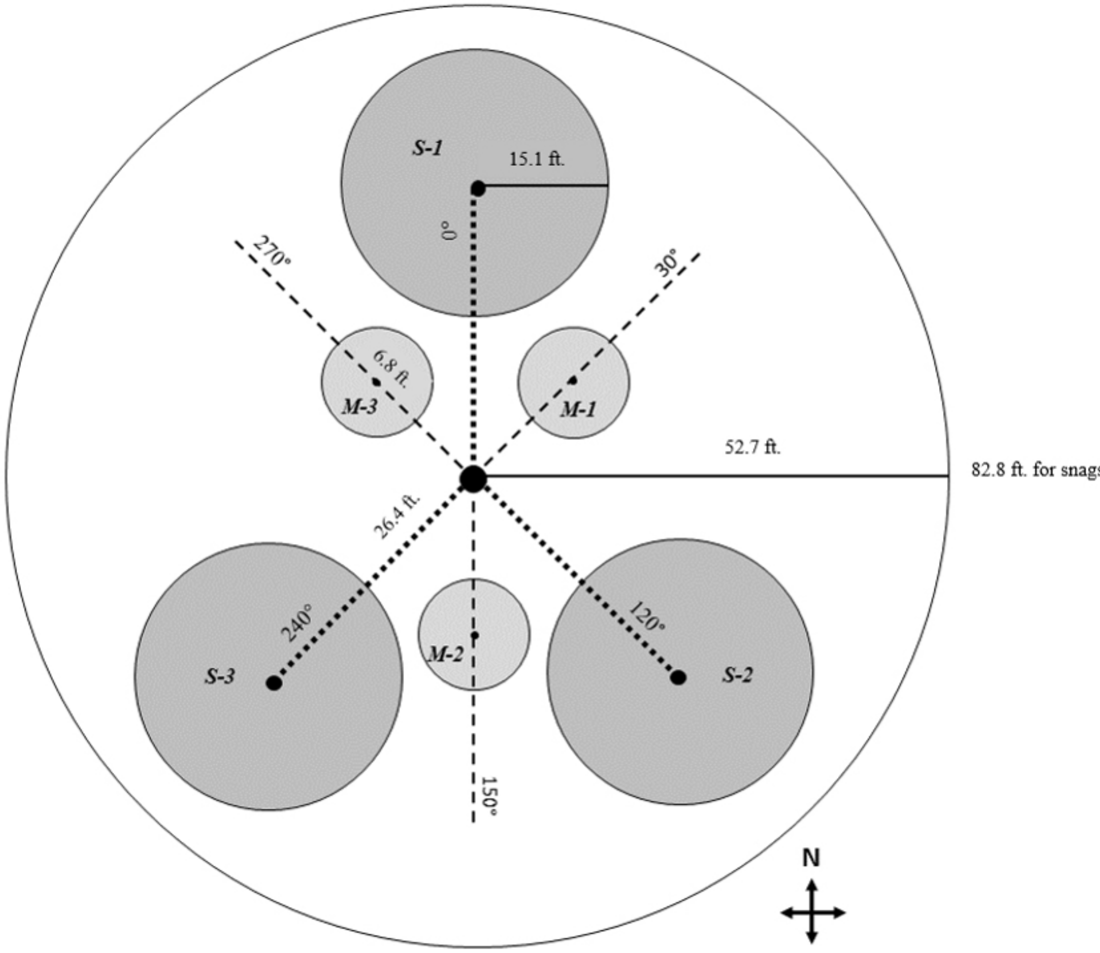

Figure 1—Sampling plot layout and size with sapling subplots (S) and seedlings and ground vegetation microplots (M).

was also converted to carbon estimates using a 0.5 ratio. All carbon estimates were converted to tons per acre estimates.

Standard stand descriptive summary statistics were calculated for tree density, basal area, quadratic mean diameter, stand density index, and site index. Site index was calculated using the curves developed by Zahner (1962) for loblolly pine in southern Arkansas as compiled by Carmean and others (1989). Overstory and sapling d.b.h. distributions were constructed and a two-parameter Weibull function was fit to each stand d.b.h. distribution to highlight differences in tree sizes among stands. The effect of the selective, partial harvests on carbon stock and distribution was tested using one-way analysis of variance (ANOVA) at an alpha level of 0.05. The analysis was conducted based on a completely randomized design. All analyses were conducted using R software version 3.0.2 (R Development Core Team 2013). No indication of patterns in residual plots were detected as evidence of violation of assumptions of normality and homogeneity of variance.

RESULTS AND DISCUSSION

As expected, harvest removals resulted in lower overstory density for managed stands (table 1). In general, the four sites were similar in their site index while their site productivity did not appear to have a confounding effect on growth potential. Overstory d.b.h. distributions were positively skewed for unmanaged stands while managed stands distributions were unimodal (fig. 2). The selective, partial harvest appeared to remove larger diameter trees while maintaining relatively high overstory basal area. Harvests appeared to maintain the pine-hardwood composition of the stands with the proportion of pine basal area remaining at 44 percent and 66 percent for East and Northeast stands, respectively (fig. 3). Harvests appeared to have removed a large portion of the saplings layer (fig. 3).

Unmanaged stands had 12 tons per acre higher aboveground carbon stores in combined overstory trees and saplings ($p < 0.01$, fig. 4). Live tree carbon estimates for unmanaged stands were on par with that reported for the Hyatt's Woods (~ 58 tons per acre; Bragg 2013).

Table 1—Post-harvest overstory attributes for four mature (80-120 years old), natural-origin, pine-hardwood stands in Cleveland County, Arkansas

Treatment Stand	Density	Basal area	QMD	SDI	SI
	trees per acre	*square feet per acre*	*inches*	*trees per acre*	*feet*
Managed					
East	51 (14)	92.6 (17.5)	18.6 (2.1)	133 (26)	103 (3)
Northeast	56 (18)	89.4 (29.7)	17.2 (1.2)	132 (43)	99 (6)
Unmanaged					
North	105 (32)	130.9 (33.8)	15.5 (2.2)	203 (52)	104 (7)
West	133 (44)	120.6 (41.8)	13.1 (2.4)	198 (64)	95 (10)

Mean values with standard deviation in parenthesis.

QMD = Quadratic mean diameter, SDI = Stand density index, SI = Site index.

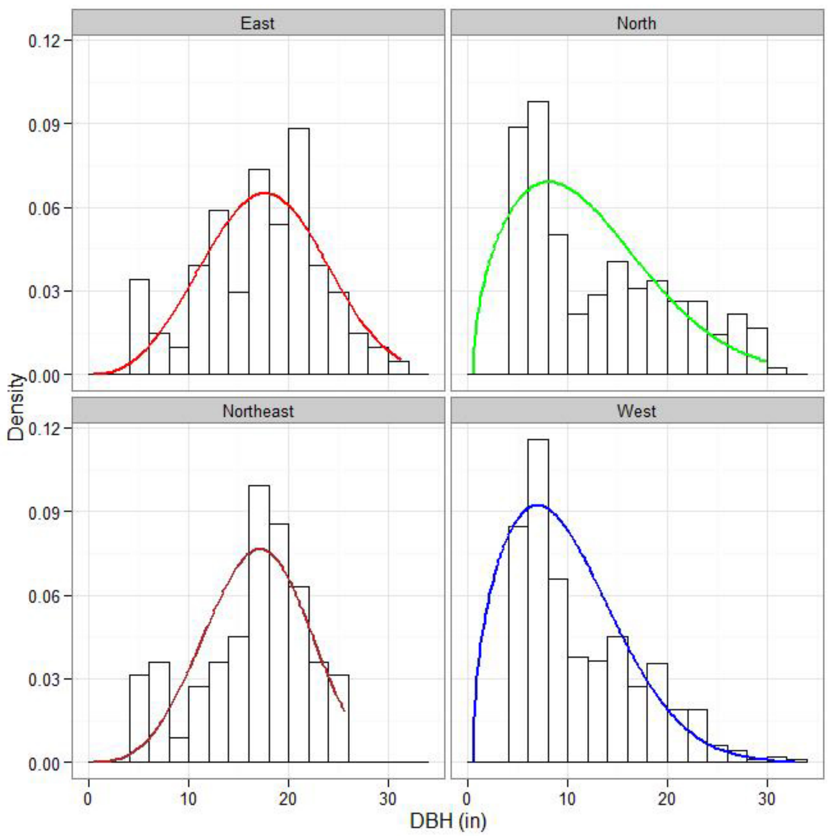

Figure 2—Overstory tree (d.b.h. ≥5 inches) d.b.h. distribution (trees per acre) with fitted two-parameter Weibull model for each of managed (East and Northeast) and unmanaged (North and West) mature (80-120 years old), natural-origin, pine-hardwood stands in Cleveland County, Arkansas.

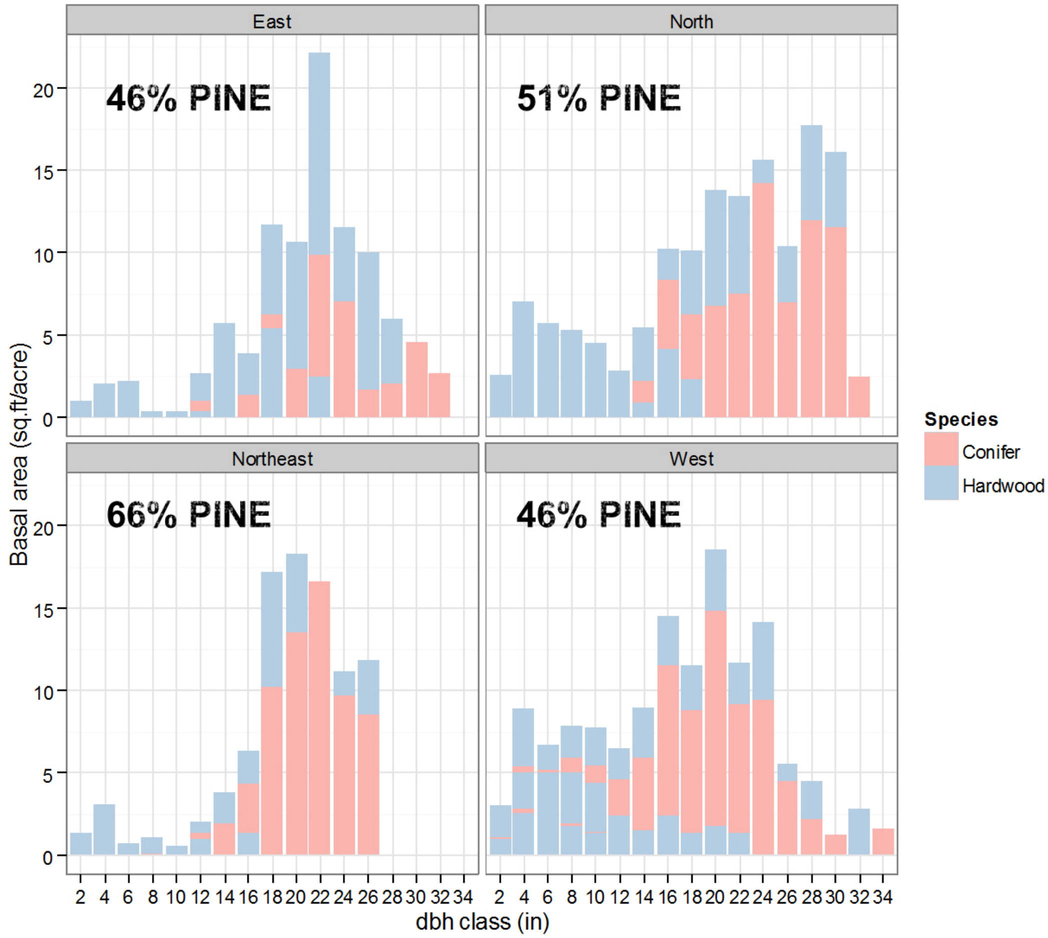

Figure 3—Combined sapling (<5 inches in d.b.h. and ≥4.5 feet in height) and overstory tree (d.b.h. ≥5 inches) d.b.h. distribution for each of managed (East and Northeast) and unmanaged (North and West) mature (80-120 years old), natural-origin, pine-hardwood stands in Cleveland County, Arkansas. Red color indicates conifer while blue indicates hardwood.

Ground vegetation and seedling carbon stores did not differ between managed and unmanaged stands ($p = 0.4$ and 0.2, respectively). DWM was 4 tons per acre higher in managed stands ($p < 0.01$, fig. 5). In general, greater within-stand variability in tree and sapling carbon stores were observed for unmanaged stands (fig. 4) while managed stands had greater within-stand variability in DWM carbon stores (fig. 5).

As stated previously, no pre-harvest data were available. However, the four examined stands shared a similar disturbance and management history and were in close proximity and of similar site quality. In other words, there was no reason or evidence to indicate that those stands had dramatically different initial structures and volumes. Therefore, harvest removals resulted in reduction in carbon stores of live trees and saplings by 12 tons per acre while increasing DWM carbon stores by 4 tons per acre (figs. 4 and 5), for a net effect of 8 tons per acre. These trends are consistent with declines in tree density following harvest and increase in DWM as a result of harvest slash (Fraver and others 2002). Given that stands were sampled within a 2-year period following harvest and that overstory basal area remained relatively high, it is not surprising that ground vegetation and seedling carbon stores did not differ from that in unmanaged stands.

CONCLUSIONS

As area of natural-origin pine forest-type in the Southeastern United States continues to decline and landscape homogeneity increases, it is imperative to document the current conditions of mature, unmanaged, natural-origin pine, pine-hardwood, and upland hardwood stands that represent a legacy of natural disturbance. A better understanding of the effect of harvesting in these compositionally and structurally complex stands will provide for management strategies that maintain carbon stores while simultaneously maintaining and/or enhancing forest complexity. A selective, partial harvest in natural-origin, mature, pine-hardwood stands in southeastern Arkansas resulted

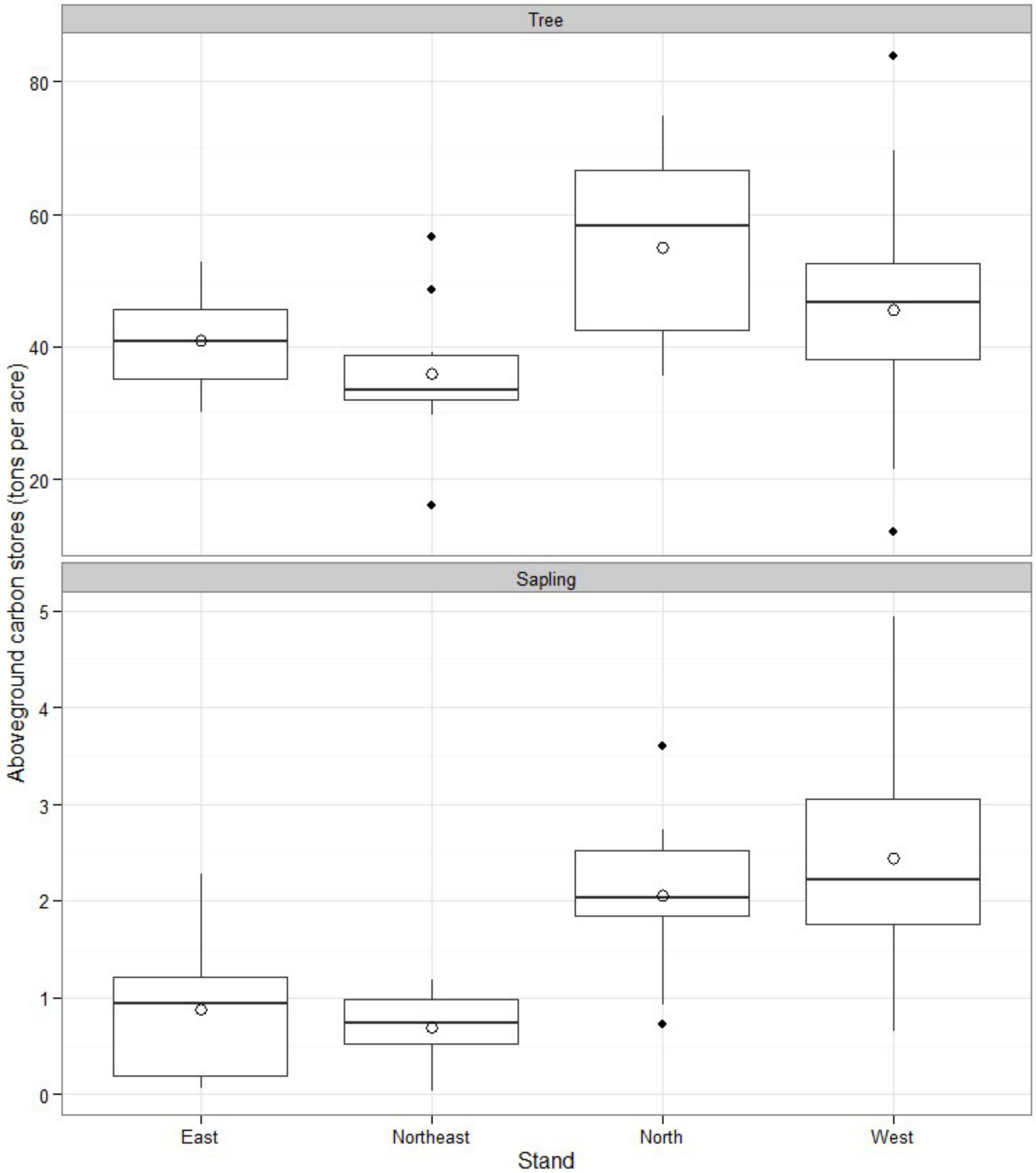

Figure 4—Box plot distribution of overstory tree (d.b.h. ≥5 inches; top) and sapling (<5 inches in d.b.h. and ≥4.5 feet in height; bottom) live, aboveground carbon stores for each managed (East and Northeast) and unmanaged (North and West) mature (80-120 years old), natural-origin, pine-hardwood stand in Cleveland County, Arkansas. Each box represents the 25th, median (50th; horizontal dash), and 75th percentiles. The error bars (whiskers) represent the 10th (below) and 90th (above) percentiles; open circles represent mean; and filled diamonds represent outliers.

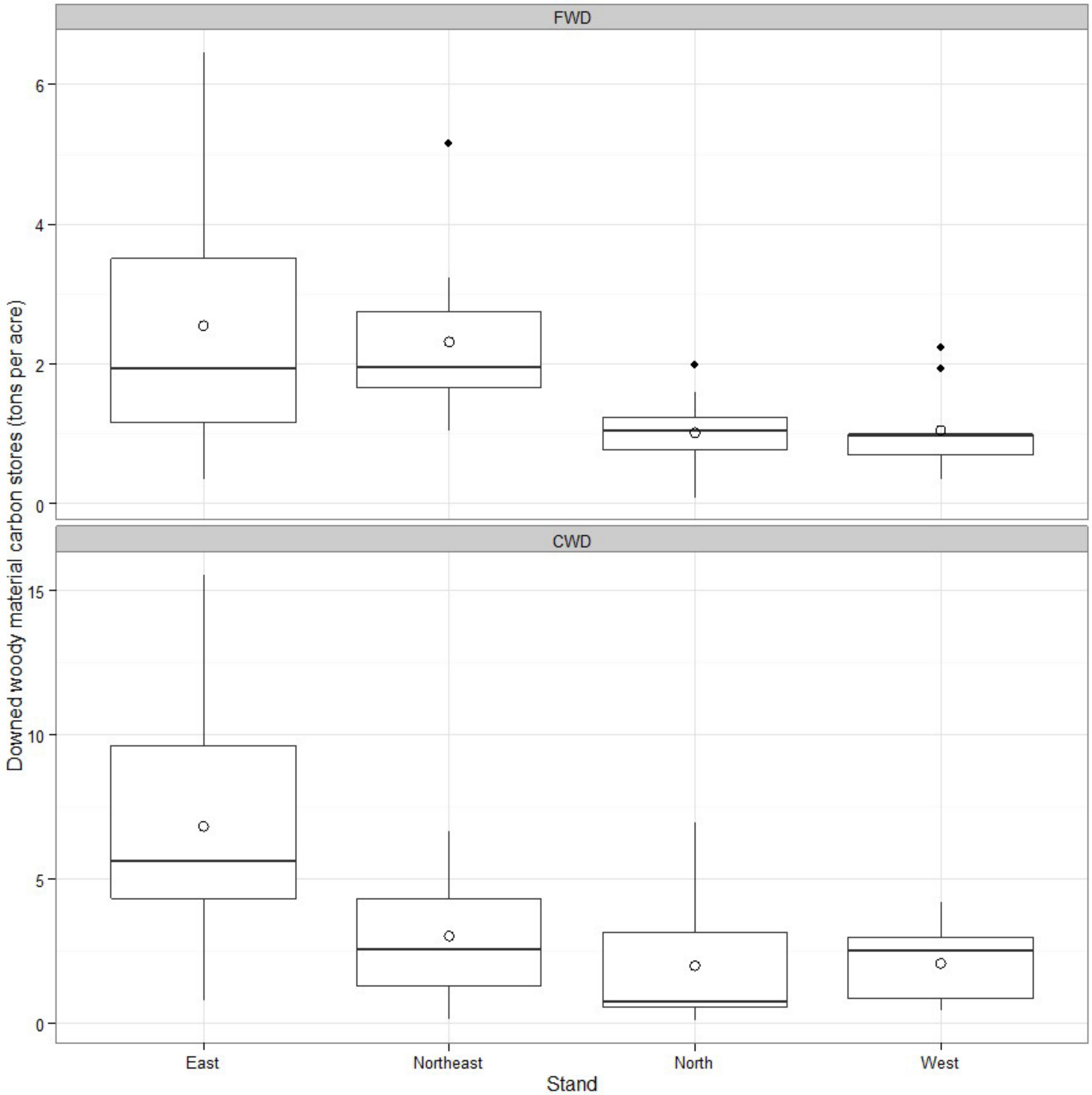

Figure 5—Box plot distribution of fine (<3 inches diameter at intersection; FWD; top) and coarse (≥3 inches diameter at intersection; CWD; bottom) downed woody material carbon stores for each managed (East and Northeast) and unmanaged (North and West) mature (80-120 years old), natural-origin, pine-hardwood stand in Cleveland County, Arkansas. Each box represents the 25th, median (50th; horizontal dash), and 75th percentiles. The error bars (whiskers) represent the 10th (below) and 90th (above) percentiles; open circles represent mean; and filled diamonds represent outliers.

in slightly more uniform stand structure and reduced aboveground carbon stores by 8 tons per acre. Post-harvest residuals of large trees maintained carbon stock at relatively high-levels with greater potential for live tree carbon increment. Carefully planned partial harvests in complex stands such as mature, natural-origin pine-hardwoods of the UWGCP may allow for greater flexibility in balancing maintenance of carbon stores while fostering structural and compositional complexity.

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