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Authors: Stokes, Tom A., Samuelson, Lisa J., Kush, John S., Farris, Marianne G., and Gilbert, John C.

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RESEARCH ARTICLE

Structure and Diversity of Longleaf Pine (*Pinus palustris* Mill.) Forest Communities in the Mountain Longleaf National Wildlife Refuge, Northeastern Alabama

Tom A. Stokes[1]
Lisa J. Samuelson
John S. Kush
Marianne G. Farris
John C. Gilbert

School of Forestry and Wildlife Sciences
Auburn University
Auburn, AL 36849-54182

[1] Corresponding author:
stoketa@auburn.edu

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ABSTRACT: The Mountain Longleaf National Wildlife Refuge (MLNWR), located in northeastern Alabama, is unique in that it holds significant acreages of young and old-growth montane longleaf pine forest (*Pinus palustris* Mill.). We conducted a study to aid in the management and restoration of longleaf pine communities on the MLNWR. Our objectives were to: (1) establish permanent forest monitoring plots; (2) document herbaceous and woody vegetation; and (3) measure forest diversity, structure, and fuel loads in montane longleaf pine communities with varying fire and management histories. We established 48 plots, 0.04 ha in area, in winter 2008 and measured all plots in summer 2008. The MLNWR has recently incorporated prescribed burning in their management plans and each plot was categorized by the year it was burned (2008, 2006, 2004, no-burn) and whether hardwood control treatments were applied. We identified 18, 19, and 22 different woody plant species in the overstory, mid-story, and understory, respectively, across plots. Longleaf pine basal area ranged from 5 to 10 m^2 ha^{-1} and represented as much as 80% of basal area across plots. Mid-story basal area and woody plant species diversity were lower in plots receiving fire or hardwood control. Longleaf pine regeneration was found in only 17 plots and was highest in burned plots or plots receiving hardwood control. Burning also increased grass and herbaceous ground cover. Fuel loads were high with an average humus layer accumulation of 35 Mg ha^{-1}. Regular fire intervals are needed to reduce fuels and mid-story density and aid in the regeneration of longleaf pine.

Index terms: diversity, fire, hardwood control, montane longleaf pine, *Pinus palustris*, regeneration

INTRODUCTION

Prior to European settlement, longleaf pine (*Pinus palustris* Mill.) forests were the largest temperate forest type in North America occupying between 24 and 36 million ha (Frost 1993; Landers et al. 1995). They extended along the Gulf and Atlantic Coastal Plains from Virginia, south into central Florida, and north into the Piedmont and mountains of northern Alabama and Georgia (Stout and Marion 1993). Land clearing for crops and pastures, logging, turpentine operations, conversion to other southern pines, and the interruption of natural fire regimes by forest fire protection policies implemented in the 1920s have reduced the longleaf pine forest to 1.2 million ha, or 3% to 5% of its original range (Outcalt and Outcalt 1994; Brockway and Lewis 1997; Gilliam and Platt 1999). The loss of much of the longleaf pine ecosystem has led to a decrease in abundance of 191 taxa of associated vascular plants including the listing of 30 species as threatened or endangered (Hardin and White 1989; Walker 1993; Glitzenstein et al. 2001). In addition, many remnant stands are severely degraded and very dissimilar to historical accounts (Noss 1989). The continued threat of longleaf pine ecosystem loss has resulted in increased interest in effectively restoring this once vast forest (Means and Grow 1985; Noss 1989; Noss et al. 1995; Brockway and Lewis 1997).

A much smaller component of this diminished ecosystem is the montane longleaf pine community. Montane longleaf pine is found in northern Alabama and Georgia in the Blue Ridge, Ridge and Valley, and Cumberland Plateau regions at elevations up to 600 m asl (Maceina et al. 2000; Varner et al. 2003). Historical accounts depict montane longleaf pine ecosystems as open park-like forests similar to Coastal Plain longleaf pine forests. Montane forests have suffered the same decline caused by logging and long-term fire suppression (Shankman and Wills 1995; Cipollini 2004). By 1995, only 40,000 ha of montane longleaf pine forest remained (Outcalt and Sheffield 1996; Varner 2000) with only 20 ha identified as old-growth (Varner 2000). Montane longleaf pine forests are well adapted to shallow, rocky soils on mountain slopes and ridges and experience occasional ice and snow at high elevations (Garland 1997) and, therefore, represent a physiographically and climatically distinct region of longleaf pine's natural range (Craul et al. 2005). Although not as extensively studied as Coastal Plain longleaf pine forests, early documents noted that montane longleaf pine occurred on south to southwest slopes in single species or mixed stands with a *Pinus echinata* Mill., *Pinus virginiana* Mill., *Quercus marilandica* Muenchh., and *Quercus prinus* L. (Mohr 1901; Harper 1905). Understory diversity in this ecosystem is thought to be enhanced due to the overlapping range limits of many

Appalachian, Coastal Plain, and Piedmont plant species occurring in the montane longleaf pine region (Mohr 1901; Lipps and Deselm 1969; Jones 1974; Maceina et al. 2000).

Previously part of Fort McClellan, the Mountain Longleaf National Wildlife Refuge (MLNWR) holds significant acreages of montane longleaf pine forest and at least 10 old-growth tracts with lush herbaceous communities on areas which experienced frequent fire (Garland et al. 2007). The MLNWR is noted as having the finest remaining stands of old-growth montane longleaf pine forest (Alabama Natural Heritage Program 1994). The primary mission of the MLNWR is the protection, restoration, and management of montane longleaf communities on the MLNWR. After over a century of frequent wildfires related to military training exercises, communities on the MLNWR face the possibility of being replaced by more aggressive fire-sensitive species without appropriate forest management (Garland 2004). Because of lack of historical information on the MLNWR, complex fuel conditions, differing community types, and variable topography, it is critical to acquire current information on forest structure and fuel loads in order to better manage existing stands and facilitate restoration. We conducted a study to aid in the management and restoration of longleaf pine communities on the MLNWR. The specific objectives of this research were to: (1) establish permanent forest monitoring plots on the MLNWR; (2) document herbaceous and woody vegetation; and (3) measure forest diversity, structure, and fuel loads in montane longleaf pine communities with varying fire regimes and management histories.

METHODS

Study Area

This study was conducted at the 3649 ha MLNWR in eastern Calhoun County, northeastern Alabama (33°42’ N, 85°45’ W). The MLNWR was established in 2003 from part of former Fort McClellan, a U.S. Department of Defense military training base. The MLNWR is located in portions of the Choccolocco and Talladega mountain range. This region has long, humid, and warm summers with short mild winters with an average annual temperature and precipitation of 17 °C and 125 cm, respectively (Varner et al. 2003). Fort McClellan has been used for military training since the Spanish American War in the late 1890s, and training-related activities induced frequent wildfires (Garland 2004). Soils are generally Rough Stony Land-Sandstone, a miscellaneous Typic Udult with frequent outcrops of quartzite and sandstone bedrock and loose rock characteristic of many montane longleaf pine ecosystems (Craul et al. 2005).

From February through April 2008, we established 48 plots, 0.1 ha in area, with a circular 0.04 ha measurement plot in the center. Plot centers were marked with a global positioning system (GPS) for future sampling. Plots were first categorized by whether or not hardwood control treatments were applied (Figure 1). In 2002, as part of an effort to determine the possible presence of unexploded ordnances, the army randomly sampled and mapped 0.1 ha plots across the MLNWR; and all vegetation (including longleaf pine) < 10.2 cm diameter at breast height (dbh, 1.36 m) was cut and removed from the plot to aid in equipment mobility. In these same plots in 2005, all hardwood stems ≥ 10.2 cm dbh were injected with imazapyr (Arsenal AC, BASF Corporation, Research Triangle Park, NC) using the “hack and squirt” method. Of these plots, we selected 26 that contained montane longleaf pine. Because the MLNWR is currently expanding hardwood control treatments beyond the 0.1 ha plot, we could not pair hardwood and no hardwood control plots. For the no hardwood control plots, six stands of montane longleaf pine were identified by aerial photography then ground-verified. Two old-growth stands (Caffey Hill and Redtail Ridge), previously studied by Varner et al. (2003), provided nine additional no hardwood control plots. Given the lack of fire records on these stands prior to the establishment of the MLNWR, plots were then categorized by the year of last known controlled burn (2008, 2006, 2004, and no-burn) (Figure 1). The 2006 and 2008 burns were conducted in March while the 2004 burn was conducted in May. According to MLNWR records, fires were ignited from a helicopter in combination with strip-firing the perimeters by hand, which generally followed the contour of the slopes beginning on the upslope position.

Forest Structure

Measurements began in May 2008 and concluded by September. Forest stand structure was examined by measuring dbh on all stems ≥ 2.5 cm by species in each 0.04 ha measurement plot. Forest stands were separated into overstory (stems > 10.2 cm) and mid-story (stems 2.5 to 10.2 cm dbh) strata. Within each measurement plot, five subplots (0.3 m^2) were sampled by random azimuth and distance from plot center. Within each subplot, all understory woody plants < 2.5 cm dbh were identified by species and the number of stems counted. Percent cover of herbaceous plants and grasses was visually estimated. Species nomenclature follows Godfrey (1988) and Samuelson and Hogan (2006).

Diversity indices were calculated for total forest stand vegetation (dbh > 2.5 cm) and included total number of species (R) and Shannon diversity index (H’) (Shannon and Weaver 1949), which is diversity based on richness and abundance. Importance values (IV200) were calculated based on relative density and basal area in the overstory and mid-story, and relative frequency and density in the understory. Mid-story IV200 and mid-story basal area in stands with different burn histories are reported for plots without hardwood control due to the removal of all vegetation < 10.2 cm dbh in hardwood control plots.

The amount of fuel also directly impacts forest structure and biodiversity; therefore, fuel loads defined by litter and humus mass were measured in a 30 cm x 30 cm square adjacent to four of the five subplots. Within these fuel load sampling points, litter layer, partially decomposing litter layer, and humus layer samples were collected, then dried and weighed. Very little coarse woody fuels (> 0.6 cm diameter) were found in litter samples, so fuels were not separated into coarse and fine fuel classes.

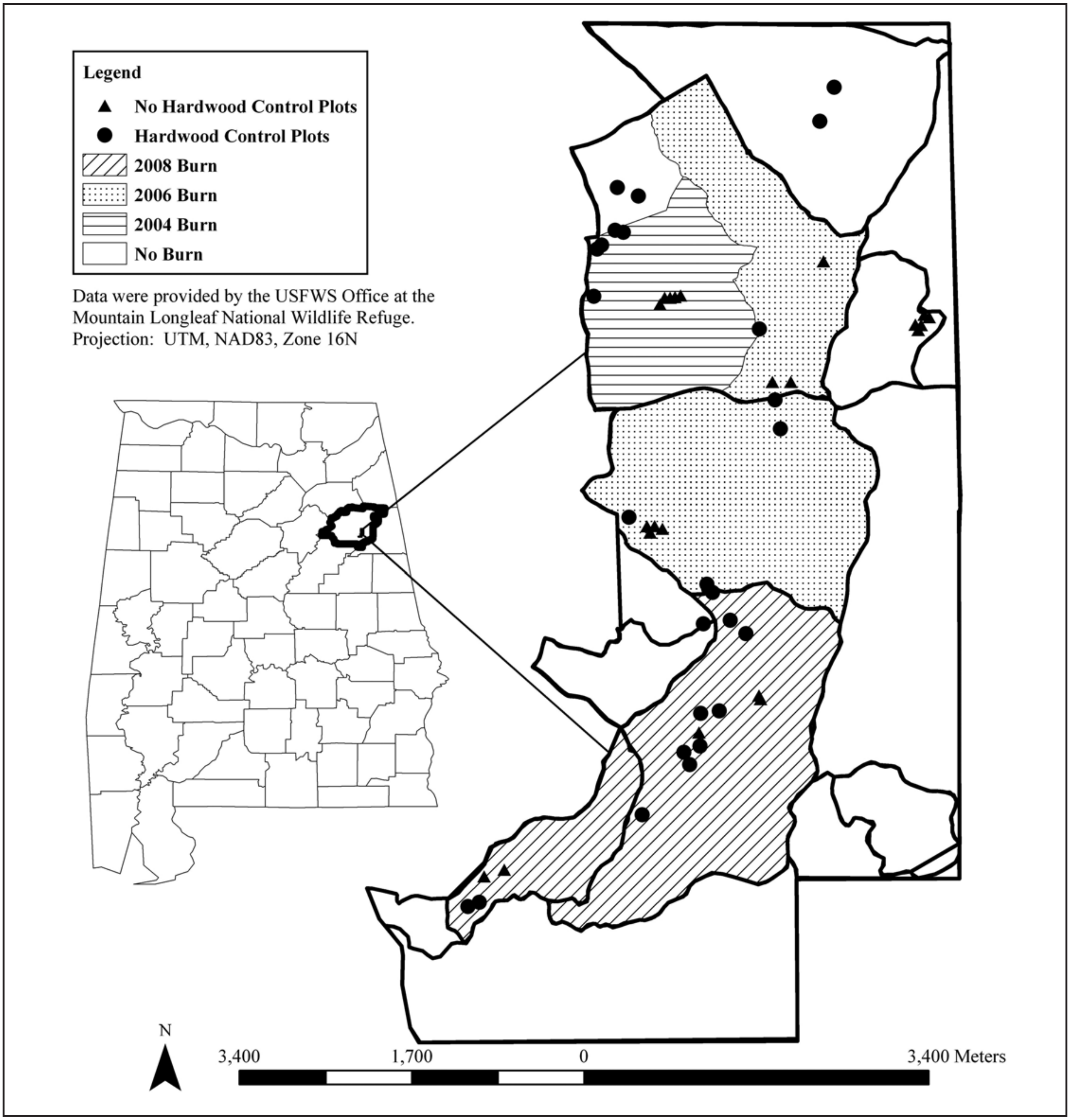

Figure 1. Map of the Mountain Longleaf National Wildlife Refuge, Calhoun County, Alabama, indicating the location of the measurement plots and the burn year and hardwood control treatment for each plot.

Burn year and hardwood control were not randomly assigned to plots and depended on MLNWR management activities, which violates the main assumption of a completely randomized design. Therefore, we discuss trends in the data rather than significant differences detected from statistical tests. We acknowledge several important potential biases in order to help safeguard against erroneous conclusions (Shaffer and Johnson 2008). First, topography and microclimate varied among stands. Second, burn history prior to 2003 is unknown and varies across the MLNWR. Third, longleaf age and diameter distributions and stand diversity potentially varied among plots prior to hardwood control and fire treatments. Finally, burn intensity likely varied among plots.

RESULTS

Forest Overstory and Mid-story

A total of 18 and 19 woody plant species were found in the overstory and mid-story of sample plots, respectively (Table 1 and 2). The IV200 for longleaf in the overstory ranged from 81 in the 2008 burn stands and 85 in the no-burn to 135 and 146 in stands burned in 2004 and 2006, respectively. Stands with hardwood control had an overstory longleaf pine IV200 of 121 versus 98 in stands with no hardwood control. In addition to longleaf pine, which was the species with the highest importance value, the most abundant species found in the overstory were *Quercus marilandica*, *Pinus echinata*, *Nyssa sylvatica* Marsh., *Quercus prinus*, and *Pinus taeda* L. (Table 1). Longleaf pine IV200 in the mid-story was as low as 9 in the no-burn stands and as high as 80 in the 2004 burn stands. Other dominant species in the mid-story included *Quercus marilandica*, *Nyssa sylvatica*, A*cer rubrum* L., *Vaccinium arboreum* Marsh., and *Oxydendrum arboreum* (L.) DC. (Table 2).

Total stand basal area ranged from 11 to 18 m^2 ha^{-1} and longleaf pine basal area ranged from 5.3 to 10.1 m^2 ha^{-1} (Figure 2). The proportion of total basal area in longleaf pine was 45% in stands burned in 2008 or stands that were not burned compared to 80% in stands burned in 2006 and 70% in stands burned in 2004 (Figure 2). Stands that received hardwood control had 65% of basal area in longleaf pine versus 54% in stands with no hardwood control. Total mid-story basal area was higher in the 2008 and no-burn plots (3.3 to 3.8 m^2 ha^{-1}) and without hardwood control (1.9 m^2 ha^{-1}) than in 2004 and 2006 burn plots (0.4 to 0.6 m^2 ha^{-1}) and in stands with hardwood control (0.1 m^2 ha^{-1}) (Figure 2). Longleaf pine density was 86 trees ha^{-1} in plots with no hardwood control and 195 trees ha^{-1} in plots with hardwood control (Figure 3). Longleaf pine density averaged 140 trees ha^{-1} across all burn years. Species richness in the 2008 burn and no-burn stands was approximately double that of stands burned in 2004 and 2006. The Shannon diversity index ranged from 1.3 in 2008 and no-burn plots to 0.9 in 2004 and 2006 burn years. Plots receiving hardwood control had lower R and H' (Figure 4).

Understory, Herbaceous Cover, and Fuel Accumulation

A total of 22 woody plant species were found in the understory, the most abundant

Table 1. Mean importance values (IV200) based on relative density and basal area for overstory tree species (dbh > 10.2 cm) in stands with varying burn history and with or without mechanical/chemical hardwood control (HC). Species nomenclature follows Godfrey (1988) and Samuelson and Hogan (2006).

	Burn Year				Hardwood Control	
Species	2008	2006	2004	No-burn	No HC	HC
Pinus palustris	**81.2**	**145.7**	**134.7**	**85.1**	**98**	**121.3**
Quercus marilandica	7.6	7.9	28.1	41.4	33	7.2
Pinus echinata	33.8	6.6	1.3	25.2	2	31.3
Oxydendrum arboreum	8.3	0	0	12.7	8.5	2.4
Nyssa sylvatica	5.7	4.3	1.5	12.1	9.9	2.3
Quercus prinus	21.1	7.1	2	8.6	15.3	6.8
Quercus velutina	6.2	1.7	3	6.4	6.9	2.2
Carya pallida	0.9	5.3	0	5.7	4.4	1.6
Acer rubrum	5.1	0	0	3	4.9	0
Pinus taeda	9	9.1	19.5	0	0	17.2
Prunus serotina	8.5	1	0	0	3.5	2.5
Quercus rubra	4.7	0	0	0	3.2	0
Carya glabra	3	3.8	0	0	4.2	0
Pinus virginiana	1.7	4.3	0	0	3.7	0
Carya tomentosa	1.4	0	0	0	0	0.8
Quercus coccinea	1.3	0.8	0	0	1.3	0
Liquidambar styraciflua	0.7	0	4	0	0.5	1.5
Quercus stellata	0	2.6	6	0	0.8	2.9

Table 2. Mean importance values (IV200) based on relative density and basal area for mid-story woody species (dbh 2.5-10.2 cm) in stands with varying burn history and no mechanical/chemical hardwood control. Species nomenclature follows Godfrey (1998) and Samuelson and Hogan (2006).

	Burn Year			
Species	**2008**	**2006**	**2004**	**No-burn**
Pinus palustris	**10**	**69**	**79.7**	**9**
Vaccinium arboreum	21	9.6	0	45.1
Nyssa sylvatica	64.4	29	0	40
Quercus marilandica	2.5	45.2	100	31.8
Acer rubrum	23.4	0	0	24.1
Oxydendrum arboreum	15.5	0	0	23.1
Carya pallida	8	6.8	17.8	9.1
Pinus virginiana	0	0	0	6
Quercus velutina	5.3	0	0	4.6
Carya glabra	10.6	20.4	0	2.2
Quercus prinus	8	10.5	0	1.8
Cornus florida	15.1	0	0	1.4
Castanea dentata	0	0	0	0.9
Prunus serotina	6.2	0	0	0.6
Sassafras albidum	3.2	0	0	0.3
Quercus rubra	5.3	0	0	0
Diospyros virginiana	0.8	3.3	0	0
Pinus echinata	0.8	0	2.5	0
Quercus coccinea	0	6.2	0	0

being *Pinus palustris, Sassafras albidum* (Nutt.) Nees, *Quercus marilandica, Nyssa sylvatica, Quercus prinus, Acer rubrum, Carya pallida* (Ashe) Engl. & Graebn., *Diospyros virginiana* L., and *Rhus copallina* L. (Table 3). The IV200 for longleaf pine regeneration was 38 in the 2004 burn and 70 in the 2006 burn year compared to 14 in the no-burn and 0 in the 2008 burn year. Longleaf regeneration ranged from 0 to 24,104 trees ha^{-1} and regeneration was highest in the 2004 and 2006 burns and in stands with hardwood control (Figure 3). Herbaceous cover was low in all treatments (Figure 5). Stands burned in 2004 had 8% herbaceous ground cover compared to 1% in stands burned in 2008 and 4% in stands with no-burn. Grass cover was 18% in stands burned in 2004 and 3% with no-burn (Figure 5). Hardwood control did not appear to have an influence on herbaceous cover or grass cover.

Burn year and hardwood control appeared to have minimal influence on fuel loads (Figure 6). Litter layer and partially decomposing litter layer averaged 12.0 and 7.0 Mg ha^{-1}, respectively. The humus layer was high in all treatments and was on average 35 Mg ha^{-1}. Average total fuel mass was 51 Mg ha^{-1}.

Caffey Hill and Redtail Ridge Stands

To examine changes in forest stand structure on the MLNWR, we measured characteristics of two stands previously studied in 1999 by Varner et al. (2003): Caffey Hill (burned in 2004) and Redtail Ridge (burned in 2006) (Table 4). In 1999, Varner et al. (2003) identified 17 woody plant species in the stand on Caffey Hill compared to the five woody species we identified in the present study. Longleaf pine density was 283 tree ha^{-1} in 1999 compared to 200 trees ha^{-1} in 2008. Longleaf pine basal area decreased from 13.0 m^2 ha^{-1} in 1999 to 7.2 m^2 ha^{-1} in 2008. However, longleaf pine IV200 increased from 102 in 1999 to 121 in 2008. There was a 42% decrease in total density and 65% decrease in total basal area from 1999 to 2008. Species that were lost from the stand with densities > 10 trees ha^{-1} include *Nyssa sylvatica, Quercus stellata* Wang., and *Prunus serotina* Ehrh. (Table 4). Longleaf pine regeneration was 413 trees ha^{-1} in 1999 and 8000 trees ha^{-1} in 2008 (data not shown).

In 1999, Varner et al. (2003) identified eight woody species in the stand at Redtail Ridge compared to 11 species we identified in 2008. Longleaf pine density was 298 trees ha^{-1} in 1999 compared to 206 trees ha^{-1} in 2008. Longleaf pine basal area increased from 8.3 m^2 ha^{-1} in 1999 to 10.7 m^2 ha^{-1} in 2008. The IV200 of longleaf pine decreased to 122 in 2008 from 150 in 1999. Total tree density at Redtail Ridge decreased by 27%; however, total basal area increased by 57% in 2008 compared to 1999. Tree species identified in 2008 that were not found in 1999 included *Carya glabra* (Mill.) Sweet, *Pinus virginiana, Prunus serotina, Vaccinium arboreum*, and *Pinus echinata* (Table 4). Longleaf pine regeneration increased from 0 trees ha^{-1} to 8333 trees ha^{-1} at Redtail Ridge from 1999 to 2008 (data not shown).

DISCUSSION

Longleaf pine continues to inhabit most of its original, albeit very fragmented, range and thus restoration appears to be feasible in some areas (Landers et al. 1995). Longleaf pine communities require an open mid-story which allows light to reach the forest floor to maintain ground cover plant diversity and to aid in longleaf pine regeneration (Mitchell et al. 2006). Decades of fire exclusion has allowed invasion of hardwoods in the understory and mid-story which, in turn, has suppressed longleaf pine regeneration and increased fuel loads in many stands throughout longleaf pine's range (Condon and Putz 2007). As a result, restoration efforts must consider approaches to control hardwood competition and reintroduce fire to the ecosystem. For example, Provencher et

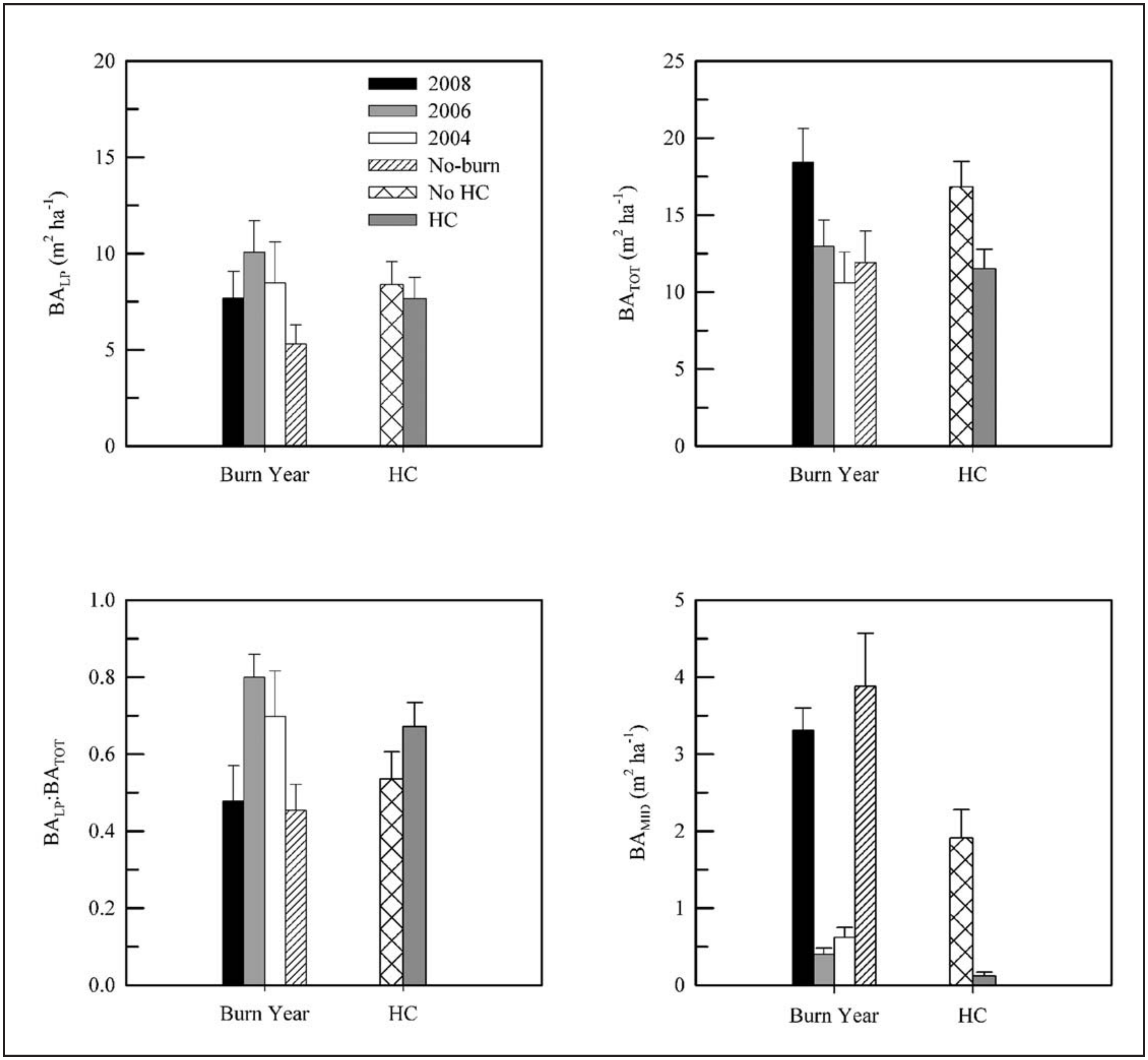

Figure 2. Mean (± SE) longleaf pine basal area (BA_{LP}), total basal area (BA_{TOT}), longleaf pine to total basal area ratio (BA_{LP}:BA_{TO}T) and mid-story basal area (BA_{MID}) in stands with varying burn history and with or without mechanical/chemical hardwood control (HC). Means for BA_{MID} by burn year are reported for plots that did not receive hardwood control.

al. (2001) reported that a reduction in mid-story stems by > 90% through felling/girdling and herbicide treatments had little effect on understory diversity in longleaf pine stands until those treatments were followed by fire three years later. In turn, the use of fire alone to reduce an established hardwood mid-story can be risky because high intensity fires could increase the likelihood of mortality in overstory longleaf pine trees (Glitzenstein et al. 1995; Varner et al. 2005; Williams et al. 2006). Mechanically or chemically removing hardwoods would allow for more frequent low-intensity fires that would aid in the restoration of understory communities without increased risk of high-intensity fires (Hiers et al. 2007). Some of the benefits from re-establishing regular fire intervals in the longleaf pine ecosystem include: excluding invasive plants, preparing a seedbed for longleaf pine regeneration, reducing understory density, releasing immobilized nutrients, and reducing fuel loads that can make this ecosystem susceptible to severe wildfires (McKee 1982; Wade and Lewis 1987; Wade and Lundsford 1990; Dickmann 1993; Brennan and Hermann 1994; Brockway and Lewis 1997).

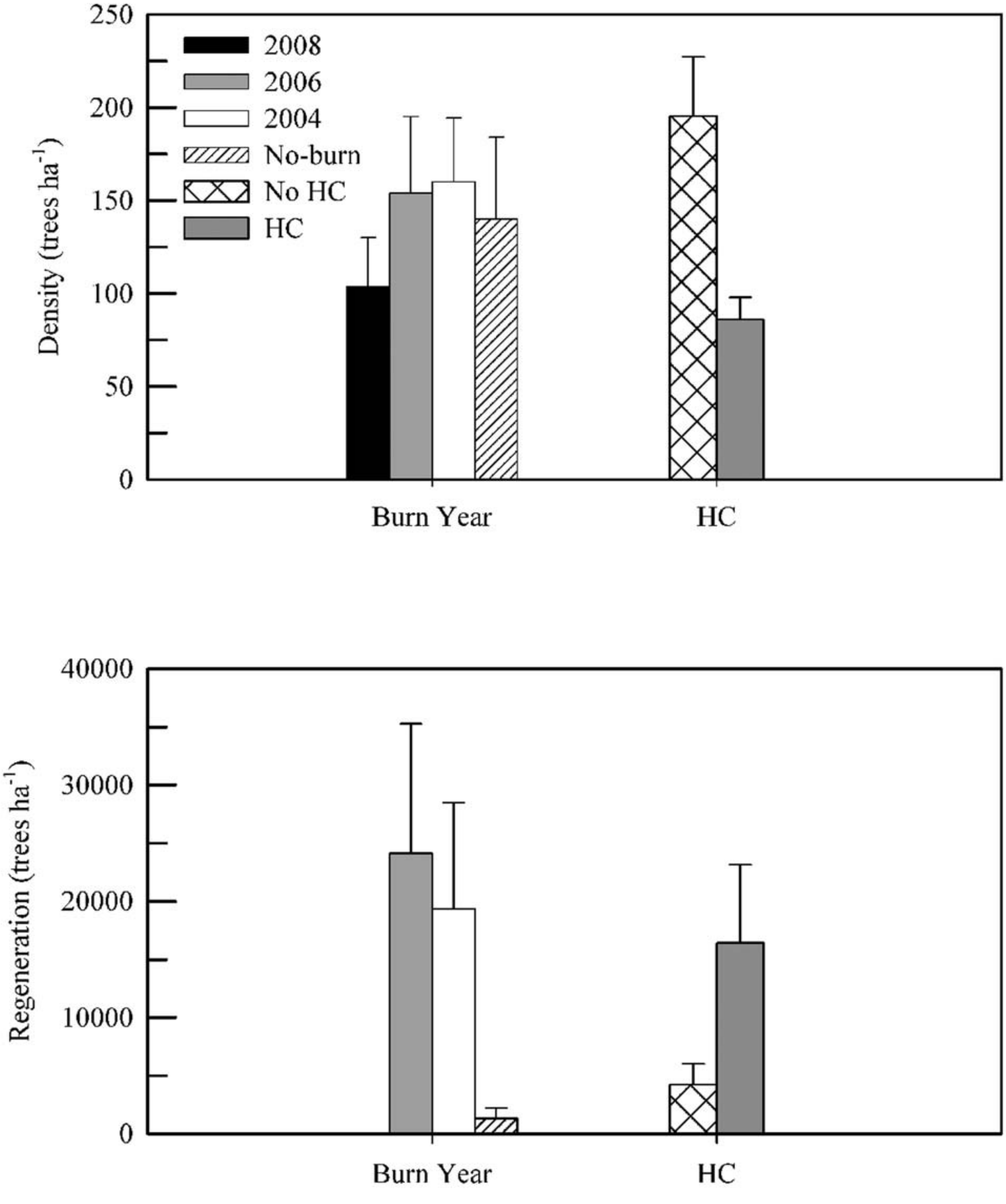

Figure 3. Mean (± SE) forest stand longleaf pine density and longleaf pine regeneration in stands with varying burn history and with or without mechanical/chemical hardwood control (HC).

Hardwood control and burning in the MLNWR appeared to be effective in reducing hardwood and mid-story basal area and overstory hardwood diversity and in increasing longleaf pine density and abundance. Maximum forest stand H' was 1.5 and maximum R was 7.1 and these values are similar to the H' and R of 1.6 and 7, respectively, for a longleaf

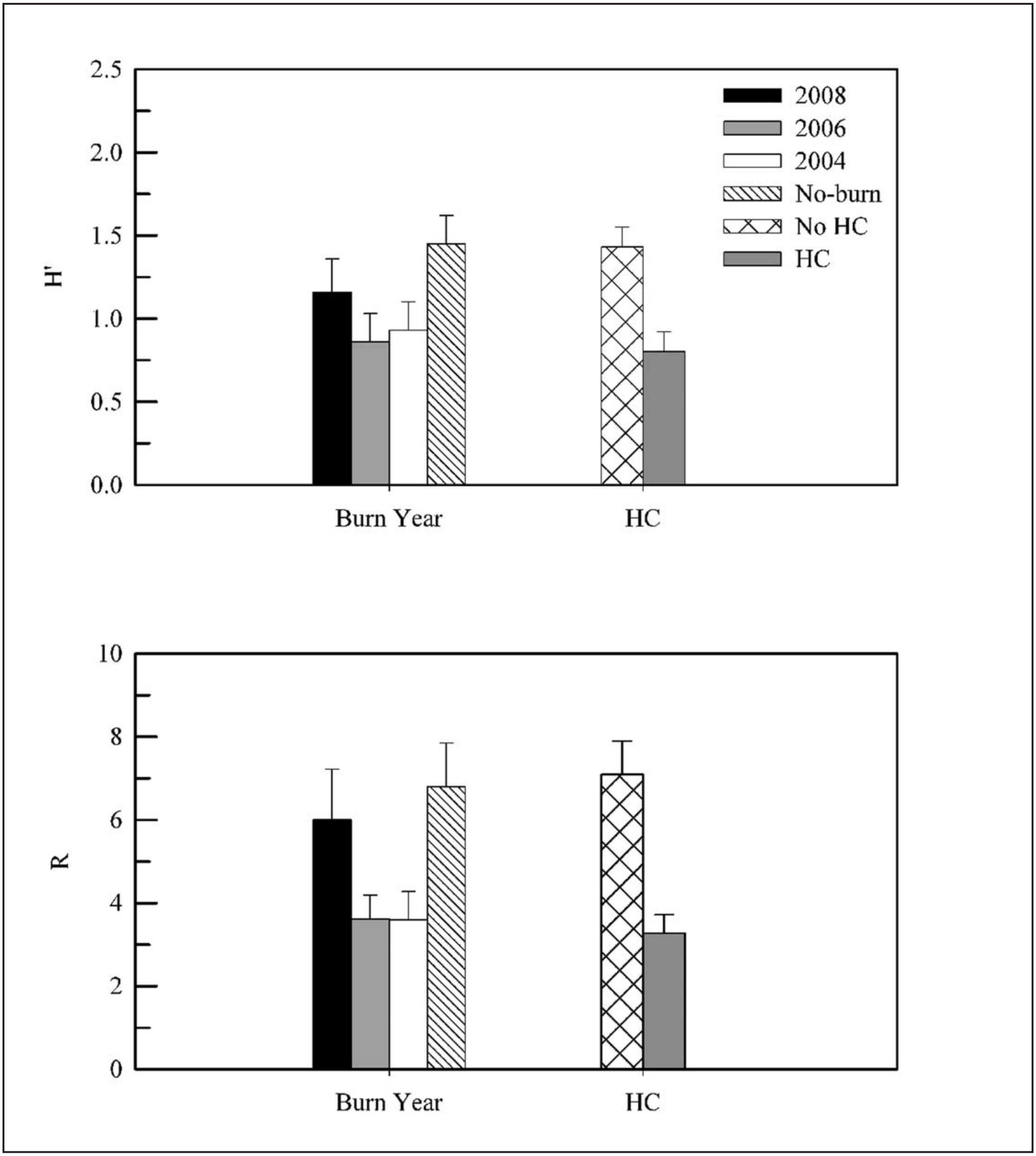

Figure 4. Mean (± SE) forest stand Shannon diversity index (H') and species richness (R) in stands with varying burn history and with or without mechanical/chemical hardwood control (HC).

pine stand on a moderately drained fluvial terrace site located at Ichauway, southern Georgia (Kirkman et al. 2004). The range in IV200 for longleaf in the overstory was 81 to 146, which is higher than the 55 reported for a virgin longleaf stand in southern Alabama (Kush and Meldalh 2000) and the longleaf IV200 of 31 and 87 recorded in old-growth stands in North Carolina

Table 3. Mean importance values (IV200) based on relative frequency and density for woody species found in the understory (dbh < 2.5 cm) in stands with varying burn history and with and without mechanical/chemical hardwood control (HC). Species nomenclature follows Godfrey (1988) and Samuelson and Hogan (2006).

	Burn Year				Hardwood Control	
Species	2008	2006	2004	No-burn	No HC	HC
Pinus palustris	**0**	**70.2**	**38.7**	**14**	**26.9**	**32.6**
Acer rubrum	75.1	21.2	0	47.5	31.8	45.3
Sassafras albidum	25.6	5.3	59.8	39.3	52.3	11.3
Carya pallida	0	19.7	6.8	21.3	10.4	11.9
Quercus prinus	12.9	9.1	0	15.8	8.8	10.7
Carya glabra	6.7	1.8	8.3	10.7	4.1	13.6
Nyssa sylvatica	6	14.3	2.5	10	9.4	7.5
Rhus copallina	25.6	5.3	59.8	9.3	52.3	11.3
Diospyros virginiana	0	0	41.4	9.3	5.3	15
Quercus velutina	0	2.2	0	2.7	1.3	1
Quercus marilandica	22.4	0	13.9	0	3.6	15.3
Malus angustifolia	14.3	4.4	0	0	0	10.5
Quercus rubra	8.1	0	0	0	5.5	0
Quercus stellata	6.7	0	5.8	0	0	6.1
Carya tomentosa	6.7	0	0	0	0	3.9
Liquidambar styraciflua	6.7	0	0	0	0	3.9
Amelanchier arborea	4	0	0	0	0	2.3
Asimina triloba	2.5	2.2	0	0	3	0
Pinus echinata	2.4	0.9	0	0	0	1.8
Oxydendrum arboreum	0	0	2.5	0	0	1
Pinus taeda	0	3.6	1.7	0	0	2.4
Rhododendron spp.	0	3.3	5.1	0	1.9	2

and southern Georgia, respectively (Gilliam and Platt 1999). Varner et al. (2003) measured two old-growth stands (Caffey Hill and Redtail Ridge) on the MLNWR in 1999 in which nine of our measurement plots were located, none of which received hardwood control. They reported an IV200 for longleaf pine in the overstory of 102 and 150 for Caffey Hill and Redtail Ridge, respectively. Since their study, Caffey Hill was burned in 2004 and Redtail Ridge in 2006. Nine years after the work by Varner et al. (2003), we observed an IV200 of 121 and 122 at Caffey Hill and Redtail Ridge, respectively, which indicates an increase in longleaf pine abundance in the overstory at Caffey Hill and a decrease at Redtail Ridge. The decrease in longleaf pine IV200 at Redtail Ridge may be due to the loss of frequent burning and a subsequent larger increase in hardwood than pine basal area once the base became a refuge. Redtail Ridge was located close to three firing ranges within Fort McClellan and probably encountered annual fires due to military training exercises (Varner et al. 2003). At Caffey Hill, total basal area, longleaf pine basal area, and longleaf density was lower in 2008 compared to 1999 possibly due to mortality in response to the 2004 burn.

Without regular fire management, gaps created by the death of large longleaf pine will be filled by mid-story species (Kush and Meldahl 2000). In the mid-story of the no-burn plots, we found several fire sensitive species such as *Acer rubrum, Oxydendrum arboreum*, and *Pinus virginiana*. Controlling these species with fire while still in the mid-story is important because mortality from fire is reported to be higher in younger and smaller stems (Reich et al. 1990; Waldrop and Lloyd 1991; Brose and Van Lear 1998; Dey and Hartman 2005). For example, in an oak stand in Kentucky, Blankenship and Arthur (2006) reported that mid-story *Acer rubrum* basal area decreased by 91% with fire while basal area of *Oxydendrum arboreum* and *Nyssa sylvatica* only decreased in the 2 to 5 cm dbh class. In our study, the 2004 and 2006 burns were effective in eliminating mid-story stems of *Acer rubrum, Oxydendrum arboreum*, and *Pinus virginiana* in stands that did not receive hardwood control. *Nyssa sylvatica* has been reported to be both fire-sensitive (Dey and Hartman 2005) and fire-resistant

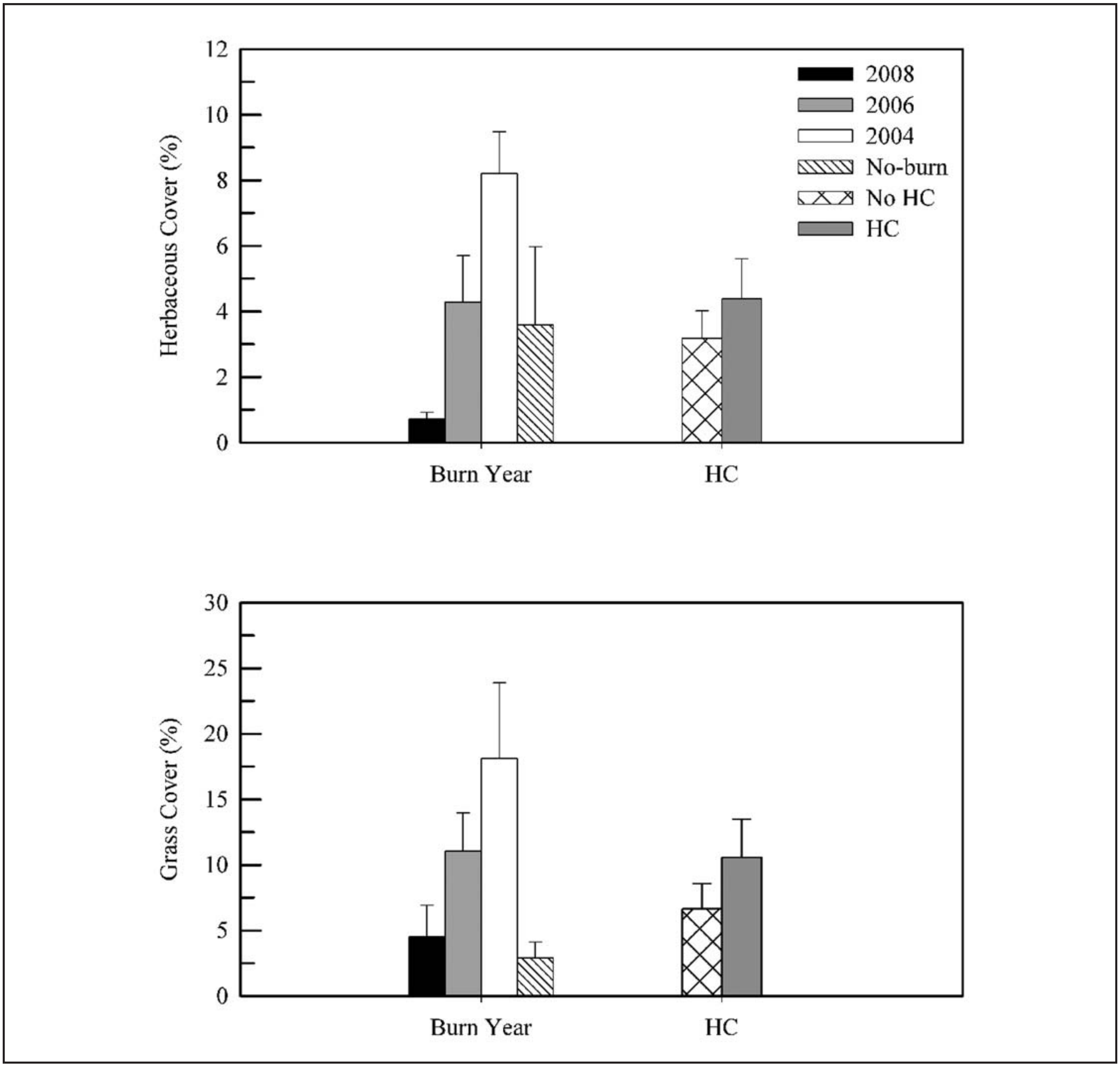

Figure 5. Mean (± SE) percent herbaceous and grass cover in stands with varying burn history and with or without mechanical/chemical hardwood control (HC).

(Abrams 2007). *Nyssa sylvatica* was a relatively dominant component of the midstory in our study plots except in the 2004 burn year; however, this slow-growing tree rarely becomes a dominant species in the overstory (Abrams 2007).

Basal area of longleaf pine greater than 7 m^2 ha^{-1} has been shown to be negatively correlated with cone production (Croker 1973). Similarly, Boyer (1993) reported that longleaf pine regeneration was not retained when overstory longleaf pine basal area exceeded 6 m^2 ha^{-1}. However, Kush et al. (2004) reported regeneration in stands with 17 m^2 ha^{-1} basal area, primarily in longleaf pine, and did not find a correlation between plot basal area and cone production. All 48 plots on the MLNWR can be considered adequately stocked for longleaf pine regeneration since longleaf basal area ranged from 5 to 10 m^2 ha^{-1}. However, only 17 of the 48 plots (35.4%) had longleaf pine regeneration. Longleaf pine regeneration was highest in stands burned in 2004 and 2006 and in stands receiving hardwood control. Low regenera-

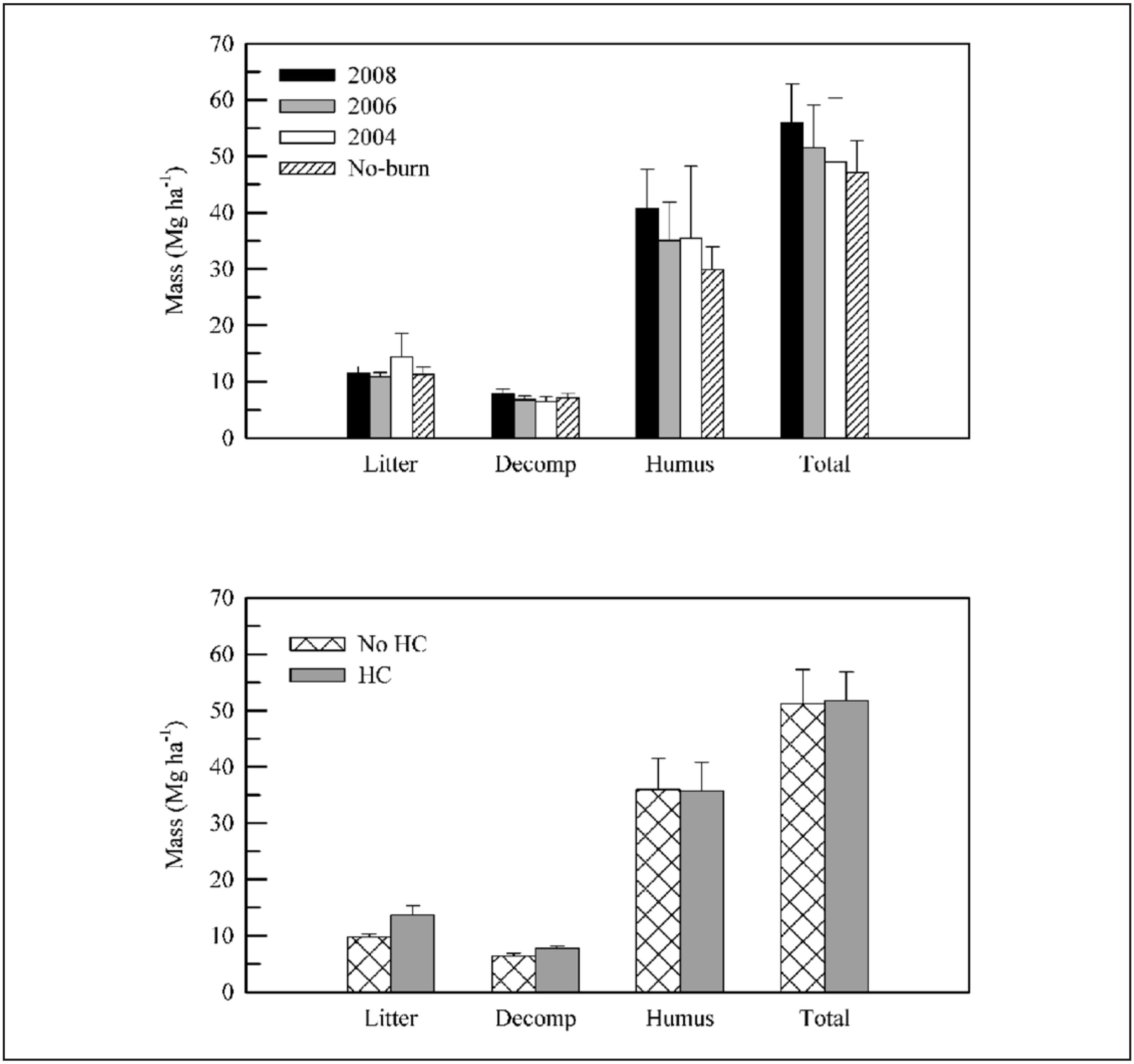

Figure 6. Mean (± SE) dry mass of litter (Litter), partially decomposing litter (Decomp), and humus (Humus) layers and total dry mass (Total) in stands with varying burn history and with or without mechanical/chemical hardwood control (HC).

tion success may be a result of high total basal areas (8 to 16 m^2 ha^{-1}) (Boyer 1993) or the high amount of fuels on the ground which can inhibit longleaf pine regeneration. All components of forest floor fuels were high on the MLNWR. Humus was on average 35 Mg ha^{-1} and total fuels were 51.0 Mg ha^{-1}. Kush and Meldahl (2006) reported 7.2, 11.8, and 19.8 Mg ha^{-1} of litter, partially decomposing litter, and humus, respectively, for a virgin longleaf pine stand in southern Alabama. Eight years after the reintroduction of fire, litter, partially decomposing litter, and humus decreased to 3.4, 12.7, and 14.0 Mg ha^{-1}, respectively (Kush and Meldahl 2006). Biennial burning has been reported to decrease organic litter biomass by as much as 66% (Kush et al. 1999), and Haywood et al. (2004) reported that burning removed over half of the available fuels. There appears to be little influence of fire on forest floor fuels in this study, probably because each stand was only recently burned once and single burns have been reported to show little change in fuel conditions (Haywood et al. 2004).

Table 4. Mean forest stand (dbh > 2.5 cm) density, basal area (BA) and importance values (IV200) based of relative density and basal area for all tree species identified at Redtail Ridge and Caffey Hill. Values in brackets are from 1999 as reported by Varner et al. (2003). Species nomenclature follows Godfrey (1988) and Samuelson and Hogan (2006).

	Redtail Ridge			Caffey Hill		
Species	Density (trees ha^{-1})	BA (m^2ha^{-1})	IV_{200}	Density (trees ha^{-1})	BA (m^2ha^{-1})	IV_{200}
Pinus palustris	**206 [298]**	**10.7 [8.3]**	**122 [150]**	**200 [283]**	**7.2 [13.0]**	**121 [102]**
Quercus marilandica	56.3 [174]	0.1 [0.3]	27.6 [36.2]	190 [163]	0.6 [1.4]	68.4 [29.6]
Quercus prinus	25.0 [21.1]	1.5 [0.1]	14.2 [4.7]	5.0 [20.9]	0.1 [1.0]	1.9 [7.7]
Carya glabra	25.0 [0]	0.4 [0]	13.4 [0]	0 [0]	0 [0]	0 [0]
Nyssa sylvatica	12.5 [4.4]	0.2 [0.02]	5.3 [1.0]	0 [65.0]	0 [1.0]	0 [13.6]
Quercus stellata	12.5 [1.5]	0.2 [<0.01]	3.8 [0.3]	0 [18.8]	0 [0.3]	0 [4.3]
Pinus virginiana	6.3 [0]	0.4 [0]	3.6 [0]	0 [3.8]	0 [0.2]	0 [4.3]
Carya pallida	12.5 [20.3]	0.1 [0.04]	3.1 [4.3]	20.0 [110]	0.1 [2.3]	7.9 [26.4]
Prunus serotina	6.3 [0]	0.1 [0]	2.8 [0]	0 [17.2]	0 [0.3]	0 [3.9]
Vaccinium arboreum	12.5 [0]	0.01 [0]	2.7 [0]	0 [8.6]	0 [0.03]	0 [1.3]
Pinus echinata	6.3 [0]	0.1 [0]	1.6 [0]	5.0 [13.4]	0.01 [0.6]	1.0 [4.6]
Quercus velutina	0 [5.1]	0 [0.01]	0 [1.1]	0 [6.4]	0 [2.5]	0 [2.1]
Acer rubrum	0 [0]	0 [0]	0 [0]	0 [4.8]	0 [0.06]	0 [1.0]
Oxydendrum arboreum	0 [1.5]	0 [0.01]	0 [0.4]	0 [2.7]	0 [0.04]	0 [0.6]
Cornus florida	0 [0]	0 [0]	0 [0]	0 [2.2]	0 [0.01]	0 [0.3]
Pinus taeda	0 [0]	0 [0]	0 [0]	0 [0.5]	0 [0.01]	0 [0.1]
Liquidambar styraciflua	0 [0]	0 [0]	0 [0]	0 [0.5]	0 [<0.01]	0 [0.1]
Sassafras albidum	0 [0]	0 [0]	0 [0]	0 [9.5]	0 [0.01]	0 [1.9]

We identified 22 woody plant species in the understory of our plots, some of which are considered fire-sensitive, such as *Nyssa sylvatica, Sassafras albidum*, and *Acer rubrum* (Signell and Abrams 2006). In addition to fire severity and burn intervals, the abundance of rocks in the MLNWR landscape possibly mitigated fire severity and acted as a buffer for nearby seedlings (Signell and Abrams 2006). Fire did appear to enhance grass and herbaceous groundcover. Brockway and Lewis (1997) reported increased groundcover in graminoids and standing biomass of herbaceous understory plants with fire treatments. They found that all fire treatments (annual, biennial, and triennial) increased grass cover to an average of 30% compared to 1.5% cover in the control treatment. Similar results were reported at Eglin Air Force Base in northwest Florida where the frequency of herbaceous groundcover species was decreased in fire-suppressed plots (Rodgers and Provencher 1999). Fire interval appears to be important in groundcover composition. Glitzenstein et al. (2003) reported that annual and biennial burns resulted in more herbaceous groundcover while three- and four-year burn intervals produced a more shrub dominated groundcover.

There has been progress in longleaf pine regeneration since the establishment of the MLNWR. On Caffey Hill and Redtail Ridge prior to the establishment of the MLNWR, Varner et al. (2003) reported longleaf pine regeneration of 413 and 0 trees ha^{-1} for Caffey Hill and Redtail Ridge, respectively. In our study of these same areas nine years later, we found 8000 and 8333 trees ha^{-1} in longleaf pine regeneration at Caffey Hill and Redtail Ridge, respectively. In addition, the 26 hardwood control plots we sampled throughout the MLNWR were surveyed by Garland et al. (2007) prior to the implementation of hardwood control in 1999. They report that only eight of these plots (30.8%) were dominated by longleaf pine basal area and only 12 plots (46.2%) had enough longleaf pine basal area for natural regeneration. Averaged across the plots measured by Garland et al. (2007), basal area was 7.2 m^2 ha^{-1} with longleaf pine representing 35% of the total basal area. They also reported that longleaf pine regeneration was absent in all but eight plots. After mechanical and chemical hardwood control, longleaf pine basal area on these plots averaged 8.4 m^2 ha^{-1} and longleaf pine accounted for 65% of the total basal area in 2008.

In conclusion, stands receiving chemical and mechanical hardwood control or fire had lower hardwood and mid-story basal area, greater longleaf pine density, and increased dominance and abundance of longleaf pine in the overstory. Fire and hardwood control aided in the regeneration of longleaf pine; however, longleaf pine regeneration is still scarce on the MLNWR. Only one prescribed burn has been applied to each plot, and regular fire intervals would facilitate the reduction in fuels and midstory density and aid in the regeneration of longleaf pine. It should also be noted that due to the lack of information on montane longleaf pine forests, much of the data presented here are compared to Coastal Plain longleaf forests, which stresses the need for future research and restoration of this highly unique ecosystem.

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Tom A. Stokes is a Research Associate in Tree Physiology and in the Center for Longleaf Pine Ecosystems at Auburn University. His research interests include tree responses to environmental stress and biodiversity, restoration, and carbon sequestration in longleaf pine ecosystems.

Lisa J. Samuelson is Professor of Tree Physiology and Director of the Center for Longleaf Pine Ecosystems at Auburn University. Her research interests include woody plant ecophysiology, climate change effects on forests, and forest carbon sequestration.

John S. Kush is a Research Fellow for the Auburn University School of Forestry and Wildlife Sciences and serves as Director of the Longleaf Pine Stand Dynamics Laboratory. His research focus for the past 25 years has been longleaf pine stand dynamics, growth and mortality, and fire and restoration ecology.

Marianne G. Farris is a Research Specialist in the Center for Longleaf Pine Ecosystems at Auburn University. Her research focuses on woody plant physiology.

John C. Gilbert is a Research Associate in the Longleaf Pine Stand Dynamics Laboratory at the Auburn University School of Forestry and Wildlife Sciences. His research interests include mapping and inventory of longleaf pine stands across the historic range, growth and mortality, and fire and restoration ecology.

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