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Structure and composition changes following restoration treatments of longleaf pine forests on the Gulf Coastal Plain of Alabama

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ABSTRACT

Longleaf pine (*Pinus palustris* Mill.) forests of the Gulf Coastal Plain historically burned every 2–4 years with low intensity fires, which maintained open stands with herbaceous dominated understories. During the early and mid 20th century however, reduced fire frequency allowed fuel to accumulate and hardwoods to increase in the midstory and overstory layers, while woody shrubs gained understory dominance. In 2001, a research study was installed in southern Alabama to develop management options that could be used to reduce fuel loads and restore the ecosystem. As part of a nationwide fire and fire surrogates study, treatments included a control (no fire or other disturbance), prescribed burning only, thinning of selected trees, thinning plus prescribed burning, and herbicide plus prescribed burning. After two cycles of prescribed burning, applied biennially during the growing season, there were positive changes in ecosystem composition. Although thinning treatments produced revenue, while reducing midstory hardwoods and encouraging growth of a grassy understory, burning was needed to discourage regrowth of the hardwood midstory and woody understory. Herbicide application followed by burning gave the quickest changes in understory composition, but repeated applications of fire eventually produced the same results at the end of this 8-year study. Burning was found to be a critical component of any restoration treatment for longleaf communities of this region with positive changes in overstory, midstory and understory layers after just three or four burns applied every 2 or 3 years.

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1. Introduction

The southern region of the United States has numerous thunderstorm days each year and therefore considerable lightning activity (Komarek, 1964; Outcalt, 2008). These lightning strikes have the potential for and do start fires, especially in the early part of the growing season following the normal spring drought (Robbins and Myers, 1992). Historically, prior to fragmentation of the landscape, fire was a frequent natural occurrence (every 1–8 years) across much of the South (Abrahamson and Hartnett, 1990; Christensen, 1981; Ware et al., 1993). Native Americans used fire regularly to manipulate and manage the environment around them (Anderson, 1996; see Robbins and Myers, 1992), thus augmenting these natural fires.

These frequent surface fires favored longleaf pine (*Pinus palustris* Mill.) and grasses by inhibiting the establishment and growth of competitive but less fire-tolerant species (Clewell, 1989). Because of this longleaf pine communities were once the most prevalent type in the Southeast occupying as much as 23 million ha, stretching from southeastern Virginia south to central Florida and west into eastern Texas (Stout and Marion, 1993). The demise of longleaf, from logging, land use changes, species conversion and fire exclusion, has been well chronicled (Croker, 1987; Frost, 2006; Van Lear et al., 2005). Reduction of longleaf pine to less than 5% of its original extent (Outcalt and Sheffield, 1996) threatens many species like the red-cockaded woodpecker (*Picoides borealis*), which are characteristic of, and largely dependent on, longleaf pine ecosystems (U.S. Fish and Wildlife Service, 2003).

Early settlers copied Native Americans and continued to burn much of the forest area occupied by longleaf pine on an annual or biennial basis. This frequent woods burning continued until the early 20th century (Shea, 1940). Although some argued that fire was necessary for maintenance of southern woodlands dominated by longleaf pine (Chapman, 1912; Greene, 1931), official federal policy during the early decades of the 1900s was to suppress all wildfires while prescribed burning was prohibited because it was perceived as destructive of timber and other values. However, in the South many continued to recognize the usefulness and need for prescribed burning to control fuel levels and reduce the incidence of destructive wildfires. The ban against prescribed burning on Forest Service lands was removed in 1943 and fire was once again

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applied to southern National Forests (Omi and Huffman, 2008). An aggressive prescribed burning program developed, which was treating around 3.2 million ha of southern forests annually during the 1980s (Wade and Lunsford, 1988).

The integral role that fire plays in maintaining healthy longleaf pine communities is well known (Myers, 1990; Ware et al., 1993). Many past studies have demonstrated the need for fire to control invasion by other southern pines, hardwoods and shrubs (Abrahamson and Hartnett, 1990; Garren, 1943; Glitzenstein et al., 1995; Platt et al., 1988). Even though there is a lot of prescribed burning in the South, there are not enough prescribed burns within the longleaf habitat to duplicate the effects of natural fire. A survey of the southeastern portion of the longleaf range from North Carolina to Florida found half of all remaining longleaf stands had not been burned for over 5 years (Outcalt, 2000). Without frequent fire longleaf loses its open park like structure as the density and cover of less fire adapted trees increases in the canopy and midstory (Gilliam and Platt, 1999; Kush and Meldahl, 2000; Provencher et al., 2001b) and shrubs increase in the understory while grasses and forbs are substantially reduced (Brockway and Lewis, 1997; Garren, 1943; Kush et al., 2000; Varner et al., 2000).

In loblolly pine (*Pinus taeda* L.) stands on the wet coastal plain in South Carolina, Waldrop et al. (1987) found that repeated burning at very frequent intervals, i.e. annually or biennially, would adjust understory composition to favor grasses and forbs over woody shrubs and reduce the density of midstory hardwoods. Others have shown the repeated burning will also remove midstory hardwoods from longleaf pine communities (Boyer, 1990; Glitzenstein et al., 1995). Thus a common recommendation for restoring this critical habitat is frequent application of prescribed burns (Brockway et al., 2005; Johnson and Gjerstad, 2006). Unfortunately, the area of forest land that can be burned at such frequent intervals is limited by the number of days available for burning. Also it is more difficult to re-introduce burning into areas with high fuel levels and shrub dominated understories so burns take more time, which means less area is burned. In addition, there are an increasing number of forest areas that are intermixed with or adjoin housing, making these locations very difficult to burn. Therefore, interest has recently grown in using other treatments to augment fire as a fuel reduction and restoration treatment or as a surrogate for fire in high-risk urban interface zones.

Recent research examining some possible fire surrogates was conducted on xeric longleaf sandhills in the panhandle region of Florida where herbicide and felling/girdling treatments produced more rapid reductions in midstory oaks than burning alone (Provencher et al., 2001a). However, the researchers also recommended follow-up burning for successful understory restoration, because this layer responded mostly to fire and not to changes in midstory density. As noted by Walker and Silletti (2006), most studies on restructuring overstory and restoring understory composition of longleaf pine systems have been done on these dry sites and responses will likely be quite different on more productive areas. To fill this void, as part of the National Fire And Fire Surrogate Study (Weatherspoon, 2000), we evaluated prescribed fire and the fire surrogate treatments of (1) control (no fire or other disturbance), (2) prescribed burning only, (3) thinning of selected trees, (4) thinning plus burning and (5) herbicide plus burning at a Gulf Coastal Plain location typical of many remaining longleaf pine forests. Our objective was to compare these treatments for effectiveness to reestablish stand structure and composition characteristic of a fire maintained longleaf ecosystem, i.e. an open canopy dominated by longleaf pine, with little midstory and an herbaceous dominated understory (Brockway et al., 2005), while minimizing negative impacts to timber and wildlife values. Thus we compared treatments based on a decrease in hardwoods in the overstory, reduction of midstory density and increased herbaceous cover in the understory, while minimizing overstory pine mortality and growth loss and providing some overstory hard mast producing stems and dead standing stems for wildlife. The focus was on accumulated differences over time rather than immediate and often ephemeral changes that occur the growing season after a treatment.

2. Methods

2.1. Study site

The study is located 35 km southwest of Andalusia, Alabama (latitude 31°9′N, longitude 86°42′W) at the Solon Dixon Forestry Education Center. As a field unit of the Auburn University School of Forestry and Wildlife Sciences, the center includes teaching and research facilities and consists of 2153 ha of forestland. When obtained by Auburn University in 1980, much of the property had not been burned for 10–16 years. To reduce accumulated fuel loads, forest managers began cautiously reintroducing fire during the dormant season with a 3-year fire return cycle. When our study began, much of the upland forest was dominated by longleaf pine, but other southern pines were also abundant including loblolly pine, shortleaf pine (*P. echinata* Mill.), slash pine (*P. elliottii* Engelm.) and spruce pine (*P. glabra* Walter). In many areas, especially the numerous bottomlands, there was a substantial hardwood component dominated by oak (*Quercus* spp.). On upland sites, the understory was dominated by woody shrubs, with yaupon holly (*Ilex vomitoria* Aiton) the most abundant, and lesser amounts of blueberries (*Vaccinium* spp.) and gallberry (*Ilex glabra* (L.) A. Gray).

The locale has a humid temperate climate, characterized by summers with high temperatures and humidity and mild winters. Moisture is abundant, with most rainfall arriving as convective afternoon thunderstorms during the summer or wet season. Average annual precipitation is 1422 mm, average annual temperature is 19 °C, and the growing season is 230 days (USDA, 1941). The study site is located in the western highlands of the Gulf Coastal Plain. Elevations range from 30 to 100 m above mean sea level covering all aspects. Slopes are moderate to steep across rolling hills dissected by numerous streams. There are also a number of small depressional sinks, some of which hold permanent water. The soils developed from unconsolidated Pleistocene sands deposited over clay layers of the Citronelle Formation. Soils on our longleaf pine study sites are paleudults from the Troup, Orangeburg, Dothan, Malbis and Bonify series. These soils have loamy sand or sandy loam surface horizons that promote rapid drainage, but the finer textured material in the lower horizons improves both moisture and nutrient holding capacity. These are moderately productive soils especially on the lower slopes that would be in the silty upland classification of Peet (2006).

2.2. Experimental design

The layout was a randomized complete block with three blocks and five treatment units in each, for a total of fifteen 12-ha stands. Units in each block were randomly assigned one of the four basic National Fire and Fire Surrogate Study (Weatherspoon, 2000) treatments: (1) control (no fire or other disturbance), (2) prescribed burning only, (3) thinning of selected trees, (4) thinning plus prescribed burning and (5) a herbicide application followed by prescribed burning, which was a treatment of local interest. Each of the fifteen treatment units were within areas having a pine-dominated overstory with longleaf as a major component. A treatment unit consisted of a 12 ha core area plus a surrounding

20 m buffer. Because of the dissected nature of the landscape, the treatment units were not adjacent contiguous areas, but rather clustered in blocks on similar soils.

2.3. Treatments

Trees were marked in thin units by staff of the Dixon Center during late 2001. Marking targeted the removal of hardwoods, other southern pines and longleaf pine with defects or in dense clumps, so as to achieve a post-treatment basal area of 11.5–13.5 m^2/ha. Thinning was performed by a commercial logger from February to April 2002 utilizing a feller-buncher, chainsaw limbing, and grapple skidders. All burns were conducted in the growing season by Dixon Center staff using drip torches. The first prescribed burning was done by Dixon Center staff on burn only and thin plus burn units in Spring 2002 (Table 1). Prior to burning thin units, piles of limbs were moved from around the base of remaining pines into adjacent areas between trees. Herbicide plots were treated with 4.5% tryclopyr[(3,5,6-trichloro-2-pyridinyl)oxy]acetic acid solution in water at rate of 4.7 L Garlon® 4 plus 657 mL of a surfactant per hectare. This was applied with backpack sprayers in fall 2002 targeting woody understory vegetation up to 2 m tall. These units were burned about 7 months later in spring 2003. Burn only and thin plus burn units were burned again in 2004, 2 years after the thinning and the first set of burns. Herbicide plus burn units received a second burn in summer 2005, which was 2 years after the first burns.

Because of drought conditions in 2006 and 2007, not all units were burned with a 2-year frequency and some units received only three of four burns scheduled (Table 1). Two each of the burn units and thin plus burn units received four prescribed burns while one of each treatment type was burned three times before the last measurements. All herbicide and burn treatments were burned three times prior to results reported in this paper.

Thin only units were given a mastication treatment with a horizontal rotating drum front mounted on a tracked vehicle, 3 years after thinning in May and June 2005. No attempt was made to grind material but rather the equipment was used more as a mower. During this mastication operation woody understory and smaller midstory hardwoods were cut at 15 cm above the soil surface, except for dogwood (*Cornus florida* L.), which were intentionally avoided because managers wanted it kept for the mast it produces for wildlife.

All units had been prescribed burned during the dormant season 2 or 3 years prior to initiation of the study in 2001. Therefore, fuel had accumulated onsite for 3–4 years prior to our first experimental burns during the 2002 growing season. For the first burn, thinned units contained extra surface fuel from the logging operation, and the herbicide units had a layer of dead standing shrubs. The initial growing season burning on burn only and thin plus burn units was performed quite slowly, an average of 10.4 h per unit, using mostly backing fires combined with some spot ignitions and flanking fires (Outcalt, 2003). During these first burns, data from on-site weather instruments showed temperatures ranged from 23 to 31 °C, relative humidity from 21 to 60% and wind from 5 to 22 kph. Most areas were burned 1–4 days following rain, except for one unit of the thin plus burn treatment where no rain had fallen for 17 days. Flame lengths, which were recorded by on-site observers using metal markers of known height located across each unit, ranged from 0.5 to 0.7 m. The exceptions were some of the flank fires where they reached 1.1 m, while on one of the herbicide plus burn units a change in wind direction produced flame lengths of 1.6 m. Strip head fires and hand ignited spot fires along with some backing fire were used for the second, third and fourth cycle of burns. It took an average of 3.5 h per unit to complete the second set of burns and 3 h for the third and fourth cycle of burns. The ranges for temperature, wind speed, and relative humidity were the same as those during the first set of burns. Days since rain was also similar at 1–4 days for most units, but two herbicide plus burn units had gone 8 days since the last rainfall.

2.4. Sampling

All units were sampled prior to treatment application in 2001 and then annually thereafter through the end of 2005. At the end of the initial 5-year study in 2006 the control units were harvested and removed from the study. Remaining treated units were sampled again at the end of the 2008 growing season. Within each treatment unit, there were 36 grid points on 50 m by 50 m spacing. The exact configuration varied for the different treatment units to fit site conditions. Within each treatment unit there were 10 rectangular 20 m by 50 m subplots established between selected grid points. The overstory tree layer (all trees >15 cm at dbh (diameter at 1.4 m)) were sampled on the entire 20 m by 50 m subplot recording diameter, species and condition of all standing stems. Tree heights were measured on five randomly selected trees in each subplot. Midstory trees (>1.4 m height but <15 cm dbh) were measured on half of the subplot (10 m by 50 m) recording dbh, species and condition. Shrub cover for stems greater than 1.4 m tall was determined by ocular estimate by species in two 10 m by 10 m nested sub-subplots located at opposite ends of 20 m by 50 m subplots. Understory plant species cover was quantified using the line-intercept method along a 15 m transect oriented north and south within each 20 m by 50 m subplot.

2.5. Data summarization and analyses

Treatments effects on overstory structure, midstory density, and understory cover were compared using unit means for each of

Table 1
Dates of treatment applications to longleaf pine stands on Solon Dixon Forest near Andalusia, Alabama.

Treatment	Thinning	Herbicide	1st burn	2nd burn	Mastication	3rd burn	4th burn
Burn			4/23/2002	5/6/2004		4/17/2007	
Burn			5/15/2002	4/15/2004		5/18/2006	4/16/2008
Burn			5/21/2002	7/6/2004		7/1/2006	6/18/2008
Thin	2/2002				5/2005		
Thin	3/2002				6/2005		
Thin	4/2002				5/2005		
Thin + burn	2/2002		4/5/2002	4/28/2004		6/14/2006	5/6/2008
Thin + burn	3/2002		5/22/2002	5/4/2004		4/21/2008	
Thin + burn	4/2002		5/1/2002	4/29/2004		7/11/2006	7/16/2008
Herbicide + burn		9/2002	4/15/2003	6/8/2005		4/24/2007	
Herbicide + burn		9/2002	5/13/2003	6/20/2005		5/5/2008	
Herbicide + burn		10/2002	4/16/2003	6/9/2005		4/23/2007	

the 15 units. Overstory variables included pine and hardwood density; pine and hardwood basal area; pine, oak–hickory and other hardwood mortality and pine and hardwood snag (dead standing tree) density. Hardwoods were analyzed as a group for density and stocking since these are critical factors in habitat suitability for the endangered red-cockaded woodpecker but oak and hickory were separated out in mortality measures because many managers are interested in these hard mast species for wildlife. Midstory hardwood density was separated by size classes, while understory variables were tall shrub cover, low woody cover, i.e. tree seedlings and small shrubs, grass cover and forb cover. Although variables were computed for each year of the study, since we were mainly interested in cumulative changes most comparisons were based on data collected at the end of 2005 and 2008 growing seasons.

Differences were determined using analyses of covariance with initial pretreatment data taken in 2001 used as the covariate to adjust for differences in units prior to treatment. A model that included block and treatment effects was used to compare the five different treatments but a factorial covariate analyses was also performed with the herbicide plus burn treatment excluded to elucidate the effect of the main factors of thinning and burning while checking for interaction. Treatment effects on overstory mortality were evaluated using percent change in stocking, which included trees removed by thinning in the hardwood groups but pine mortality included only trees that died during the study and excluded those cut during the thinning operation. Changes between years within treatments were determined using repeated measures analyses of variance and appropriate contrasts when a significant year effect was found. Understory cover values were transformed using square root arcsine to normalize variance prior to analyses. All significant differences were determined using a significant *F* and Fisher's least significant difference measure at the .05 probability level. Statistical analyses were performed using NCSS software (Hintze, 1995).

3. Results

3.1. Overstory

The pretreatment forests were dominated by pines with longleaf pine the most prevalent but stands also contained loblolly, slash, shortleaf, and spruce pine (Outcalt, 2005). Stands had a variety of hardwood species as well. The oak–hickory group included blackjack oak (*Quercus marilandica* Muenchh.), bluejack oak (*Q. incana* Bartram), southern red oak (*Q. falcata* Michx.), turkey oak (*Q. laevis* Walter), laurel oak (*Q. laurifolia* Michx.), water oak (*Q. nigra* L.), post oak (*Q. stellata* Wangenh.), pignut hickory (*Carya glabra* [Mill.] Sweet), and mockernut hickory (*C. alba* [L.] Nutt.). Other hardwoods present included black cherry (*Prunus serotina* Ehrh.), American holly (*Ilex opaca* Aiton), sweetgum (*Liquidambar styraciflua* L.), sweetbay (*Magnolia virginiana* L.), southern magnolia (*M. grandiflora* L.), blackgum (*Nyssa sylvatica* Marsh.), and sassafras (*Sassafras albidum* [Nutt.] Nees). The pines had a mean diameter of 29.1 cm and mean height of 22.3 m. Trees in the oak–hickory group were somewhat smaller at 24.4 cm diameter and 15.8 m height, while other hardwood trees were smallest with mean diameter of 19 cm and height of 11.9 m.

Pine density was very uniform among the stands prior to treatment, with a mean density of about 200 stems/ha. The effect of thinning in 2002 was a 25% reduction in density. Additional pines were lost during subsequent years to mortality from fire, lightning and wind. In 2008 the burn and herbicide plus burn units had 190 and 185 pine/ha while thinned and thinned plus burned units had significantly less ($F_{3,11}$ = 110.2, P < .001) at 145 and 130 pine/ha, respectively. Hardwood stocking was much more variable across treatments when the study began ranging from 110 stems/ha on thin units to 55 stems/ha on units selected for burn treatment while other treatments had 75 hardwood stems/ha. Because hardwoods were targeted during thinning, their density was reduced by about 60% by this treatment. Burning and wind combined to reduce hardwood density further from 2003 to 2008.

Table 2
Mortality in the overstory of longleaf pine stands near Andalusia, Alabama 4 and 7 years after different treatments.

Treatment	Species group		
	Pines	Oak–Hickory	Other Hardwoods
	Mortality (%)		
2005			
Control	3a[a]	8a	0a
Burn	7a	12a	4a
Thin	7a	72d	79b
Thin + burn	12a	79d	98b
Herbicide + burn	8a	25b	72b
2008			
Burn	7a	21b	10a
Thin	7a	72d	83b
Thin + burn	12a	82d	98b
Herbicide + burn	8a	37c	81b

[a] Within a column values with different letters are significantly different at $P \leq 0.001$.

Overstory pine mortality, excluding those removed by thinning, was not significantly different among treatments ($F_{4,14}$ = 1.71, P = .24; Table 2), although control units had a much lower rate of attrition. Losses of 1.75 pines/ha/yr on control units and 3–5/ha/yr in treated stands were observed over the first 4 years. There were no additional losses of pines during the next 3 years. Thin treatments reduced the oak–hickory group by more than 75% and the herbicide plus burn treatment caused almost a 40% decline. Burning alone did not significantly increase oak–hickory mortality levels over the control units after two burns, but mortality increased significantly after two additional burns to over 20%. Other hardwoods were greatly reduced on the thin, thin plus burn and herbicide plus burn treatments with mortality rates above 80% after three or four prescribed burns.

Total pine basal area, like density, was quite similar among all treatments in 2001 (Fig. 1), with a mean value of 14.6 m^2/ha. Only

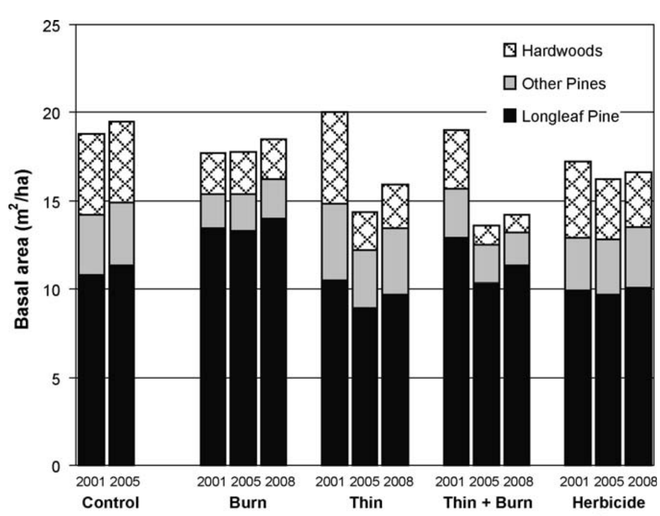

Fig. 1. Basal area of longleaf pine, other pines and hardwoods in the overstory by restoration treatment in longleaf pine stands near Andalusia, Alabama before treatment in 2001 and 4 and 7 years after treatment.

the treatments that included thinning, which removed 2.08 and 2.51 m^2/ha from thin and thin plus burn treatments respectively, significantly ($F_{4,14}$ = 11.7, P = .003) reduced pine basal area in 2005. Pine growth rates over the 4 years were the same ($F_{4,14}$ = 0.94, P = .49) on all treatments including the control with a mean value of 0.274 m^2/ha/yr. Hardwood basal area, which accounted for 21% of the pretreatment stand basal area, was not as uniform across treatments, but differences were not significant ($F_{4,14}$ = 1.28, P = .36). As with pines, only the thin treatments decreased hardwood basal area, with a removal cut of 2.74 m^2/ha from thin units and 1.75 m^2/ha from the thin plus burn units.

In 2001 prior to treatment, there were five hardwood snags and five pine snags per ha. By 2005, the herbicide plus burn treatment contained 14 hardwood snags/ha, while all other treatments were significantly less at 3 or 4 snags/ha ($F_{4,14}$ = 9.92, P = .003). In 2008 there was only 1 hardwood snag/ha on thin units, while burn units had 6, thin plus burn 4 and herbicide plus burn had the most at 13 snags/ha ($F_{3,11}$ = 5.02, P = .044). Pine snags were also highest on the herbicide plus burn treatment with 9 snags/ha in 2005. Treatments that included burning had significantly more pine snags with 5 stems/ha for the burn and 6 stems/ha for the thin plus burn treatments, compared to the 2 snags/ha for the control and 3 snags/ha for the thinned treatment ($F_{4,14}$ = 8.71, P = .008). By 2008 there were no differences ($F_{3,11}$ = 0.92, P = .49) with 5 pine snags/ha on single treatments of burn or thin and 9 pine snags/ha on the combination treatments of thin plus burn and herbicide plus burn.

3.2. Midstory

This layer was dominated by hardwoods, which composed 75% of all stems in 3.01–15 cm size class, while 25% were pine saplings. Density of hardwood stems in this size class was reduced by the thinning treatment (Fig. 2A). Burning prevented hardwoods from recovering in the thin plus burn treatment, where only a few remained in units given this treatment in 2005. This size class of hardwoods increased with time on the thin treatment but was reduced again by the mastication treatment in 2005. On the herbicide plus burn treated units there was a gradual decline in these hardwoods. At the end of the 2005 growing season, this treatment had lower stocking of these hardwoods than the control but significantly more than the thin treatments ($F_{4,14}$ = 9.70, P = .006). The burn treatment had the same density of these midstory stems in 2005 as it started with before treatment. After the additional prescribed burns in 2006 through 2008, all four remaining treatments had essentially equal density of larger midstory stems in 2008.

Burning treatments resulted in a significant decline in density of the smallest hardwood stems (0.05–1 cm diameter) the first growing season following the burn, as shown for burn and thin plus

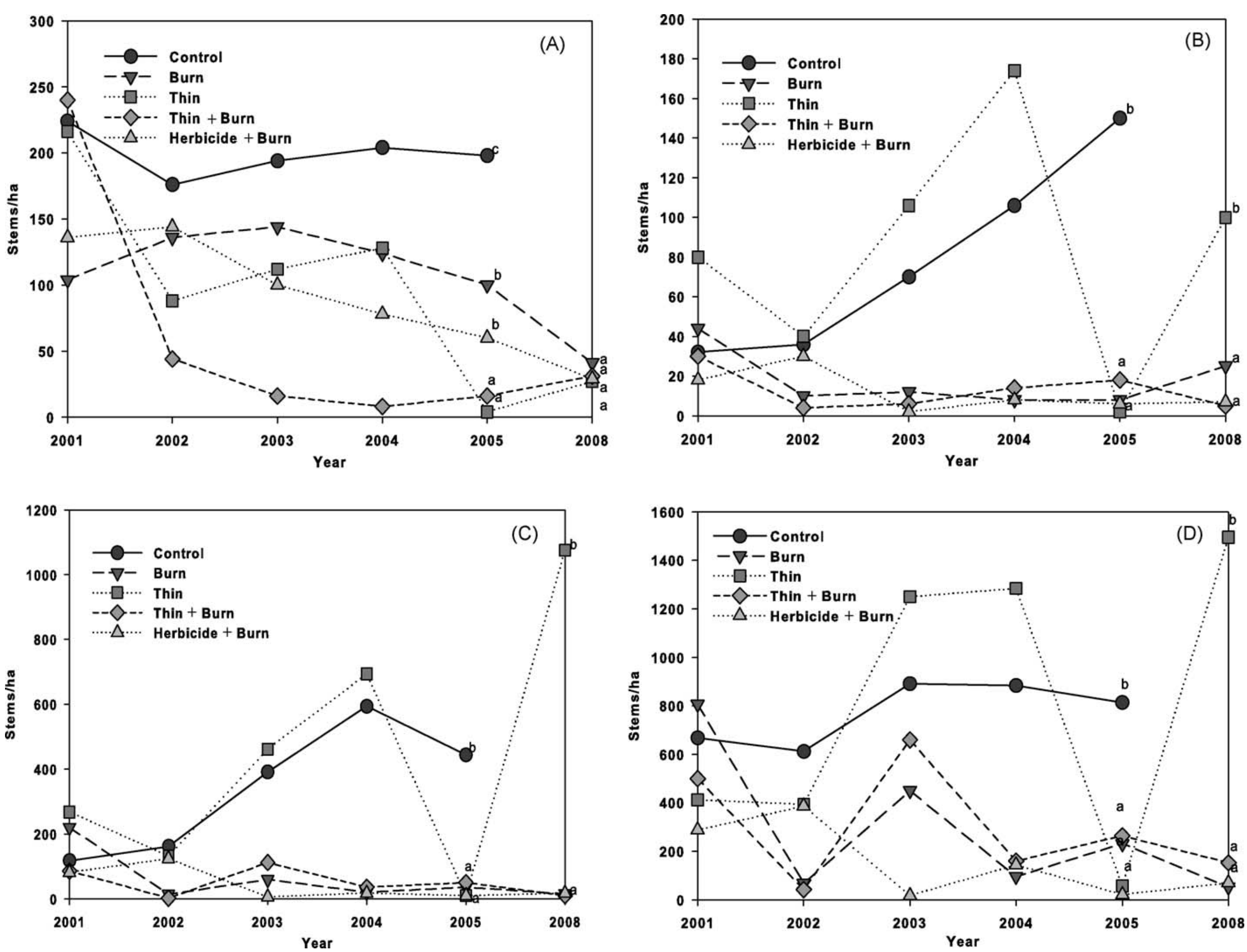

Fig. 2. Density of midstory hardwoods with diameter greater than 3–15 cm (A), 2.01–3 cm (B), 1.01–2 cm (C) and 0.05–1 cm (D) in longleaf pine stands near Andalusia, Alabama before treatment in 2001 through 7 years after treatment. Within a year values with different letters are significantly different at $P \leq 0.05$.

burn treatments in 2002 ($F_{4,14}$ = 8.74, P = .007) and herbicide plus burn treatment in 2003 (Fig. 2D). All treatments that included prescribed burning produced a significant reduction in this hardwood size class by 2005 ($F_{4,14}$ = 33.53, P < .001), which was maintained by subsequent burns through 2008. The mastication treatment applied to the thin treatments in 2005 also significantly reduced stocking of these smallest hardwood stems, but they recovered to double initial stocking by 2008. Although the numbers were different, both the 1.01–2 cm (Fig. 2C) and 2.01–3 cm (Fig. 2B) size class of hardwood stems responded similarly. Thus, a significant reduction in small hardwood stems occurred on all treatments compared to the control in 2005 with this reduction maintained on treatments that included burning, while the density increased again following the mastication on the thinned only units.

3.3. Understory

Cover of shrubs taller than 1.4 m was fairly uniform across treatment units at the beginning of the study, with a mean value of 12% (Fig. 3A). This tall shrub cover increased on control plots, doubling from 2001 to 2005. Burning reduced this tall shrub cover but it recovered between burns. The herbicide plus burn treatment greatly reduced this layer, as did the mastication applied to thin treatments in 2005, which resulted in a significantly lower cover compared to burn and thin plus burn treatments ($F_{4,14}$ = 33.61, P < .001). All treatments that included burning had a significant decline in tall shrub cover in 2008 after multiple burns, but on the thin treatment this component had recovered to its starting level in the 3 years following mastication ($F_{3,11}$ = 10.43, P = .009). Tree seedlings and small shrubs less than 1.4 m tall, covered about 50% of the understory layer of stands prior to treatment. Burning reduced this woody layer by about half, the season following application (Fig. 3B). This layer recovered between burns and only the herbicide plus burn treatment caused a significant sustained decline through 2005 ($F_{4,14}$ = 9.11, P = .007). However, with additional burns, all treatments that included burning had significantly less woody understory cover compared to the thin only treatment by 2008 ($F_{3,11}$ = 22.33, P = .001).

Through the first 3 years following treatment, there were no significant differences in grass cover (Fig. 3C). By 2005, grass cover was highest on the thin plus burn treatment, and while the thin only and burn only treatments had less, they still had significantly greater grass than the control units ($F_{4,14}$ = 9.27, P = .004). However, by the end of the 2008 growing season, all treatments that included burning had a significant increase in grass cover, compared to their beginning values, to about 30% and were greater than the thin only treatment ($F_{3,11}$ = 4.62, P = .03).

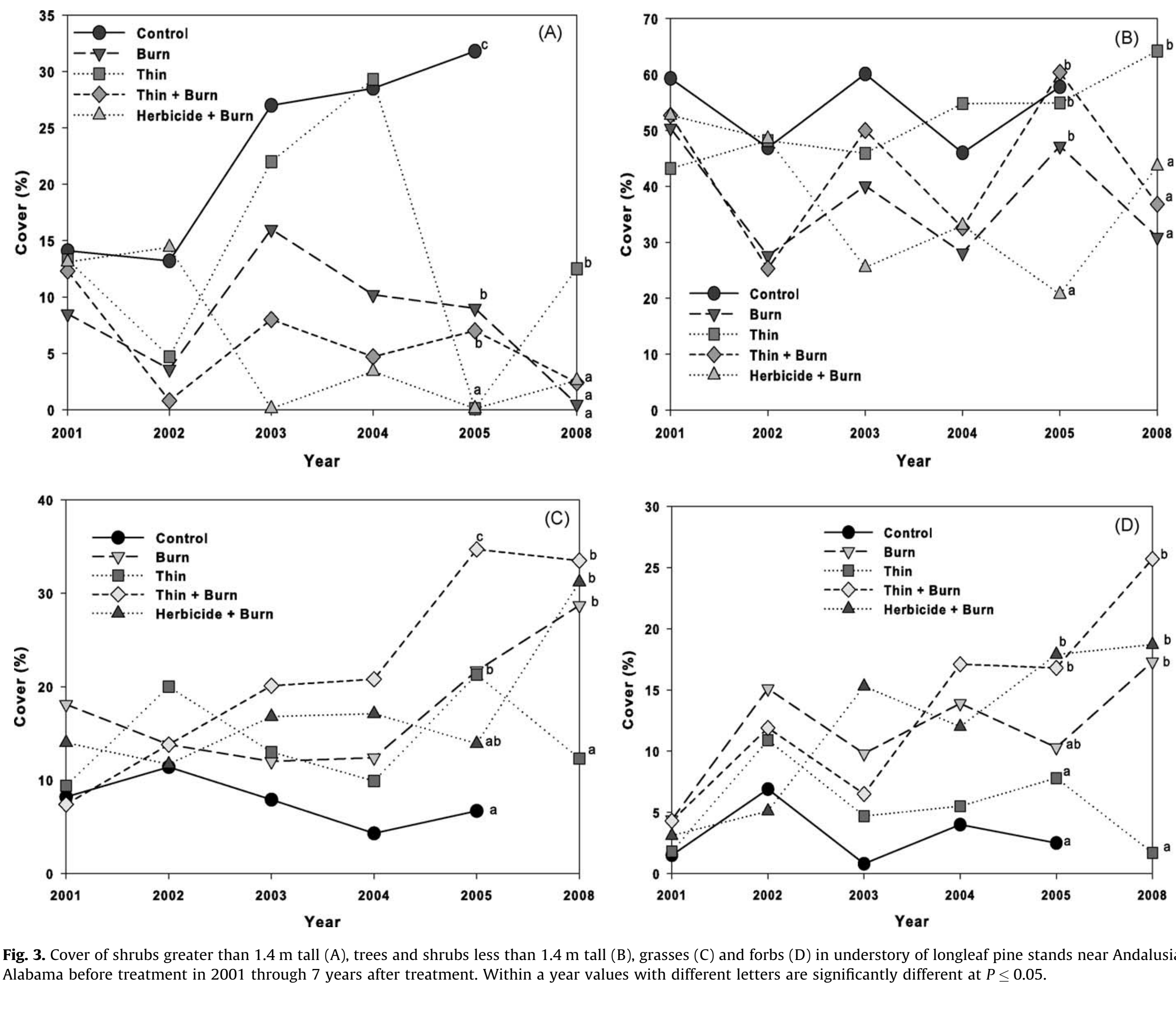

Fig. 3. Cover of shrubs greater than 1.4 m tall (A), trees and shrubs less than 1.4 m tall (B), grasses (C) and forbs (D) in understory of longleaf pine stands near Andalusia, Alabama before treatment in 2001 through 7 years after treatment. Within a year values with different letters are significantly different at $P \leq 0.05$.

Forbs responded to all disturbances, increasing after burning, thinning and herbiciding (Fig. 3D). The combination treatments however, were the only stands where there was a sustained response, with a four-fold increase in forb cover on thinning plus burning and herbicide plus burning treatments by 2005 ($F_{4,14}$ = 5.02, P = .025). By the end of the 2008 growing season, forb cover was equally high on all treatments that included burning compared to the thin only treatment ($F_{3,11}$ = 9.12, P = .01).

4. Discussion

4.1. Vegetation dynamics

When our study began, these forests were in a condition typical of many longleaf pine stands in the region, having a pine-dominated overstory with a significant component of hardwoods, mostly oaks, in the overstory as a consequence of periods of reduced fire frequency. The thinning operations were improvement cuts that produced income while also reducing the hardwood component and the presence of slash and loblolly pine. Thus by design, the thinning treatments had the most immediate impact on the overstory composition and structure, with greater than a 70% reduction in hardwood density.

The herbicide plus burn treatment also killed a substantial portion of the oak–hickory overstory and much of the other hardwood component. The higher intensity fires that resulted from dead standing fuel seemed to produce a greater impact on hardwoods than growing season burns lacking this fuel type. However, with multiple fires, burning alone top-killed hardwoods. Burns caused basal wounds on overstory hardwoods, which were often enlarged during subsequent burns. Many of those overstory hardwoods broke off at these wounds during the hurricane or other storms with high winds.

The 0.6% annual mortality rate for longleaf pine on our control areas was similar to the 0.4% rate reported for longleaf pine in southwest Georgia (Palik and Pederson, 1996), but higher than the 0.18% rate for trees in the panhandle region of Florida (Boyer, 1979). Our higher rate was caused by Hurricane Ivan impacting the study area during September 2004. Although there were no significant differences among treatments in terms of pine mortality, we know that some pines were killed by fire. In the burn but especially in the thin plus burn and herbicide plus burn treatments, there were hot spots where fuel accumulations resulted in higher intensity fires and flame lengths that caused pine mortality. In another study, a complete survey, rather than a sample of the units, showed greater mortality rates on the thin plus burn plots compared to thin, burn or control units (Campbell et al., 2008). They also found that fire was the leading cause of pine mortality, killing the vast majority of trees that died during the 4 years. Higher mortality occurred following the first two prescribed burns over the initial 5 years of the study. This higher mortality when fire is re-introduced into longleaf pine sites that have accumulated fuels during a period of no or reduced burning is common (Boyer, 1990; Varner et al., 2005). The maximum annual rate was 2.4% or 5 trees/ha/yr, which included losses to hurricane Ivan. During the third and fourth prescribed burns there were no pines killed by fire. Thus, after the initial readjustment period, very few overstory pines should be killed by prescribed burning in these types of longleaf pine stands.

After two prescribed burns, there was no effect on overstory pine growth rates, as basal area growth was the same on all treatments. This differs from the reduction reported for longleaf pine from similar biennial growing season burns in stands about 50 km west of our study site (Boyer, 1987). However, the trees in that study were 12-year-old saplings and more vulnerable to fire damage than the mature 60–80-year-old longleaf pine of our study. Weise et al. (1990) also reported growth declines for young southern pines when crown loss was 66% or higher. Our results fit the general pattern as noted by Boyer and Miller (1994) of no growth loss from periodic burning of longleaf trees larger than sapling size.

Thinning initially knocked down some existing snags, but on thin plus burn plots these were replaced with trees killed by burning. Even after losses during the hurricane, all treatments that included burning had about the same density of snags in 2005 as occurred prior to treatment. Thus, burning did consume some existing snags, but generated new ones to replace those lost. Burned stands also contained at least the recommended density of 5 snags/ha for maintaining good wildlife habitat conditions (McComb et al., 1986).

Thinning reduced the density of midstory hardwoods because some were harvested and others were knocked down by equipment during the logging operation. There was a subsequent hardwood recovery on thin only treatment units, which continued until the mastication treatment again removed many midstory hardwood stems in 2005. In the combination thin and burn treatment, burning maintained these larger midstory hardwoods at low density by killing some and keeping other smaller sized stems from growing into this class. After two fires, burning alone did not seem to have much effect on these larger midstory hardwood stems, but after two additional burns their density was reduced to the same low level found on all other treated units. On xeric sandhills sites in Florida, Provencher et al. (2001a) reported a 41% topkill of oaks after a single spring burn. It took additional burns on our more productive site but 60% topkill of these larger midstory hardwoods did occur on units burned biennially after four prescribed burns. Glitzenstein et al. (1995) also reported significant mortality of midstory hardwoods following multiple growing season burns in sandhills longleaf stands in Florida. Frequent growing season burns have also been shown to reduce hardwood density on more productive sites in South Carolina (Waldrop et al., 1987). Once top-killed these hardwoods often produced multiple sprouts resulting in densities exceeding pre-burn conditions or non-burned plots (Waldrop et al., 1992). Repeat fires in this study top-killed many of these sprouts and kept them from expanding as they rapidly did on thin and control treatments.

Burning also kept the tall shrub layer from increasing in cover, and with multiple frequent applications greatly reduced this woody component. This differs from findings on a flatwoods site in Georgia where shrub cover was the same on burned and unburned sites, although cover of the dominant shrub, gallberry did decline from repeated burning (Brockway and Lewis, 1997). Even though we found herbicide application prior to burning gave the quickest reduction in tall shrubs, all treatments that included burning were equally effective after multiple burns. Mastication also reduced the cover of tall shrubs, which like the herbicide was successful because it directly targeted this layer of woody vegetation. However, the stems quickly sprouted and recovered on the mastication units much as they did after the initial thinning. This rapid recovery of shrubs following mastication also occurred in longleaf stands on Ft. Benning, Georgia (Brockway et al., 2009). Similar to tall shrubs, the herbicide plus burning treatment was able to quickly reduce woody understory species less than 1.4 m tall on our study units because it killed some of the rootstocks. On other treatments, the top-killed stems were quickly replaced by sprouts with no net loss in overall understory woody cover after the second set of burns. Repeated biennial growing season burns however did eventually reduce cover of understory woody shrubs and trees, but it will likely require a number of burning cycles before rootstocks are reduced (Waldrop et al., 1987).

Many managers favor increasing the cover of grasses and forbs as a means of addressing both fuel management and biodiversity concerns. Burning increased grass cover by an average of 14% over controls after two burns. This was likely a response to reduced duff thickness, which was decreased 42% by burning, because, as reported by Hiers et al. (2007), grasses are quite sensitive to duff accumulation and respond positively to its reduction following fire. Grass cover responded to thinning treatments also, increasing by an average of 14%, and thus as shown by past work flourishes in more open stand conditions (Boyer, 1995; Gaines et al., 1954). When combined, burning and thinning did provide an additive effect and increased grass cover by 28% after two burns. This seems to differ from results for grass on xeric sandhills, where reduction of the midstory did not affect grass as its density on burned sites was the same as on sites where hardwoods were reduced by cutting before burning (Provencher et al., 2001a). Both ecosystems had about the same density of stems in the midstory prior to treatment, i.e. 1575 stems/ha on our mesic site and 1250 stems/ha on xeric sandhills (Provencher et al., 2001a), so there should be no difference in the amount of competition removed in the midstory. The difference is likely the treatments, since the mechanical thinning and the mastication at our study site did adversely impact the small woody midstory and tall shrub layer more than the chainsaw felling operation without removal used on the sandhills study. This is supported by the decline in grass cover on our thinned units between 2005 and 2008 as the small midstory hardwoods and understory woody layer recovered to pretreatment levels.

Forbs responded similarly to grasses, with a 5% increase from both burning and thinning, which were additive on the thin plus burn treatment. Forb cover continued to increase with additional burns. This benefit of repeated burning at frequent intervals to forbs has been shown for many southern pine ecosystems (Brockway and Outcalt, 2000; Brockway et al., 2009; Glitzenstein et al., 2003; Waldrop et al., 1992).

4.2. Treatment comparison

Prescribed burning is an accepted standard practice for reducing fuels and wildfire hazards across the southern United States (Pyne et al., 1996). It is also widely prescribed as a restoration treatment for longleaf pine communities (Barnett, 1999; Brockway et al., 2005; Johnson and Gjerstad, 2006). While there is often increased overstory pine mortality following initial restoration burns, as shown in our study, with repeated burns mortality of adult longleaf becomes quite rare. Overstory and midstory hardwoods however, were reduced with repeated burning as were understory shrubs and trees. These repeated frequent burns also fostered an increase in grass and forbs cover. Thus, a frequent and repeated application of prescribed burning is an effective treatment for ecological restoration of longleaf pine forests in the southern region.

Thinning produces income plus directly targets removal of specific species and trees. Thus, it more quickly restores the overstory structure and composition of longleaf pine stands leaving larger more fire resistant trees. Where possible, it will often be preferable to remove excess hardwoods from the overstory and midstory by thinning with a commercial timber sale rather than killing and leaving them in place with prescribed burning. A follow-up prescribed burn is needed to reduce fuels from logging, keep woody sprouts from proliferating and reduce wildfire risk. Although there may be some extra pine mortality, the cumulative effect from burning will aid in restoration by favoring grasses and forbs over woody species. This treatment provided the most positive changes in the shortest time toward the general community restoration objective, i.e. an open longleaf pine-dominated stand with little midstory and an herbaceous dominated understory.

Thinning without burning produces income and allows targeted changes in overstory composition. However, it soon became apparent following thinning that further treatment was needed to control woody sprouts in midstory and understory layers. Mastication was successful at reducing woody growth in these layers and even increased grass cover, but the woody species soon recovered and grasses again declined. It would be necessary to reapply mastication on a frequency similar to prescribed fire, i.e. every 2–3 years. The cumulative cost of these repeated mechanical treatments seems to limit the application of thinning and mastication to high-risk areas where burning is not an option.

Herbicide followed by prescribed burning killed more overstory hardwoods than burning alone. This accelerated mortality rate for hardwoods when combining herbicides and fire for restoration has also been reported for xeric sandhills sites (Brockway and Outcalt, 2000). This treatment was also equal to all others for keeping woody midstory species under control, was best at reducing woody species in the understory and improved grass and forb cover relative to controls. The extra cost of herbicide application must be justified by the advantage gained through an accelerated rate of restoration, which depends on each particular management situation. Another advantage of this treatment over burning only is the larger burning window afforded by the change in fuel. Without herbicide treatment, the dense shrub layer requires more exacting conditions for burning, since there is a narrow range of conditions between when it will not carry a fire and when the fire will be too intense. Following herbicide treatment, because of changes in fuel moisture and wind flow, an area will carry fire sooner after precipitation, with less wind and higher humidity.

5. Conclusion

All treatments that included burning examined in this study could be useful, depending on site-specific conditions and the outcome desired by forest managers. Unfortunately, there were no good surrogates for fire as alternatives like thinning and herbicide facilitate the application or compliment rather than replace the ecological effects of fire. The wise approach is to weigh all the costs and benefits of each option and then make a choice based on how effective each may be in achieving management objectives for the area in question. For example, if the area needing treatment is small, then waiting for the right burning conditions could be a good option. If many areas need treatment, then treating those with the densest understory shrub layer with herbicide to facilitate burning could be appropriate. Where hardwood markets exist and timber sales are permitted, thinning followed by prescribed burning can be broadly applied with very good results. It is worth noting that the dynamics on our study area are still in flux, since ecosystem restoration is an iterative process of setting plant communities on a trajectory toward achieving a longer-term desired future condition. However, it is already quite apparent that burning alone repeatedly applied every 2–3 years, after just three or four burns, will produce substantial changes that improve the condition of longleaf pine communities of the Gulf Coastal region and that such a burning regime is critical to restoration success even when augmented by other treatments.

Products disclaimer

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