Understory plant community response after 23 years of hardwood control treatments in natural longleaf pine (*Pinus palustris*) forests

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Abstract: In 1973, a study was established in South-central Alabama, U.S.A., to determine the effects of hardwood control treatments on understory succession and overstory growth in natural stands of longleaf pine (*Pinus palustris* Mill.). The treatments were seasonal biennial burns and a no-bum check, each combined with three supplemental hardwood control treatments (one-time chemical, periodic mechanical, and untreated check). Green vegetation less than 1 cm DBH and organic litter were destructively sampled to determine the effects of 23 years of treatments on understory vegetation and identify changes in this community since last sampled in 1982. Among the hardwood control treatrnents, the only significant differences occurred in the shrub and green biomass (total of tree, shrub, woody vine, and herbaceous species masses) component of the understory. There were significant differences for al1 vegetation components when comparing the buming to no-burn treatment. Green biomass estimates were variable but showed an increase for al1 but two of the 12 treatment combinations when compared to 1982 biomass. The major change occurred in the accumulation of organic litter, which increased 119% when averaged across al1 treatments. The chemical treatment did not eliminate any species when compared with the other hardwood control treatments.

Résumé : En 1973, une étude a été initiée dans le centre-sud de l'Alabama, aux États-Unis, pour déterminer les effets de traitements visant à contrôler les feuillus, sur l'évolution du sous-étage et la croissance de l'étage dominant dans un peuplement naturel du pin des marais (*Pinus palustris* Mill.). Les traitements étaient les suivants : brûlage saisonnier bisannuel et témoin sans brûlage, chacun combiné avec trois traitements supplémentaires pour contrôler les feuillus (traitement chimique unique, traitement mécanique périodique et témoin non traité). La végétation verte d'un dhp inférieur à 1 cm ainsi que la litière ont été échantillonnées par prélèvements destructifs en vue de déterminer les effets de 23 ans de traitements sur la végétation du sous-bois et d'identifier les changements survenus dans cette communauté échantillonnée pour la dernière fois en 1982. Parmi les différents traitements visant à contrôler les feuillus, les seules différences significatives sont apparues dans la biomasse des arbustes et la biomasse verte du sous-étage (masse totale des arbres, des arbustes, des vignes ligneuses et des espèces herbacées). Des différences signifícatives existaient chez toutes les composantes de la végétation lorsqu'on comparait les traitements avec et sans brûlage. Les estimés de la biomasse verte étaient variables, mais montraient une augmentation pour 10 des 12 combinaisons de traitements lorsque comparés à la biomasse de 1982. Le changement majeur s'est produit dans le cas de l'accumulation de la litihe, qui s'est accrue de 119% en moyenne pour l'ensemble des traitements. Le traitement chimique n'a éliminé aucune espèce, par opposition aux autres traitements de contrôle des feuillus.

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Introduction

Forests dominated by longleaf pine (*Pinus palustris* Mill.) and maintained by high-frequency, low-intensity surface fires occurred throughout most of the southeastern United States Atlantic and Gulf coastal plains prior to European settlement. Stretching in a broad arc along the Atlantic Ocean to the Gulf of Mexico, longleaf pine and its associated communities once covered an estimated 37 × 10^6 ha, or approximately two thirds of the southeastern United States (Frost 1993). These forests were described as open and parklike, with a monospecific overstory and the most species-rich understory in temperate North America (Peet and Allard 1993). The open canopy was not due to an arid climate or soil infertility but was the result of frequent fire. Low-intensity, nonlethal fires swept through the presettlement longleaf savannas at intervals ranging from 1 to 10 years (Mattoon 1922; Chapman 1932; Christensen 1981). These fires were ignited by a combination of frequent lightning strikes (Komarek 1974) and aboriginal fires (Robbins and Myers 1992). The frequent fires had a significant impact on the flora of the longleaf landscape. Mesic longleaf woodlands may contain 140 vascular species per 1000 m^2, the largest values reported for the temperate Westem Hemisphere (Peet and Allard 1993).

It has been well documented that, in the absence of frequent buming, the diverse ground cover of the longleaf landscape is rapidly replaced by hardwood trees and shrubs

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(Christensen 1981; Streng and Harcombe 1982). Competing understory vegetation may deter optimum growth of overstory pine, particularly at young ages. Controlling this competition is the main reason for many cultural operations in pine management. These operations include (*i*) mechanical treatments, usually for preplanting site preparation; (*ii*) chemical herbicides, for either site preparation or pine release; and (iii) prescribed fire, which if regularly applied, can prevent or retard the encroachment of hardwoods into pine stands. While chemical and mechanical treatments are considered expensive, their cost is justified based on expected increases in pine volume yields. Fire may be a less costly operation, but there may be a loss in pine volume resulting from prescribed burning (Boyer 1987).

Longleaf pine, as a species, seems to be more sensitive to competition than any of the other southern pines (Baker 1949). Elimination of understory hardwoods should promote a growth response at least as great as that observed in other pines. Little information is available on longleaf pine growth responses to competition control beyond the seedling stage. Nor is there information on the effects of various competition control treatments on understory plant succession.

A 1995 U.S. Biological Survey report listed the longleaf pine ecosystem as the third most endangered ecosystem in the United States (Noss et al. 1995). Consequently, interest has escalated in the recovery and management of the longleaf pine ecosystem. Among the issues that can be aided with these data are ecosystem restoration and management decisions, forest health evaluations, biodiversity, impacts of silvicultura1 treatments, and plant and animal habitat suitability. In addition, plant succession inforrnation on longleaf pine communities can provide data to improve fire and fuel management decisions.

A study was initiated in 1973 to determine the effects of hardwood control treatments on understory plant succession and overstory growth in naturally regenerated stands of longleaf pine (Boyer 1983). At the time of study establishment, the stands of longleaf pine were 14 years old. These treatments were combinations of mechanical, chemical, and fire (seasonal and no burn). Boyer (1995) reported on responses of understory vegetation before treatment and 7 and 9 years after treatments. Although treatments (biennial burns and mechanical removal) have continued, lack of resources prevented sampling understory vegetation since 1982. This study examines effects of 23 years of different seasonal biennial bums (or no bum) plus supplemental hardwood control treatments on the long-term response of understory vegetation in naturally regenerated longleaf pine forests.

Study area

The study was conducted at the Escambia Experimental Forest in South-central Escambia County, Alabama (3 1 °01′N, 87°04′W). The forest is maintained by the U.S. Department of Agriculture, Forest Service, Southern Research Station in cooperation with T.R. Miller Mill Company.

The climate is humid and mild with plentiful rainfall well distributed throughout the year. The warmest months are July and August with average daily maximum and minimum temperatures of 33 and 20°C, respectively. The coldest months are December and January with average daily maximum and minimum temperatures of 18 and 3°C, respectively. The growing season average is 250 days. Annual precipitation averages 156 cm with October being the driest month.

The predominant soil series on this coastal plain study site is the Troup (Grossarenic Paleudult, loamy siliceous thermic) series. Wagram, Dothan, and Fuquay are also present. These soils formed in unconsolidated marine sediments of loamy sands, sandy loams, and sandy clay loams. They are very low in natural fertility and organic-matter content.

Methods

Boyer (1983) described the establishment, methods, and treatment regimes for this study. The study was set up as a ramdomized complete block design with two types of treatments that were randomly assigned. Treatments included biennial burns in winter (December to February), spring (April, May), and summer (July, August), plus a no-bum check. Each burning treatment was combined with three supplemental treatments. These were (*i*) initial and only treatment of hardwoods and woody shrubs injected with metered amounts (1 mL per 2.54 cm DBH) of undiluted 2,4-D amine during the late spring of 1973 (woody stems too small to inject were wounded or cut with the injector bit, and the metered amount of herbicide was allowed to flow over the wound); (*ii*) a periodic mechanical treatment which consisted of hand-clearing of al1 hardwood stems >1.3 m in height in 1973 and at regular intervals thereafter, as needed; and (iii) an untreated check that received no supplemental hardwood control. Al1 treatments were replicated in three blocks. Each block consisted of 12 square, 0.16-ha treatment plots. A 0.04-ha net measurement plot was centered in each 0.16-ha treatment plot.

At the time of study establishment in 1973, al1 plots were thinned to 50 pines in each 0.04-ha net plot. The longleaf pine were 14 years old from seed, and 12 years from parent overstory removal. They averaged 6.7 m in height and 8.1 cm in DBH. Understory biomass was harvested but was not sorted by species as was done for this study. Pretreatment total biomass averaged 9247 $kg \cdot ha^{-1}$ of which 90% was organic litter. Woody biomass averaged 508 $kg \cdot ha^{-1}$, and herbaceous biomass 422 $kg \cdot ha^{-1}$ (Boyer 1995). Pretreatment wood, herbaceous, and organic litter biomass, respectively, averaged 62 1.5, 190.7, and 8458.7 $kg \cdot ha^{-1}$ on the one-time chemical treatment; 368.2, 194.3, and 8577.5 $kg \cdot ha^{-1}$, on the periodic mechanical treatment; and 537.1, 177.9, and 79 ll .7 $kg \cdot ha^{-1}$ on the no supplemental hardwood control treatment. Within the season of bum treatments, pretreatment wood, herbaceous, and organic litter biomass, respectively, averaged 533.5, 167.4, and 9685.6 $kg \cdot ha^{-1}$ on the winter-bum treatment; 373.2, 148.6, and 8572.6 $kg \cdot ha^{-1}$ on the spring-burn treatment; 495.4, 87.7, and 5868.9 $kg \cdot ha^{-1}$ on the summer-bum treatment; and 620.2, 158.9, and 9136.8 $kg \cdot ha^{-1}$ on the no-bum treatment.

In late September – early October 1996, living material less than 1 cm DBH was destructively sampled from nine systematically located 0.89-m^2 sample plots per treatment plot. This was done to coincide with the sampling methods used in 1982. The vegetation was sorted by species using the taxonomy of severa1 authorities (Grelen and Duvall 1966; Radford et al. 1968; Clewell 1985; Godfrey 1988; Kartesz 1994). It was oven-dried at 70°C for 72 h, and weighed. Organic litter was collected from one 30.5-cm^2 subplot within each of these sample plots, dried, and weighed. The last winter-season burn before sampling was in February 1996; the spring, in May 1995; and the summer, in July 1995.

At the time of sampling, al1 trees larger than 1 cm DBH on each 0.04-ha treatment plot were tallied as longleaf pine, other pine, or hardwood, and their DBH was measured. This measurement provided current year basal area and number of living stems.

The plant species biomass was combined into four vegetation categories: trees, shrubs, woody vines, and herbaceous species (which included forbs and grasses). Analysis of variance (ANOVA) was used to test for significant effects on understory biomass and overstoxy longleaf pine basal area. Orthogonal contrasts were used to identify differences within the supplemental hardwood control treatrnent and within the season of bum treatment. A test of the interaction between these treatments indicated no significant differences. No transfonnations of the data were employed.

Results and discussion

Overstory

Boyer (1994) reported al1 measures of longleaf pine growth had been significantly reduced by buming. The significant effect of fire on diameter and height growth did not extend beyond age 24, although effects on basal area and volume growth continued through age 30. Supplemental hardwood control treatments had not affected pine volume growth.

Analyses and interpretation of overstory responses to burning and supplemental hardwood control treatments were complicated by the stand management activities conducted in 1990. The treatment plot inventories in 1989 showed overstory pine basal area ranging from 15.4 to 27.1 $m^2 \cdot ha^{-1}$ with an average of 22.3 $m^2 \cdot ha^{-1}$. As described by Boyer (1993), the plots were commercially thinned to promote optimum development of dominant residual pines and reduce natural mortality from competition. Target residual pine density was 16.1 $m^2 \cdot ha^{-1}$, and the three plots that had basal areas less than 17.2 $m^2 \cdot ha^{-1}$ were not thinned. The thinning operation also resulted in the loss of some small hardwoods (5-cm DBH class) on the unburned and winter-burned plots. Because the thinning operation focused on equalizing pine basal area and stems/ha was not considered (but was affected by the operation) the results presented will be restricted to differences in basal area.

Since thinning, longleaf pine basal area has been unaffected by either the burning treatments or supplemental hardwood control treatments. Basal area of the overstory in September 1996 averaged 22.3 $m^2 \cdot ha^{-1}$ on the one-time chemical and no supplemental hardwood control treatment and 22.5 $m^2 \cdot ha^{-1}$ on the periodic mechanical treatment. Among the burning treatments, basal area averaged 22.9, 22.8, 22.0, and 21.8 $m^2 \cdot ha^{-1}$ on the no-burn, winter-, spring-, and summer-burn plots, respectively.

The average hardwood basal area was only 0.62 $m^2 \cdot ha^{-1}$ but ranged from 0.00 to 7.53 $m^2 \cdot ha^{-1}$. Basal area averaged 2.17 $m^2 \cdot ha^{-1}$ on the no supplemental hardwood control treatment and 1.20 $m^2 \cdot ha^{-1}$ on the one-time chemical treatment. As expected, there were no hardwood stems on the periodic mechanical treatment. Within the season of bum treatments, spring buming has removed all hardwood stems. The summer-bum treatment had only 0.47 $m^2 \cdot ha^{-1}$ with 2.58 and 2.09 $m^2 \cdot ha^{-1}$ on the no-bum and winter-bum treatments, respectively.

Understory plant community

One hundred forty-three species were identified in the understory plant community in the early autumn sampling. Table 1 presents the number of species for each vegetative classification among the supplemental hardwood control treatments. There was very little difference in the number of species in each respective vegetation category except for the fewer number of forbs found in the no-burn treatment. Species diversity among the supplemental hardwood control treatments was similar. The one-time chemically treated plots had 117 plant species compared with 114 and 110 species on the periodic mechanical and no supplemental hardwood control treatment plots. The one-time chemical treatment did not eliminate any species compared with the other two supplemental hardwood control treatments. Within the burning treatment, the highest number of species was found on the winter-burn plots with 114. The spring-, summer-, and no-burn plots had 104, 105, and only 84 species, respectively. As might be expected, the no-bum plots had the highest number of tree species because the lack of fire has allowed them to survive. The no-bum and winter-bum plots favored woody vine survival when compared with the growing season bums of the spring and summer. In the no-bum plots, the lack of fire and the build up of a heavy organic litter layer eliminated severa1 forb and grass species when compared with the burning treatments.

Table 1. Total number of understory species by treatments and vegetation components from a 23-year-old hardwood control study in southern Alabama.

Treatment	Trees	Shrubs	Woody vines	Forbs	Grasses
Supplemental hardwood control treatment[a]					
Chemical	12	14	13	62	16
Mechanical	14	17	11	57	15
None	14	11	10	60	15
Season of burn treatment					
Winter	12	10	13	63	16
Spring	11	12	9	59	13
Summer	10	14	8	57	16
No bum	16	12	12	34	10

[a]Chemical, one-time chemical treatment; mechanical, periodic mechanical treatment; none, no supplemental hardwood control treatment.

Understory biomass: hardwood control effects

Table 2 presents the ANOVA results and selected linear contrasts by vegetation component of the supplemental hardwood control effects on understory biomass. The only significant differences occurred in the shrub and green biomass (the sum of the oven-dried masses of trees, shrubs, woody vines, and herbaceous species) at the 0.05 level (Table 2). The contrasts revealed that the no supplemental hardwood control treatment was different from the other supplemental hardwood control treatments for only the green biomass and shrub components. This is an unexpected result because neither the one-time chemical treatment nor the periodic mechanical treatment should have had much impact on the shrub component. In addition, differences in tree biomass were expected among the treatments, but there were none (Table 2). In a comparison of the one-time chemical to periodic mechanical treatments only, these same significant differences occurred.

Total biomass and organic litter

There was no statistically signiticant difference in total biomass and organic litter among the supplemental hardwood control treatments (Table 2). The periodic mechanical

Table 2. Significance levels of ANOVAs and selected linear contrasts by vegetation components from a 23-year-old hardwood control study in southem Alabama,

	Total biomass	Organic litter	Green biomass[a]	Trees	Shrubs	Woody vines	Herbaceous species
Biomass component							
Replicate	0.7241	0.9151	0.0010	0.4320	0.0078	0.6782	0.0113
SHC treatment[b]	0.6219	0.7721	0.0062	0.9708	0.0010	0.6779	0.2188
Burn[c]	0.0001	0.0001	0.0003	0.0443	0.0019	0.0009	0.0001
Treatment x bum	0.4955	0.5677	0.268 1	0.9478	0.3300	0.2528	0.1004
Contrasts[d]							
N vs. CM	0.7332	0.9230	0.0086	0.9972	0.0118	0.5303	0.1639
C vs. M	0.3661	0.4810	0.0435	0.8098	0.0024	0.5414	0.2882
0 vs. WSG	0.0001	0.0001	0.0001	0.0070	0.0003	0.0001	0.0001
W vs. SG	0.7754	0.7872	0.9442	0.5300	0.4365	0.8998	0.3609
S vs. G	0.8451	0.8554	0.9354	0.6126	0.263 1	0.2705	0.6900

Note: Probabilities are for greater *F* values.
[a]Green biomass = trees + shrubs + woody vines + herbaceous species.
[b]SHC treatment refers to supplemental hardwood control treatment.
[c]Bum refers to season of bum treatment.
[d]N, no supplemental hardwood control treatment; C, one-time chemical treatment, M, periodic mechanical treatment; 0, no burn treatment; W, winter bum; S, spring burn; G, summer bum.

Table 3. Understory oven-dry biomass ($kg \cdot ha^{-1}$) by supplemental hardwood control treatment and vegetation components from a 23-year-old hardwood control study in southem Alabama.

	Supplemental hardwood control treatment[a]		
Component	Chemical	Mechanical	No treatment
Trees	131.4	155.0	143.5
Shrubs	1 027.0	435.9	321.8
Woody vines	216.1	276.7	192.4
Herbaceous	288.4	343.7	252.5
Green biomass[b]	1 662.9	1211.3	910.2
Organic litter	21 326.3	19 478.0	20 183.8
Total biomass	22 989.2	20 689.3	21 094.0

[a]Chemical, one-time chemical treatment; mechanical, periodic mechanical treatment.
[b]Green biomass is as defined in Table 2.

and no supplemental hardwood control treatment had 2 1 000 $kg \cdot ha^{-1}$, while the one-time chemical treatment had 23 000 $kg \cdot ha^{-1}$. Among al1 treatments, organic litter accounted for more than 90% of total biomass.

Green biomass

The no supplemental hardwood control treatment was significantly different from the other two treatments and the one-time chemical treatment was different from the periodic mechanical treatment (Table 2). In both cases, these differences were driven by the shrub component. Shrubs accounted for 61.3% of the one-time chemical treatment green biomass compared with 36.0 and 35.3% for the periodic mechanical and no supplemental hardwood control treatment, respectively.

Tree biomass

ANOVA found no statistical difference in tree biomass among the supplemental hardwood control treatments, which indicates that the one-time chemical treatment was as effective as the periodic mechanical treatment (Table 2). Tree biomass was less than 16% of the total green biomass among the supplemental hardwood control treatments (Table 3). The major tree species were the oaks (*Quercus* spp.). They accounted for 84.6, 48.0, and 56.6% of the tree biomass among the one-time chemical, periodic mechanical, and no supplemental hardwood control treatment, respectively. The predominant species were water and sand post oak (***Qucus nigra*** L. and ***Quercus margaretta*** Ashe), flowering dogwood (***Cornus florida*** L.), persimmon (***Diospyros virginiana*** L.), and southern magnolia (***Magnolia grandiflora*** L.).

Shrub biomass

The one-time chemical injection treatment had 2.5-3 times more shrub biomass than the other two supplemental hardwood control treatments (Table 3). The reason for this difference is unclear. A possible explanation may be an artifact of the treatments. On the no supplemental hardwood control treatment plots, severa1 of the shrubs had a DBH larger than 1 cm, which means they were not sampled. Hardwood stems >1.37 m on the periodic mechanically treated plots had been periodically cut down. The 23 years since the one-time chemical injection may have been enough time for the shrub component to recover and (or) re-establish themselves on the plots.

The majority of the biomass belonged to inkberry (***Ilex glabra*** (L.) A. Gray), a small, rhizomatous shrub that forms extensive colonies. It accounted for 72.9, 64.1, and 72.3% of the shrub biomass in the one-time chemical, periodic mechanical, and no supplemental hardwood control treatments, respectively.

Woody vine biomass

There was no difference in woody vine biomass among the supplemental hardwood control treatments (Tables 2 and 3). Carolina jessamine (***Gelsemium sempervirens*** (L.) Jaume St. Hil.) accounted for more than 60% of the woody vine biomass across al1 treatments.

Herbaceous biomass

There were no differences in herbaceous biomass among the supplemental hardwood control treatments (Tables 2 and 3). Herbaceous biomass accounted for 28% of the green biomass on the periodic mechanical and no supplemental hardwood control treatments and 17.2% on the one-time chemical treatrnent. The major species on these treatments were slender bluestem *(Schizachyrium tenerum Nees.)* and golden aster (*Chrysopsis mariana* (L.) Ell.). Slender bluestem averaged 29.2% of the total herbaceous biomass across al1 treatments and golden aster accounted for 18.3%. No other herbaceous species averaged more than 10%.

Understory biomass: burning effects

Contrasts revealed a significant difference among al1 vegetation components when comparing the no-burn with the buming treatments (Table 2). When comparing a dormant-season bum with growing-season bums there were no significant differences. Likewise, there were no differences when comparing spring to summer bums.

Total biomass and organic litter

Total biomass on the no-bum treatment averaged nearly 45 000 $kg \cdot ha^{-1}$, which is more than three times that of the buming treatments (Table 4). The largest component of total biomass was organic litter, which accounted for more than 90% of total biomass. There was a significant difference between total biomass and organic litter on the no-bum treatment compared with the buming treatments (Table 2). Organic litter on the no-bum treatment was more than three times that of any buming treatment. This result is to be expected since buming treatments occur every 2 years. While the fires may not remove heavy wood fuels, they remove most of the pine needles and leaves that have accumulated over the 2-year period. The no-bum plot had experienced 34 years without fire at the time of sampling. While the linear contrasts indicated a significance difference between the no-bum treatment and buming treatments, no significant differences were identified between dormant-season bums and growing-season bums or between spring and summer bums.

Green biomass

The no-bum treatment was significantly different from any of the buming treatments (Table 2). These differences were driven by the shrub component (Table 4). The shrub component of the no-bum treatment, alone, was larger than the total green biomass for any of the buming treatments. While the linear contrasts indicated a significance difference between the no-bum treatment and buming treatments, no significant differences were identified between dormant-season bums and growing-season bums or between spring and summer bums.

Tree biomass

There were differences among the buming treatments for understory tree biomass (Table 2). The no bum was statistically different from the buming treatments. Tree biomass was the smallest component among the burning treatments, accounting for less than 12% of the green biomass (Table 4). The growing season burns have been effective in reducing tree species biomass. Severa1 studies have shown that frequent growing season bums favor herbaceous species over woody species (Streng et al. 1993). Tree biomass on the no-bum treatment was three times higher than any of the burning treatments but still only accounted for 18% of the green biomass in that treatment. The understory tree species present at the initiation of the study have grown out of the understory and into the midstory. The predominant species were the oaks accounting for 73.2, 63.2, 47.9, and 59.1% of the tree biomass on the winter-, spring-, summer-, and no-bum treatments, respectively. Black cherry (*Prunus serotina* Ehrh.) and persimmon constituted 29.0 and 17.9%, respectively, of the tree biomass on the summer-bum treatment. Sand post oak accounted for 54.3 and 53.0% of the tree biomass on the spring- and winter-bum treatments, respectively, with sassafras (*Sassafras albidum* (Nutt.) *Nees)* accounting for an additional 24.5% on the spring bum and flowering dogwood, 17.6% on the winter bum. Water oak and southem magnolia, which are fne-intolerant species, comprised more than 53% of the tree biomass on the no bum treatment. While the linear contrasts indicated a significance difference between the no-bum treatment and buming treatments, no significant differences were identified between dormant-season bums and growing-season bums or between spring and summer bums.

Table 4. Understory oven-dry biomass ($kg \cdot ha^{-1}$) by buming treatment and vegetation components from a 23-year-old hardwood control study in south Alabama.

	Season of bum treatment			
Component	Winter	Spring	Summer	No bum
Trees	116.7	83.6	26.2	346.8
Shrubs	327.7	350.0	578.6	1 123.4
Woody vines	127.0	178.3	50.8	557.5
Herbaceous	416.2	380.6	356.9	25.7
Green biomass	987.6	992.5	1012.5	2 053.4
Organic litter	12 378.1	12 808.4	13 357.3	42 773.6
Total biomass	13 365.7	13 800.9	14 369.8	44 827.0

Note: Green biomass is as detined in Table 2.

Shrub biomass

The largest component of green biomass for al1 treatments except the winter and spring bums was the shrubs. Similar to the supplemental hardwood control treatments, shrub biomass accounted for one third to one half of the green biomass for al1 buming treatments. The predominant species was inkberry accounting for 59.6, 65.3, 78.4, and 70.3% of the shrub biomass on the winter-, spring-, summer-, and no-bum treatments, respectively. While the linear contrasts indicated a significance difference between the no-bum treatment and buming treatments, no significant differences were identified between dormant-season bums and growing-season bums or between spring and summer bums.

Woody vine biomass

Woody vine biomass was statistically different on the no-bum treatment compared with the buming treatments (Tables 2 and 4). It accounted for 27.1% of the green biomass in this treatment. Summer burning has nearly eliminated the woody vine component as it accounted for only

Table 5. Understory oven-dry biomass ($kg \cdot ha^{-1}$) in relation to assigned treatments from a 23-year-old hardwood control study in southern Alabama.

Buming treatment	Hardwood treatment[a]	Creen biomass	Percent change[b]	Organic litter	Percent change	Total biomass	Percent change
Winter	Chemical	1299.8 (409.5)	31.6	15 854.1 (8 624.9)	220.4	17 153.9 (8 981.2)	188.9
	Mechanical	872.7 (424.0)	-17.6	7 794.1 (2 054.1)	75.7	8 666.8 (1 754.4)	57.7
	None	790.2 (318.7)	7.9	13 486.1 (2 749.8)	212.9	14 276.3 (2 819.6)	83.1
Spring	Chemical	1020.9 (481.2)	16.3	12495.4 (4210.5)	75.2	13 516.3 (4 561.5)	68.7
	Mechanical	949.6 (454.6)	10.8	11 982.3 (2 739.8)	55.2	12 931.9 (2 457.0)	50.7
	None	1007.1 (339.5)	9.8	13 947.3 (5 088.6)	49.2	14 954.4 (5 382.0)	45.7
Summer	Chemical	1399.4 (338.2)	16.9	14 126.7 (3 706.4)	52.1	15 526.1 (3 823.6)	48.1
	Mechanical	1104.1 (637.2)	22.0	ll 483.6 (1 220.0)	116.8	12 587.7 (618.3)	102.9
	None	533.9 (335.4)	-38.4	14 461.6 (4 935.2)	43.9	14 995.5 (5 080.9)	67.1
None	Chemical	2931.4 (1494.1)	107.0	42 829.1 (ll 181.1)	177.1	45 760.5 (9 743.7)	171.2
	Mechanical	1919.0 (988.2)	41.6	46 651.8 (4409.3)	156.8	48 570.8 (5 218.6)	148.8
	None	1309.9 (988.2)	17.0	38 840.1 (ll 003.8)	128.9	40 150.0 (10 564.7)	122.0
Mean	Chemical	1662.9 (1051.4)	43.0	21 326.3 (14 548.2)	131.6	22 989.2 (15 124.0)	122.6
	Mechanical	1211.3 (676.8)	14.2	19 478.0 (16 652.5)	118.7	20 689.3 (17 100.4)	07.9
	None	910.2 (571.1)	-1.0	20 183.8 (12618.4)	108.4	21 094.0 (12 799.8)	99.1
Winter	Mean	987.6 (410.3)	7.3	12 378.1 (5 866.3)	171.1	13 365.7 (6 074.1)	43.3
Spring	Mean	992.5 (373.4)	12.3	12 808.4 (3 682.6)	58.8	13 800.9 (3 842.5)	54.2
Summer	Mean	1012.5 (550.8)	0.2	13 357.3 (3 448.4)	76.6	14 369.8 (3 470.4)	68.0
None	Mean	2053.4 (1214.3)	55.2	42 773.6 (8 822.1)	153.7	44 827.0 (8 498.9)	46.8
Total	Mean	1261.5 (831.8)	18.7	20 329.4 (14 293.7)	119.4	21 590.9 (10 659.3)	139.3

Note: Values in parentheses are SDs.
“Chemical, one-time chemical treatment; mechanical, periodic mechanical treatment; none, no supplemental hardwood control treatment.
[b]Percent change from 1982 to 1996.

5.0% of the green biomass. The no-bum treatment was dominated by Carolina jessamine that comprised over 83% of the woody vine biomass. However, there were differences in Carolina jessamine's response to buming. Summer bums have nearly eliminated this species, while on the spring burn treatment it accounted for 65.0% of the biomass. The summer-burn treatment was dominated by blackberry (*Rubus* spp.) and greenbrier (*Smilax pumila* Walt.), accounting for nearly 70% of the biomass. The most biomass on the winter-bum treatment belonged to gopher apple (*Licania michauxii* Prance), with Carolina jessamine, greenbrier, and blackberry totaling more than 88% of the biomass. While the linear contrasts indicated a significanct difference between the no-burn treatment and buming treatments, no significant differences were identitied between dormant-season bums and growing-season burns or between spring and summer burns.

Herbaceous biomass

Herbaceous biomass was statistically different between the no-burn plot and those treatments receiving tire (Tables 2 and 4). It was only 1.3% of the green biomass on the no bum treatment compared to 38%, on average, for the burning treatments. The heavy litter layer and midstory has virtually eliminated the herbaceous component from the no-bum treatment. A little more than on -half of the herbaceous biomass on the no-bum treatment was slender bluestem and mallow (*Hibiscus aculeatus* Walt.). Slender bluestem and golden aster were the principle species on the spring- and winter-bum plots accounting for one half of the biomass. No one or two species dominated the summer bum treatment. In addition to slender bluestem and golden aster, deer's tongue (*Carphephorus odoratissimus* (Gmel.) Herb.), and mallow were prevalent species. While the linear contrasta indicated a significance difference between the no-bum treatment and buming treatments, no significant differences were identified between dormant-season burns and growing-season burns or between spring and summer burns.

1982-1996 comparison: biomass trends

Understory biomass data are variable, but there were some consistent trends from 1982, the last time the understory plant community was sampled, to 1996 (Table 5). Green biomass showed an increase for al1 but two of the 12 treatment combinations. Among the supplemental hardwood control treatments, green biomass increased 43.0 and 14.2% on the one-time chemical and periodic mechanical treatments, respectively, while decreasing 1.0% with no supplemental hardwood control treatment. Green biomass increased 7.3, 12.3, 0.2, and 5.2% on the winter-, spring-, summer-, and no-bum plots, respectively.

On average, organic litter increased 119.4% across al1 treatments since 1982. The reason for this dramatic increase may be due to a major increase of woody debris over the last 14 years of the study. As the overstory ages, and self-pruning of branches occurs, woody material is added to the organic litter component. In addition, some of the debris may have been added during the 1990 thinning operation. In both 1982 and 1996, the organic litter was not separated out and weighed by its various components.

Conclusions and implications

Control of understory hardwoods in young pine stands can increase growth of the overstory, reduce fuel loads, reduce cost of future site or seedbed preparation, and increase cover of grasses and other herbaceous vegetation. Understory plant community response to season of burn and supplemental hardwood control treatments was studied in naturally regenerated longleaf pine forests in South-central Alabama, U.S.A. The treatments were initiated in 1973 and the understory community was last studied in 1982. Boyer (1994) reported that the supplemental hardwood control treatments had not affected pine volume growth through age 30. However, burning reduced volume growth 19% compared with the no-bum treatment. Among the three buming treatments, there was no significant difference in volume growth.

Understory biomass in natural longleaf pine forests is responding differently to hardwood control treatments 23 years after initiation. Among the supplemental hardwood control treatments, the only significant differences occurred in the shrub and green biomass (the total of tree, shrub, woody vine, and herbaceous species weights) component of the understory. There were significant differences for al1 components among the buming treatments. In examining selected linear contrasts, there was a significant difference among al1 vegetation components when comparing the no bum to the buming treatments. There was no difference in any biomass component among the burning treatments. Green biomass has increased from 1982 to 1996. Green biomass estimates showed an increase for al1 but 2 of the 12 treatment combinations when compared to 1982 green biomass. The major change that has occurred is the accumulation of organic litter, which increased 119% across al1 treatments since 1982. However, biennial buming has reduced the forest floor organic litter biomass by 66%.

A one-time chemical treatment was as effective as periodic mechanical removals, except for the shrub component, on the understory community. In addition, no plant species were eliminated with this treatment. However, neither of these two treatments was different from the no supplemental hardwood control treatment. Dormant-season burns were not significantly different from growing-season bums, had more plant species, and represent less of a threat to the survival and growth of the overstory longleaf pine. However, buming increases biodiversity in forbs, grasses, and reduces the risk of a catastrophic fire in these fire-adapted and fire-maintained ecosystems.

This study was sampled in the late summer – early autumn to coincide with the understory sampling made in 1982. It remains to be seen what differences there might be in flora diversity if the sampling were conducted during the spring or summer.

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