Forage production after thinning a natural loblolly pine–hardwood stand to different basal areas

David G. Peitz, Michael G. Shelton, and Philip A. Tappe

Abstract Mixed pine (*Pinus* spp.)–hardwood forests are common in the southern United States (U.S.), but little quantitative information exists on the response of understory forage to reductions in basal area from thinning. We determined understory forage characteristics before thinning and 2 and 4 years after thinning a 35-year-old natural loblolly pine (*P. taeda*)–hardwood stand (initially 27 m^2/ha of pine and 8 m^2/ha of hardwood basal area). A combination of 3 loblolly pine (15, 18, and 21 m^2/ha) and 3 hardwood (0, 3.5, and 7 m^2/ha) basal areas was replicated 3 times, resulting in 27 0.08-ha plots. Understory coverage and forage biomass were determined on 25 understory plots systematically located within each plot, with data analyzed using analysis of variance and regression. Herbaceous forage biomass and coverage and light intensity were correlated negatively ($P<$ 0.05) with retained pine and hardwood basal areas, with hardwood basal area being the more important factor. Stand thinning improved herbaceous forage availability for wildlife, but the response was time-dependent. Forage from woody browse and vines also increased following stand thinning, although responses were not as time-dependent as herbaceous forages. Results of our study indicate that managers can manipulate forage production by thinning stands to prescribed basal areas and compositions.

Key words Arkansas, basal area, biomass, browse, competition, coverage, forage, hardwoods, *Pinus taeda*, thinning

Mixed pine (*Pinus* spp.)–hardwood forests and naturally regenerated pine forests containing an element of hardwoods are important resources in the southern United States, comprising 26.9 and 41.0 million ha, respectively (United States Forest Service 1988). Many wildlife species use pine-hardwood stands to secure food (Blair and Brunett 1980, Thompson et al. 1991), vertical structure for screening cover (Masters et al. 1993, Pollock et al. 1994), and trees for denning, nesting, and mast production (Fenwood et al. 1985, Thorn and Tzilkowski 1991, Kenward et al. 1992, Johnson et al. 1995). However, the wildlife value of midcanopy hardwoods that typically occur in pine-dominated stands may be limited because trees are generally too small in size and low in vigor for prolific mast production (Drake 1991). Midstory hardwoods also may cast such dense shade that they suppress forage production of the understory, reducing mast and forage food sources. However, releasing desirable hardwoods through thinning may improve mast production potential by enhancing crown

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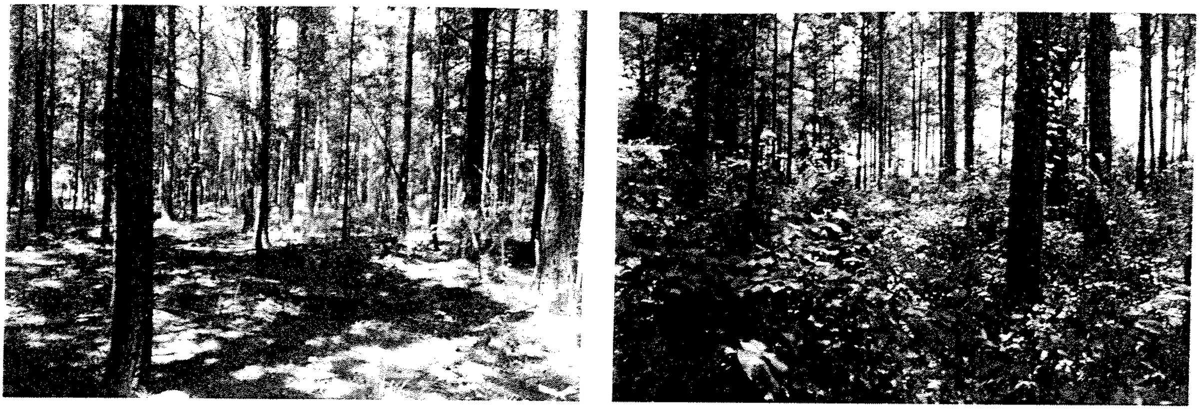

Residual basal areas after thinning strongly affect the response of understory vegetation: at left, a sparse understory beneath loblolly pine (21 m²/ha) and hardwoods (7 m²/ha); at right, a dense understory beneath loblolly pine (15 m²/ha) with no overstory hardwoods.

development and stimulate forage production by increasing understory light levels.

Other studies have addressed forage production and habitat quality in pine-hardwood stands of differing pine and hardwood basal areas (Hurst et al. 1979, Blair and Brunett 1980, Conroy et al. 1982, Fenwood et al. 1984). However, these studies were conducted in existing stands at single points in time, with stand basal area and age determined at the time of the study. By contrast, Wigley et al. (1989) and Masters et al. (1993) examined habitats across controlled pine and hardwood basal areas, but their results were restricted by a narrow range in treatment levels. Wigley et al. (1989) evaluated stands with 15 m²/ha of total basal area and Masters et al. (1993) evaluated stands with the merchantable pine component removed and hardwoods thinned to a basal area of 9 m²/ha or areas harvested by clearcutting. In this paper we report results from a study comparing biomass and coverage responses of vines, woody browse, grasses, forbs, sedges, and composites 2 and 4 years after thinning a loblolly pine (*Pinus taeda*)-hardwood stand to a range of pine and hardwood basal areas.

Study area

We established our study in a naturally regenerated, even-aged, 35-year-old natural loblolly pine-hardwood stand located in the school forest of the University of Arkansas at Monticello, Drew County, Arkansas, USA. Soils of the area included Henry (Typic Fragiaqualfs) and Calloway (Glossaquic Fragiaqualfs) series (Larance et al. 1976). Both soils have silt loam surfaces and were formed on windblown silt. These poorly drained soils occur on broad upland flats and have a site index of 28 m at 50 years for loblolly pine.

The stand was regenerated from an existing pine-hardwood stand in the early 1950s; the hardwood component was killed and a new loblolly pine stand established from seeds produced by retained trees. A few remnants of the original stand still existed prior to study installation. This stand was typical of many unmanaged pine stands in the South that have developed a dense hardwood midcanopy. Before thinning, loblolly pine basal area averaged 27 m²/ha and hardwood basal area averaged 8 m²/ha. Most hardwoods formed a uniform midcanopy, with occasional individuals extending into the loblolly pine canopy. The hardwood component was principally willow (*Quercus phellos*) and water oak (*Q. nigra*), with lesser amounts of southern red oak (*Q. falcata*) and sweetgum (*Liquidambar styraciflua*).

Methods

Study design and treatment implementation

We established 27 circular 0.08-ha sampling plots and surrounded them by 10-m isolation strips, resulting in total plot areas of 0.21 ha. Treatments consisted of 9 combinations of 3 overstory basal areas of loblolly pine (15, 18, and 21 m²/ha for trees ≥9.1 cm in diameter at 1.37 m [dbh]) and 3 basal areas of hardwoods (0, 3.5, and 7 m²/ha). Treatments were assigned randomly to plots as much as possible in a block design with 3 replications of each block. Blocking was based on proximity to an ephemeral drain. Although treatments were assigned randomly to plots, we reassigned a few treatments if existing basal area was below the level randomly assigned.

The pine component of each plot was harvested as a free thinning. Most of the harvested trees were below the stand's mean dbh, but a few low-quality dominant and codominants also were harvested. Thinning hardwoods favored retention of larger and higher-quality oaks. However, hardwood treatments were difficult to implement on some plots and compromises were made to meet specific basal area requirements. The sampling plots and their adjoining isolation strips were thinned to the same basal areas. The area between the sampling plots and isolation strips were thinned to basal areas of about 18 m^2/ha of pines and 3 m^2/ha hardwoods.

All trees were harvested as pulpwood in 1.5-m bolts to minimize damage to the residual stand. Pine thinning began in fall 1988 and was completed during late spring 1989, but unusually wet weather during summer prevented completion of the hardwood thinning until summer 1989. During late winter and early spring 1990, all submerchantable hardwoods 2.5 to 9.0 cm dbh were killed with stem-injected glyphosate.

Data collection

Before thinning, we recorded species and dbh for all trees $\geq$2.5 cm dbh on each plot. After completion of thinning, we assigned permanent numbers to all retained trees on a plot; we measured dbh (cm), total height (m), and crown dimensions (m). Age was determined on a subsample of about one-third of the retained trees.

We determined biomass and estimated percentage coverage of each forage species on 25 systematically located subplots before thinning (summer 1988) and 2 (summer 1991) and 4 (summer 1993) years after thinning. We determined forage biomass by clipping the current annual increments of growth ($\leq$1.0 m in height) for each species. Each subplot consisted of 4 adjacent 1 × 1-m quadrants, but only one quadrant was used during each evaluation so that clipping did not influence subsequent measurements. We determined green weights and a subsample of each species was oven dried at 40° C to a constant weight to determine green-weight to dry-weight ratios. We estimated percentage coverage of each forage species ($\leq$1.0 m in height) ocularly (Mueller-Dombois and Ellenberg 1974) and overstory canopy coverage using a spherical densiometer.

We determined photosynthetically active radiation (light intensity) at a height of 1.4 m on 39 temporary points systematically located within each sampling plot during clear sky conditions on 31 July 1991 and 25 July 1993 using a sunfleck ceptometer (Decagon Devices, Inc., Pullman, Wash.). We made all measurements within ±1.5 hours of solar noon and also made measurements in full sunlight to calculate relative light intensity.

Data analyses and modeling

We tested the null hypothesis that no changes in loblolly pine and hardwood basal areas, canopy coverage, and light intensity occurred over time (immediately after thinning and after 2 and 4 years) for each basal area treatment using one-way analysis of variance. Differences among years were isolated by the Ryan-Einot-Gabriel-Welsch multiple range test at $\alpha = 0.05$ (Procedure GLM, SAS Institute 1989). Biomass of individual species on each of the 25 subplots within a 0.08-ha plot was summed by forage group (vines, woody browse, grass, forbs, sedge, and composites). Means were then determined for biomass by forage groups for each 0.08-ha plot. We tested homogeneity of variance for each forage group using Bartlett's test (Steel and Torrie 1980). When we rejected the null hypothesis of homogeneous variances at $\alpha = 0.05$, we transformed data and conducted the test again until we accepted the null hypothesis. Variables requiring transformations were vines, forbs, and sedges (square root) and grasses and composites (cube root). We then tested the null hypothesis that basal area treatment (9 pine-hardwood combinations) and years after thinning (before thinning and after 2 and 4 years) did not affect forage biomass using 2-way analysis of variance. Because many of the interaction terms were significant at $\alpha = 0.05$, we followed the recommendation of Littell et al. (1991) that differences among means should be isolated separately for each level of the 2 factors. We isolated differences among means using Ryan-Einot-Gabriel-Welsch multiple range test at $\alpha = 0.05$ after conducting one-way analyses of variance for basal area treatments at each year and then for years at each basal area treatment.

Basal areas of individual plots varied within treatment classes because of tree mortality from logging damage and natural causes, growth during study installation, and the inability to precisely control basal areas on small plots. Basal areas after study installation ranged by a mean of 1.5 m^2/ha within treatment classes for pine and hardwoods. To develop and enhance predictive capabilities for similarly thinned forest stands, we analyzed data further using regression analysis. This allowed use of actual basal areas for each plot rather than its class designation. We evaluated several candidate equations to analyze our data. However, based on residual plots and fit indices, we selected the following equation:

$$Y = b_0 + T^{b1} \cdot \exp(b_2 + b_3 P + b_4 H),$$

where Y was the response variable at the specified year, T was the number of years after thinning, P and H were retained loblolly pine and hardwood basal areas after thinning, respectively, and the b_i's were coefficients to be determined. Response variables were mean forage biomass (kg/ha) and percentage coverage, relative light intensity (%), and canopy coverage (%). By definition, the response variable was equal to the value of b_0 when T was zero. Thus, we set the value of b_0 to the before-thinning mean calculated from the 27 plots for the specified response variable. We calculated other coefficients in the equation by nonlinear least squares regression using SAS procedure MODEL (SAS Institute 1988). Data were mean forage biomass, forage coverage, relative light intensity, and canopy coverage on the 27 plots evaluated at 2 and 4 years after thinning, providing 54 observations for each respective response variable. We eliminated variables from the full model if their coefficient did not differ significantly from zero at $\alpha = 0.05$.

Results

Post-thinning environment

Thinning reduced the loblolly pine basal area by an average of 26, 32, and 41% and the hardwood component by an average of 27, 44, and 100% on high, medium, and low treatment basal areas, respectively. Pine basal areas increased an average of 1.5 m^2/ha across all treatments by 2 years and 3.2 m^2/ha by 4 years after thinning. Mean annual increase in loblolly pine basal area was greatest on areas retaining the largest basal areas (0.9, 0.8, and 0.7 m^2/ha, for high, medium, and low basal areas, respectively). However, all treatments demonstrated significant ($P<0.05$) increases in pine basal area by 4 years after thinning (Table 1). Mean annual increase in hardwood basal area of 0.2 m^2/ha for areas retaining high and medium basal areas was significant ($P<0.05$) at 2 and 4 years after thinning.

Canopy coverage averaged 96.5% before thinning. Two years after thinning, canopy coverage ranged from 65.5 to 95.0% (Table 1). Recovery to before-thinning values for canopy coverage was influenced most by crown growth of the pine component. Canopy coverage increased an average of 6.1, 2.0, and 2.1%/year for treatments retaining 0, 3.5, and 7 m^2/ha of hardwood basal area, respectively, between 2 and 4 years after thinning. Relative light intensity was related negatively to the retained loblolly pine-hardwood basal areas and their corresponding canopy coverages, with the hardwood component being the most significant factor. Light intensities did not vary significantly between 2 and 4 years after thinning for all basal area treatments, except for a significant ($P=0.02$) decline for a pine basal area of 21 m^2/ha and no hardwoods (Table 1).

Forage production

Basal area treatments ($P<0.01$) and years after thinning ($P=0.001$) significantly affected the biomass of all forage groups and the total. The interaction of treatments and years was significant for vines, grasses, forbs, and total biomass ($P<0.03$), but was not significant ($P>0.05$) for composites, sedges, and woody biomass. Vines had the greatest sustained increases in forage biomass across all treatments; the average increase was 155 kg/ha at 2 years and 382 kg/ha at 4 years (Table 2). The second greatest increase was for woody browse, which averaged 96 kg/ha at 2 years and 132 kg/ha at 4 years. Across all treatments, combined herbaceous biomass increased significantly by an average of 207 kg/ha at 2 years after thinning. The 2-year increase for the combined herbaceous groups was a greater increase than the vine or woody browse groups. The ranking of the 2-year increase in herbaceous biomass by forage group was: grasses (153 kg/ha)>sedges (25 kg/ha)>forbs (17 kg/ha)>composites (12 kg/ha). By 4 years after thinning, however, herbaceous biomass declined from 2-year values by 71% for sedges, 44% for grasses, 24% for composites, and 5% for forbs; total herbaceous biomass averaged 121 kg/ha at 4 years. Total forage biomass increased an average of 426 kg/ha at 2 years after thinning and 632 kg/ha at 4 years.

Forage biomass and coverage of all groups and the combined totals were negatively influenced ($P<0.05$) by amount of retained hardwood basal area, except for sedge coverage, which was not influenced ($P>0.05$) by retained hardwoods (Table 3). Forbs and composites were the forage groups influenced most negatively by increased hardwood

Table 1. Mean (±SE) stand characteristics for various levels of pine–hardwood basal areas in a thinned 35-year-old natural loblolly pine–hardwood stand in southeastern Arkansas before thinning and immediately, 2, and 4 years after thinning.

Stand characteristics, pine–hardwood basal area	Before thinning	After thinning[a]		
		Immediately	2 years	4 years
Pine basal area (m^2/ha)				
15–0[b]	26.8 (2.4)	15.3 (0.3)b	16.5 (0.8)b	18.4 (1.0)a
15–3.5	25.3 (3.3)	14.9 (0.4)c	16.3 (0.5)b	17.8 (0.7)a
15–7	24.1 (4.7)	14.5 (0.5)c	15.7 (0.7)b	17.1 (0.8)a
18–0	29.8 (2.2)	18.1 (0.3)c	19.6 (0.2)b	21.5 (0.3)a
18–3.5	26.9 (0.6)	18.2 (<0.1)c	19.7 (0.2)b	21.4 (0.2)a
18–7	23.6 (1.6)	18.1 (0.4)c	19.6 (0.3)b	21.2 (0.7)a
21–0	33.9 (0.6)	21.6 (0.5)c	23.5 (0.2)b	25.7 (0.3)a
21–3.5	29.5 (2.3)	21.9 (0.2)b	23.1 (1.1)b	25.2 (1.2)a
21–7	25.5 (1.3)	21.8 (0.3)c	23.6 (0.6)b	25.3 (0.4)a
Hardwood basal area (m^2/ha)				
15–0	7.0 (1.9)	0	0	0
15–3.5	7.0 (0.3)	4.0 (0.1)c	4.2 (0.2)b	4.7 (0.2)a
15–7	10.8 (1.6)	6.7 (1.0)b	7.2 (1.1)ab	7.8 (1.5)a
18–0	5.9 (1.2)	0	0	0
18–3.5	7.0 (0.2)	4.2 (0.2)c	4.6 (0.2)b	5.0 (0.3)a
18–7	8.5 (0.7)	6.7 (0.6)b	7.2 (0.6)b	7.6 (0.6)a
21–0	4.9 (1.3)	0	0	0
21–3.5	8.3 (0.9)	4.2 (0.1)c	4.5 (<0.1)b	4.9 (0.1)a
21–7	8.4 (0.4)	6.7 (0.3)c	7.1 (0.4)b	7.4 (0.5)a
Canopy coverage (%)				
15–0	95.3 (1.1)	na[c]	72.5 (13.3)	83.4 (4.0)
15–3.5	96.7 (1.2)	na	86.6 (2.0)	93.1 (2.1)
15–7	97.2 (0.5)	na	85.7 (5.5)	93.2 (2.9)
18–0	95.5 (3.1)	na	65.5 (6.2)	85.8 (4.8)
18–3.5	96.9 (1.0)	na	90.2 (2.1)b	94.7 (3.8)a
18–7	95.8 (1.4)	na	92.4 (4.6)	95.3 (2.1)
21–0	97.2 (1.0)	na	86.1 (3.8)	91.2 (4.2)
21–3.5	96.8 (0.8)	na	90.8 (3.0)	91.6 (2.7)
21–7	97.2 (0.9)	na	95.0 (4.7)	97.2 (0.7)
Light intensity[d] (%)				
15–0	na	na	49.5 (5.1)	45.7 (12.3)
15–3.5	na	na	24.7 (3.4)	19.5 (3.4)
15–7	na	na	20.7 (5.0)	18.7 (2.8)
18–0	na	na	39.2 (6.3)	34.1 (10.0)
18–3.5	na	na	15.9 (2.6)	18.1 (5.8)
18–7	na	na	11.1 (1.1)	12.2 (2.2)
21–0	na	na	30.8 (3.2)b	22.5 (2.7)a
21–3.5	na	na	14.7 (1.3)	15.5 (1.8)
21–7	na	na	11.4 (3.9)	11.3 (3.3)

[a] After thinning treatment means (rows) followed by the same lower case letter or without letters did not differ ($\alpha = 0.05$) between years.

[b] First number is loblolly pine basal area (m^2/ha); second is hardwood basal area (m^2/ha).

[c] na = stand characteristic was not measured.

[d] Percentage full sunlight.

retention. Retained pine basal area also negatively influenced biomass and percentage coverage of vines, forbs, and total forage. Time after thinning (2 versus 4 years) was not a significant factor ($P>0.05$) in determining biomass and coverage for woody browse, forbs, and composites. However, biomass and coverage for grasses and sedges were influenced negatively by time after thinning, whereas vines and total forage were influenced positively by time after thinning.

Discussion

Basal areas retained after thinning this 35-year-old natural loblolly pine–hardwood stand strongly affected stand growth and understory forage production. Basal area and canopy coverage increased with time after thinning, whereas light intensity in the understory decreased. After showing large increases immediately after thinning, herbaceous forage biomass declined from 2 to 4 years and the rate of increase for woody browse slowed. Only vines displayed a steady rate of increase over the 4-year period after thinning. Similar results have been demonstrated elsewhere when basal areas of pine–hardwood stands have been manipulated through silvicultural practices. For example, Masters et al. (1993) showed that herbaceous vegetation was quickly replaced by woody vegetation when a stand was not disturbed repeatedly. Blair (1971) reported that even woody browse declined in stands undisturbed for more than 6 years.

In our study, greatest forage biomass occurred on

Table 2. Mean (±SE) forage biomass (kg/ha) in response to various levels of pine-hardwood basal areas in a thinned 35-year-old natural loblolly pine-hardwood stand in southeastern Arkansas before thinning and 2 and 4 years after thinning.

Forage group, pine-hardwood basal area	Before thinning	After thinning[a]	
		2 years	4 years
Vine			
15-0[a]	34.6 (49.2)B[b]	501.2 (157.1)Aa[c]	1039.4 (226.6)Aa
15-3.5	35.8 (47.2)B	247.4 (84.6)Aab	499.1 (34.6)Abc
15-7	31.8 (53.3)C	108.1 (136.6)Bb	214.7 (155.6)Abcd
18-0	13.7 (17.9)C	203.1 (153.7)Bab	536.5 (98.6)Ab
18-3.5	7.4 (8.8)C	63.4 (32.2)Bb	187.1 (115.5)Acd
18-7	38.2 (44.9)C	151.9 (95.2)Bab	379.2 (143.9)Abcd
21-0	26.2 (38.6)C	156.0 (94.7)Bab	411.2 (175.0)Abcd
21-3.5	11.8 (10.2)B	80.1 (49.6)ABb	184.3 (144.5)Ad
21-7	26.9 (38.1)C	114.0 (106.6)Bb	211.4 (160.3)Abcd
Woody			
15-0	21.9 (30.5)B	212.5 (137.9)A	225.3 (124.9)Aab
15-3.5	64.3 (94.9)B	173.6 (107.2)AB	230.6 (96.7)Aab
15-7	24.5 (41.9)B	46.8 (67.3)AB	81.2 (69.6)Abc
18-0	68.7 (114.1)	223.6 (69.4)	303.2 (89.4)a
18-3.5	11.8 (19.5)	87.4 (93.5)	136.2 (116.5)bc
18-7	19.6 (19.1)C	64.3 (38.1)B	119.1 (17.6)Abc
21-0	10.1 (15.1)	209.2 (169.2)	193.7 (77.4)abc
21-3.5	11.1 (15.4)	42.6 (12.9)	96.9 (63.0)bc
21-7	16.2 (25.9)	55.1 (86.2)	51.2 (68.9)c
Grass			
15-0	1.5 (1.7)C	359.1 (187.4)Aa	103.9 (43.1)B
15-3.5	1.7 (1.4)B	97.9 (35.7)Aab	56.5 (27.9)A
15-7	2.0 (2.5)	98.7 (87.7)ab	96.2 (71.9)
18-0	4.5 (7.1)B	472.5 (443.9)Aa	132.7 (80.6)A
18-3.5	1.7 (2.7)B	57.2 (72.6)Aab	94.4 (121.5)A
18-7	2.7 (3.3)C	17.5 (21.4)Bb	55.2 (44.9)A
21-0	1.0 (1.7)B	174.9 (105.6)Aab	118.1 (138.8)A
21-3.5	1.6 (2.1)B	87.6 (60.7)Aab	102.5 (59.4)A
21-7	4.4 (7.5)	34.4 (38.9)b	30.8 (45.9)
Forb			
15-0	0.1 (0.2)B	63.4 (45.5)Aa	43.2 (25.9)Aa
15-3.5	0.9 (0.8)	16.3 (10.7)ab	10.5 (4.2)ab
15-7	0B	1.6 (1.5)Ab	4.2 (3.8)Ab
18-0	0.5 (0.9)B	38.5 (21.8)Aab	43.6 (31.5)Aa
18-3.5	0.3 (0.5)	5.6 (5.1)b	13.5 (15.8)ab
18-7	0.2 (0.2)	10.9 (14.7)ab	9.9 (6.7)ab
21-0	0.6 (1.0)B	10.5 (5.0)Aab	15.4 (5.8)Aab
21-3.5	0.8 (1.4)	10.0 (9.1)ab	8.5 (8.2)ab
21-7	0.8 (1.4)	3.3 (4.0)b	2.9 (3.0)b

(continued)

[a] First number is loblolly pine basal area (m^2/ha); second is hardwood basal area (m^2/ha).

[b] Row treatment means followed by the same upper case letter or without letters within a forage group did not differ (α =0.05).

[c] Column treatment means followed by the same lower case letter or without letters within a forage group did not differ (α =0.05).

areas with least overstory basal area, and least biomass was on areas with the greatest basal area. This response to thinning was similar to those observed in other pine-hardwood stands in the southeastern United States. Wigley et al. (1989) reported a range of total understory biomass between 462 kg/ha and 756 kg/ha 2 years after thinning and 298 kg/ha to 717 at 4 years. Masters et al. (1993) reported forage biomass values as great as 3,495 kg/ha at 4 years after stand treatments consisting of complete removal of all merchantable pines, thinning the remaining hardwoods, and annual burning. By contrast, Masters et al. (1993) found an average mean of 208 kg/ha for forage biomass on control areas and areas not thinned but burned on a 4-year cycle: these values were similar to those reported in our study for the greatest retained basal areas.

Our findings suggest that hardwood basal area and its associated canopy coverage exert more influence on understory vegetative response than the loblolly pine basal area and its associated canopy coverage. Both at 2 and 4 years after thinning, light intensities and understory vegetative responses were greater in pure loblolly pine stands, regardless of the retained basal areas, than in loblolly pine-hardwood stands of equal total basal area. These results suggest that hardwoods produce more shade and thus suppress understory vegetation to a greater extent than loblolly pine. Other investigators have reported similar findings (Guo and Shelton 1998, Miller et al. 1999).

Table 2 (*continued*). Mean (±SE) forage biomass (kg/ha) in response to various levels of pine–hardwood basal areas in a thinned 35-year-old natural loblolly pine–hardwood stand in southeastern Arkansas before thinning and 2 and 4 years after thinning.

Forage group, pine–hardwood basal area	Before thinning	After thinning[a] 2 years	After thinning[a] 4 years
Sedge			
15–0	0B	33.9 (8.1)A	17.5 (19.3)A
15–3.5	0	18.6 (21.8)	5.7 (6.5)
15–7	0	23.3 (27.6)	8.7 (7.4)
18–0	0C	55.9 (19.0)A	10.4 (8.9)B
18–3.5	0B	13.5 (9.5)A	5.1 (1.9)A
18–7	0	13.0 (13.5)	2.8 (2.4)
21–0	0B	34.8 (28.8)A	3.9 (4.0)B
21–3.5	0C	25.1 (14.1)A	7.5 (3.2)B
21–7	0C	6.6 (2.0)A	2.9 (0.6)B
Composite			
15–0	0B	52.1 (67.3)Aa	24.3 (20.4)A
15–3.5	0	5.9 (7.2)ab	7.5 (6.2)
15–7	0.1 (0.1)	1.1 (1.2)ab	1.6 (1.8)
18–0	0.1 (0.2)B	21.5 (19.8)Aab	10.8 (11.6)AB
18–3.5	1.2 (2.0)	3.7 (4.1)ab	5.6 (9.6)
18–7	0.2 (0.2)	0.3 (0.5)b	3.9 (3.6)
21–0	0.1 (0.2)B	13.0 (5.9)Aab	20.6 (6.0)A
21–3.5	0	9.7 (15.0)ab	6.5 (7.6)
21–7	0	<0.1 (0.1)b	<0.1 (0.1)
Total biomass			
15–0	58.3 (81.4)B	1222.3 (219.3)Aa	1453.6 (182.9)Aa
15–3.5	102.7 (143.1)B	560.4 (176.4)Abc	809.9 (47.9)Abc
15–7	58.5 (97.8)B	279.5 (231.3)Ac	406.6 (207.7)Acd
18–0	87.6 (140.1)B	1015.1 (290.1)Aab	1037.2 (84.8)Ab
18–3.5	22.5 (33.6)	230.7 (162.9)c	441.9 (371.2)cd
18–7	60.8 (67.3)C	258.0 (155.9)Bc	570.1 (187.0)Acd
21–0	38.2 (56.7)B	598.4 (210.5)Abc	762.8 (171.6)Abc
21–3.5	25.3 (28.2)B	255.1 (129.3)Ac	406.2 (147.8)Acd
21–7	48.2 (72.9)	213.4 (228.7)c	299.3 (274.1)d

[a] First number is loblolly pine basal area (m^2/ha); second is hardwood basal area (m^2/ha).

[b] Row treatment means followed by the same upper case letter or without letters within a forage group did not differ (α =0.05).

[c] Column treatment means followed by the same lower case letter or without letters within a forage group did not differ (α =0.05).

The vine and woody browse groups increased in forage biomass from 2 to 4 years after thinning, whereas all the herbaceous plant groups declined. Some of the decline in herbaceous vegetation with time after thinning can be attributed to increasing canopy coverage in the overstory and its associated shading, but the influence of other forage groups in the understory cannot be ignored. Vines and woody plants undoubtedly compete with herbaceous groups for water, light, and nutrients. In addition, the greater stature and height-growth potential of vines and woody vegetation create a growth advantage for these groups over herbaceous vegetation. In fact, many of the woody plants will eventually grow into midstory hardwoods.

Our findings suggest that reducing stand basal area through thinning can improve the value of a stand for many wildlife species by increasing available forage biomass; reducing hardwood basal area results in greater increases in forage biomass than reducing loblolly pine basal area. However, use of thinning alone to improve wildlife habitat quality results in only a short-lived increase in quantity of herbaceous vegetation available. Wildlife species that consume mostly herbaceous vegetation, such as woodchuck (*Marmota monax*), hispid cotton rat (*Sigmodon hispidus*), southern bog lemming (*Synaptomys cooperi*), and prairie vole (*Microtus ochrogaster*), will derive the most benefit about 2 years after thinnings. However, wildlife such as the white-tailed deer (*Odocoileus virginianus*) and eastern cottontail rabbit (*Sylvilagus floridanus*) will benefit from thinning over a longer period of time because their diets include the browse provided by woody plants, vines, and herbaceous vegetation. Repeated stand disturbance from subsequent thinnings will help maintain improved forage production and wildlife habitat quality because it: 1) scarifies the forest floor, 2) destroys some of the existing understory vegetation (vines and woody plants), and 3) reduces overstory shading and competition. This stand was growing at a mean annual rate of 0.8 m^2/ha in pine basal area, and thus

Table 3. Regression coefficients and associated statistics to estimate the forage biomass and coverage, canopy coverage, and light intensity at 2 and 4 years after thinning in a 35-year-old natural loblolly pine–hardwood stand in southeastern Arkansas. Forage biomass and coverage were evaluated by forage groups.

Forage group or stand attributes	Regression coefficients[a]					RMSE[b]	Fit index[c]
	b_0	b_1	b_2	b_3	b_4		
Biomass (kg/ha)							
Vine	25.2	1.240	7.308	−0.139	−0.187	145.0	0.70
Woody	27.6	ns[d]	5.311	ns	−0.195	88.7	0.36
Grass	2.4	−1.320	6.703	ns	−0.276	127.5	0.38
Forb	0.5	ns	6.070	−0.134	−0.325	15.8	0.51
Sedge	0.0	−1.877	5.021	ns	−0.164	13.2	0.49
Composite	0.2	ns	3.162	ns	−0.347	17.3	0.24
Total	55.8	0.328	8.283	−0.095	−0.194	205.9	0.75
Coverage (%)							
Vine	9.7	0.998	3.820	−0.066	−0.092	14.7	0.49
Woody	6.8	ns	3.044	ns	−0.108	9.3	0.21
Grass	1.5	−0.543	3.250	ns	0.119	6.0	0.31
Forb	0.5	ns	3.132	−0.044	−0.174	3.3	0.49
Sedge	0.0	−0.747	2.079	ns	ns	1.8	0.22
Composite	0.1	ns	1.187	ns	−0.161	1.4	0.32
Total	18.7	0.354	4.999	−0.045	−0.100	21.5	0.55
Canopy coverage (%)	96.5	−1.184	5.697	−0.096	−0.231	5.1	0.69
Light intensity (%)	5.276	−0.057	na[e]	−0.080	−0.155	4.6	0.87

[a] For forage biomass, the equation was $B_t = b_0 + T^{b_1} \exp(b_2 + b_3P + b_4H)$, where B_t was the biomass (kg/ha) of a specified forage group at t years after thinning, b_0 was the pre-thinning mean biomass (kg/ha) of the specified forage group, T was the years after thinning, P was the loblolly pine basal area after thinning (m^2/ha), and H was the hardwood basal area after thinning (m^2/ha). For forage coverage, the equation was $F_t = b_0 + T^{b_1} \exp(b_2 + b_3P + b_4H)$, where F_t was forage coverage (%) of the specified forage group at t years after thinning and other symbols were previously defined. For canopy coverage, the equation was $C_t = b_0 - T^{b_1} \exp(b_2 + b_3P + b_4H)$, where C_t was coverage(%) of the canopy at t years after thinning, and other symbols were previously defined. For light intensity, the equation was $L_t = \exp(b_0 + b_1T + b_3P + b_4H)$, where L_t was light intensity (%) at 1.4 m for a specified treatment basal area at t years after thinning and other symbols were previously defined except for b_0, which was the intercept of the regression equation.

[b] Root mean square error.

[c] The fit index is equivalent to the coefficient of determination reported in linear regression (SAS Institute 1988).

[d] Regression coefficient was not significant (ns) at $P \leq 0.05$.

[e] Regression coefficient was not fit for light intensity.

operable thinnings could be conducted about every 5 years during this stage of stand development.

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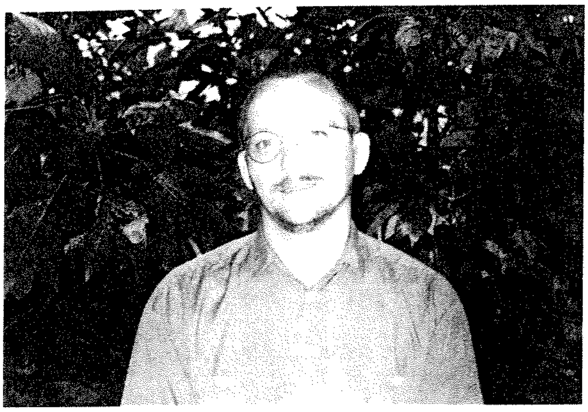

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Associate editor: Miller