MIDSTORY REMOVAL METHODS TESTED FOR TIMELY RELEASE OF NEWLY ESTABLISHED OAK SEEDLINGS UNDER OAK SHELTERWOODS

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Abstract.—The oak shelterwood method calls for the removal of shade-tolerant, undesirable midstory species to create adequate diffuse light conditions at the forest floor for oak seedling establishment, preferably timed to coincide with a large acorn crop. Injection (INJ) with an herbicide, chainsaw felling and girdling with herbicide application (SAW), and a low-volume basal bark herbicide application (BAS) were tested for efficacy and timely removal of the midstory to quickly increase light reaching newly established oak seedlings in Indiana. All three midstory treatments killed the majority of treated trees by the beginning of the second growing season. The BAS treatment produced the most rapid decline in treated tree survival across diameter classes and across the range of species, with the exception of hickory. Although all BAS-treated hickory ultimately died, INJ and SAW treatments produced more rapid control. Mean BAS treatment cost was $0.20 per diameter-inch treated (DIT), approximately two times more costly than the SAW treatment at $0.11 per DIT and the INJ treatment at $0.09 per DIT.

INTRODUCTION

Timely removal of shade-tolerant, undesirable midstory species before or after acorn dispersal is important to the establishment and survival of a cohort of oak seedlings. In undisturbed mature oak forests with well developed shade-tolerant midstory canopy layers, more than 70 percent of planted oak seedlings died within 5 years of planting (Lorimer and others 1994). Loftis (1983) reported that survival of a cohort of northern red oak (*Quercus rubra* L.) seedlings in undisturbed oak forests in the southern Appalachians after 12 years was less than 10 percent. For new oak seedlings to develop into competitive oak advance reproduction, adequate understory light conditions must be obtained. Removing too much of the overstory may allow sufficient light to the forest floor to stimulate germination and establishment of fast-growing, sun-loving competitors to oak, such as yellow-poplar (*Liriodendron tulipifera* L.). Thinning from below to 60 to 70 percent of initial stand stocking, starting with the shade-tolerant midstory may provide the optimum diffuse light levels required to establish competitive oak seedlings prior to overstory removal (Loftis 1990, Larsen and Johnson 1998). This silvicultural treatment has come to be known as the "oak shelterwood method" (Stringer 2006).

Techniques and herbicides for controlling undesirable noncommercial trees in intermediate stand management operations are well established. When appropriately applied, these methods provide good control. What is less well known, however, is the rate at which these various techniques and herbicides inflict tree mortality across a range of species and diameter distributions. A new cohort of oak seedlings requires release from a well developed shade-tolerant midstory fairly quickly to ensure adequate light levels to maintain

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an acceptable proportion of that cohort into the future canopy (Phares 1971, Crow 1988). Forest managers may not recognize the need for midstory removal until after oak seedlings are observed. Thus, treatments to remove the midstory must be relatively quick as well as cost-effective.

The purpose of this study was to test three different methods for removing midstory canopy trees for overall efficacy over a range of species and midstory tree sizes, rate of mortality over time, and cost-effectiveness.

METHODS

The study was initially established in October 2005 to test the use of soil scarification for incorporating acorns into the soil to improve oak reproduction establishment. The scarification methods are described in Rathfon and others (2008). The study was established in three approximately 4-acre blocks located in three different forest tracts (stands I, N, and P) at the Southern Indiana Purdue Agricultural Center located in south-central Indiana. All three stands were oak-hickory forest cover types; overstories were dominated by mature oak, primarily white (*Q. alba* L.), northern red, and black oak (*Q. velutina* Lam.). Stand I was on a mesic to dry-mesic site on Gilpin-Berks complex soils with a southwest aspect, 20- to 30-percent slopes, and a northern red oak site index, base age 50 (SI_{50}) = ~80 feet. Stand N was on a mesic to dry-mesic site on a Zanesville silt loam soil with a northwest aspect, 15-percent slope, and a northern red oak SI_{50} = ~70 to 80 feet. Stand P was on a dry-mesic site on Zanesville and Gilpin silt loam soils with a west aspect, 12-percent slope, and a northern red oak SI_{50} = ~70 feet.

Each 4-acre block was divided into four approximately 1-acre plots and randomly assigned one of three different methods for removing midstory trees, plus a no-treatment control. A 100-percent inventory of midstory trees was conducted prior to treatment in each treatment plot. Trees were tallied by species and 1-in. diameter classes (e.g., 1-in. diameter class is 0.5 in. to 1.4 in.) as measured at breast height (d.b.h.). Species were grouped by abundance and genera. Individual species occurring in low numbers were grouped into two miscellaneous categories according to potential stature at maturity. Species groups were as follows: sugar maple (*Acer saccharum* Marsh.) (SUM), American beech (*Fagus grandifolia* Ehrh.) (AMB), elm (*Ulmus* spp.; American, slippery, and winged elm were included) (ELM), hickory (*Carya* spp.; bitternut, pignut, and shagbark hickory were included) (HIC), miscellaneous large species (including blackgum, yellow-poplar, black cherry, sassafras, white ash, hackberry, and red maple) (MISCL), and miscellaneous small species (including American hornbeam, flowering dogwood, eastern hophornbeam, redbud, and pawpaw) (MISCS).

Treatments were applied from June 29 to July 7, 2006, following emergence of a new cohort of oak seedlings. To provide consistency, one applicator applied all treatments. For the injection treatment (INJ), the applicator used an ax with a 1.75-in. bit to make evenly spaced incisions around the trunk circumference at approximately 3 to 4 feet above the ground, one for each inch in tree diameter. Approximately 3 ml of undiluted Pathway®[2] herbicide (5.4 percent picloram [4-amino-3,5,6-trichloropicolinic acid], 3 percent acid equivalent [ae] + 20.9 percent 2,4-D [2,4-dichlorophenoxyacetic acid, triisopropanolamine salt], 11.2 percent ae) was delivered to each incision using a piston pump backpack sprayer and gunjet nozzle with adjustable cone tip at a pump pressure of less than 20 lbs per in.^{2} In a second treatment a Stihl MS 200T professional arbor chainsaw (2.15-cu. in. displacement) was used to make a single, continuous girdle cut around the circumference of trees ≥4 in. d.b.h. Girdle cuts were no more than 1 in. deep. Smaller stems were felled. The

[2]Pathway® and Garlon 4® are registered trade names of Dow AgroSciences.

same Pathway® herbicide as was used with the INJ treatment was applied to the girdle cut or cut stump using an ordinary garden pump spray bottle. Herbicide was sprayed to wet the cut surfaces, but not to the point of runoff. A low-volume basal bark (BAS) herbicide spray was applied using a diaphragm pump backpack sprayer with adjustable cone nozzle. A 20-percent triclopyr (61.6 percent 3,5,6-trichloro-2-pyridinyloxyacetic acid, butoxyethyl ester, 44.3 percent ae) solution diluted in AX-IT[3] oil-surfactant low-volume basal oil was sprayed on the lower 12 to 15 in., and around the full circumference of treated stems. Finally, a no-removal control treatment was maintained. The objective of the mid- and understory removal was to remove the low shade component while maintaining intact the high shade of the extant overstory. All midstory trees ≥ 1 in. d.b.h. were treated, with the exception of a small number of oaks or occasional shade-tolerant trees growing in overstory canopy gaps. All treated dead trees were tallied by species and 1-in. diameter classes in each treatment plot at 1, 2, 4, 11, 12, 16, and 24 months after treatment (MAT), between July 2006 and June 2008.

A generalized linear model was initially fit to the number of live midstory stems surviving in each treatment plot *i* to provide parameters for fitting generalized estimating equations in a repeated-measures analysis. Parameter estimate significance was determined at $\alpha = 0.05$. This model is essentially a repeated measures analysis of variance, except that errors are assumed to be Poisson, rather than normally, distributed. The Poisson model is more appropriate for count data. The predictors were midstory control treatment (INJ, SAW, BAS), tree species groups (AMB, ELM, HIC, SUM, MISCL, and MISCS), and diameter classes (1 to 9 in. with the 9-in. class including all trees 9 in. and larger). To account for problems associated with potential pseudoreplication, stand was initially included in the model as a predictor variable to test for random effects. Random effects due to stand were insignificant; therefore stand was dropped from the final model.

In this hierarchical design, the experimental unit is the finest level of resolution for which the data were collected—in this case, the individual stem counts for each treatment, species group, diameter class, and stand combination. A full-factorial model was fit initially, including all possible interaction terms. Interaction terms were subsequently dropped if the associated regression coefficients were not significant ($\alpha = 0.05$). Data were reported as proportion of stems surviving. Labor time, herbicide volume dispensed, and saw fuel and bar oil volumes used were recorded for each treatment plot. Cost data were calculated by diameter inches treated (DIT). DIT was calculated as the sum of the d.b.h. measurements of all treated trees in each treatment plot. Cost analyses were performed using a one-way ANOVA, using the Ryan-Einot-Gabriel-Welsch Multiple Range Test Means Separation procedure at $\alpha = 0.05$. Analyses were performed using SAS, version 9.1.3 (SAS Institute, Cary, NC).

RESULTS

STAND COMPOSITION

Across the three stands, oak basal area averaged 89 ft^2/acre. Oak composed 67 percent of the overstory basal area and 57 percent of the total basal area. Midstory trees accounted for 24 to 29 ft^2 of basal area per acre (Table 1) or 15 to 19 percent of the total basal area across all three stands. A total of 3,953 midstory stems ranging from 1 to 15 in. d.b.h. were tallied across all three stands. Only 118, less than 3 percent, of midstory stems were not treated, the majority of these being oak species. Stands I and N had similar midstory tree diameter distributions (Fig. 1). Stand P deviated a little from the other two in that it had smaller numbers of the 1-in. diameter class, had no stems greater than 11 in. d.b.h., and carried larger numbers of stems in the 3- to 6-in. diameter classes.

[3]AX-IT® is a registered trade name of Townsend Chemical.

Table 1.—Midstory stem and basal area stocking for three mature upland oak stands (I, N, and P) in southern Indiana receiving midstory removal treatments.

Midstory Stocking	Tract I	Tract N	Tract P	Mean
Midstory Stems		(no. stems/acre)		
Sugar maple	176	268	304	248
American beech	48	3	6	20
Elm spp.	30	4	3	12
Hickory spp.	3	10	19	11
Miscellaneous large	21	11	21	18
Miscellaneous small	45	29	12	29
Total	324	324	364	338
Midstory basal area		(ft^2/acre)		
Sugar maple	12.9	19.5	23.9	18.7
American beech	3.7	0.2	0.1	1.4
Elm spp.	2.0	0.1	0.1	0.8
Hickory spp.	0.7	2.0	2.0	1.5
Miscellaneous large	4.1	2.1	3.0	3.9
Miscellaneous small	1.0	0.3	0.2	0.5
Total	24.4	24.2	29.2	26.8

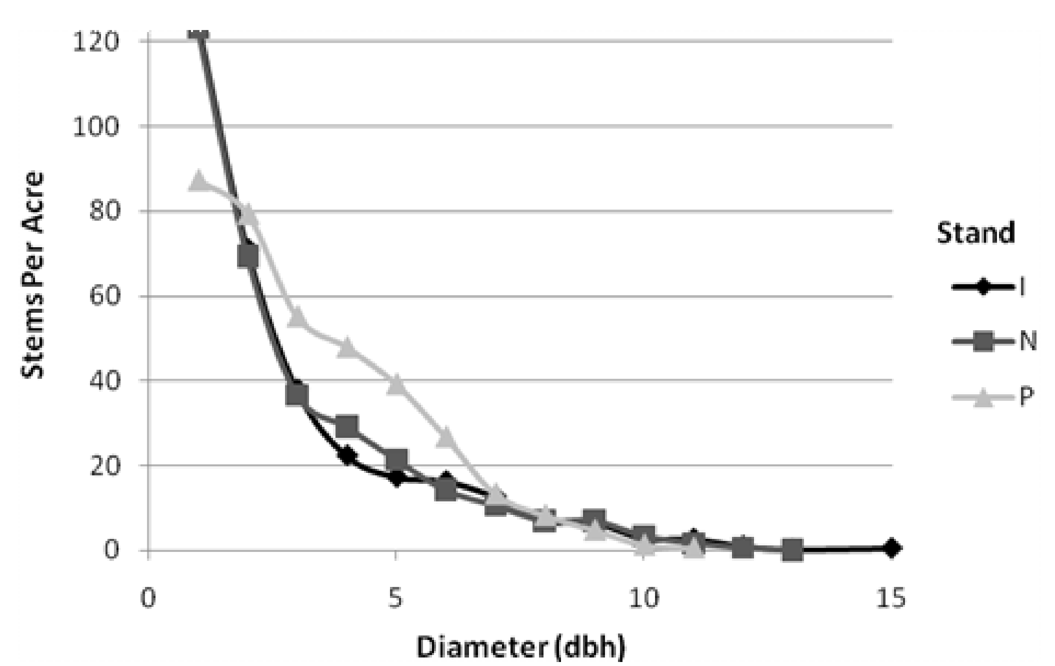

Figure 1.—Pretreatment midstory diameter distributions for three oak-dominated stands in southern Indiana receiving midstory removal treatments.

Sugar maple was overwhelmingly the most abundant midstory species in stands N and P. Across all three stands, sugar maple accounted for 73 percent and 70 percent of total number of midstory stems and midstory basal area, respectively (Table 1). American beech was the next most abundant species, making up 6 percent of midstory stems.

OVERALL EFFECTS

All three midstory control treatments resulted in fewer live stems compared to the untreated control (CON) beginning 1 MAT (Table 2). All MAT had fewer live stems than the pretreatment (0 MAT). There were overall slight differences in survival rates between some species groups. However, there were significant treatment (TRT) x species group (SPP) interactions. Overall survival rates were higher with increasing d.b.h. Treatment differences between d.b.h. classes decreased over time. However, there were significant TRT x D.B.H. interactions. These will be explored further below. By 16 MAT, survival for all three treatments was at or near zero (Fig. 2).

Table 2.—Generalized estimating equation parameter estimates for the effects of midstory removal treatment (TRT), species (SPP), diameter class (d.b.h.), and months after treatment (MAT) on treated stem survival (n = 3,834)

Parameter			Estimate	SE	Z	Pr > |Z|
Intercept			0.7026	0.0738	9.52	<.0001
MAT	1		-0.2597	0.0434	-5.98	<.0001
	2		-0.6024	0.0808	-7.45	<.0001
	4		-0.8559	0.1138	-7.52	<.0001
	11		-1.0372	0.1331	-7.79	<.0001
	12		-1.0963	0.1420	-7.72	<.0001
	16		-1.2414	0.1668	-7.44	<.0001
	24		-1.2468	0.1677	-7.44	<.0001
TRT	INJ[a]		-0.4359	0.1096	-3.98	<.0001
	SAW		-0.4673	0.0721	-6.48	<.0001
	BAS		-0.5958	0.0888	-6.71	<.0001
SPP	AMB[b]		-0.0153	0.0118	-1.29	0.1966
	SUM		-0.0164	0.0065	-2.53	0.0115
	ELM		-0.0276	0.0136	-2.03	0.0423
	HIC		0.0080	0.0087	0.92	0.3599
	MISCL		-0.0492	0.0254	-1.94	0.0524
d.b.h.	1		-0.0201	0.0097	-2.06	0.0390
	2		-0.0373	0.0128	-2.92	0.0035
	3		-0.0401	0.0183	-2.19	0.0286
	4		-0.0545	0.0207	-2.64	0.0084
	5		-0.0209	0.0097	-2.16	0.0308
	6		-0.0147	0.0084	-1.76	0.0783
	7		-0.0041	0.0071	-0.58	0.5599
	8		-0.0323	0.0277	-1.17	0.2439
Interactions	INJ	AMB	0.5163	0.1062	4.86	<.0001
	INJ	SUM	0.0938	0.0827	1.13	0.2565
	INJ	ELM	-0.3810	0.1259	-3.03	0.0025
	INJ	HIC	-0.5737	0.1217	-4.72	<.0001
	INJ	MISCL	-0.5407	0.1328	-4.07	<.0001
	SAW	AMB	-0.0383	0.0566	-0.68	0.4985
	SAW	SUM	0.0520	0.0210	2.48	0.0132
	SAW	ELM	-0.3434	0.2414	-1.42	0.1549
	SAW	HIC	-0.6068	0.1146	-5.30	<.0001
	SAW	MISCL	-0.4845	0.1383	-3.50	0.0005
	BAS	AMB	-0.0554	0.0731	-0.76	0.4480

(Table 2 continued on next page.)

Table 2 (continued).—Generalized estimating equation parameter estimates for the effects of midstory removal treatment (TRT), species (SPP), diameter class (d.b.h.), and months after treatment (MAT) on treated stem survival (n = 3,834)

Parameter			Estimate	SE	Z	Pr > |Z|
Interactions	BAS	SUM	-0.0829	0.0660	-1.26	0.2092
	BAS	ELM	-0.2547	0.0988	-2.58	0.0100
	BAS	HIC	0.3292	0.0877	3.75	0.0002
	BAS	MISCL	-0.2597	0.0882	-2.94	0.0033
	INJ	1	-0.9593	0.0876	-10.95	<.0001
	INJ	2	-0.8443	0.0902	-9.36	<.0001
	INJ	3	-0.7405	0.0781	-9.48	<.0001
	INJ	4	-0.4082	0.0782	-5.22	<.0001
	INJ	5	-0.2193	0.0851	-2.58	0.0100
	INJ	6	-0.0561	0.0893	-0.63	0.5300
	INJ	7	-0.1456	0.1088	-1.34	0.1810
	INJ	8	-0.0609	0.1166	-0.52	0.6018
	SAW	1	-1.3393	0.0726	-18.46	<.0001
	SAW	2	-1.3155	0.0733	-17.95	<.0001
	SAW	3	-1.2391	0.0741	-16.72	<.0001
	SAW	4	-0.6278	0.1045	-6.01	<.0001
	SAW	5	-0.4418	0.1131	-3.91	<.0001
	SAW	6	-0.2432	0.0874	-2.78	0.0054
	SAW	7	-0.2010	0.1296	-1.55	0.1207
	SAW	8	-0.1198	0.0969	-1.24	0.2164
	BAS	1	-0.7943	0.0806	-9.86	<.0001
	BAS	2	-0.6127	0.0638	-9.60	<.0001
	BAS	3	-0.4548	0.0707	-6.43	<.0001
	BAS	4	-0.3110	0.0673	-4.62	<.0001
	BAS	5	-0.2161	0.0727	-2.97	0.0029
	BAS	6	-0.1852	0.0727	-2.55	0.0108
	BAS	7	-0.1909	0.0986	-1.94	0.0529
	BAS	8	-0.0074	0.1158	-0.06	0.9492

[a]Midstory treatments (TRT): Injection (INJ), chainsaw girdle (SAW), and low- volume basal bark spray (BAS).

[b]Species groups (SPP): American beech (AMB), sugar maple (SUM), elm spp. (ELM), hickory spp. (HIC), and miscellaneous large trees (MISCL).

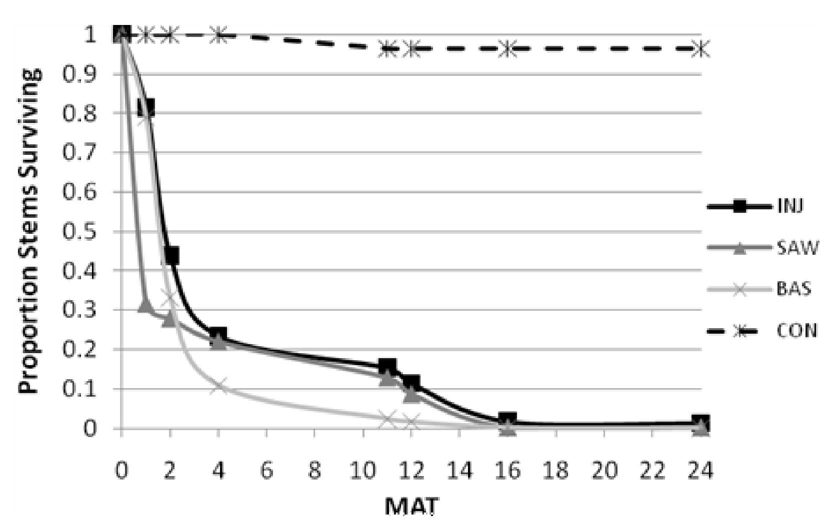

Figure 2.—Mean proportion of stems surviving over the 24-month period following treatment (MAT) with injection (INJ), chainsaw cutting/girdling (SAW), and low-volume basal bark (BAS) midstory removal methods, and a no-treatment control (CON).

MIDSTORY TREATMENT (TRT) EFFECTS

Midstory stems were reduced to 32-percent survival 1 MAT in the SAW treatment, primarily because all stems less than 4 to 5 in. d.b.h. were cut down (Fig. 2). By the end of the first growing season, 4 MAT, the BAS treatment reduced the number of live stems to 11-percent survival, surpassing both INJ and SAW treatments in early efficacy.

Early in the second growing season, 12 MAT, 98 percent of BAS-treated stems were dead. Only 11 and 9 percent of INJ- and SAW-treated stems, respectively, remained alive at 12 MAT. By the end of the second growing season, 16 MAT, only 2 percent of INJ-treated stems remained alive, while all of SAW-treated stems were dead. By 24 MAT, a remnant 14, or 1 percent, of INJ treated trees ranging in size from 6 to 9+ in. d.b.h were still alive.

SPECIES DIFFERENCES

Significant TRT x SPP interactions indicated further differences in the rate of stem mortality among species in response to the treatments (Table 2). INJ produced the most rapid declines in tree survival among the elm, hickory, and MISCL species groups (Fig. 3). Elm survival at 1 and 2 MAT was 42 and 10 percent, respectively. By 4 MAT, all INJ elm stems were dead. Although hickory did not respond immediately to INJ 1 MAT, only 19 percent survived at 2 MAT. By 4 MAT, only 5 percent of hickories survived; complete mortality occurred by 12 MAT. Beech and sugar maple survival rates under the INJ treatment were higher than for other species groups. Their temporal pattern of mortality was similar to each other, with beech having slightly higher rates of survival over time.

Differences in SAW treatment survival 1 MAT between species groups reflect differences in relative proportions of stems in the smaller d.b.h. classes. For instance, MISCS had 0-percent survival 1 MAT because all stems in this species group were less than 5 in. d.b.h. Following 1 MAT, beech and sugar maple mortality rates slowed, compared to other species groups, to 29 and 25 percent survival, respectively, 4 MAT.

Two MAT the BAS treatment had reduced survival to between 9 and 33 percent for all species but hickory. For elm, MISCL, and MISCS species groups, the BAS treatment reduced survival to the same degree as the INJ and SAW treatments 4 MAT. For beech and sugar maple, however, the BAS treatment surpassed the INJ and SAW treatments by reducing stem numbers to 4 and 11 percent survival, respectively, 4 MAT. Hickory responded more slowly to the BAS treatment than did all other species. By the end of the first growing season, 4 MAT, hickory still had 67-percent survival. By 12 MAT, 25 percent of hickory stems remained alive. However, only 4 percent of hickory stems survived to 16 MAT; 100-percent control occurred by 24 MAT with the BAS treatment.

D.B.H. CLASS DIFFERENCES

Significant TRT x D.B.H. interactions indicated differences in the rate of stem mortality among d.b.h. classes in response to the treatments (Table 2). In general, the smaller d.b.h. classes had lower survival rates beginning 1 MAT (Fig. 4). The SAW treatment reduced small d.b.h. stem numbers by nearly 100 percent 1 MAT because, as stated earlier, virtually all stems less than 4 in. d.b.h. were cut down. Some 4- and 5-in. d.b.h. stems were felled and some girdled in the SAW treatment, accounting for much of the stem reduction seen 1 MAT in these d.b.h. classes. In larger d.b.h. classes (> 6 in.), stem survival was similar between treatments 1 MAT, ranging between 85 and 100 percent.

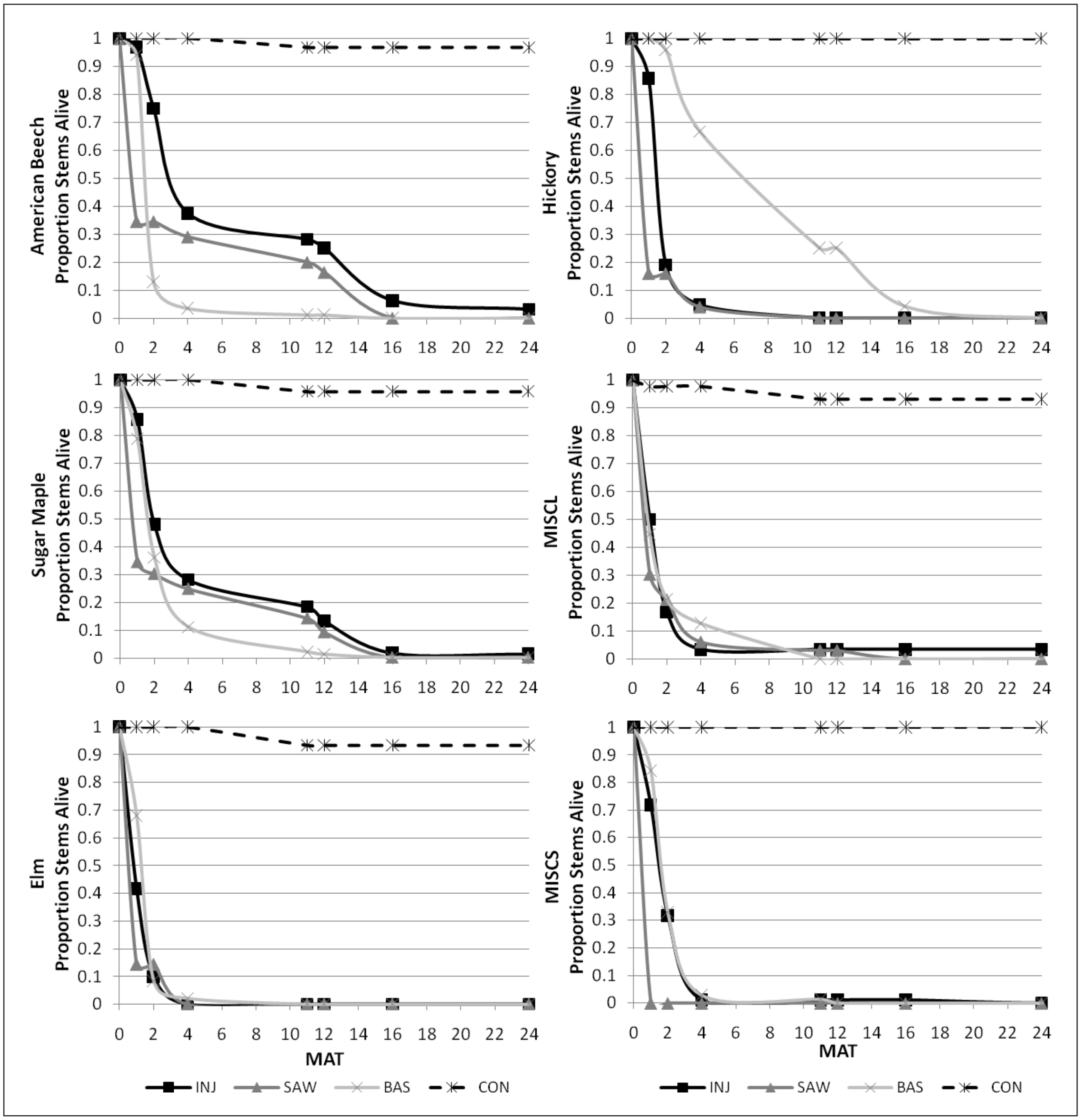

Figure 3.—Mean proportion of stems surviving for six species or species groups over the 24-month period following treatment (MAT) with injection (INJ), chainsaw cutting/girdling (SAW), and low-volume basal bark (BAS) midstory removal methods, and a no-treatment control (CON). MISCL are miscellaneous tree species capable of attaining forest tree stature and include blackgum, yellow-poplar, black cherry, sassafras, white ash, hackberry, red maple, and others. MISCS are miscellaneous tree species that typically are of low stature and include American hornbeam, flowering dogwood, eastern hophornbeam, redbud, pawpaw, and others.

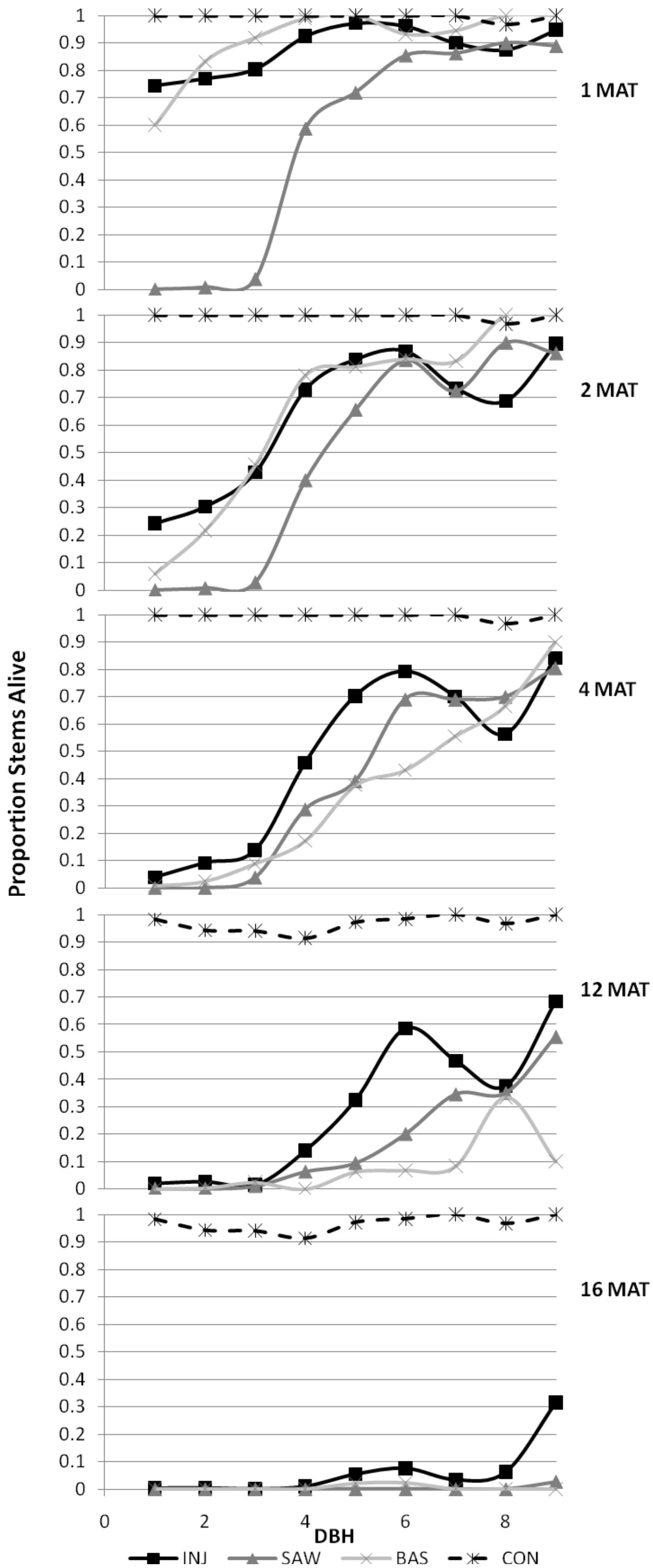

Figure 4.—Mean proportion of stems surviving across a range of stem diameters (d.b.h.), 1, 2, 4, 12, and 16 months following treatment (MAT) with injection (INJ), chainsaw cutting/girdling (SAW), and low-volume basal bark (BAS) midstory removal methods, and a no-treatment control (CON).

By the end of the first growing season, 4 MAT, most stems less than 4 in. d.b.h. for all three treatments were dead. The BAS treatment produced a more rapid reduction of stems larger than 4 in. d.b.h. between 4 MAT and 12 MAT compared to INJ and SAW treatments. By 12 MAT, however, most trees in all three treatments showed symptoms of herbicide damage and had thinning or partially damaged crowns.

By the end of the second growing season, 16 MAT, SAW and BAS treatments produced nearly 100-percent mortality in treated stems across all d.b.h. classes. The INJ treatment still had from 1- to 8-percent survival in 4- to 8-in. d.b.h. class stems and 32-percent survival in 9 in. and larger d.b.h. stems. At 24 MAT, three out of the originally treated 19 stems, or 16 percent, of 9 in. d.b.h. and larger stems in the INJ treatment were still alive. By 36 MAT only two of those stems remained alive.

TREATMENT COSTS

The BAS treatment proved most efficient in labor time (Table 3). Mean DIT per hour was 495, which was 1.7 times more productive than the SAW treatment. The INJ treatment was not significantly less productive than the BAS treatment. Foresters typically think of production rates on a per-acre basis. This approach is not the most accurate way to reflect treatment differences in labor and cost rate since it may not account for differences in stocking and diameter distributions between the treated areas. For this study, nevertheless, SAW, INJ, and BAS treatments had labor productivity rates of 2.9, 2.2, and 1.7 hrs per acre, respectively.

The BAS and INJ treatments required similar volumes of herbicide concentrate. However, the cost per unit volume between the two different herbicides plus the cost of the oil carrier used in the BAS treatment made herbicide costs for the BAS treatment more than 4 times that of the INJ treatment and 11 times that of the SAW treatment. Mean BAS treatment cost was $0.20 per DIT, nearly two times more costly than the SAW treatment at $0.11 per DIT and more than twice as costly as the INJ treatment at $0.09 per DIT. SAW and INJ treatment costs were not significantly different from each other. For these three stands, treatment costs per acre at a labor rate of $25 per hour averaged $169.64, $86.46, and $82.75 across the three stands for BAS, SAW, and INJ treatments, respectively.

Table 3.—Cost analysis for three midstory removal methods used in the implementation of the oak shelterwood method in three mature oak stands in southern Indiana. Differences in means indicated by letters within columns (α = 0.05).

Trt	Per acre DIT[a] (in./ac)	Per acre labor time (hr/ac)	Per hour DIT (in./hr)	Per acre BAT[b] (ft^2/ac)	Per hour BAT (ft^2/hr)	Labor[c] cost per DIT ($/in.)	Labor cost per BAT ($/$ft^2$)	Labor cost per acre ($/ac)
INJ	977 a	2.2 b	453 a	23.1 a	10.7 a	0.06 a	2.35 a	54.03 b
SAW	842 a	2.9 a	299 b	23.9 a	8.4 a	0.09 b	3.05 a	72.41 a
BAS	852 a	1.7 c	495 a	18.4 b	10.7 a	0.05 a	2.37 a	43.38 c

Trt	Herb[d] cost Per DIT ($/in)	Herb cost per BAT ($/$ft^2$)	Herb cost per acre ($/ac)	Saw cost per DIT ($/in)	Saw cost per BAT ($/$ft^2$)	Total cost Per DIT ($/in)	Total cost per BAT ($/$ft^2$)	Total cost per acre ($/ac)
INJ	0.03 b	1.26 b	28.71 b			0.09 b	3.61 b	82.75 b
SAW	0.01 b	0.47 c	11.24 c	0.003	0.12	0.11 b	3.64 b	86.46 b
BAS	0.10 a	4.72 a	86.01 a			0.15 a	7.09 a	129.39 a

[a]DIT = diameter inches treated or the sum of diameters of all treated trees.
[b]BAT = basal area (ft^2) treated or the sum of basal areas of all treated trees.
[c]Labor costs based on labor rate of $25 per hour.
[d]Herbicide costs based on $35.25 per gallon of Pathway® concentrate (INJ and SAW), $104.85 per gallon of Garlon4® plus $14.70 per gallon of AX-IT® basal oil (BAS).

DISCUSSION

Given that the overall midstory species composition of the three stands included in this study was predominantly sugar maple, the BAS treatment was the most effective of the three treatments in removing the midstory canopy in the timeliest manner across the range of stem diameters encountered. By the end of the first growing season following treatment (4 MAT), the BAS treatment reduced total midstory stem numbers by 89 percent. By 12 MAT, or the beginning of the second growing season, the BAS treatment had killed 98 percent of all treated midstory stems. However, both the INJ and the SAW treatments removed a significant amount of the midstory canopy, 77 and 78 percent respectively, by the end of the first growing season. Early in the second growing season, they had removed 89 and 91 percent, respectively, of the midstory stems, greatly increasing forest floor light levels over pretreatment conditions. Tree d.b.h. within the range treated did not influence the final outcome 2 years following treatment, regardless of treatment used. In general, however, the larger the d.b.h., the longer it took for tree mortality to occur, with important differences occurring between the three treatments. Up to the end of the first growing season, mortality was strongly related to stem d.b.h. in the BAS treatment. After the first growing season, BAS treatment survival collapsed dramatically across all d.b.h. classes. Mortality rates were highly variable in the INJ and SAW treatments when stems exceeded 5 in. d.b.h. up to the beginning of the second growing season. By the end of the second growing season, however, most remaining INJ- and SAW-treated stems died irrespective of d.b.h., except for 9 in. and larger d.b.h. stems in the INJ treatment. The remaining stems in the INJ treatment continued to slowly die over the next 20 months, with a small remnant surviving to the present.

Although species did not influence the final outcome, there were important differences in how species groups responded to the three treatments. Beech and sugar maple responded more slowly to INJ and SAW treatments than did elm, hickory, MISCL, and MISCS species groups. While beech and/or sugar maple stands may respond most quickly to the BAS treatment, stands with midstory canopies composed primarily of hickory species would likely respond much more slowly to the BAS treatment. In such stands INJ and SAW treatments provide the most rapid mortality.

Kochenderfer and others (2004) demonstrated near 100-percent crown control of 6- to 11-in. and larger d.b.h. American beech in West Virginia 12 months after treatment in August using a similar injection method with a 50-percent solution of glyphosate. In the same study, a basal bark treatment using a 10-percent solution of triclopyr ester in an oil carrier provided 99-percent crown control of 1- to 6-in. d.b.h. beech. A 25-percent solution of triclopyr ester in oil applied in late winter top killed 92 percent of sugar maple stems 2 years following treatment in a study in Missouri (Thomas and Garrett 1993). In an Arkansas study, Williams and others (1996) showed decreasing efficacy of various triclopyr + imazapyr basal bark combinations applied in January with increasing d.b.h. for sweetgum, southern red oak, and hickory, approximately 9 months after treatment. For the predominantly sugar maple midstories of this study, stem diameter did not appear to be a factor in BAS treatment efficacy after the first growing season (4 MAT). Stem diameter continued to influence INJ and SAW treatment efficacy up to the end of the second growing season (16 MAT). However, most of these trees had reduced leaf area and thus were allowing more light to pass through their crowns. Hickory mortality in Williams and others' (1996) study was substantially lower (37.9 percent) for the 4-in. d.b.h. class than for the same size stems of the other two species treated. This result is comparable to the low 43-percent hickory mortality following the BAS treatment in this study at the end of the first growing season.

There is interest in reducing or removing the midstory as quickly as is financially feasible to provide to a new cohort of oak seedlings the light needed to sustain positive growth and maintain survival (Phares 1971). A new large cohort of oak seedlings is often not detected in a stand until after seedling emergence. New northern red oak seedlings establishing in undisturbed forest understories rely on the reserves stored in the seed cotyledons to sustain them through the first growing season (Crow 1988). Low light level stress-induced mortality in northern red oak therefore may be limited in the first growing season (Crow 1992). First-year oak seedling mortality may be more related to other factors, such as predation (Rathfon and others 2008). However, low light levels also reduce carbon allocation to the roots, resulting in oak seedlings with lower root: shoot ratios than needed for competitive advance oak reproduction (Kolb and others 1990). After cotyledon reserves are exhausted, seedling mortality in undisturbed stands with well developed midstory canopies commences. Crow (1992) found that after 6 years, 36 percent of a cohort of northern red oak seedlings survived under an intact overstory canopy (undisturbed), compared to 54 and 92 percent survival for partial and no overstory or open conditions where understory vegetation was initially controlled by a broadcast herbicide application. The 2006 cohort of oak seedlings in the three subject stands of this study had 48- and 80-percent greater survival at the end of the first growing season in the INJ and SAW treatments, respectively, compared with seedlings growing in the CON treatment (Rathfon and others 2008).

Photosynthetically active radiation (PAR) data were measured on the forest floor prior to implementation of the midstory control treatments and for 2 years after. These data are not presented. However, understory light levels increased substantially in all three treatments, but not until the second growing season. During the first growing season, dead foliage did not immediately drop off, thereby still providing shade. The felling of trees in the SAW treatment provided an immediate small increase in ambient understory light levels. When performing intermediate stand treatments, many foresters choose to fell, rather than girdle, larger stems than were felled in this study. Thus, a more substantial immediate increase in light could be attained. However, complete midstory control as prescribed in the oak shelterwood method would require the felling of many more stems than would normally be done in most standard timber stand improvement operations.

Yet another factor for forest managers to consider when choosing midstory control options is potential herbicide damage to oak reproduction. First-year oak seedling survival was substantially reduced in the BAS treatment due to volatilization of triclopyr ester that was absorbed as a vapor by the foliage of the young seedlings (Rathfon 2008). At least 59 percent of seedlings tallied as dead were top killed by triclopyr ester exposure. Nontarget hardwood seedling damage in stands treated with the basal bark treatment is not well documented in the literature. Ester formulations of triclopyr, however, volatilize when air temperatures exceed 85 to 90 °F (Tu and others 2001). Midsummer applications of the BAS treatment may be ill-advised in midstory control applications where a new cohort of oak seedlings has recently emerged or established.

Cain (1995) reported labor productivity rates for cleaning hardwoods in shortleaf pine stands in Arkansas. It required approximately 2 to 3 hrs per acre for chainsaw felling and 3 to 4 hrs per acre for injection using a tube type injector to clear 300 to 400 hardwood stems per acre. In hardwood stands in West Virginia where primarily beech stems 1 to 6 in. d.b.h. were treated, a basal bark treatment required approximately 2 hrs per acre (Kochenderfer and others 2004). Midstory stems 6 in. d.b.h. and larger treated in the same study using an injection treatment similar to that used in this study required 2.7 hrs per acre.

Given the substantially greater costs of applying the BAS treatment for an already costly silvicultural treatment, land managers faced with limited budgets will likely choose lower cost alternatives. The SAW treatment remains financially attractive at labor rates below $25 per hr. At higher labor costs, the INJ treatment becomes the lower-cost alternative. If lower herbicide concentrations were used in a BAS treatment that would still prove effective over a broad range of species and stem diameters, BAS treatment could become more cost-effective. However, reducing the triclopyr concentration by half to 10 percent would still make the BAS treatment $0.07 per DIT or $51.90 per acre, more costly than the INJ treatment, where labor rates are $25 per hr. Some employers are looking for safer ways to implement silvicultural treatments to reduce insurance costs. This objective often means looking for alternatives to the use of chainsaws. Although the INJ treatment left a small number of residual surviving stems, both the lower cost and the potential to reduce chainsaw use, along with its overall effectiveness, make this an attractive choice.

CONCLUSIONS

INJ, SAW, and BAS treatments all were effective in removing nearly all or the majority of the midstory canopy by the end of the first or the beginning of the second growing season of a cohort of oak seedlings. Although a substantial number of stems greater than 5 in. d.b.h. continued to survive during the second growing season in INJ and SAW treatments, most of these had damaged crowns that admitted much more light than prior to treatment. BAS treatment costs are considerably higher than INJ and SAW treatments costs when applied to midstory control work where 300 or more stems per acre will be treated.

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