PRESCRIBED GRAZING FOR MANAGEMENT OF INVASIVE VEGETATION IN A HARDWOOD FOREST UNDERSTORY

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Abstract.—Land managers considering prescribed grazing (PG) face a lack of information on animal stocking rates, timing of grazing, and duration of grazing to achieve desired conditions in natural ecosystems under invasion stress from a variety of nonnative invasive plant (NNIP) species. In this study we tested PG treatments using goats for reducing NNIP brush species and measured impacts to native vegetation after 1 year. The hardwood forest understory was dominated by nonnative multiflora rose (*Rosa multiflora*) and the native spicebush (*Lindera benzoin*). Treatments consisted of two levels of grazing intensity (16 and 48 goats per acre) and two levels of grazing frequency: a single late spring grazing and both late spring and a repeat early fall (October) grazing. All grazing treatments greatly reduced leaf cover of most species of ground layer vegetation at the time of grazing. One year later multiflora rose leaf cover was reduced by an average of 8 to 10 percent from pretreatment cover with no significant differences between grazing treatments. Spicebush cover was reduced by 12 to 16 percent. Although some herbaceous species increased and some decreased under PG treatments, herbaceous species diversity increased slightly overall. Herbaceous cover declined for high stocking rate PG treatments. Multiple years of prescribed grazing may be needed to substantially reduce NNIP cover.

INTRODUCTION

The ecology, impacts on native forest vegetation, and control of many nonnative invasive plant (NNIP) species have received extensive study in recent years. However, research and control efforts in eastern U.S. forests have focused on various combinations of mechanical removal and herbicide treatment. Research on biological controls exclusively refers to insect predators or pathogens of target NNIPs. Prescribed or targeted grazing (PG) is the use of grazing animals as a component in an integrated vegetation management system to achieve certain land management objectives or ecosystem conditions. Although the idea of using animal grazing to manage vegetation is not new, the use of prescribed grazing for managing unwanted NNIP populations is a relatively recent development (Hedtke et al. 2009, Johnstone and Peake 1960, Kleppel and LaBarge 2011, Sharrow et al. 1989). Much of the research and experience using PG for NNIP management comes from western U.S. rangelands. More recently, eastern U.S. researchers and land managers have looked to PG to help manage undesirable vegetation in a wide variety of management contexts, from maintaining power line rights-of-way to managing habitat vegetation for the endangered bog turtle (*Clemmys muhlenbergii*) in New Jersey (Reshetiloff 2011). The development of intensive rotational grazing techniques and mobile fencing systems allows entrepreneurs to provide PG services to landowners (i.e., herd for hire). As such, PG services can provide an alternate source of income for livestock growers. However, such PG services are few in number in the eastern U.S., and research on the effectiveness of PG to suppress NNIP species and impacts to nontarget native vegetation in eastern hardwood ecosystems is almost nonexistent.

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Many factors must be considered when implementing PG for achieving desired ecosystem conditions. The variable feeding behavior of livestock species and breeds makes certain ones better suited for selectively feeding on target vegetation, thus better meeting management objectives. Age, sex, and previous foraging experience may also influence feeding behavior. Domestic goats (*Capra aegagrus hircus)* are well suited to providing prescribed grazing services in hardwood forest environments, particularly where reducing invasive woody species is desired (Hart 2001). The narrow muzzles and tough, dexterous tongues of goats allow them to more efficiently reach and extract leaf tissue from dense, thorny thickets (Campbell and Taylor 2006). They also browse much more than other domestic livestock and are better adapted to extracting nutrients and detoxifying secondary compounds such as tannins and terpenes from woody plants.

In addition to the lack of PG services, land managers face a lack of information on animal stocking rates needed, timing of grazing, and duration of grazing to achieve desired conditions in natural forests under invasion stress from a variety of NNIP species. Information is also needed on how grazing impacts native plant communities so land managers can weigh their options when designing an integrated vegetation management plan.

The objectives of this study were (1) to test grazing intensity (low and high goat stocking rates) and two grazing frequencies within a growing season using goats to reduce a NNIP infestation in a mature hardwood forest understory, and (2) to quantify impacts of those treatments on nontarget native vegetation, including hardwood tree regeneration. This paper reports first-year results.

METHODS

The study was located on a 10-acre site at the Southern Indiana Purdue Agricultural Center (SIPAC) in Dubois County, Indiana. The site was an east-northeast aspect with 30 percent slopes on Gilpin silt loam soils. Yellow-poplar site index at base age 50 was approximately 100 feet. A mature, well-stocked, mixed hardwood forest grew on the site. Average basal area stocking for trees greater than 1 inch diameter at breast height (d.b.h.) was 130 square feet/acre. Overstory tree composition consisted of mature yellow-poplar (*Liriodendron tulipifera*), accounting for 50 percent of the basal area; maple (mostly sugar maple, *Acer saccharum*) and oak (black, *Quercus velutina*; chinkapin, *Quercus muhlenbergii*; northern red, *Quercus rubra*; and white, *Quercus alba*) each accounted for 11 percent of the basal area. Other minor species included sycamore (*Platanus occidentalis*), black walnut (*Juglans nigra*), white ash (*Fraxinus americana*), hickory (*Carya spp.*), and black cherry (*Prunus serotina*). Several exotic invasive shrub and vine species were common in the forest understory; dense, mature multiflora rose (*Rosa multiflora*) (MFR) provided a uniform, nearly impenetrable understory shrub layer throughout most of the stand. Amur honeysuckle (*Lonicera mackii*) (BHS), Japanese honeysuckle (*Lonicera japonica*) (JHS), and autumn olive (*Eleagnus umbellatum*) (AO) also occurred as minor nonnative invasive components in the understory. The native spicebush (*Lindera benzoin*) was also abundant.

Treatments included two levels of grazing intensity (goat stocking) and two levels of grazing frequency. A conventional invasive brush control treatment was included to compare levels of control of target invasive vegetation and levels of damage to nontarget native vegetation. A control in which no disturbance occurred was included as well. The treatments were:

1. Control (C)
2. Manual cutting + herbicide (M+H)
3. Low stocking with two grazings (LS2)
4. Low stocking with one grazing (LS1)
5. High stocking with two grazings (HS2)
6. High stocking with one grazing (HS1)

Treatments were assigned to ¼-acre plots in a completely randomized design, with three replications. In the M+H treatment, target shrubs more than 5 to 6 feet tall were cut using a clearing saw followed by application of a 50 percent solution of Garlon® 3A (31.8 percent acid equivalent triclopyr) to the cut stumps. Target shrubs too small or otherwise missed in the cutting operation were sprayed, using a backpack sprayer, with a 4 percent solution of glyphosate (41 percent a.i.) + ¼ percent non-ionic surfactant to the foliage. Target species included MFR, BHS, AO, JHS, and spicebush. M+H treatment was applied between October 18 and November 2, 2012.

Goats assigned to the project were mature commercial does that were not pregnant and not lactating (no kids). The goats were meat goats from the existing herd at SIPAC and from a Kentucky State University herd. They were a relatively hardy, self-sustaining cross-breed of Boer, Kiko, Savanna, and Spanish influence. Mature does used in the study ranged from 80 to 120 pounds, averaging 90 pounds, and ranged from 2.8 to 3.2 feet in head height. A total of 48 goats were randomly assigned to treatment paddocks (the ¼-acre treatment plots). Paddocks were fenced using portable electric netting. Initial stocking in the first grazing period for the high stocking treatments (HS2 and HS1) was 12 goats per plot (48 goats per acre) and for the low stocking treatments (LS2 and LS1) was 4 goats per plot (16 goats per acre).

Due to the limited number of available goats, only half the treatment plots for the initial grazing period could be grazed at a time. Thus, the first grazing for LS2 and HS2 began on May 9, 2012. The duration of a grazing event at each plot depended on the amount of suitable forage in the plot. Grazing treatments were monitored almost daily, particularly as plots neared being depleted of forage. Goats were moved off of paddocks as they depleted plot forage. Between May 18 and May 21, goats were moved off HS2 paddocks and rotated to HS1 paddocks after 9 to 12 days. On June 11, the goats were moved off LS2 paddocks and rotated to LS1 paddocks after 33 days of grazing. Between May 30 and June 1, goats were removed from HS1 paddocks after 9 to 11 days. The first grazing period ended for all treatment plots on July 2 when goats were removed from LS1 paddocks after 21 days of grazing. The second grazing period was to begin when sufficient regrowth of forage justified returning goats to the paddocks. Severe drought began in early July and lasted through the end of summer. Sufficient regrowth did not materialize until early October and then forage quantity was marginal at best. Goat stocking rates were reduced by half to better match the low amounts of forage available. The second grazing began on October 8 with 6 goats (24 goats/acre) in the high stocking paddocks (HS2) and 2 goats (8 goats/acre) in the low stocking paddocks (LS2). Again, plots were monitored daily and goats were removed when forage was depleted. Goats were removed from HS2 paddocks on October 15 after 7 days of grazing. The second grazing period ended on October 24 when goats were removed from LS2 paddocks after 16 days of grazing.

Within each experimental unit (¼-acre treatment plot), sixteen 6.6 foot by 6.6 foot sample quadrats were permanently marked in a systematic grid on an approximate 26 foot spacing. Foliage cover of ground layer woody vegetation (less than 2 inches d.b.h.) was visually estimated by species as a percent. Height of the tallest point of living foliage was measured for each species of ground layer woody vegetation that had at least one individual that was 1.6 feet tall or taller. Five randomly selected 6.6 foot by 6.6 foot sample quadrats were subsampled within each treatment plot to estimate cover of ground layer herbaceous vegetation. Cover of herbs was visually estimated for each species as the percentage of ground covered by all living tissue. Some species were grouped, such as grasses, sedges, and violets. Each subsample also measured tree reproduction by tallying individual seedlings and saplings by species according to the following size classes:

1. 0 – 1.6 feet
2. 1.6 – 3.3 feet
3. > 3.3 feet, < 2 inches. d.b.h.

All measurements were taken immediately before treatments (May 2012) and 1 year later (May 2013).

ANOVA was used to determine whether measured differences occurred among treatments. Because percent cover data do not meet assumptions of normality, ANOVA was used to test the difference between pretreatment and post-treatment cover estimates. The count data of the tree reproduction tallies were converted to an aggregate height (AH) index combining numbers of seedlings and seedling size in the following formula:

$$AH = 0.25s_1 + 0.75s_2 + 1.5s_3$$

Where AH = aggregate height, $s_{1...3}$ = number of seedlings tallied in each of size classes 1 - 3, respectively. ANOVA then was performed on AH. Duncan's multiple range test was used to separate means where significant differences occurred.

RESULTS

Goats in the high stocking rate treatments (HS1 and HS2, 48 goats per acre) took 9 to 12 days in the spring grazing period to deplete the forage (Table 1). In the low stocking rate treatments (LS1 and LS2, 16 goats per acre), the goats took 21 to 33 days. In the fall grazing period the goats depleted the forage in 7 and 16 days in the high stocking (HS2, 24 goats per acre) and low stocking (LS2, 8 goats per acre) treatment plots, respectively. Severe mid- to late-summer drought prevented vigorous regrowth of shrub layer foliage and stems. Even by early October when the second grazing was deployed, regrowth was still quite low, thus necessitating the lower goat stocking levels. Substantial to nearly complete defoliation of all shrub layer vegetation up to 6 to 7 feet tall was achieved before goats were removed from treatment plots. Defoliation occurred through grazing of leaf blades, browsing of stem growth, and in some cases debarking or breaking of small stems that resulted from horn rubbing. No evidence of feeding on bark was observed, nor did the goats cause any other damage to midstory and overstory trees. The ground layer herbaceous vegetation was also heavily grazed.

Table 1.—Goat stocking and grazing duration in a study testing prescribed grazing for control of invasive brush in a hardwood forest understory

	1st Grazing		2nd Grazing	
Treatment	Stocking (goats/acre)	Duration (days)	Stocking (goats/acre)	Duration (days)
LS2	16	33	8	16
LS1	16	21	n/a	n/a
HS2	48	9-12	24	7
HS1	48	9-11	n/a	n/a

Table 2.—Woody plant species diversity before (0) and 1 year following (1) and changes in species distribution following prescribed grazing and conventional mechanical + herbicide treatments in a hardwood forest understory

	Species diversity				Species distribution change				Cover		
Treatment	0	1*	0	1	new	incr.	decr.	no change	0	1†	
	(spp./quadrat)		(tot. spp.)		(spp)				(percent)		
Control	4.9	5.4ns	28	30	3	13	3	12	99.0	101.5	b
M+H	6.7	6.6	34	35	2	14	13	7	68.9	18.1	a
LS2	4.0	4.3	29	26	3	9	12	8	80.8	54.0	ab
LS1	4.5	5.0	28	25	1	12	9	7	102.5	71.8	a
HS2	4.0	4.1	27	25	2	8	12	7	95.7	68.7	ab
HS1	4.6	5.1	30	33	5	15	10	5	96.3	70.4	ab
Overall	4.8	5.1	43	46	4	21	12	10	90.5	64.1	

* Treatment differences tested for the difference in number of spp/quadrat between time 0 and 1. Pr>F=0.6360

† Treatment differences are indicated for the difference in cover (cov_1- cov_0) between time 0 and 1. Pr>F=0.0411, α=0.05.

Woody Shrub Layer Distribution, Cover, and Height

Before treatment, 43 different species of woody plants (trees, shrubs, and vines) occurred in the forest understory; five of those species were nonnative invasive species (Table 2). The mean number of woody species occurring per sample quadrat across the entire study area was 4.8. The most abundant NNIP species, MFR, occurred on 278 of 288 of the sample quadrats, or 96 percent (Table 3). Mean MFR cover ranged from 39 percent to 67 percent (Fig. 1) with overall mean cover of 56 percent across all sample quadrats. Average height ranged between 5 and 6 feet (Fig. 2); some individual MFR reached 20 feet high. JHS distribution ranged from 13 to 44 percent, with an overall mean distribution of 34 percent, but had less than 2 percent cover. BHS distribution ranged from 4 to 21 percent (11 percent overall mean), and AO ranged from 0 to 13 percent (7 percent overall mean). BHS and AO each had 1 percent or less of overall mean cover.

The most abundant and widely distributed native understory woody plant species was spicebush, occurring in 69 percent of sample quadrats (Table 3) and ranging from 11 to 27 percent cover (Fig. 3) with a mean of 19.7 percent cover overall. Spicebush mean height ranged from 4.8 to 7.1 feet (Fig. 4) with an overall mean height of 6.2 feet. The next most widely distributed native understory woody plant species were Virginia creeper (*Parthenocissus quinquefolia*) (67 percent), sugar maple (36 percent), and hydrangea (*Hydrangea arborescens*) (35 percent). However, all other native woody species each provided 4 percent or less cover.

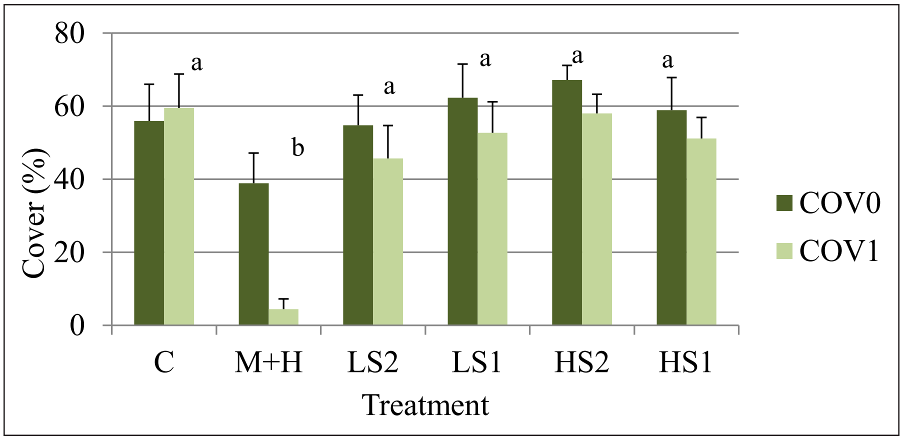

Figure 1.—Percentage of ground cover for multiflora rose growing in plots before (COV0) and 1 year after (COV1) prescribed grazing and conventional mechanical + herbicide treatments. Change in cover (COV1 – COV0) for treatments marked with the same letter is not significantly different from one another using ANOVA, P>F=0.0043, α<0.05.

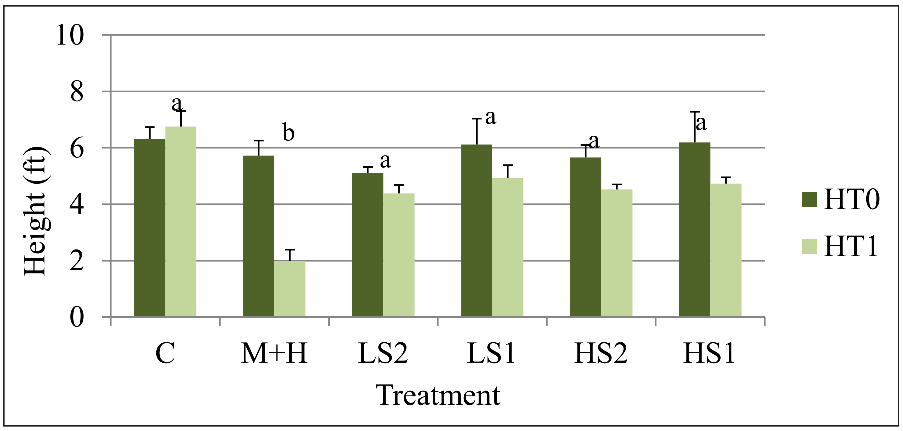

Figure 2.—Multiflora rose height in plots before (HT0) and 1 year after (HT1) prescribed grazing and conventional mechanical + herbicide treatments. Change in height (HT0 – HT1) for treatments marked with the same letter is not significantly different from one another using ANOVA, P>F=0.035, α<0.05.

One year after treatment, 46 woody plant species were recorded across all sample quadrats, for a net gain of 3 (Table 2). All but one treatment, M+H, increased slightly in woody species diversity. Neither the M+H nor any of the PG treatments were significantly different from the control. Few new woody species were tallied after the first growing season (Table 2). Twenty-one species increased their overall distribution, 12 decreased, and 10 did not change. The control had the fewest species decreasing in distribution. The PG treatments with two grazing periods in the growing season (LS2 and HS2) had fewer woody species increasing and more species decreasing their distribution than PG treatments with only one grazing period (LS1 and HS1).

While MFR distribution increased by 1 sample quadrat in the control, it declined by 15 quadrats, or 31 percent, in M+H (Table 3). There was no change in MFR distribution in any of the PG treatments. JHS distribution increased by 8 percent in the control and decreased by 6 percent in M+H. There was virtually no change in JHS distribution among the PG treatments. Little change occurred in distribution of BHS and AO across all treatments, except a 6 percent increase in BHS in the control and a 7 percent increase in the LS2 PG treatment. Overall distribution of spicebush decreased to 65.3 percent, a 3.5 percent decline, with small decreases occurring in every treatment. Although not widely distributed, pawpaw (*Asimina triloba*), where it occurred, was not grazed or browsed at all. Some stem debarking and breaking did occur, however.

Table 3.—Frequency distribution as percent of sample quadrats occupied by the most widely distributed woody and herbaceous species in a hardwood forest understory before (0) and 1 year following (1) prescribed grazing and conventional mechanical + herbicide treatments

	Treatment											
	Control		M+H		LS2		LS1		HS2		HS1	
	Time Relative to Treatment (year)											
Species	0	1	0	1	0	1	0	1	0	1	0	1
Woody:	---------- percent ----------											
nonnative												
multiflora rose	94	96	88	67	96	96	96	96	98	98	98	98
Jap. honeysuckle	38	46	27	21	44	44	17	17	33	31	13	15
Amur honeysuckle	21	27	8	8	8	15	4	2	8	6	4	2
autumn olive	10	10	13	10	4	4	4	4	0	0	6	4
native												
spicebush	73	69	56	54	60	54	92	90	67	63	65	63
Virginia creeper	73	87	87	100	53	47	53	60	60	60	73	67
maple	31	31	69	69	27	27	31	23	31	25	35	40
hydrangea	8	19	42	44	10	8	69	73	25	31	58	63
elm	19	15	33	38	23	25	19	27	21	19	23	31
Herbaceous:												
sedge	87	93	93	93	73	87	60	73	60	73	80	93
violet	80	73	93	100	73	80	87	87	100	87	93	87
jewelweed	87	87	67	73	53	73	60	67	73	87	67	80
white snakeroot	73	87	87	100	40	53	60	53	67	60	60	67
Christmas fern	60	60	60	60	53	47	80	73	67	67	60	60
white avens	67	67	53	53	47	53	47	53	67	53	13	60
grass	73	53	47	40	73	80	40	33	53	53	53	67
jack-in-the-pulpit	53	67	27	40	47	53	27	40	40	40	40	33

The control had practically no change in MFR cover or height (Figs. 1 and 2). Only M+H resulted in large cover and height reductions, from 39 percent pretreatment to 4 percent post-treatment cover, and 3.9 feet in mean height reduction 1 year later. The PG treatments initially resulted in near complete defoliation of MFR immediately after treatment. By the following spring, only modest MFR cover and height reductions were evident. Those reductions ranged from 7.8 to 10 percent for cover and from 0.8 to 1.4 feet for height. Neither cover nor height reductions for PG treatments were significantly different from each other or from the control. JHS, BHS, and AO cover were all low before treatment. PG treatments reduced cover of these minor NNIP species, but not significantly.

Spicebush cover was reduced by 12 to 16 percent and height reductions ranged from 1.6 to 3.1 feet (Figs. 3 and 4) for the PG treatments. M+H reduced spicebush cover by 8 percent and height by 2.6 feet. Although mean cover reduction for PG treatments and M+H were all greater than for the control, no differences were significant, suggesting large amounts of variation. LS2 and HS1, along with M+H, reduced height significantly from the control.

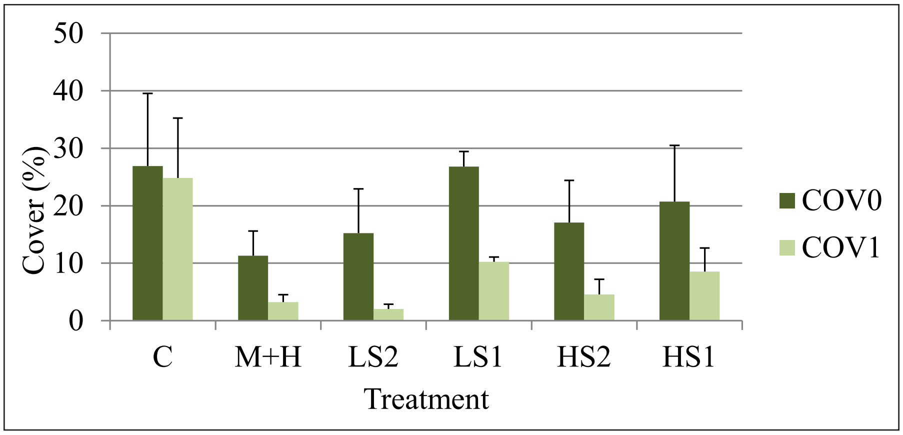

Figure 3.—Percentage of ground cover for spicebush growing in plots before (COV0) and 1 year after (COV1) prescribed grazing and conventional mechanical + herbicide treatments. Change in cover (COV1 – COV0) for treatments marked with the same letter is not significantly different from one another using ANOVA, P>F=0.0043, α<0.05).

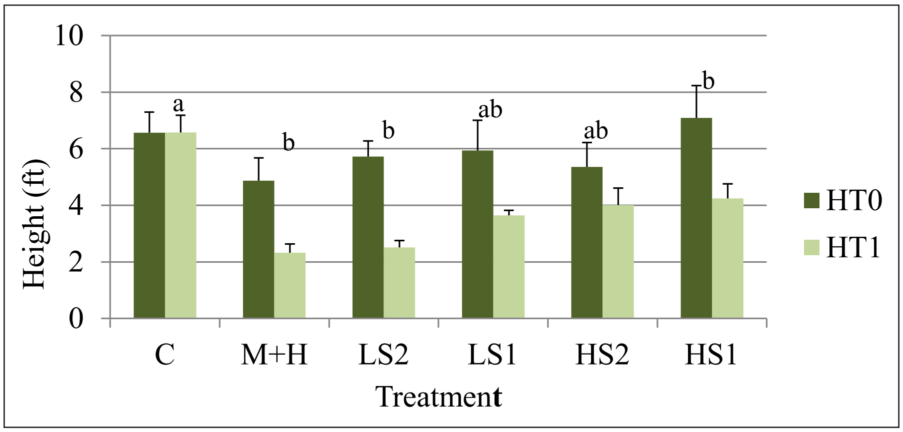

Figure 4.—Spicebush height in plots before (HT0) and 1 year after (HT1) prescribed grazing and conventional mechanical + herbicide treatments. Change in height (HT0 – HT1) for treatments marked with the same letter is not significantly different from one another using ANOVA, P>F=0.035, α<0.05.

Herbaceous Plant Diversity, Distribution, and Cover

Before treatment, 78 different herbaceous plant species occurred across all sample quadrats (Table 4). The mean number of herbaceous species occurring on each sample quadrat across the entire study area was 10.4. Total herbaceous cover ranged from 35 to 55 percent with an overall average of 46 percent. The most widely distributed herbaceous understory plants were violet species (*Viola spp.*), occurring on 88 percent of all sample quadrats. Other widely distributed species were sedge species (*Carex spp.*) (76 percent), jewelweed (*Impatiens capensis*) (68 percent), white snakeroot (*Eupatorium rugosum*) (64 percent), Christmas fern (*Polystichum acrostichoides*) (63 percent), grass species (57 percent), and white avens (*Geum canadense*) (49 percent). Violet species had the highest mean cover for an herbaceous species group with 5.4 percent. White snakeroot, grass species, and sedge species had 4.7, 4.2, and 3.5 percent cover, respectively.

One year after treatment, 86 herbaceous plant species were recorded across all sample quadrats (Table 4). All but one treatment (LS1) increased slightly in herbaceous species diversity. Neither the M+H nor any of the PG treatments were significantly different from the control.

Overall, 18 new herbaceous species were tallied after the first year of treatment. Thirty-two species increased their distribution (Table 4), five of them by 10 percent or more. Thirteen species did not change; 33 species decreased in distribution, the vast majority by less than 5 percent. There were no clear patterns in species distribution changes among the treatments over the first year (Table 4). The

Table 4.—Herbaceous plant species diversity, changes in species distribution, and cover before (0) and 1 year following (1) prescribed grazing and conventional mechanical + herbicide treatments in a hardwood forest understory

	Species diversity				Species distribution change				Cover	
Treatment	0	1*	0	1	new	incr.	decr.	no change	0	1†
	(spp./quadrat)		(tot. spp.)		(spp)				(percent)	
Control	10.5	10.7 ns	30	35	9	8	12	10	34.5	28.3 c
M+H	10.1	11.4	33	37	10	13	12	8	51.6	37.0 abc
LS2	10.8	12.5	43	46	10	16	13	14	41.3	26.4 abc
LS1	10.1	10.1	36	43	12	9	13	14	38.5	28.7 bc
HS2	10.3	11.8	34	40	11	11	11	12	52.6	24.3 a
HS1	10.8	12.5	40	49	15	11	15	14	55.3	31.3 ab
Overall	10.4	11.5	78	86	18	32	33	13	45.6	29.3

* Treatment differences tested for the difference in number of spp/quadrat between time 0 and 1. Pr>F=0.3078.
† Treatment differences are indicated for the difference in cover (cov_1- cov_0) between time 0 and 1. Pr>F=0.0532, α=0.05.

control appeared to have slightly fewer new species observed and slightly fewer species that increased in distribution than occurred in other treatments. M+H appeared to have slightly fewer species that had no change in distribution than all other treatments.

Some patterns in changes in individual herbaceous species distribution began to appear in the first year among the most widely distributed species (Table 3). Sedges appeared to increase their distribution in PG treatments. Jewelweed remained unchanged in the control but increased irrespective of disturbance treatment. Violet species and jack-in-the-pulpit (*Arisaema triphyllum*), on the other hand, increased their distribution in M+H, increased or remained unchanged in the low stocking PG treatments but declined in the high stocking PG treatments. Christmas fern remained stable in all treatments except the low stocking PG treatments where declines in distribution occurred. Although not widely distributed, ginger (*Asarum canadense*) appeared to be one of the few herbaceous species completely avoided by goats.

Herbaceous cover declined for all treatments (Table 4). The control declined by 6 percent and the M+H treatment declined by 15 percent. Herbaceous cover declined by 10 to 15 percent for the low stocking PG treatment. Only the high stocking rate PG treatments reduced herbaceous cover significantly from that of the control, by 24 (HS1) and 28 (HS2) percent.

Tree Reproduction

Before treatment, 3,912 small (<1.6 feet), 292 medium (1.6 to 3.3 feet), and 135 large (3.3 feet to 2 inches d.b.h.) tree reproduction stems per acre (Table 5) grew across the study site. The most abundant regeneration species were the maples, primarily sugar maple, with more than 1,664 total stems per acre, accounting for 38 percent of advance regeneration stems. Elm (*Ulmus spp.*), black cherry, and white ash made up more than 641, 573, and 472 stems per acre, respectively. Aggregate height for total tree advance regeneration ranged from 2,268 to 7,082 feet/acre.

The control had a 606 stems per acre decline in total advance regeneration. M+H reduced total advance regeneration by 135 stems per acre. Total advance regeneration loss of PG treatments ranged

Table 5.—Tree reproduction stocking by three size classes before (0) and 1 year following (1) and regeneration aggregate height reduction following prescribed grazing and conventional mechanical + herbicide treatments

	Size class						
	<1.6 feet		1.6 – 3.3 feet		3.3 feet – 2 inches d.b.h.		
	Time relative to treatment						
Treatment	0	1	0	1	0	1	Aggr. Ht.* Reduction
	-------------------------stems/acre -------------------------						(ft./ac)
Control	4,249	3,440	67	337	67	0	332 ns
M+H	5,801	6,070	540	270	202	67	1,107
LS2	3,777	2,833	472	270	472	270	2,545
LS1	3,979	2,023	0	0	0	0	1,604
HS2	2,158	1,619	202	67	0	0	775
HS1	3,575	3,035	472	337	67	67	775
Overall	3,912	3,170	292	214	135	67	1,134

* Treatment differences tested for the difference in aggregate height between time 0 and 1. Pr>F=0.7328.

from 674 to 1,956 stems per acre; the low stocking rate treatments had the largest losses on average. Average aggregate height declined across all treatments and the control. Aggregate height reduction for the control was 332 feet/acre. M+H had a 1,107 feet/acre reduction. Aggregate heights were reduced by 775 feet/acre for each of the high stocking rate PG treatments. The low stocking rate PG treatments reduced aggregate height by 1,604 and 2,545 feet/acre. However, because of high variability in the data, no differences between treatments were significant.

DISCUSSION

The high stocking treatments used three times the number of goats as the low stocking treatment, yet low stocking treatments took from 1.8 to 3.7 times longer in the summer grazing, or an average of 2.75, and 2.3 times longer in the fall grazing compared to high stocking treatments, to deplete plot forage. Variability of total pretreatment forage quantity between treatment plots may account for some of the variability in time to depletion of forage and the phenomenon of the low stocking treatment requiring, on average, less than three times the amount of time to deplete plot forage. Although efforts were made to remove goats from plots based on visual depletion of forage as judged from daily inspections, it is also possible that subjectivity in judging forage depletion resulted in goats being removed from some plots before complete forage depletion and some being removed one to several days beyond complete forage depletion. Yet another potential explanation for this apparent incongruity in forage depletion rates between high and low stocking PG treatments may have been a more rapid loss of grazing efficiency in high stocking rate treatments as forage was nearing depletion—a sort of diminishing returns for effort expended by the goats to extract forage that was increasingly difficult to access. Goats in this circumstance may have had less than optimal nutrition the last few days before removal. For example, the most palatable and easily accessed forage—forage acquired with the least amount of physical effort—was consumed first. In the case of MFR, the newest, most tender, and succulent leaves and shoot tips located at the goats' head level were first grazed and browsed. When that was gone, the goats would stretch their necks a little higher. Finally, expending more energy, goats would stand on hind legs to reach more woody stems or work harder to penetrate to the interior of MFR thickets to graze older interior leaves. This point of diminishing returns may be reached more quickly, and before managers decide the forage is depleted, under high stocking conditions. High intensity grazing using high stocking rates for short durations are frequently recommended for controlling invasive brush infestations in western U.S. rangelands (Campbell and Taylor 2006).

Visual impacts immediately after PG treatments showed heavy to near complete defoliation of woody plants up to 6 to7 feet high and severe reductions in herbaceous plant cover for most species. PG had a somewhat muted effect, however, on MFR cover and height 1 year after initiation of treatments and had no impact on distribution. Additional reductions in woody cover and height occurred through goat debarking or girdling of stems by horn rubbing, particularly on spicebush stems. Large variations in height reduction occurred between replicate plots within treatments. Manually cutting shrubs more than 8 feet high and the random girdling of stems by goats rubbing their horns may have confounded first-year data, particularly for spicebush.

Although reductions in MFR and other NNIP species cover and height under PG treatments were not statistically different from the control, they may indicate a trend beginning to develop in the first year toward future reductions. Followup multiple grazings in one growing season, if applied soon after sufficient regrowth from the first grazing, should significantly amplify the weakening effect of PG on target vegetation (Olson and Launchbaugh 2006). However, no real differences in woody plant cover or height occurred between PG treatments for the target brush species. Sufficient vegetative regrowth did not occur until early October due to severe drought. Thus, the second grazing periods for LS2 and HS2 treatments were delayed until early fall. The fall grazing may have had minimal effect on plant health. Animal stocking rate did not influence MFR, other NNIP species, or spicebush cover and height in the first year.

Species diversity increased for both woody and herbaceous plant species across most treatments and the control. Although there were no differences between any of the treatments, properly applied PG appeared to promote, or at worst, not diminish species diversity in the first year, even where multiple grazings occurred. However, there were shifts in distribution, with some species increasing and some decreasing. Overall, these increases and decreases seemed to balance each other, especially for herbaceous species. Where two grazings occurred in the growing season (LS2 and HS2), more woody species declined in their distribution than increased. Because a similar pattern did not emerge for herbaceous species, we might conclude that these treatments may have had a disproportionately negative impact on woody species. Considering that the second grazing occurred in the fall after a severe drought, it is likely that many herbaceous species had already completed their annual life cycle leaving relatively little herbaceous vegetation available as forage.

On this site, well-distributed species like the violets and jack-in-the-pulpit decreased in their distribution under the high stocking rate treatments. These and similar species may serve as early indicators of grazing intensity that exceeds optimal levels needed to reduce target plants while minimizing negative impacts to nontarget plants (Hendrickson and Olsen 2006). High stocking rate treatments seemed to disproportionately decrease herbaceous cover compared to low stocking rate treatments but did not differ from low stocking rates in its reduction of woody vegetation cover. The combination of far less herbaceous forage being available compared to woody forage and herd behavior changes at high stocking rates may have reduced grazing selectivity (Adler et al. 2001).

Goats are considered generalists in their feeding behavior. However, some selectivity occurs depending on palatability and the individual animal's previous experience with different plants. In this study few plant species within reach were not ultimately fed upon. Notable exceptions included pawpaw and wild ginger.

Selective feeding by sheep reduced competing vegetation, red alder (*Alnus rubra*) in particular, in coastal Oregon Douglas-fir (*Pseudostuga menziesii*) plantations, resulting in increased tree height and d.b.h. compared to non-grazed plantations (Sharrow et al. 1992). PG with Scottish Highland cattle was used to help restore an oak savannah community in Wisconsin (Harrington and Kathol 2009) where woody stem densities declined by 44 percent under grazing. In this case management objectives called for the reduction of woody shrub layer vegetation to benefit herbaceous species. In Central Hardwood forest management, PG objectives call for the selective grazing/browsing of competing shrubs and herbs to benefit desirable tree reproduction. In this study, tree advance regeneration was grazed along with other woody brush. Low stocking rate treatments appeared to produce larger, yet not significant, aggregate height reductions in tree regeneration than high stocking rate treatments. The M+H allowed greater selectivity to encourage desirable regeneration.

An immediate benefit of PG in dense nonnative brush infestations was the significant reduction of both the visual and physical barriers to applying conventional mechanical and herbicide treatments. PG cleared areas between large shrubs, which could allow workers much easier access to much of the area that was largely inaccessible due to thorny, dense brush. The reductions in leaf cover and height would also reduce herbicide application costs.

CONCLUSIONS

First-year results show only modest reductions in target NNIP cover and height. PG will likely need to occur over several years to gradually reduce target species and improve conditions for desirable species to recruit and gain the competitive advantage. Results from this research thus far are preliminary. Long-term results are needed to determine whether and how PG can be deployed to selectively and substantially reduce nonnative invasive woody vegetation to favor desirable native species in hardwood forest environments. PG alone will likely be insufficient to eradicate nonnative invasive infestations but may be used in combination with conventional mechanical and herbicide treatments to reduce costs and chemical inputs into the environment.

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