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Research Article

Prescribed Browsing by Goats Shows Promise in Controlling Multiflora Rose in a Deciduous Forest at the Erie National Wildlife Refuge in Northwestern Pennsylvania

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ABSTRACT

Multiflora rose (*Rosa multiflora* [MFR]) is an invasive, nonnative plant that has invaded many temperate forests across the eastern United States, often outcompeting native plants for sunlight and other resources. Herbicides can control MFR, but they can also reduce nontarget plant species and threaten aquatic ecosystems. In a black cherry-red maple forest in the Erie National Wildlife Refuge in Pennsylvania, the US Fish and Wildlife Service introduced prescribed goat-browsing as an exploratory control method. In four treatments, browsed, browsed/herbicide, cut/herbicide, and an unmanaged reference, we evaluated preliminary effects of these treatments on MFR and non-MFR herbaceous vegetation. For MFR, the browsed treatment had 56% lower leaf/stem mass ratios and 35% shorter stem lengths than the reference; the leaf/stem ratio in the cut/herbicide treatment was 55% lower than the reference. Stem density was not reduced because goats did not kill the MFR plants in this first year of treatment. The herbicide treatment had fewer non-MFR plants than the reference treatment. Light levels at ground level did not differ among the treatments. Overall, 33% of trees in the browsed treatment were affected by the goats, with 9% being completely girdled; red maple and ironwood were the most commonly browsed species. Preliminary results suggest that goats can be an effective control for MFR, however long-term success will be best evaluated after consecutive treatment seasons. Goats may increase tree mortality and shift tree species composition in stands dominated by trees with high browsing rates, but effects on diverse stands may be less pronounced.

Index terms: goat browsing; herbicides; invasive plant management; multiflora rose; temperate hardwood forest

INTRODUCTION

Invasive plant species can have a multitude of negative impacts on ecosystems, including increasing soil toxicity (Bailey et al. 2001; Charles and Dukes 2008), outcompeting native plants for water (Lemke et al. 2011), and altering nutrient (Rodgers et al. 2008) and light regimes (Funk 2013). Nonnative, invasive plant species pose a major threat to ecosystem biodiversity (Stinson et al. 2007) and often reduce populations of native plant species (Wilcove et al. 1998). Forty-two percent of all threatened or endangered species are considered to be at risk because of invasive species (Pimentel et al. 2005). Invasive plants tend to have a number of properties that contribute to their domination of ecosystem processes, including rapid growth and prolific seed production (Rejmanek and Richardson 1996; Huebner 2003), that allows them to colonize rapidly and outcompete native plants (Mesléard et al. 1993). They can also have a resource use-efficiency that enables them to compete successfully in low-resource conditions (Funk 2013). Invasive species in the United States incur control expenses and cause losses for crops, pastures, and forests, leading to economic damages estimated (for 2005) at nearly $120 billion annually (Pimental et al. 2005).

Among invasive plant species in the United States, multiflora rose (*Rosa multiflora* Thunb.; hereinafter MFR) is particularly abundant. MFR is native to eastern China and was introduced to the United States in the late 1880s. It presently infests approximately 45 million acres in the United States (Epstein and Hill 1999) in 39 states and 5 Canadian provinces (Kurtz and Hansen 2013). MFR had been believed initially to have conservation and ornamental value (Steavenson 1946; Epstein et al. 1997), and from the 1930s until the 1950s (Doll 2007) it was promoted for use in producing living hedges. It was also planted to provide wildlife with food and shelter (Kurtz and Hansen 2013).

MFR is generally considered a harmful plant that can inhabit diverse ecosystems, including forest understories, pastures, open fields, and roadsides (Myster and Pickett 1990; Hummer and Janick 2009; Huebner et al. 2014). It can exist in fully sunlit as well as shaded environments, although it cannot grow in extremely wet or dry areas (Kurtz and Hansen 2013). MFR often grows into dense thickets of thorn-covered stems. Each rose bush can produce one million seeds per year, which can remain viable for up to 20 y (Banasiak and Meiners 2008; Kurtz and Hansen 2013). Furthermore, fruit consumption by frugivores facilitates the spread of the species (Lafluer et al. 2007). Collectively, these attributes enable MFR to dominate areas where it invades.

MFR often grows in dense thickets that limit available light and nutrients for surrounding native vegetation (Kurtz and

Hansen 2013), and invasions of MFR in fields have been shown to cause a reduction in plant and bird species richness (Yurkonis et al. 2005; Massé and Vulinec 2010). MFR thickets can be a prime habitat for deer ticks, facilitating the spread of Lyme disease (Adalsteinsson et al. 2018).

Removing MFR is challenging because any removal method must be sustained for multiple years for eradication to be successful; seeds remain viable in the soil for many years and new plants can sprout easily from existing roots (Loux et al. 2005). Traditional MFR removal methods include physical removal followed by annual control of new seedlings (Loux et al. 2005), and mowing and application of a variety of herbicides (e.g., glyphosate; Johnson et al. 2007). Mowing alone is only moderately effective due to resprouting from roots and manual removal of roots is a labor-intensive process that can increase soil vulnerability to erosion (Loux et al. 2005). Although herbicides are typically effective, their use brings a number of concerns, including water contamination (Scribner et al. 2007), effects on soil biota (Nguyen et al. 2016), and health impacts on nontarget plants, mammals, birds, fish, aquatic and terrestrial invertebrates, and crucial pollinators such as honeybees (Solomon and Thompson 2003; Relyea 2005; Gill et al. 2018; Motta et al. 2018; Gunstone et al. 2021). These concerns have stimulated research into solutions that avoid herbicide use.

One alternative method of control is the use of browsing mammals such as domestic sheep, cattle, or goats to reduce or clear invasive plant species (Luginbuhl et al. 1998; Abaye et al. 2009). Using goats can be advantageous because they can be contained in defined areas, they have a varied diet (Huston 1978), and have a propensity for consuming leaves and twigs when available (Cory 1927). They defoliate plants and reduce seed viability in their digestive tract (Marchetto et al. 2020) and can be cost-effective (Luginbuhl et al. 1998) when compared to labor-intensive cutting practices or herbicide applications (Magadlela et al. 1995). Although few studies have investigated the effectiveness of using goats, 4 y of grazing by goats in cattle pastures in the Appalachian region of North Carolina drastically reduced MFR and increased favorable native forage species (Luginbuhl et al. 1998).

Despite potential advantages of using goats to eliminate MFR, several concerns give pause to their use. Due to their wide-ranging diet, extensive browsing by uncontrolled feral goats has caused habitat disruption and biodiversity loss in a variety of ecosystems (García et al. 2012), creating hesitation in using them as browsers (Hart 2001). Additionally, repeated browsing is usually necessary to reduce the presence of established invasive plants (e.g. Luginbuhl et al. 2000).

On protected and managed lands, including wildlife refuges, managers aim to protect biodiversity, but they have constraints on how they can maintain that protection. The Erie National Wildlife Refuge (ENWR), in northwestern Pennsylvania, has areas with high MFR density that threaten native biodiversity, thus there is a desire to reduce MFR abundance. However, the refuge must also protect surrounding ecosystems (US Fish and Wildlife Service 2014). Due to numerous aquatic habitats on the refuge, goats had been suggested previously as a means to reduce areas with a high MFR population (Brown et al. 2020), thus eliminating risks of water contamination due to herbicide application.

Prescribed browsing may be a promising method of managing nonnative invasive species in some locations, but its effectiveness needs to be quantified to determine if it is an appropriate replacement for traditional management practices. The ENWR has experimentally implemented goats as a control method for one summer season in a management area where use of herbicides could be detrimental to nearby streams. A previous study (Brown et al. 2020) had identified the area as a location with a high abundance of MFR and suggested using goats as a sustainable control option. The goats were clearly browsing on MFR, but an unintended consequence of this approach was that goats also browsed on the accessible bark of subcanopy or canopy trees. Such browsing can reduce the viability of trees, increase the likelihood of disease or insect damage, and if completely girdled, cause immediate tree mortality (Neely 1988). Tree damage or mortality can reduce forest productivity and lead to changes in forest composition.

The purpose of our study was to evaluate, following the first year of a planned 4-year experiment, the effectiveness of goat herbivory as a control method for MFR. We compared four treatments (browsed, browsed/herbicide, cut/herbicide, unmanaged reference) to (1) determine if MFR abundance and plant performance were reduced, (2) determine if non-MFR plant populations were affected by the treatments, (3) assess changes in the availability of light on the forest floor caused by treatments, and (4) quantify damage to trees caused by goat browsing.

METHODS

Prior to planning and initiation of our study, the ENWR began an experimental goat-browsing operation in 2019 at a site of approximately 2 ha area that had been identified previously as having a high density of MFR (Brown et al. 2020). Areas selected for browsing were estimated to have approximately 80% of the area occupied by MFR. The management goals for this site included protecting native plants and increasing biodiversity, thus reducing MFR was critical to achieving those goals. Additionally, the site had some wet areas and was in close proximity to a nearby stream, thus wide scale herbicide use was not desired.

This area was located in the Sugar Lake division of the ENWR, a temperate deciduous forest in northwestern Pennsylvania (Figure 1). Northwestern Pennsylvania has an average annual temperature of 13.3 °C and an average annual rainfall of 105 cm (NOAA 2021). The site of our study lay on a gentle slope (7°) with a northeasterly aspect, and was formerly used as farmland, evident from its overall level soil surface, piles of field stones, abandoned farm machinery, and a line of trees that appear to have grown along the edge of a former open field. The distinct lack of pit and mound structures (i.e., tip-up mounds from fallen trees) suggested that the site was a relatively young forest and had been plowed. The overstory was approximately 20 m high, and dominated by black cherry (*Prunus serotina* Ehrh.) and red maple (*Acer rubrum* L.), which represented 42.1% and 28.9% of total stems, respectively. The basal area of the site was 22.7 ±

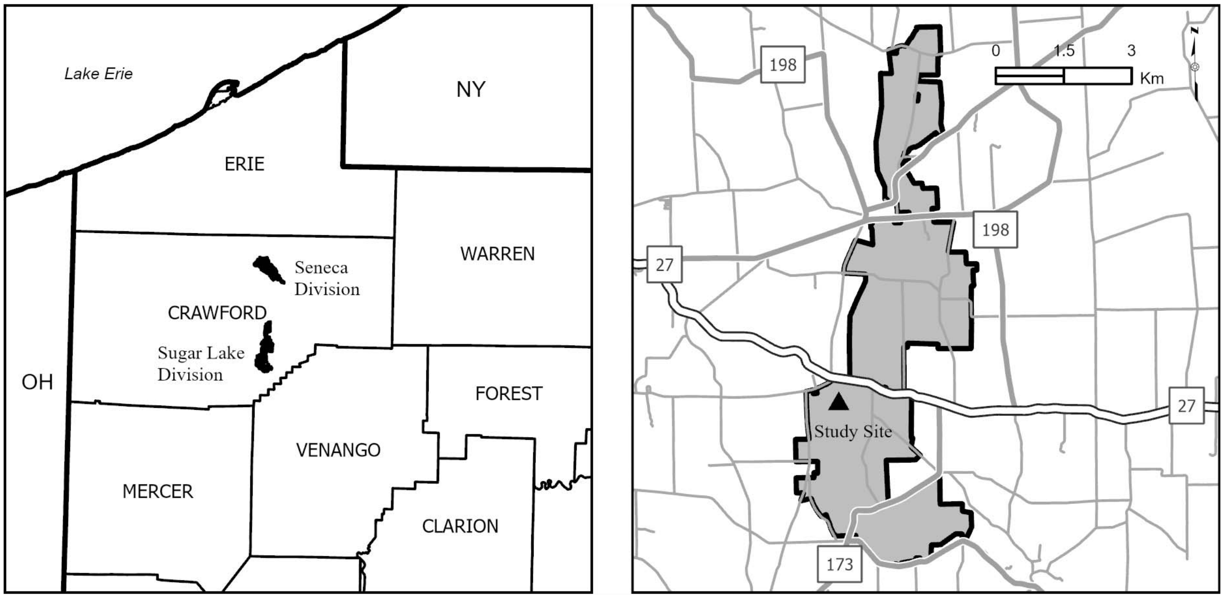

Figure 1.—Location of goat-browsed study site in the Erie National Wildlife Refuge, Crawford County, Pennsylvania. Maps created with ArcGIS Pro.

4.3 m^2 ha^{-1}. Mean black cherry diameter at breast height (dbh) was 27.3 ± 1.3 cm and red maple was 20.8 ± 1.5 cm. The subcanopy consisted of apple (*Malus domestica* auct. non Borkh.), hawthorn (*Crataegus* sp.), and ironwood (*Carpinus caroliniana* Walter). Species in the category entitled "other" were not abundant and included shagbark hickory (*Carya ovata* Mill), sugar maple (*Acer saccharum* Marshall), quaking aspen (*Populus tremuloides* Michx.), white ash (*Fraxinus americana* L.), and white oak (*Quercus alba* L.). The forest understory was sparsely covered by herbaceous plants and limited tree regeneration. Soils are silt loams of the Chenango, Holly, and Scio soil series (USDA NRCS 2020).

Three treatments were established at the initiation of the goat-browsing management operation—browsed, browsed/herbicide, and cut/herbicide. The browsed area was approximately 0.8 ha, the browsed/herbicide area was approximately 0.2 ha, and cut/herbicide area was approximately 0.1 ha. We established an approximate 0.2 ha reference section, immediately adjacent to the browsed section, which had MFR density, plant height, and tree overstory characteristics that visually resembled the treatment plots. The browsed and browsed/herbicide treatments were divided into subsections, each of approximately 0.1–0.3 ha.

Browsed and browsed/herbicide subsections had portable, electrified fences to contain eight goats and one donkey that were leased from Allegheny Goatscape (https://www.alleghenygoatscape.org/), a 501(c)(3) nonprofit organization located in Pittsburgh, Pennsylvania. The herd was rotated among the subsections approximately each week, with the herd in each subsection for approximately 8–10 d total. Goats were initially introduced to each of these core units and, when enough regrowth occurred to sustain the herd for a repeat visit, the herd was returned. Subsequently revisited units were often larger than the original units to ensure there was enough browse to sustain the herd. Total browsing pressure for both browsed treatments was 7.3 ± 2.1 animals ha^{-1} d^{-1}. The animals received supplemental feeding to maintain proper nutrition. Donkeys are both browsers and grazers (Moody 2016); the donkey both browsed and grazed at the site, although its primary importance was to deter potential predators. The fences were entirely removed from the goat-occupied areas at the end of the summer following the departure of the goats.

The MFR in the cut/herbicide plots was cut by hand in July and regrowth was then treated on 6 September 2019 with the herbicide Rodeo as a 1.5% foliar spray applied via a backpack sprayer to individual plants. The active ingredient in Rodeo is 53.8% isopropylamine salt of glyphosate; Rodeo is formulated for use in or near aquatic environments (Corteva Agriscience 2022). A nontoxic dye was added to the mixture to track potential drift and overspray, and to be sure that target plants were treated. The browsed/herbicide plots were browsed by goats, and then the regrowth was treated with the herbicide on 9–10 September 2019, approximately 1 mo before we began field measurements, allowing sufficient time for the herbicide to kill the plants. For analyses, we used the entire browsed/herbicide and cut/herbicide treatment areas, and five of the core subsections in the browsed treatment.

In each treatment area, we randomly selected 1 m^2 plots for measurements, with 8 plots each located in the cut/herbicide and browsed/herbicide treatments, 24 in the reference, and 40 in the browsed treatment. The number of plots was selected to provide an approximately equal number of plots per treatment area. Beginning approximately 3 wk after the goats were removed from the site, MFR characteristics were measured within each plot from 19 September to 24 October. First, the stem was cut directly above the root ball, and each stem was stretched and measured from the root ball to the farthest leaf of the plant. Given that the stems bend over as they mature, we defined this measurement as stem length rather than height. After removing all the rose plants from the plot, we counted the number of non-MFR vascular herbaceous plants in the plot; we did not identify these plants, but common plants included avens (*Dryas* L.), hepatica (*Hepatica* L.), Christmas (*Polystichum acrostichoides*

Figure 2.—Trees that have been browsed (left) and girdled (right) by goats in the Erie National Wildlife Refuge in northwestern Pennsylvania where goats were used to control multiflora rose. Photos by Grace Hemmelgarn.

(Michx.) Schott) and bracken fern (*Pteridium aquilinum* (L.) Kuhn var. *latiusculum* (Desv.), blue cohosh (*Caulophyllum thalictroides* (L.) Michx.), and common blue violet (*Viola sororia* Willd.). Except for ferns, most non-MFR plants were generally less than 10 cm tall.

MFR stems were separated into stems, mature leaves, and new growth sprouts. Rose hips were not common; any we found were removed from the plants, but not included in analyses. New growth was defined as the new leaves (leaflets and petioles; there were no stems) emanating laterally from the mature stems. They could be distinguished easily by their light green color and soft texture, although we do not know when new growth was initiated. Samples were dried at 105 °C for 48 hr and weighed.

To determine the influence of MFR on ground level light, we used Plexon LX1010B Lux Meters to measure the light level at each 1 m^2 quadrat, above the uppermost layer of rose plants, at ground level in the middle of each plot, and in an open area with direct daylight.

Tree damage was measured from January to February of 2020. The goats had been observed actively browsing tree bark in the plots, leaving distinctive teeth marks, and there are no other local species that are known to browse tree bark in the same manner. To evaluate damage to the trees by goats, we randomly selected 67–74 trees per management unit that were at least 2 cm dbh and recorded their species and dbh. If the tree was browsed through the bark and the cambium, we measured the circumference of the tree and the browsed arc of the circumference at the point of greatest browsing. A tree was considered to be girdled if 100% of the circumference was browsed through the cambium and browsed if girdling was not complete. A tree was designated as nibbled if there were teeth marks on the bark, but the browsing did not extend through the cambium (Figure 2).

None of our data were normally distributed, thus treatment comparisons were analyzed using Kruskal-Wallis nonparametric ANOVA and Dunn's tests using SigmaPlot 12.5 (https://astatsa.com/KruskalWallisTest/).

RESULTS

Stem Density and Length

The density of MFR stems (Table 1) among the treatments differed significantly ($P < 0.005$), ranging from 3.5 ± 1.5 stems m^{-2} in the cut/herbicide treatment to nearly four-fold greater in the browsed treatments. MFR stem lengths (Table 1) were shorter in all the treatment plots than the reference plots ($P < 0.001$), with a 35% reduction in the browsed treatment and a 40% reduction in the browsed/herbicide treatment. Browsed and browsed/herbicide treatments did not differ in length.

Biomass

Total MFR mass ($P = 0.067$), as well as stem ($P = 0.074$) and mature leaf mass ($P = 0.769$) (Table 1) did not differ among treatments. New growth mass was higher in the browsed treatment than in the cut/herbicide treatment, but did not differ from the reference and browsed/herbicide treatments ($P < 0.002$). The mature leaf mass as a percentage of stem mass (leaf/stem ratio) was reduced by 56% in the browsed treatment ($P = 0.016$; Figure 3). The new growth as a percentage of stem mass did not differ among treatments ($P = 0.062$). The cut/herbicide treatment was excluded from tissue/stem analyses because cutting and herbicide applications resulted in too few leaves or new growth for statistical analysis.

Table 1.—Multiflora rose stem density, length, and biomass within the four browsed treatments at the Erie National Wildlife Refuge, Pennsylvania. Treatments with the same letter within each column are not statistically different. SE = standard error.

				Biomass (g m^{-2})			
Treatment		Stem density (# m^{-2})	Stem length (cm)	Stems	Leaves	New growth	Total
Reference	Ave	4.9^{a}	79.0^{a}	31.1^{a}	1.0^{a}	0.8^{ab}	32.9^{a}
	SE	1.6	4.5	12.9	0.4	0.6	13.7
Browsed	Ave	12.1^{b}	51.3^{b}	34.7^{a}	0.7^{a}	0.7^{a}	36.0^{a}
	SE	1.7	1.8	7.6	0.2	0.2	7.7
Browsed/ Herbicide	Ave	11.1^{ab}	47.3^{bd}	23.8^{a}	0.5^{a}	0.2^{ab}	24.5^{a}
	SE	4.5	2.7	15.8	0.3	0.1	16.2
Cut/Herbicide	Ave	3.5^{ab}	35.6^{c}	17.9^{a}	0.3^{a}	0.004^{b}	18.2^{a}
	SE	1.5	11.1	14.8	0.2	0.00^{4}	15.0

Table 2.—Light above and below multiflora rose among the four treatments at the Erie National Wildlife Refuge, Pennsylvania. Treatments with the same letter within each row are not statistically different. Light at ground level differed significantly, however differences among treatments could not be detected. SE = standard error.

		Light (lux)			
		Control	Browsed	Browsed/Herbicide	Cut/Herbicide
Above MFR	Ave	6.6^{a}	9.2^{a}	10.8^{a}	4.9^{a}
	SE	0.9	1.7	0.8	0.6
Ground-level	Ave	4.3^{a}	6.2^{ab}	8.3^{b}	3.3^{ab}
	SE	0.7	1.1	0.6	0.3

Light

Full daylight during the study period averaged 76,100 ± 8,900 lux, fluctuating among sampling dates, as well as within the same days of fieldwork. Light within the forest and above MFR plants ranged from 4.9% to 10.8% of full sunlight (Table 2) and differed among treatments ($P = 0.045$; differences among treatments could not be detected). Because light above MFR among treatments varied across the site, we normalized light measurements by calculating ground level light as a percentage of light levels above the MFR plants. Normalized measurements showed no detectable difference in ground level light among treatments ($P = 0.131$).

Non-Multiflora Rose Plants

The number of plants other than MFR (Figure 4) ranged from 25.1 ± 6.8 (SE) to 73.7 ± 14.7 (SE) plants m^{-2}. Cut/herbicide plots had fewer plants than the reference or browsed treatments ($P = 0.015$), but there were no differences among the reference, browsed, or browsed/herbicide treatments.

Tree Browsing by Species

Of the 356 trees sampled, 8.7% were girdled, 18.3% were browsed, and 6.5% were nibbled (Table 3). Red maple and ironwood were browsed and girdled most frequently by goats, with 41.2% and 46.7% of trees browsed and 23.5% and 13.3% of trees girdled, respectively (Figure 5). Apple and hawthorn were browsed less frequently; black cherry was least browsed, with 88.0% of trees untouched by goats. No trees in the "other" category were browsed. Nibbling remained fairly consistent among species, ranging from 5.9% of red maples to 7.7% of "other" trees. Apple trees were not nibbled. Of the trees with goat damage extending through the cambium, the average proportion of the circumference that was disconnected ranged from 39% to 63% among species, with no significant differences among species (Figure 6). The percentage of circumference browsed was highly variable within most of the species.

Tree Browsing by Tree Size

For nearly all tree species examined, there was no significant difference among the sizes of trees that were browsed or girdled, nibbled, and not browsed (Figure 7). Only hawthorn showed a significant difference ($P = 0.009$) in tree diameter between browsed and unbrowsed trees, with browsed trees approximately 50% larger than unbrowsed trees.

DISCUSSION

We were not surprised that the browsed plots had a greater MFR stem density than control plots and the total mass of MFR did not differ among treatments, given that goats were placed into areas at the ENWR site where MFR density appeared to be greatest when the management effort began (MFR visually covering 80% of the treatment areas). Our study was conducted after the management operation was initiated. Despite selecting reference plots that visually resembled the treated plots, our

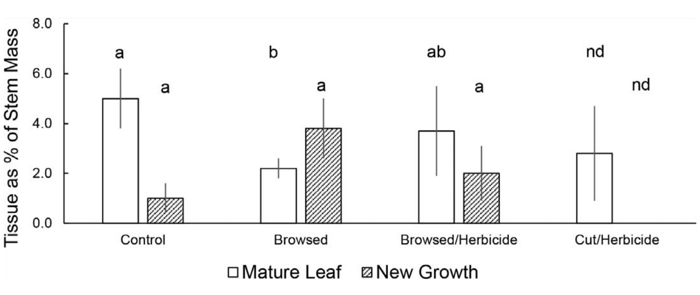

Figure 3.—Mature multiflora rose leaf and new growth mass as a % of stem mass (leaf/stem ratio) within the four treatments at the Erie National Wildlife Refuge, Pennsylvania. Treatments with the same letter within each tissue type are not statistically different. nd: not determined. Lines are standard errors.

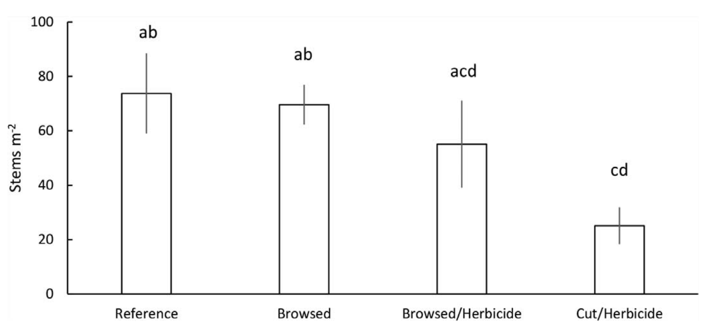

Figure 4.—Non-multiflora rose plant abundance within the four treatments at the Erie National Wildlife Refuge, Pennsylvania. Treatments with the same letter are not statistically different. Bars represent means; lines are standard errors.

Table 3.—Percent of total trees ($n = 356$) girdled, browsed, nibbled, and not browsed by goats during multiflora rose treatment in a goat-browsed forest stand at the Erie National Wildlife Refuge, Pennsylvania.

Browsing type	% of total trees
Girdled	8.7
Browsed	18.3
Nibbled	6.5
Not browsed	66.6

reference plots had a lower stem density than the browsed treatment plots. We did not expect stem density to decline during a single summer of treatment because goats do not remove the entire stem while browsing, but rather eat the conveniently accessible upper portions, leaving behind the remainder of the plant (Odo et al. 2001). In the first year, complete plant mortality did not occur. In the long run, biomass will likely be reduced; studies of feral goats have shown that vegetation mass is reduced by goat browsing (Gizicki et al. 2017).

Even though goats did not remove the entire stem, goats still hindered the plant's productivity and ability to survive by reducing stem mass and removing leaves, thus depleting the plant's stored energy and reducing photosynthetic potential. Stem length was reduced by a third or more in the browsed and browsed/herbicide treatments, attesting to the impact of browsing by goats on plant length. Importantly, there was a major reduction in the proportion of photosynthetic tissue on remaining stems. Goats selectively consume vegetation that is soft and within their reach (Hart 2001), thus leaves and the soft upper portions of stems were the primary tissues that were browsed. Stems that remained in the browsed plots were generally less than 50 cm tall and constituted the lower, thicker portions of the stems that had fewer leaves. Loss of leaves will result in reduced photosynthesis, and the plants will gradually weaken after a few seasons of leaf removal (e.g., Meyer 2002). Similar reductions in productivity due to browsing have been noted in studies of white-tailed deer, where chronic browsing of terminal buds on young tree saplings reduces sapling survival and can stunt growth over a tree's lifetime (e.g., Holm et al. 2013). Importantly, we found that browsing did not spur

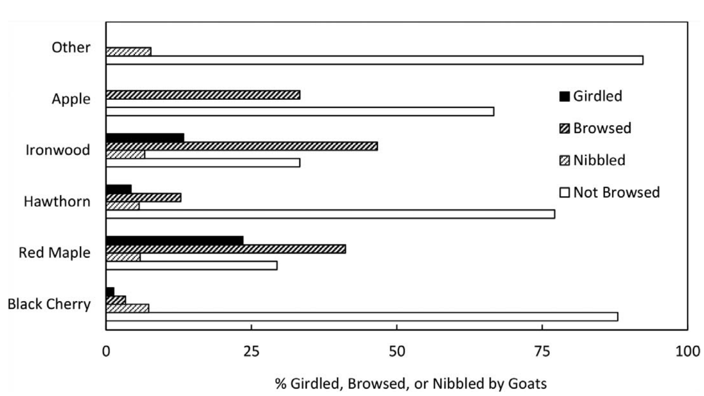

Figure 5.—Percentage of each tree species girdled, browsed, nibbled, and not browsed by goats during multiflora rose treatment in a goat-browsed forest stand at the Erie National Wildlife Refuge, Pennsylvania.

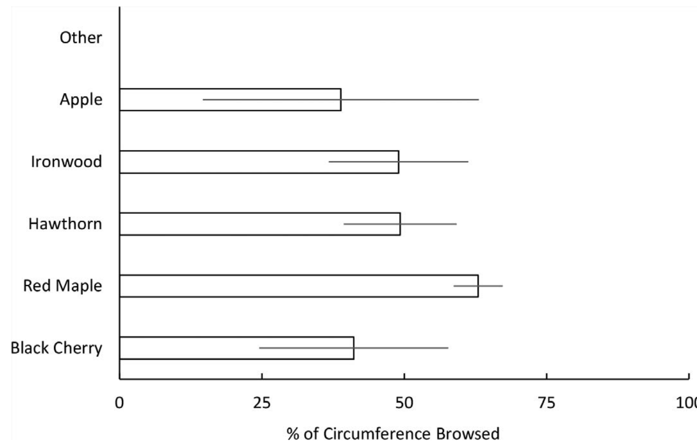

Figure 6.—Percentage of tree circumference disconnected by goats in browsed trees during multiflora rose treatment in a browsed forest stand at the Erie National Wildlife Refuge, Pennsylvania. Bars represent means; lines are standard errors. There were no significant differences among treatments.

increased new growth in either of the browsed treatments. We do note that new growth was found even in the herbicide treatments, but at much lower proportions of total biomass (2.4% of total biomass in the reference treatment vs. 0.02% in the cut/herbicide treatment). Reemerging new growth is likely due to stems that were missed during the hand-spraying application.

In this first year of treatment, browsing did not increase light at ground level among treatments, even though browsing reduced the leaf/stem ratio. Light within forests is notoriously variable, and distributions of branches and leaves within tree crowns influence daily sunfleck frequency and intensity, thus affecting light variability near or at the forest floor (Chazdon 1988; Canham et al. 1990, 1994; Baldocchi and Collineau 1994). As goats continue to remove leaves in subsequent years of treatment, we expect that more light will reach ground level, thus influencing understory vegetation diversity and productivity (Su et al. 2019).

Despite concern about effects of goats on nontarget plant species, browsing did not reduce the density of non-MFR

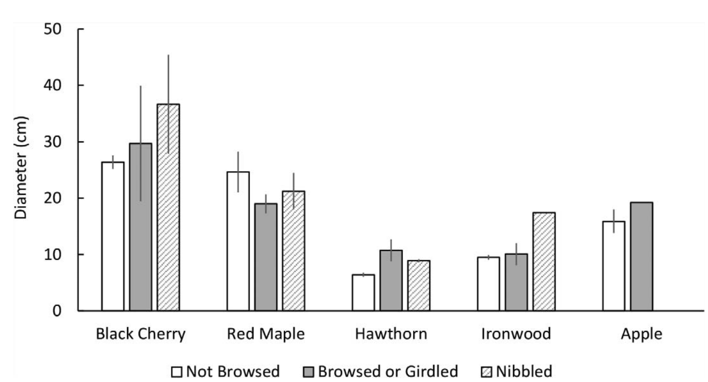

Figure 7.—Tree diameters of tree species not browsed, nibbled, and browsed or girdled by goats during multiflora rose treatment in a goat-browsed forest stand at the Erie National Wildlife Refuge, Pennsylvania. Bars represent means; lines are standard errors.

herbaceous plants in this first summer of treatment. Even if longer-term browsing does reduce the quantity and diversity of non-MFR plants, rapid recovery of plant populations has been observed following feral goat removal (Campbell and Donlan 2005). Other studies using goats to control MFR have resulted in an increase in the abundance of desirable herbaceous species (Luginbuhl et al. 1998, 2000).

The cut/herbicide plots, which had the most extensive management treatment and the shortest stems, did have lower non-MFR plant density than the reference or browsed plots, perhaps caused by herbicide application. With much shorter stems in the cut/herbicide treatment than the browsed/herbicide treatment, the herbicide may have more easily reached ground level where non-MFR plants were located.

Goats did have the unintended consequence of browsing on mature trees and exhibited clear browsing preferences among tree species that may be influenced by physical and chemical characteristics of the trees. For example, both red maple and ironwood, the two most browsed species, have thin, smooth bark, whereas black cherry, hawthorn, and apple trees have rough, scaly bark and were browsed much less. The high sugar content and low acidity of red maple sap may also promote its selection by goats (Jones and Alli 1987; Burns and Honkala 1990). Black cherry bark contains cyanogenic glycosides that can harm domestic livestock (Burns and Honkala 1990) and may have discouraged goat browsing on black cherry. Interestingly, goats showed no preference for any particular tree diameter within any of the species, thus browsing or girdling is not likely to alter the distribution of tree sizes within a treatment area. Although hawthorn was significantly smaller than the other species, trees of this species do not grow very large, and the smallest trees may not be conducive to browsing. Hawthorn was not a species preferred by the goats.

Even though browsing by feral goats can alter the structure, productivity, and composition of plant communities (Coblentz 1978; Coblentz and Van Vuren 1987; Walker 1991), in this management study the goats were managed intensively. They were on site only during the summer growing season when MFR was at its peak productivity and provided abundant food resources. They were maintained within fenced areas and were rotationally grazed across the site when MFR showed noticeable browsing. Hence, managed browsing by goats is not likely to result in landscape-wide negative effects as seen in locations where feral goat populations are uncontrolled. Nonetheless, goats can certainly alter forest composition. Although only 8.7% of all trees were girdled completely, the difference in browsing rates among tree species could change the forest composition at this specific management site. Red maple and ironwood had the highest percentage of trees girdled both partially and completely. Complete girdling kills trees by disconnecting vascular tissues that transport water, nutrients, and food throughout the tree. Incomplete girdling may not initially kill a tree, but it can expose it to insect and microbial damage (Neely 1988). Red maple, the most browsed and second-most abundant species in the study area, may be most severely impacted by goat browsing. Only 29% of red maple trees were untouched by goats and nearly one-fourth were completely girdled, likely to result in their mortality. An additional 41% of red maples were browsed with an average of nearly two-thirds of the circumference girdled. Partial girdling is especially harmful to red maples, as they seal wounds slowly and are highly susceptible to trunk rot (Hutnik and Yawney 1961; Shortle et al. 1995). Goat browsing in the management site may cause a decline in red maple, which has some wildlife value; red maple is known to be a browse species (Walters and Yawney 1990), and its flowers are consumed by fox and red squirrels (Reichard 1976). Little is reported on the wildlife value of red maple seeds. In this site, a reduction of red maple in selected stands would cause little concern, however. Since 1980, red maple in the eastern United States has increased its abundance throughout much of its range (Alerich 1993; Abrams 1998; Fei and Steiner 2007), and the management area that was browsed is an extremely small fraction of the entire refuge.

Certainly where goats are used as an MFR control method, potential changes in tree species composition at the site level will need to be considered. In stands dominated by unpalatable or rough bark, goats may cause little or no change in forest composition. However, in stands dominated by species with smooth, thin, palatable bark, goats may cause significant tree damage, causing site-level increases of mortality, loss of productivity, and altered tree species composition.

Goats did not eliminate the MFR from the site, but based on the drastically reduced stem length and lower leaf/stem ratio, we suggest that the goats may reduce MFR growth without use of an herbicide. Goat browsing can also be used in tandem with other control methods if so desired. Utilizing goats to physically clear space in an MFR infestation can increase access for manual cutting and clearing, and damage caused to the rose allows herbicides to more readily enter the plant (Rathfon et al. 2014). However, there is still uncertainty and concern about runoff of glyphosate-based herbicides into surface waters (Brovini et al. 2021), hence avoiding herbicides that are toxic to aquatic species can reduce potential unwanted effects.

We emphasize that our findings represent only preliminary results following one year of treatment, and the intention of managers at the ENWR is to continue this effort for multiple years. A further limitation of this study is that the management treatments were not established as a robust experimental design. As such, our results represent findings for one site only, and are not replicated across different areas infested with MFR. This approach limits our ability to extrapolate these findings more broadly (Binkley 2008). Future studies may consider the long-term costs of a goat browsing management program, the potential role of goat feces in transporting and fertilizing multiflora rose seeds if they browse in autumn when mature fruits are produced, the long-term success of goats as a treatment for MFR, and long-term impacts of goats on forest structure and composition. Nonetheless, given the paucity of studies examining this management approach, our findings indicate that in areas where herbicide application may create undesired effects, goats may prove to be a suitable alternative for control of multiflora rose.

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