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Managing Understory *Fagus grandifolia* for Promoting Beech Bark Disease Resistance in Northern Hardwood Stands

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Many Allegheny hardwood stands contain dense understories of very shade-tolerant American beech, resulting from partial disturbances that have accelerated root sucker development. The low-shade produced by these sprouts hampers silvicultural regeneration efforts to maintain species diversity in new cohorts. An increasing proportion of sprouts result from stressed trees infested with beech bark disease. The clonal sprouts also have a genetic affinity for the disease. A mixture of Accord® and Oust® herbicides, applied to understory vegetation after shelterwood establishment cuts, can significantly reduce understory beech density. Yet, retention of some overstory beech, with demonstrated disease resistance, is ecologically desirable. The root sprouts from these parent trees should also have resistance to the disease. We used broadcast herbicide application to kill understory vegetation after shelterwood harvests in three stands, and tested the effect of herbicide on beech sprouts associated with resistant trees. Eight years after treatment, plots that had received herbicide had similar densities of beech to no-herbicide plots. However, there were significant differences in seedling densities among stands ($P = .0303$) and species ($P = .0014$). Our results indicate that there is much temporal variability in regeneration dynamics after treatment. Resistant beech sprouts are still competitive in the long term, even after herbicide application.

Keywords: *Fagus grandifolia*, beech bark disease, shelterwood establishment cuts, herbicides

During the late 1970s, silvicultural practices combining understory herbicide treatments with shelterwood cutting were tested for ameliorating threats to regeneration biodiversity in Allegheny hardwood forests (Marquis 1979, Horsley 1981, 1982, Horsley and Bjorkbom 1983). Forest understories in northwestern Pennsylvania and southwestern New York are dominated by shade-tolerant species resulting from a history of non-silvicultural partial harvesting (Trimble 1971, Fajvan et al. 1998, Grushecky and Fajvan 1999, Nyland 2005) and herbivore browsing (Horsley et al. 2003). Most forests in the region are plagued by high population densities of white-tailed deer (*Odocoileus virginianus*) (Horsley et al. 2003) and in some cases moose (*Alces alces*) (Faison et al. 2010), which find very shade-tolerant American beech (*Fagus grandifolia* Ehrh.) less palatable than most other tree species. Selective browsing also promotes the development of herbaceous understories of ferns (hayscented fern *Dennstaedtia punctilobula* Michx. and New York fern *Thelypteris noveboracensis* L.), grasses, and sedges (Horsley et al. 2003). Dense beech understories, combined with these herbaceous invaders, interfere with the establishment and survival of many other tree species (Horsley and Marquis 1983, Horsley 1993).

American beech is a component of most eastern forest types from extreme southeastern Canada westward into the Mississippi River Valley in the United States (Cogbill 2005). It has low timber value compared to most of its associates (Kochenderfer et al. 2004) and historically was left behind after logging (Filip 1978, Kochenderfer et al. 2013). In the northern and western limits of its range, root suckering is common. Root injuries from logging or canopy disturbances (Fajvan 2006, Nolet et al. 2008) accelerate root sucker development up to 32.8 ft (10 m) from parent trees (Jones and Raynal 1986, Tubbs and Houston 1990, Nyland et al. 2006), even if the parent trees are killed.

Understory herbicides are sometimes applied to reduce the density of beech and other interfering vegetation. Herbicide applications, sometimes combined with other site preparation, 5–10 years before final overstory removal in shelterwood systems,

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reduce low shade and create growing space for the establishment of less shade-tolerant regeneration (Marquis et al. 1975, Horsley 1994, Oliver and Larson 1996, USDA Forest Service 2007a, p. 3-130 to 3-132). Herbicide treatments conducted either before (Kelty and Nyland 1981, Horsley 1994), or after (Nelson and Wagner 2011) shelterwood establishment cuts, reduced beech density and competitive status (height) up to 10 years after treatment. Herbicide concentration, residual overstory basal area, and deer browse pressure have cumulative impacts on regeneration composition and height growth (Bose et al. 2018).

The presence of beech bark disease (BBD) intensifies the problem of understory beech overabundance. BBD is an insect–fungus complex initiated by bark injury from the exotic beech scale insect (*Cryptococcus fagisuga* Lind.), which pre-disposes the tree to fungal infection with either *Neonectria ditissima* (Tul. & C.Tul) Samuels & Rossman or *Neonectria faginata* Castl. & Rossman (Ehrlich 1934, Castlebury et al. 2006). The beech scale makes minute (1 mm) wounds in the bark and feeds on parenchyma cells, resulting in small fissures, which provide the entryway for the fungal inoculation (Ehrlich 1934). The insects are covered with a white, wax-like material; hence, white bark patches indicate infestation. Growth of the fungal mycelium kills large areas of bark tissue, weakens the stems, and, eventually, may girdle and kill the tree. Beech scale was accidentally introduced to Halifax, Nova Scotia from Europe, around 1890 (Ehrlich 1934). It has since spread into New England, New York, Pennsylvania, West Virginia, Virginia, North Carolina, Tennessee, Michigan and Wisconsin, invading over 54 percent of beech basal area (Morin et al. 2007, USDA Forest Service 2015). Beech trees either die relatively quickly or become severely cankered and linger for years. A small percentage are genetically resistant to BBD (Houston 1983, Koch et al. 2010). Mortality or harvesting of diseased trees initiates root sprouting, which creates dense “thickets” of genetically related sprouts, also susceptible to the disease (Houston 1975). The extreme shade tolerance, longevity, and prolific sprouting allow beech to flourish at the expense of other species.

Historically, three phases of BBD are recognized: (1) the “advancing front,” corresponding to areas recently invaded by scale; (2) the “killing front,” representing areas where fungal invasion has occurred, and tree mortality begins; and (3) the “aftermath forest,” where the disease is endemic (Shigo 1972, Houston 1994, Morin et al. 2007). The loss of healthy, quality beech stems decreases the economic value of the forest (Houston 1975, Kochenderfer et al. 2004, Morin et al. 2007), as well as wildlife habitat, as beech trees and nuts are important for a variety of birds and mammals (Heyd 2005).

In forests where BBD has been present for ≥20 years, an estimated 1–5 percent of American beech trees remain disease-free (Houston 1983, Koch et al. 2010). These trees commonly grow in close proximity, indicating either a clonal relation with non-diseased neighbors (Koch et al. 2010) or a genetic association because of limited seed dispersal distance (Tubbs and Houston 1990). Disease resistance is associated with the insect portion of the disease complex (Houston 1983) and may be related to genetic (Koch et al. 2010) or phenotypic (smooth bark) (Houston 1983) characteristics. Spatial and temporal fluctuations of scale populations also make it difficult to distinguish resistant from susceptible trees unless observations occur for many years (Houston and Valentine 1988).

Managing Beech with Potential Resistance to BBD

Silvicultural practices to increase the proportion of disease-resistant beech through periodic removal (or killing with herbicide) of diseased and dying beech have been tested and adopted on some ownerships. Remaining trees are assumed to be more resistant, even if not fully so. Visually resistant parent trees (>11 in.; 28 cm) also serve as future sources of seeds/sprouts (Kelty and Nyland 1981, Ostrofsky and McCormack 1986, Heyd 2005, Leak 2006). Studies have addressed timing and intensity of harvesting, removal of diseased trees, and understory control of beech with herbicides (Kelty and Nyland 1981, Horsley 1994, Leak 2006, Bose et al. 2018). The amount of overstory removed (Bose et al. 2018), season of harvest, and degree of root damage (Jones and Raynal 1986, Houston 2001) influence the number of new beech seedlings and sprouts produced after harvest.

The BBD advancing front has existed on the Allegheny National Forest (ANF) in northwestern PA, since the late 1980s, and the killing front since around 1990. Root suckers have become quite dense in many stands, and any overstory disturbance further promotes understory beech growth, in addition to that of herbaceous fern and grass species (Horsley 1994). A dense understory of striped maple (*Acer pensylvanicum* L.) also exists in some stands. Like beech, this species persists in heavy shade and also interferes with regeneration of more desirable species (Gabriel and Walters 1990, Nyland et al. 2006).

The majority of silvicultural prescriptions on the ANF follow even-aged management guidelines, with the shelterwood system being the most common regeneration method (USDA Forest Service 2007a, p. 3–130 to 3–132). During the establishment cut, diseased beech stumps are sometimes treated with herbicide to reduce sprouting (Kochenderfer et al. 2013). Following the harvest, felling of nonmerchantable (1–5 in.; 2.5–12.5 cm) stems of interfering species (primarily beech and striped maple) typically occurs. Broadcast understory herbicide application is typically conducted up to 2 years later, following seed bed germination, herbaceous vegetation invasion, and stump sprouting of

Management and Policy Implications

During understory broadcast herbicide applications, forest managers do not need to protect American beech root suckers associated with parent trees having visual resistance to beech bark disease complex. Applying broadcast herbicides after shelterwood establishment cutting did not reduce subsequent root sprouting from beech parent trees compared to areas protected from herbicide. On-the-ground applications are much easier if air-blast sprayer vehicles can travel throughout the entire understory and do not have to avoid spraying regeneration associated with resistant beech. After 8 years, beech re-sprouting, along with a diversity of new seedlings, was sufficient for overstory removal harvests to occur. Retention of visually resistant parent beech trees during shelterwood establishment cuts may facilitate a higher proportion of beech sprouts that show resistance to beech bark disease in the new cohort. Herbicide can also be directly applied to stumps of diseased beech to eliminate sprouting from susceptible trees. After removal cutting, beech sprouts will continue to have a clumped distribution within these stands, which may require future thinnings to facilitate beech development.

beech and other undesirable woody species. Foresters can refine the herbicide treatment to protect new regeneration and target other areas as needed. This flexible silvicultural prescription has been successful in reducing beech density and enhancing diversity of understory tree regeneration prior to final overstory removal for several decades (USDA Forest Service 2007a, p. 3–139 to 3–140).

In stands where the BBD killing front zone has been present for at least 10 years, beech regeneration from visually resistant trees is a desired enhancement of new cohorts. However, ANF forest managers questioned if current broadcast herbicide application methods significantly reduced root sprouting from resistant parent trees during shelterwood treatments. If new sprouts are negatively impacted, then perhaps consideration should be given to protecting existing sprouts from herbicide, or altering the herbicide prescription or application method.

The objective of our study was to compare beech regeneration development after shelterwood establishment cuts where overstory beech without signs of BBD were retained as residuals, and associated offspring were either protected from, or sprayed with, herbicide. We periodically measured sprout/seedling densities of all species in the vicinity of these potentially resistant trees for 8 years. Because temporal species fluctuations are typical in the early years following treatment (Horsley 1994), the ultimate goal was to determine how beech densities in sprayed plots compared to protected plots at the end of the 8-year measurement period.

Study Area

The ANF in northwestern Pennsylvania has been impacted by BBD for almost 30 years. The ANF is located near the town of Warren (41.65°N, 79.04°W), covers about 517,000 ac (210,000 hectares), and is 90 percent forested. The mean elevation is 1,500 ft (427 m). Summers are typically warm, and humid, with mean daytime high temperatures between 75 and 80° F (23.9–26.7° C). Winter daytime highs average 20–25° F (–3.9 to –6.7° C). Annual precipitation averages about 40 in. (1,016 mm) (http://www.fs.usda.gov/main/allegheny/about-forest/about-area).

Vegetation consists of second-growth, 70–100-year-old mixed Allegheny hardwood species, dominated by black cherry (*Prunus serotina* Ehrh.), red maple (*Acer rubrum* L.), black birch (*Betula lenta* L.), yellow birch (*Betula alleghaniensis* Britt.), northern red oak *(Quercus rubra* L.), sugar maple (*Acer saccharum* Marsh), and American beech. According to ANF forest inventory data, beech comprises the third highest proportion of basal area (around 8 percent), although the proportion is declining because about two-thirds have died from BBD.

Methods

In 2003, USDA Forest Service personnel from the ANF and State and Private Forestry systematically identified all beech trees in three small stands in the northeastern portion of the ANF where the killing front had existed since 1990. Regeneration surveys indicated the stands had inadequate desirable advanced regeneration (<70 percent of inventory plots), and more than 30 percent of plots contained interfering vegetation, which is considered a barrier to desirable tree seedling establishment (Horsley et al. 1994). Stand 13 is 23 ac (9 hectares), stand 36 is 31 ac (12.6 hectares), and stand 42 is 10 ac (4 hectares). Prior to harvest, stand basal areas ranged from 96 to 117 ft^2/ac (22–27 m^2/hectare), and relative stand densities averaged around 60 percent. American beech comprised 14–29 percent of the basal area before harvest (Table 1). Prior to marking, 23–27 overstory beech in each stand were identified as desired residuals because of their lack of visible beech scale/BBD infection; all other beech would be harvested. Residual beech diameters, measured at 4.5 ft (1.37 m) above the ground (dbh), ranged from 8 to 25 in. (20–63 cm), with 70 percent of trees >11 in. (29 cm). Larger trees were favored for retention because there is a general positive correlation of root sprouting potential and tree diameter (Jones and Raynal 1986). In spring 2004, these stands were marked for shelterwood establishment cuts.

In June of 2004, treatment plots were established using each of the residual resistant beech as a plot center. Resistant beech trees were randomly assigned to each treatment (half to each of herbicide or no-herbicide) within each of three stands. A 0.1-ac (0.04-hectare) circular plot was established using 37.2-ft (11.3-m) radii originating from the approximate center of each beech stem at 4.5 ft (1.37 m) above the ground. This plot size was considered large enough to capture the majority of current sprouts and seedlings associated with the parent tree (Jones and Raynal 1986), and any new sprouts that would be stimulated by the pending harvest (Houston 2001). Because many of the plots in each stand overlapped because of clumping of the beech stems, 11, 19, and 18 discrete plots were established in stands 42, 36, and 13, respectively. Unfortunately, during the layout of the timber sale, six no-herbicide plots in each of stands 36 and 13 were contained within the "reserve area," which is a mandatory uncut percentage of the stand according to USDA Forest Service harvest guidelines. Hence, the no-herbicide plot sample was reduced to five, six, and four plots in stands 42, 36, and 13, respectively, resulting in a total of 15 no-herbicide plots, and 21 herbicide plots. The shelterwood establishment cuts were conducted during January to March of 2005. Additional herbicide application to beech stumps was not included because environmental approval was still pending for the procedure. Postharvest

Table 1. Preharvest (2004) and postharvest (2005) mean basal areas for all trees >1 in. (2.54 cm) dbh in three stands identified as 13, 36, and 42, on the Allegheny National Forest, Pennsylvania.

Stand	Basal area ft^2/ac (m^2/hectare)	Red maple	Sugar maple	Black cherry	Beech	Yellow birch	Black birch	Other[a]
13 Pre	117.0 (26.9)	15	8	61	14	0	0	2
13 Post	75.7 (17.4)	26	4	51	17	1	0	1
36 Pre	97.6 (22.4)	12	15	39	14	1	2	17
36 Post	62.2 (14.3)	8	8	36	37	4	2	5
42 Pre	98.3 (22.6)	8	10	41	29	0	2	10
42 Post	45.2 (10.4)	7	0	17	52	2	2	20

Note: Individual species basal areas are depicted as a percentage of the total for each stand.
[a]Other species include: *Tsuga canadensis*, *Pinus strobus*, and *Quercus* sp.

residual basal areas ranged from 45 to 76 ft^2/ac (10–17 m^2/hectare); beech and black cherry had the highest percentages of residual basal area in each stand (Table 1).

In August of 2005, an air-blast sprayer mounted on a tracked vehicle was used to spray the understory with a mixture of the herbicides Accord® (glyphosate) (1 quart/acre; 2.3 liters/hectare), and Oust® (sulphometuron methyl) (2 ounces/acre; 0.15 liters/hectare). One pint per acre (1.2 liters/hectare) of ChemSurf 90® was included as a surfactant. The mixture of Accord® and Oust® is the standard protocol for understory control in conjunction with ANF shelterwood establishment cuts and is based on long-term research (Horsley 1988, Horsley 1990, Horsley 1994). Accord Concentrate® is labeled for broadcast applications in forest sites for application rates of 1.5–7.5 quarts per acre (3.4–17.2 liters/hectare) (www.cdms.net/LDat/ld4TL015). Research by Horsley and Bjorkbom (1983) determined that a rate of 1 quart/acre (2.3 liters/hectare), with 1.3 pounds/acre (1.5 kg/hectare) of active ingredient, is effective in controlling interfering beech stems when applied after August 1. Oust® was included because it provides excellent control of ferns, grasses, and sedges (Horsley 1994), which were present and can thrive after soil disturbance from harvesting (Horsley 1993). Late summer herbicide applications, after full leaf-out and before autumn senescence, generally give the best control of beech (Nyland et al. 2006). Beech seedlings within the 0.1-ac (0.04-hectare) circular plots associated with the no-herbicide residual trees were protected from herbicide spray drift with a "no-spray" buffer zone surrounding each circular plot. The buffer zones varied in width depending on plot location and movement of the machine. The protective buffers were hand-treated with backpack sprayers, targeting nonbeech species, using the same herbicide mixture.

Three weeks after herbicide application (early September 2005), three 0.002-ac (0.0008-hectare) circular subplots with a radius of 6 ft (1.8 m) were established in three cardinal directions (azimuth 0°, 120°, 240°), 18.6 ft (5.7 m) from all plot center beech trees in herbicide and no-herbicide plots. At the same time, tree seedlings and sprouts ≤1 in. (2.54 cm) dbh that were ≥1 ft (0.3 m) tall were tallied by species and height, only on no-herbicide plots. Vegetation on herbicide plots was declining from the herbicide application, so no measurements were collected on them in 2005. Because beech sprouts are often clumped at a single point on a parent root, multiple sprouts arising from the same rootstock were counted as one sprout, and the height of the tallest individual was measured. The tallest sprout in the clump is considered to be the dominant individual that will probably outgrow the others (Jones and Raynal 1986). The study areas were not fenced to exclude deer, and we assumed deer browse impacts would be similar across all stands and treatments.

In July 2006, an ANF forester assessed herbicide efficacy throughout each stand, contingent with the contractual agreement of the herbicide applicator. The herbicide application was considered effective if less than 30 percent interfering understory vegetation remains, including beech (Marquis et al. 1992, Horsley et al. 1994). In September 2006, chainsaws were used to fell all striped maple (*Acer pensylvanicum* L.) and beech, <6 in. (15.2 cm) dbh, except for beech stems within the 0.1-ac (0.04-hectare) circular plots, because these were possibly associated with resistant residual trees. All regeneration subplots were measured again in 2008, 2010, and 2013. In accordance with standard ANF shelterwood prescriptions, ANF foresters systematically sampled regeneration throughout each stand in 2015. Removal harvests are planned when >70 percent of well-distributed plots are stocked with regeneration of desired tree species (Horsley et al. 1994).

Analyses

The intent of the study was to determine whether beech densities, 8 years after herbicide treatment, provided representation in the new cohort prior to overstory removal. Seedling (sprouts included) densities in 2013, for herbicide-treated and untreated plots, were analyzed using a mixed-model, split-plot, experimental design (PROC MIXED: SAS Institute Inc. 2009). Each stand (whole plot) contained 0.1-ac (0.04-hectare) circular subplots around each resistant beech: subplot = tree. Each subplot contained three sub-subplots (seedling subplots). Seedling data from each sub-subplot were averaged by species within each subplot to account for variance. The response variable was the mean density of seedlings ≤5 ft (1.5 m) tall, present at the final measurement in 2013. Large regeneration >5 ft (1.5 m) was rare, so species densities were not tested statistically because of the low sample size. Because of the scarcity of sugar maple and yellow birch seedlings, these were combined with red maple or black birch, respectively, as simply "maple" or "birch" groups.

The fixed effects in the model are species, treatment, and species × treatment interaction. The random effect is plot (stand). Least-squares means of 2013 seedling densities were computed for each species × treatment interaction, along with the standard error and *P*-value. The *P*-value tests the probability that the differences between actual and predicted seedling densities are different from zero. Differences for each species × treatment interaction were tested using pairwise comparisons (Tukey–Kramer adjusted *P*-values), if the test of the fixed-effect indicated a significant interaction. All analyses were evaluated at an $\alpha = 0.1$ level.

Seedling densities from all measurement periods were summarized by stand and treatment to describe species-development trends. Our original intent was to use a mixed-model with repeated measures to capture the temporal species changes that might influence beech development. However, attempts to build statistically sound covariance structures failed because of small sample sizes (missing study plots in reserve areas), and extreme temporal variability in data, especially in stand 42 where measurable seedlings did not appear until 2010. In addition, because these data measure the vegetation dynamics adjacent to residual beech stems, we did not assume representation of an entire stand response to the treatment. ANF personnel surveyed herbicide efficacy in 2006 and monitored stand-level regeneration development in 2015 as part of the shelterwood prescription protocol. Data from those surveys are not reported here.

Results

Herbicide efficacy in all stands met the ANF criteria of <30 percent interfering vegetation coverage in the first growing season after application. The test for the fixed effects indicated significant stand and species effects for 2013 data, but no significant effect for herbicide treatment or the species × herbicide interaction. Hence, none of the tests of the differences between each species × herbicide combination indicated that pairwise comparisons were significantly different (Table 2). Least-squares means of 2013 seedling densities for each species on herbicide and no-herbicide plots are presented in Table 3. Predicted probabilities of the least square means of black cherry and maple densities on herbicide plots, and striped maple on no-herbicide plots, were not significantly different among the three stands.

With no treatment effect, we further examined mean regeneration ≥1 ft (0.3 m) densities summarized by stand and species, because these were significant effects in the model (Table 4). Beech densities were similar across all stands and treatments, except for stand 42 where mean densities were almost double for no-herbicide plots. Compared to no-herbicide, maple densities on herbicide plots were double for stands 13 and 42, and similar for stand 36. Birch had slightly lower densities than maple on herbicide plots and was scarce on untreated plots, except for stand 42. Black cherry was scarce on no-herbicide plots and had low representation on herbicide plots.

From 2008 to 2013, herbicide plots in stands 13 and 36 had the following trends: the percentage of beech decreased 24 and 14 percent, respectively, maple percentages increased 33 and 3 percent, respectively, and birch percentages increased 17 and 2 percent, respectively. Striped maple had consistent representation with 6 percent in stand 13 and 27 percent in stand 36. On no-herbicide plots, beech and striped maple densities were higher in 2008 and 2010 than preharvest, but decreased by 2013.

In stand 42 herbicide plots, all regeneration was <1 ft (0.3 m) in 2008 and was below the measurement criteria for the study. However, by 2010 there was a major increase in seedling densities for both treatments, and birch and maple comprised at least 50 percent of the regeneration. Between 2010 and 2013, all species densities decreased at least 50 percent, except for maple, which increased 20 percent on herbicide plots.

By 2013, beech represented 100 percent of the taller >5 ft (1.5 m) regeneration on no-herbicide plots in stands 13 and 36, and 34 percent in stand 42. The rest of the tall regeneration in stand 42 was birch (66 percent). Taller beech was also found on the herbicide plots with 100, 51, and 37 percent in stands 13, 36, and 42, respectively. In 2015, regeneration stocking evaluations by ANF personnel indicated that all stands met the criteria of having >70 percent of plots stocked with desirable or acceptable species, and interference was <30 percent.

Table 2. Tests of the fixed effects of the mixed-model, split plot design for mean seedling densities/ac (hectare) in year 2013.

	Type 3 tests of the fixed effects		
Effect	df	*F* value	Pr > *F*
Stand	2	3.62	.0303
Species	4	4.29	.0014
Herbicide	1	0.16	.6884
Species × herbicide	4	0.91	.4760

Note: All analyses were evaluated at an α = 0.1 level.

Discussion

Eight years after shelterwood establishment cuts and understory broadcast herbicide application, plots that had received herbicide had a similar abundance of beech sprouts in the vicinity of parent trees to no-herbicide plots. The 2008 and 2010 measurements indicated short-term species increases/decreases, regardless of treatment. Even without herbicide, the harvest caused a temporary increase in beech, and some other species, depending on stand characteristics. In 2010, stand 42 showed the most dramatic increase in densities of maple and birch. The efficacy of the herbicide, and possibly excessive deer browsing, was most evident in this stand because any seedlings present in 2008 were very small (<1 ft [0.3 m]) and not measured. On all herbicide plots, sprouting beech root suckers competed with a flush of new seedlings initiated by the shelterwood harvest. After 8 years, only striped maple had similar seedling densities to beech in stand 36; maples, birches, and black cherry (combined) had seedling densities equal to or higher than that of beech in stands 13 and 42 (Table 4).

We monitored regeneration development specifically located in areas with a high probability of beech sprouting. Harvesting combined with herbicide application resulted in higher stocking of other species, but temporal and spatial changes in growing space, seed crops and deer browsing caused fluctuations in seedling densities across stands, and a high variability in stocking among plots by 2013. Other studies have reported similar short-term species fluctuations (Horsley 1994, Nelson and Wagner 2011) until a more stable population of beech and other species reoccupy the growing space (Marquis 1979, Kelty and Nyland 1981), height

Table 3. Least-squares means of 2013 seedling densities/ac (hectare) for each species × treatment combination including the standard error.

Least-squares means					
Species	Herbicide	Seedling/ac (hectare) estimate	Standard error/ac (hectare)	*t* Value	Pr > |t|
Beech	No	1,500.9 (3,707.2)	227.1 (560.9)	6.61	<.0001
Beech	Yes	1,178.2 (2,910.2)	191.6 (473.3)	6.15	<.0001
Birch[a]	No	1,324.2 (3,270.8)	446.1 (1,101.9)	2.97	.004
Birch[a]	Yes	910.4 (2,248.7)	244.7 (604.4)	3.72	.0003
Black cherry[b]	Yes	254.9 (629.6)	314.8 (777.6)	0.81	.4198
Maple[c]	No	566.2 (1,398.5)	359.9 (888.9)	1.57	.1188
Maple[c]	Yes	1,182.2 (2,920.0)	202.1 (499.2)	5.85	<.0001
Striped maple	No	326.3 (806.0)	333.9 (824.7)	0.98	.3307
Striped maple	Yes	550.7 (1,360.2)	238.0 (587.9)	2.31	.0227

Note: The *P*-value tests the probability that the differences between actual and predicted seedling densities are different from zero. Differences for each species × treatment interaction were tested using pairwise comparisons (Tukey–Kramer adjusted *P*-values) if the test of the fixed-effect indicated a significant interaction. Comparisons were evaluated at an α = 0.1 level. Plots treated with herbicide = Yes, or not treated with herbicide = No.

[a]Birch species group is primarily black birch with a minor yellow birch component.

[b]Black cherry seedlings were only present on no-herbicide plots in one stand in 2013.

[c]Maple species group is primarily red maple with a minor sugar maple component.

Table 4. Species mean densities in 2013 by treatment (Herbicide, No-Herbicide) and Stand (13, 36, 42).

	No herbicide			Herbicide		
	Stand			Stand		
Species	13	36	42	13	36	42
Beech (ac)	865 (205)	1,000 (137)	1,847(291)	805 (162)	1,153 (202)	989 (416)
Beech (hectare)	2,137 (506)	2,470 (338)	4,562 (719)	1,988 (400)	2,848 (499)	2,423 (1,027)
Black cherry (ac)	0	0	256 (0)	128 (0)	256 (81)	128 (0)
Black cherry (hectare)	0	0	632 (0)	316 (0)	632 (200)	316 (0)
Birch (ac)	0	128 (0)	983 (299)	470 (186)	513 (272)	1,261 (413)
Birch (hectare)	0	316 (0)	2,428 (738)	1,161 (459)	1,267 (672)	3,115 (1,020)
Striped maple (ac)	128 (0)	727 (468)	171 (43)	192 (64)	806 (310)	359 (63)
Striped maple (hectare)	316 (0)	1,796 (1,156)	422 (106)	474 (158)	1,991 (766)	887 (156)
Maple (ac)	385 (256)	513 (385)	577 (356)	817 (263)	471 (317)	1,652 (534)
Maple (hectare)	951 (632)	1,267 (951)	1,425 (879)	2,018 (650)	1,163 (783)	4,080 (1,319)

Note: Densities are in trees/acre (±standard error) and trees/hectare (±standard error), of seedlings, sprouts, and advance regeneration ≤5 ft (1.5 m) tall. Sample subplots were located within 0.1-acre (0.04-hectare) circular plots surrounding residual American beech trees, 8 years after understory herbicide treatment and shelterwood establishment harvests..

growth slows (except for beech) (Bose et al. 2018), and removal cuts occur. However, as we found in our study, a high degree of variability in regeneration density existed among species across plots (Bose et al. 2018). Without herbicide, species diversity is reduced in the long term (Horsley and Marquis 1983, Horsley 1994, Bose et al. 2018).

Residual overstory basal area, and subsequent canopy closure, also plays an important role in regeneration composition and development over time (Bose et al. 2018). All stands had similar preharvest basal areas, but postharvest residual basal areas were much lower in stand 42 (Table 1). Hence, we can infer this stand also had a lower overstory basal area in 2013, which may have allowed for greater species abundance. Stand 42 generally had higher densities of each species (except for striped maple), regardless of treatment (Table 4). Red maple is classified as shade-tolerant but achieves height growth rates similar to some intolerant species after disturbance (Tift and Fajvan 1999). Black and yellow birch seedlings are shade-intolerant (Lamson 1990), but remain competitive through prolonged positive height growth in low light, compared to black cherry (Fajvan et al. 2006). Black cherry comprised 40 and 50 percent of residual overstory basal area in stands 36 and 13, respectively (Table 1). Yet, even with a potential seed source, black cherry regeneration was scarce in all stands and treatments (Table 4). Black cherry seed has historically produced annual seed crops with above-average production approximately every 3 years; soil seed beds are viable for about 3 years (Marquis 1990). However, black cherry regeneration has been declining in recent years across the Allegheny Plateau (Robert Long, pers. commun., USFS Warren, PA, November 16, 2017), even though it is not a preferred browse species by white-tailed deer (Marquis 1990).

Using broadcast herbicides to treat understory vegetation in conjunction with shelterwood establishment cutting is a common practice on the ANF and across industrial forest lands on the Allegheny Plateau. The amount of Accord Concentrate® used in our study was sufficient to minimize beech interference, and is far less than the allowable labeled rate of up to 7.5 quarts per acre (17.2 liters/hectare) for ground-based application in forestry sites. Managers can achieve desired understory vegetation control and reduce potential negative environmental impacts through carefully planned herbicide application (USDA Forest Service 2007a, p. 3-139 to 3-142; USDA Forest Service 2007b, p. 55–59).

The goal of our study was to determine whether beech sprouts associated with disease-free beech parent trees should also be targeted by the herbicide or protected. Our data indicate that the herbicide was not detrimental to sprout productivity 8 years after treatment. We expected less beech on herbicide-treated plots by 2013. However, after 8 years, the initial invasion or release of other species resulting from the shelterwood cut may have hampered the growth of beech sprouts in no-herbicide plots. We recommend that it is not necessary to go through the extra effort to protect the sprouts, and to apply the treatment uniformly throughout the understory.

Long-term silvicultural approaches to manipulate the genetic features of natural beech regeneration are more cost-effective than genetic manipulations of seedlings for eventual planting (Koch et al. 2010). The parent beech trees selected for this study had no visual signs of BBD and tended to occur in clumps. It is unknown if this distribution is due to microsite conditions less favorable to BBD or clonal propagation and limited seed dispersal. Artificial inoculations of putative resistant trees can be conducted to confirm their resistance, but this testing is currently experimental.

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