Received: 5 October 2017 | Revised: 29 March 2018 | Accepted: 3 April 2018

DOI: 10.1002/ldr.2962

RESEARCH ARTICLE

WILEY

Survival and growth of 20 species of trees and shrubs on Appalachian surface mines

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Funding information
USDI Office of Surface Mining Reclamation and Enforcement, Grant/Award Number: S15AC20022

Abstract

The Forestry Reclamation Approach recommends that 2 tree types be planted during reclamation reforestation projects to reclaim the site to a forest ecosystem. Late succession trees such as oaks (*Quercus*), maples (*Acer*), poplars (*Liriodendron*), and pines (*Pinus*) are planted as crop trees, but understory trees and shrubs of native forests are not often planted or planted in fewer numbers, so less is known of their survival and growth in mine soils. This study evaluated survival and growth of 20 species of small trees and shrubs planted on 4 surface mines in Appalachia. Survival and height were determined at the end of the first year after planting, and then again after 7 or 9 years depending on the site's planting date. Soil properties varied across sites with pH ranging from 3.8 to 7.5 and percent soil material (≤2 mm) ranging from 58% to 82%. Extracted nutrient concentrations (P, K, Ca, Mg, and S) were also variable across sites. Five of the 20 species had survival ≥50% (black chokeberry [*Aronia melanocarpa* Michx.], black cherry [*Prunus serotina* Ehrh.], Washington hawthorn [*Crataegus phaenopyrum* L. f.], nannyberry [*Viburnum lentago* L.], and hazelnut [*Corylus avellana* L.]). Eleven species survived from 37% to 47% and 4 species experienced ≤30% survival. Almost all species at least doubled their height and many increased 3 to 4 times above their initial planted seedling height. The species that survived ≥50% are recommended for forestry plantings and those that survived ≥37% may be considered as candidates for planting during forestry reclamation.

KEYWORDS

Appalachian Regional Reforestation Initiative (ARRI), Forestry Reclamation Approach (FRA), reclamation, reforestation, early-successional forest species, mine soil properties

1 | INTRODUCTION

The overall goal of land reclamation is to return the land to a condition equal to or better than the land's original condition before mining (Avera, Strahm, Burger, & Zipper, 2015; MacDonald et al., 2015). Reforestation of mined lands aims to return the land back into a sustainable forest after disturbance (Evans, Zipper, Burger, Strahm, & Villamagna, 2013; Zipper et al., 2011). The Appalachian Regional Reforestation Initiative is a cooperative effort by states in Appalachia and the United States Department of the Interior, Office of Surface Mining Reclamation and Enforcement to encourage restoration of high quality forests on reclaimed coal mines in the eastern USA (Angel, Davis, Burger,

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Graves, & Zipper, 2005). The Forestry Reclamation Approach (FRA) was developed by a multidisciplinary group of researchers, industry, and regulatory personnel (foresters, soil scientists, ecologists, hydrologists, and economists) with the goal to provide best practices that will successfully establish commercially valuable tree species on mined sites and to assure their rapid growth and development.

The FRA is described in five steps (Burger, Graves, Angel, Davis, & Zipper, 2005). Step 1 of the FRA encourages creating a suitable rooting medium that is no less than 1.2 m deep and composed of topsoil, weathered sandstone, and/or the best available material. Growth media with low to moderate levels of soluble salts, equilibrium pH of 5.0 to 7.0, low pyritic sulfur content, and textures conducive to proper drainage and nutrient holding capacity are preferred (Skousen, Zipper, Burger, Angel, & Barton, 2011). Coarse fragment content should be less than 50% with the majority of the soil material passing through a ≤2 mm sieve. A mixture of brown (weathered) and gray (unweathered) sandstones, when loosely graded, can form a soil medium suitable for trees (Skousen, Zipper, Burger, Barton, & Angel, 2011; Zipper, Burger, Barton, & Skousen, 2013). Step 2 of the FRA proposes that operators should loosely grade the topsoil or topsoil substitutes because excessive soil compaction can have a major negative effect on survival and growth of trees (Sweigard et al., 2007). Step 3 recommends using ground covers that are compatible with growing trees. Ground cover vegetation used in reforestation must control erosion but not out-compete tree seedlings for light, water, and space. Ground covers should include grasses and legumes that are slow-growing, have sprawling growth forms, have low nutrient requirements, and are tolerant of a wide range of soil conditions (Burger et al., 2009; Franklin, Zipper, Burger, Skousen, & Jacobs, 2012). Steps 4 and 5 endorse planting early succession species and commercially valuable crop trees in the correct manner on reclaimed sites (Davis, Burger, Rathfon, Zipper, & Miller, 2012; Davis, Franklin, Zipper, & Angel, 2010).

Small trees and shrubs that are present in understories of Appalachian forests and that provide important wildlife benefits and ecosystem services are not often planted in surface mine reforestation projects or only sparsely planted. Reclamation planners in the past have focused on planting commercially valuable, late successional trees on mined lands such as oaks (*Quercus*), maples (*Acer*), poplars (*Liriodendron*), and pines (*Pinus*), with less emphasis on forest ecosystem restoration that may include planting a wide variety of understory species. The late succession crop trees generally comprise more than 90% of the planting stock. The remaining 10% of the trees planted are often black cherry (*Prunus serotina* Ehrh.), dogwood (*Cornus*) eastern redbud (*Cercis canadensis* L.), and black locust (*Robinia psuedoacacia* L.). Davis et al. (2012) acknowledge that more than 100 tree and shrub species grow in Appalachian forests and they recommend planting a variety of trees and shrubs in mined land reforestation projects in addition to crop trees. Among the tree and shrub species recommended by these scientists are eastern redbud, gray or flowering dogwood (*Cornus*), American hazelnut (*Corylus americana* L.), green hawthorn (*Crataegus viridis* L.), common persimmon (*Diospyros virginiana* L. f.), and elderberry (*Sambucus canadensis* L.). Because these small understory tree and shrub species are not commonly planted on reclaimed surface mines, less is known about their seedling survival and growth. Thus, information is needed about which early succession or wildlife habitat woody species should be planted with commercially valuable crop trees in Step 4 of the FRA.

Early succession trees and shrubs are ecological enhancers that provide many benefits to the ecosystem. When soil or soil substitutes have been placed in a noncompacted manner and the herbaceous ground cover has been reduced during reclamation, native and unplanted species from surrounding forests will slowly colonize and reinhabit the site. But foresters acknowledge that planting a diversity of tree types at the start of forest re-establishment will more rapidly develop the functional and structural diversity of the ecosystem (Aerts & Honnay, 2011; Cardinale, Palmer, & Collins, 2001). The intent of FRA reclamation is to develop a forest plant community with all the ecological components necessary for maximizing multiple use of the reclaimed area (MacDonald et al., 2015; Zipper et al., 2011). A diverse plant community composed of early succession and late succession species enhances the wildlife habitat potential, recreational, aesthetic, and productive value of the reclaimed land (Burger, 2011).

The objective of this study was to evaluate the growth and survival of 20 small tree and shrub species planted on four surface mines in 2008 and 2010. Site characteristics and soil properties at each site were also determined. The results of this research will help foresters and reclamation planners select additional woody species that could be planted during reclamation in order to enhance ecosystem development and services.

2 | METHODS

2.1 | Study sites

Williams Forestry established shrub and small tree plantings on four surface mines in West Virginia. The four sites are Elk Run and Hobet (planted in 2008) and Fola and ICG (planted in 2010). These sites are located in the Appalachian Plateau physiographic region of central and southwestern West Virginia (Figure 1). The Elk Run Mine is located in eastern Boone County, WV, (38°04′20″ N, 81°43′27″ W) and covers roughly 2,000 ha. The Hobet Mine near Madison, WV, covers approximately 5,000 ha in western Boone and Lincoln Counties (38°07′38.76″ N, 81°52′37.83″ W). ICG is located in Webster County and covers approximately 2,000 ha (38°26′08.45″ N, 80°37′05.74″ W). Fola is located in Clay and Nicholas Counties and covers approximately 4,000 ha (38°35′24.66″ N, 81°08′94.19″ W).

2.2 | Experimental design

The experiment was a completely randomized block design. At each site, four blocks, each measuring 0.42 ha (4,160 m^2), were established (Figure 2). Two blocks were located on east-facing slopes and the other two blocks on west-facing slopes. In each block, 20 plots, each measuring 208 m^2 (14.4 m × 14.4 m), were delineated and one of 20 different small tree or shrub species (Table 1) was randomly assigned to each plot with 25 individuals of that species planted on 2.4 m × 2.4 m spacing in the plot. The sites planted in 2008 (Elk Run and Hobet) only had 19 species plots per block due to the absence of hazelnut (*Corylus avellana* L.), which was planted in the 2010 plantings at ICG and Fola. A total of 1,900 plants were planted at each of the Elk Run and Hobet sites,

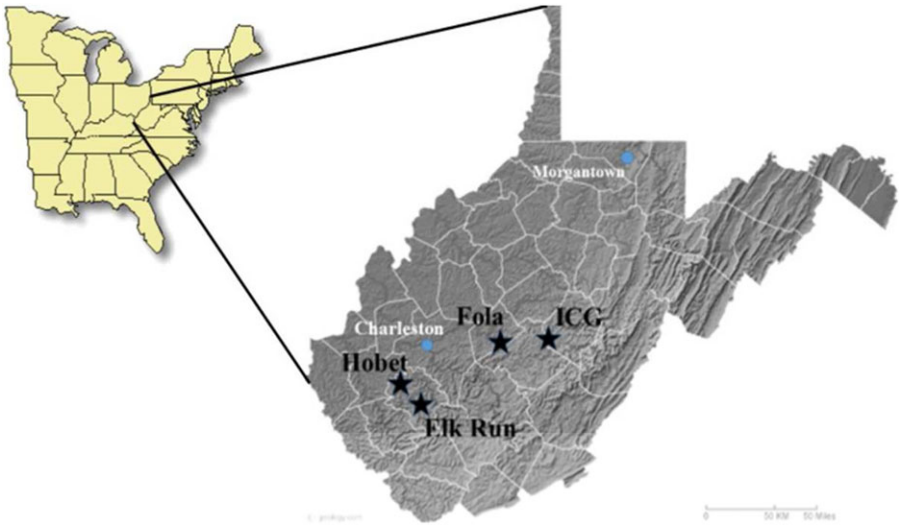


FIGURE 1 Location of small tree and shrub plantings on surface-mined sites in central and southern West Virginia. Elk Run and Hobet plantings were established in 2008 and Fola and ICG were established in 2010 [Colour figure can be viewed at wileyonlinelibrary.com]

	Block 1 East					Block 2 East				
14	1	18	2	3	5	16	18	11	20
4	20	15	13	19	4	1	8	10	7
11	7	9	6	12	15	14	17	19	12
17	10	8	16	5	9	3	6	13	2
	Block 3 West					**Block 4 West**			
10	5	9	4	18	7	11	17	14	8
7	11	14	3	13	2	10	13	12	4
2	19	8	16	15	18	9	19	3	16
1	6	20	17	12	6	1	5	20	15

FIGURE 2 An example of the randomized complete block design used at each site. The block design here is that used at ICG. Numbers within plots for each block represent different tree and shrub species (Table 1). Twenty-five individuals of each species were planted in each plot on 2.4 × 2.4 m spacing

whereas 2,000 plants were planted at each of the ICG and Fola sites, with a total of 7,800 individual plants transplanted for the project. The species selected for transplanting included understory species in Appalachian forests, and all provide important ecosystem services such as wildlife food (browse, nuts and seeds, insect pollinators) and habitat (bird nesting, and cover and shelter), and structural, functional, and aesthetic diversity in forests (Table 1).

2.3 | Planting and first year monitoring

All seedlings were planted as 1-year-old, bare root seedlings by workers of Williams Forestry and were kept refrigerated with the roots contained in bags until the day of planting, with the exception of highbush blueberry that were transplanted from containers. Approximately 300 of each species were purchased each year of planting (2008 and 2010) even though only 200 were planted (100 at each site). Bare root seedlings were separated into bundles of 25 with the largest and smallest individuals being culled during separation so that moderately sized individuals would be planted in the study plots. Seedlings were planted according to standard practice with the roots dipped in a TerraSorb™ suspension before planting. Each planted seedling was marked with a colored pin flag to aid in subsequent location and measurement.

A survey of all planted trees and shrubs was conducted for survival and growth at the end of the first growing season by personnel of Williams Forestry. Height was measured from ground level to the height of the highest living tissue. The data collected by Williams Forestry personnel the first year after planting were made available for use and analysis in this study.

2.4 | 2015/2016 tree and soil monitoring

Another complete survey of planted trees and shrubs was conducted in 2015 and 2016 with survival and growth of each individual plant determined both years. Height was measured using a meter stick.

Slope steepness was determined in each plot with a handheld clinometer and averaged for each site. Herbaceous ground cover percentage was visually estimated in ¼-m^2 quadrats. The quadrat was randomly placed in three places in each species plot, and the herbaceous species and their cover in the quadrat were recorded.

Soil sampling and analysis were performed to determine mine soil properties. Soil samples were collected to a depth of 15 cm at three random locations in each plot and composited into one sample to represent the soil characteristics in each species plot. Therefore, 20 soil samples were collected for each block, and 80 samples were collected per site for a total of 320 soil samples for analysis. Soil samples were air-dried, weighed, and sieved into coarse and fine soil fractions (material passing through a 2 mm sieve), then weighed to determine the soil percentage. A subsample of the soil fraction was analyzed for chemical properties including soil pH using a 1:1 soil : water ratio and soluble salts (as electrical conductivity using 2:1 soil : water ratio). Phosphorus (P), potassium (K), magnesium (Mg), calcium (Ca), sodium (Na), and

TABLE 1 The list and characteristics of 20 tree and shrub species used in reforestation experiments

Common name	Scientific name	Growth potential (m)	Seedling vigor	Shade tolerance	Tolerance to poor drainage	Drought tolerance	Ecosystem services
Trees							
American crabapple	*Malus coronaria* L.	15	Moderate	Moderate	Low	Moderate	Nests, shelter, food, flowers
Black cherry	*Prunus serotina* Ehrh.	38	High	Low	Low	Moderate	Food, medicine, fruit
Choke cherry	*Prunus virginiana* L.	10	High	High	Moderate	Moderate	Food, shelter, windbreaks
Common apple	*Malus pumila* Mill.	18	Low	Moderate	Low	Moderate	Food, orchard crop, nesting habitat, pollinators
Common pear	*Pyrus communis* L.	10	Moderate	Moderate	Low	Low	Food, bird habitat, pollinators
Eastern redbud	*Cercis canadensis* L.	6	Moderate	High	Low	High	Early pollen, browse, medicine
Elderberry	*Sambucus canadensis* L.	8	Moderate	Low	Moderate	Low	Food, seeds, pollinators
Flowering dogwood	*Cornus florida* L.	10	Low	High	Low	Moderate	Food, early flowers
Pawpaw	*Asimina triloba* L.	12	Low	High	Low	Low	Food, fruit, bark, medicine
Persimmon	*Diospyros virginiana* L. f.	16	Moderate	Moderate	Low	Moderate	Food, fruit, medicine
Red mulberry	*Morus rubra* L.	25	Moderate	High	Moderate	Moderate	Food, fruit, nesting habitat
Serviceberry	*Amelanchier arborea* Michx. f. Fernald	10	High	High	Moderate	Low	Food, early flowers
Washington hawthorn	*Crataegus phaenopyrum* L. f.	7	High	Moderate	Low	Moderate	Winter food, pollinators
Wild plum	*Prunus americana* Marshall	10	High	Low	Moderate	Low	Food, fruit, medicine
Shrubs							
Black chokeberry	*Aronia melanocarpa* Michx.	4	High	Low	Moderate	Moderate	Food, flowers, seeds
Gray dogwood	*Cornus racemose* Lam.	5	High	Moderate	Low	Moderate	Shelterbelts, food, habitat
Hazelnut	*Corylus avellana* L.	3	Moderate	High	Low	Moderate	Food, nuts, pollinators
Highbush blueberry	*Vaccinium corymbosum* L.	3	Moderate	Low	Moderate	Low	Late year food, seeds
Highbush cranberry	*Viburnum trilobum* L.	6	High	Low	Low	Low	Winter food, seeds
Nannyberry	*Viburnum lentago* L.	6	High	Moderate	Moderate	Low	Shelter, food, color

Note. Growth forms were determined using the USDA, NRCS Plants Database (2016).

other elements (Fe, Al, Mn, Zn, Cu, and Ni) were analyzed after extracting the soil with Mehlich 1 solution.

2.5 | Statistical analysis

The survival data were left-skewed, and transformations did not correct the lack of normality in the data. Therefore, the data were treated as categorical, and Mantel–Haenszel frequency analysis was used. Chi-square analysis of survival by species was used to compare survival by year (2015 and 2016). The effect of aspect on survival was explored through frequency analysis (chi-square) for all species combined and separately by species and by site. Repeated frequency analysis using the ridit scores of the Mantel–Haenszel procedure measuring the nonzero correlation of age and survival was done to test the effect of age on survival.

For plant height, a repeated measures ANOVA was performed. Age was used as the repeated measure factor in a model with age, site, aspect, and their interactions as independent variables on height. After finding significant main effect(s) or interaction(s) in the repeated measure ANOVAs, Tukey–Kramer adjustments were applied to multiple comparisons to control type 1 errors. Statistical analyses were performed using SAS 9.4 software (Statistical Analysis System, 2011). Significance for all tests was an α of ≤ 0.05.

3 | RESULTS AND DISCUSSION

3.1 | Site and soil properties

Mine soil composition at these sites was a mixture of brown and gray sandstone substrate. The brown sandstone material was found from the surface to a depth of about 10 m, whereas gray sandstone was found below 10 m. The sandstone mixtures were developed when materials from both depths were used to rebuild the landscape and graded at the surface with bulldozers for reclamation. Site and soil properties varied across the four sites (Table 2) due to differences in geology, mining and reclamation techniques, and mixing of materials. Elk Run and Fola had a lower average slope (15%) compared with about 22% at Hobet and ICG. The research plots had a wide range of herbaceous ground cover from 0% to 100%,

TABLE 2 Mean values for site and soil characteristics at each site measured in 2016

	Sites				
	Elk Run	Hobet	ICG	Fola	
Site/soil properties	Year planted (2008)		Year planted (2010)		*p* value
Slope (%)	14	22	23	16	.004*
Ground cover (%)	27	39	50	67	.08
Soil fines (%)	74	82	58	66	.0003*
Average pH (pH range)	6.4 (4.9–7.9)	4.5 (3.9–6.2)	7.5 (7.3–7.6)	3.8 (3.4–4.0)	<.0001*
EC (μS m^{-1})	85	73	84	261	<.0001*
P (mg kg^{-1})	36.71	12.58	36.30	6.48	.06
K (mg kg^{-1})	0.11	0.22	0.36	0.13	.12
Ca (mg kg^{-1})	7.21	0.57	5.34	0.35	.006*
Mg (mg kg^{-1})	2.56	0.28	2.16	0.11	<.0001*
Na (mg kg^{-1})	0.04	0.02	0.03	0.04	.34
Al (mg kg^{-1})	62.72	91.77	35.98	235.60	<.0001*
Cu (mg kg^{-1})	1.79	1.47	3.96	2.92	.10
Fe (mg kg^{-1})	0.04	0.02	0.03	0.04	.25
Mn (mg kg^{-1})	38.91	13.82	47.12	10.67	.03*
Ni (mg kg^{-1})	0.80	0.31	0.78	1.46	.003*
Zn (mg kg^{-1})	1.99	2.44	3.79	2.85	.27

Note. Element concentrations were extracted with Mehlich 1 solution. The probability of significant difference (p value $\leq$ .05) is shown for mean values among sites.

*Data denote significant mean soil/site property differences among sites.

which averaged 27% at Hobet to 67% at Fola. Ground cover species that were commonly found on these sites were a mix of seeded and native species including birdsfoot trefoil (*Lotus corniculatus* L.), orchardgrass (*Dactylis glomerata* L.), tall fescue (*Schedonardus arundinacea* Schreb.), perennial ryegrass (*Lolium perenne* L.), sericea lespedeza (*Lespedeza cuneate* Dum.-Cours.), knotweed (*Polygonum aviculare* Siebold & Zucc.), white aster (*Symphyotrichum ericoides* L.), casper spurge (*Euphorbia lathyris* L.), wild carrot (*Daucus carota* L.), coltsfoot (*Tussilago farfara* L.), thistle (*Onopordum acanthium* L.), yarrow (*Achillea millefolium* L.), and broomsedge bluestem (*Andropogon virginicus* L.). Natural encroachment of woody plants onto the mine sites from the surrounding forest was observed and included autumn olive (*Elaeagnus umbellata* Thumb.), black locust (*Robinia pseduoacacia* L.), sycamore (*Platanus occidentalis* L.), and princess tree (*Paulownia tomentosa* Thumb.).

ICG had the lowest percent soil material (≤2 mm) at 58%, whereas the other sites had higher levels from 66% to 82% (Table 2). A higher level of soil material usually improves water relations and nutrient holding capacity for plants (Haering, Daniels, & Galbraith, 2004). ICG and Elk Run soils had the highest pH values (average was above pH 6.0), whereas Fola and Hobet soils were below pH 5.0. Soluble salts (EC) were high at Fola, being three times higher than the average EC values at other sites. The low soil pH at Fola probably caused dissolution and release of elements into the soil solution, which contributed to the higher EC levels at that site. Extracted concentrations of elements in these soils at the four sites were also variable. Elk Run and ICG, with soil pH above 6, had high extractable concentrations of Ca, Mg, and Mn. Fola had the highest extractable concentration of Al and Ni, which would be expected in soils with pH below 4.

3.2 | Tree and shrub survival

No significant differences in average survival were found between the 2015 and 2016 sampling years for all species (p = .51, 41% vs. 40%). For individual species, survival percentages were <2% difference between 2015 and 2016. Therefore, the 2016 data were chosen to represent survival percentages in further detail. For the entire study, including all species and all sites, survival was 40% in 2016 (Table 3).

Significant differences in survival were found among species across the four sites (Table 3). Five species had ≥50% average survival across sites. Eleven of the 20 species were between 37% and 47% survival and two species had survival percentages between 25% and 37%. Two species in the study had survival percentages ≤10%: flowering dogwood (10%) and pawpaw (9%). Overall, Elk Run showed the overall highest survival for all planted seedlings at 51%, ICG and Fola were intermediate at 42% and 45%, respectively, and Hobet was lowest at 25% (Table 3). Only black cherry and hazelnut survivals were not significantly different among sites.

Aspect significantly affected survival of these species, and west-facing aspects had an overall greater survival than the east-facing aspects (44% vs. 36%, respectively) across all species and sites. Of the 20 species, nine species had significantly greater survival on west-facing aspects (American crabapple, common apple, flowering dogwood, pawpaw, Washington hawthorn, wild plum, black chokeberry, blueberry, and gray dogwood), whereas two had greater survival on east-facing aspects (hazelnut and highbush cranberry). Although tree and shrub survival was generally greater on west-facing compared with east-facing aspects in this study, the results were highly influenced by four species with much higher survival on the

TABLE 3 Mean survival by species on each site and average for all sites in 2016

Species	Elk Run	Hobet	ICG	Fola	Ave	
	Age 9 (%)		Age 7 (%)		Ages 9 and 7 (%)	*p* value
Trees						
American crabapple	55	48	20	34	40	<.0001*
Black cherry	53	59	48	66	55	.17
Choke cherry	73	26	41	26	44	<.0001*
Common apple	24	36	57	54	41	<.0001*
Common pear	32	18	49	64	37	<.0001*
Eastern redbud	76	8	47	56	45	<.0001*
Elderberry	23	12	37	46	27	<.0001*
Flowering dogwood	6	5	22	6	10	<.0001*
Pawpaw	0	0	31	4	9	<.0001*
Persimmon	62	6	41	42	37	<.0001*
Red mulberry	64	3	48	56	41	<.0001*
Serviceberry	76	46	26	14	44	<.0001*
Washington hawthorn	41	30	70	98	54	<.0001*
Wild plum	82	16	43	26	44	<.0001*
Average Trees	47	22	41	42	38	
Shrubs						
Black chokeberry	45	40	69	82	56	<.0001*
Gray dogwood	82	2	50	40	44	<.0001*
Hazelnut	N/A	N/A	48	54	50	.56
Highbush blueberry	18	70	18	0	30	<.0001*
Highbush cranberry	75	22	42	54	47	<.0001*
Nannyberry	81	25	38	74	52	<.0001*
Average Shrubs	60	32	44	51	47	
Average Trees/Shrubs	51	25	42	45	40	

Note. The probability of significant difference (p value $\leq .05$) is shown for mean survival for each species among sites.

*Data denote significant mean survival differences for that species among sites in 2016.

west-facing aspects (common apple—53% vs. 30%, Washington hawthorn—70% vs. 40%, black chokeberry—76% vs 37%, and blueberry —50% vs. 10%; data are not shown but are available in Monteleone, 2017). These results conflict with most studies that show better survival of woody plants on east-facing aspects due to less intense sunlight, cooler soils, and better soil moisture conditions (Fekedulegn, Colbert, Rentch, & Gottschalk, 2004). These conflicting results deserve further study but may be related to microsite and microclimate variability.

At Elk Run and Hobet, average shrub survival was slightly better (73%) than average tree survival (63%) after the first year, which dropped to 46% for shrubs and 35% for trees at Age 9 (Table 4). Eleven of the 19 species on these sites exhibited ≥70% survival at Age 1. Four species had <50% survival at Age 1. At ICG and Fola, average shrub and tree survivals were similar at 80% at Age 1 (Table 4). Sixteen of the 20 species had ≥70% survival after the first year, with nine of them having ≥90% survival at Age 1.

Persistence after planting is one of the most important characteristics of planted seedlings. At Age 9, only five species had ≥50% survival at Elk Run and Hobet (Table 4). Choke cherry went from 91% survival after the first year to 50% at Age 9. Serviceberry started with 80% survival and declined to 61% at Age 9. Most of the species declined in survival to about half of what had survived at Age 1; for example, Washington hawthorn declined in survival from 71% to 36%. Pawpaw had the lowest survival percentage at Age 9, and the decline from 64% survival after the first year to 0% was the largest decline of all planted species. The best-surviving trees and shrubs at these two sites were primarily from the *Rosaceae* family, all being important species for wildlife habitat and food. Nannyberry is from the *Caprifoliaceae* family.

Of the 20 species planted at ICG and Fola, nine species had ≥50% at Age 7, with most showing survival declines of about half from Ages 1 to 7. Black chokeberry began with 100% survival after the first year that declined to 73% at Age 7. Washington hawthorn had 99% survival at Age 1 and 79% survival at Age 7. Conversely, highbush blueberry started with 43% survival that declined to 12% at Age 7. Species with ≤37% survival after several years suggest that they may not be suitable candidates for planting in reforestation projects on reclaimed mine soils.

From Table 3, which averaged the survival of all four sites, five species were categorized with good (≥50%) survival. Eleven species had moderate survival (37% to 47%), and four species fell into

TABLE 4 Mean survival after the first growing season (Age 1) and after 9 years (Age 9) on the sites planted in 2008 (Elk Run and Hobet), and after the first growing season (Age 1) and after 7 years (Age 7) on the sites planted in 2010 (ICG and Fola)

Species	Elk Run and Hobet			ICG and Fola		
	Age 1 (2008)	Age 9 (2016)	*p* value	Age 1 (2010)	Age 7 (2016)	*p* value
	%			%		
Trees						
American crabapple	56	52	.56	35	25	.46
Black cherry	67	56	.38	91	54	.05*
Choke cherry	91	50	.005*	87	36	.01*
Common apple	81	30	.005*	97	56	.009*
Common pear	44	25	.15	97	54	.008*
Eastern redbud	61	42	.27	87	50	.28
Elderberry	48	18	.11	48	40	.96
Flowering dogwood	12	6	.15	71	17	.008*
Pawpaw	64	0	.0002*	73	22	.005*
Persimmon	80	34	.007*	94	41	.005*
Red mulberry	55	34	.23	95	51	.06
Serviceberry	80	61	.40	65	22	.03*
Washington hawthorn	71	36	.02*	99	79	.12
Wild plum	84	49	.05*	95	37	.03*
Average Trees	63	35		81	42	
Shrubs						
Black chokeberry	84	43	.02*	100	73	.06
Gray dogwood	45	42	.64	89	47	.11
Hazelnut	—	—	—	93	50	.06
Highbush blueberry	73	44	.15	43	12	.03*
Highbush cranberry	75	49	.09	83	46	.10
Nannyberry	86	53	.02*	73	50	.29
Average Shrubs	73	46		80	46	
Average Trees/Shrubs	66	38		81	43	

Note. The probability of significant difference (p value $\leq .05$) is shown for mean survival for each species between Ages 1 and 9 for Elk Run and Hobet, and between Ages 1 and 7 for ICG and Fola.

*Data denote significant mean survival differences for that species between Ages 1 and 9 or 7.

the poor survival category (≤30%). Except for nannyberry, the best-surviving species are semidrought tolerant (Table 1) and can survive in high solar conditions. The five worst-surviving species generally have low tolerance to droughty conditions and are often found in shaded environments. Newly reclaimed surface mines generally have soil conditions that are droughty (coarse, rocky soils), and planted seedlings are exposed to high solar radiation.

Weather conditions experienced by the plants in the first year of establishment may have greatly influenced survival. In 2008, when Elk Run and Hobet were planted, temperatures for WV were below normal for spring and summer, and near normal for winter, whereas precipitation was above normal in the spring, near normal in the summer, and below normal in the fall (NOAA, 2009). The sites planted in the spring of 2010 (Fola and ICG) experienced a much warmer than normal spring with normal precipitation (NOAA, 2011), summer was warmer than normal with a normal amount of precipitation, whereas fall was hotter and precipitation was below normal for WV (NOAA, 2011). Survival after the first year on sites planted in 2008 was 66% and in 2010 was 81%. It would appear from these average weather conditions during the years of establishment that weather was not indicative of the difference in survival during 2008 and 2010.

Seedling survival of small trees and shrubs in this study were slightly lower than seedling survival of oaks (*Quercus* spp.), poplars (*Liriodendron* and *Populus* spp.), and maples (*Acer* spp.) in other reforestation studies. In this region, survival of planted oak and poplar seedlings is usually between 80% and 90% after the first year (Casselman, Fox, Burger, Jones, & Galbraith, 2006; Chazdon, 2008; Koropchak, Zipper, Burger, & Evans, 2013; Skousen et al., 2009). Survival after 7 or 9 years across all species in this study was 40%, which was generally lower (Emerson, Skousen, & Ziemkiewicz, 2009; Skousen et al., 2009) or similar (Wilson-Kokes, Emerson, DeLong, Thomas, & Skousen, 2013) to other tree planting efforts on reclaimed sites in the region, which are around 60%. Factors responsible for lower survival over time may be due to the planting stock's health and quality at planting, planting techniques, the stresses the individual plants experience in the soil environment at each site (moisture and nutrients), and the species' tolerance to the stressful conditions of mine soils.

The absence of a tree canopy in the study areas, which is an important growth requirement for some small tree and shrub species, appeared to affect survival in this study. Species having a partial-shade requirement such as pawpaw and flowering dogwood had poor survival. Shading would be beneficial to many of these species by decreasing the amount of solar radiation received, decreasing soil temperature, and increasing the amount of soil moisture. Most species needing shade also require moist soil conditions and organic matter in soils to thrive, both of which are deficient in Appalachian mine soils.

Three species planted in this study were also monitored for survival in a study by Wilson-Kokes et al. (2013) on reclaimed mines close to this study. They found after 8 years that black cherry survival was 11%, dogwood was 44%, and eastern redbud was 33%, all of which were lower than the 60% average survival of red oak (*Quercus rubra* L.), tulip-poplar (*Liriodendron tuliperfa* L.), white ash (*Fraxinus americana* L.), and white oak (*Quercus alba* L.) in their study. In this study, black cherry survival was 55%, dogwood was 10%, and eastern redbud was 45%, which indicates the wide variation in survival of trees and shrubs on reclaimed sites in Appalachia.

3.3 | Tree and shrub height

Significant differences in height across sites in 2016 were found for 13 species (Table 5) with most of the differences being related to lower average species height at Hobet. Elk Run, ICG, and Fola almost always had taller plants than Hobet. Poor growth of trees and shrubs at Hobet (0.83 m average height) corresponded to the overall poor survival at that site (25%). Fola apple and pear trees were found to be significantly taller than those at the three other sites. For shrubs, height of black chokeberry was significantly higher at Fola compared with Hobet. Surprisingly, Fola had a complete die out of highbush blueberry, which should have grown better on the low pH soils at Fola.

The effect of aspect on average height of these species was mostly insignificant (data are not shown but are available in Monteleone, 2017). Three species (common apple, flowering dogwood, and Washington hawthorn) had significantly greater height on west-facing aspects than east-facing aspects, and no species grew significantly taller on east-facing aspects. As mentioned, the soil conditions of east-facing aspects are generally acknowledged to be better for survival and growth for most woody species because these aspects

TABLE 5 Mean seedling height for each species after the first growing season (average of all sites, Age 1) and after 9 years (Age 9) at Elk Run and Hobet, and after 7 years (Age 7) at ICG and Fola

Species	Average	Elk Run	Hobet	ICG	Fola	Average	*p* value
	Age 1	Age 9		Age 7		Ages 9 and 7	
	M						
Trees							
American crabapple	0.19	1.31	0.72	0.79	1.20	1.00	.03*
Black cherry	0.57	1.60	1.43	1.67	1.93	1.66	.10
Choke cherry	0.34	1.62	0.91	1.07	1.79	1.35	.08
Common apple	0.45	0.81	0.84	0.97	1.71	1.08	.02*
Common pear	0.32	1.86	0.77	1.42	2.32	1.59	.01*
Eastern redbud	0.37	1.33	0.62	0.76	1.56	1.07	.50
Elderberry	0.11	1.15	0.68	0.79	0.98	0.90	.80
Flowering dogwood	0.29	0.82	1.03	0.84	0.79	0.87	.09
Pawpaw	0.20	—	—	0.74	0.61	0.68	.30
Persimmon	0.31	1.53	0.66	1.01	0.95	1.04	.04*
Red mulberry	0.41	1.45	0.58	1.06	1.80	1.22	.001*
Serviceberry	0.29	2.12	1.09	1.00	1.07	1.32	.01*
Washington hawthorn	0.50	1.34	0.62	1.27	1.96	1.30	.003*
Wild plum	0.53	1.78	0.81	1.09	1.76	1.36	.005*
Average Trees	0.35	1.44	0.83	1.04	1.46	1.18	
Shrubs							
Black chokeberry	0.39	0.77	0.58	0.85	1.20	0.85	.01*
Gray dogwood	0.40	1.79	1.23	1.26	0.96	1.31	.71
Hazelnut	0.35	—	—	0.62	1.07	0.85	.01*
Highbush blueberry	0.15	0.63	0.87	0.57	—	0.69	.0001*
Highbush cranberry	0.30	1.73	0.53	1.25	1.23	1.19	.0004*
Nannyberry	0.35	1.70	0.88	1.11	1.60	1.32	.03*
Average Shrubs	0.32	1.32	0.82	0.94	1.01	0.93	
Average Trees/Shrubs	0.34	1.38	0.83	0.99	1.23	1.06	

Note. The probability of significant difference (p value $\leq .05$) is shown for mean height for each species among sites.

*Data denote significant p values for mean height differences for that species among sites in 2016.

normally result in cooler and wetter soil conditions than west-facing aspects. But this aspect effect was not reflected by growth of these species on our sites.

As expected, trees and shrubs on these sites showed substantial growth between the first year after planting (Age 1) and the next sampling time in 2016 (Table 5). Five species grew about 1 m from Ages 1 to 7 or 9, including black cherry (difference between average height [1.66 m in 2016] and at Age 1 [0.57 m] = 1.09 m), choke cherry (1.01 m), common pear (1.27 m), serviceberry (1.03 m), and gray dogwood (0.91 m). The only species that showed poor growth from the earlier to later sampling time was pawpaw (0.48 m). When compared with other studies, Wilson-Kokes et al. (2013) showed after 8 years that black cherry height was 1.5 m compared with 1.66 m in this study, gray dogwood was 1.4 m compared with 1.31 m here, and eastern redbud was 1.45 m tall compared with 1.07 m in this study.

The effects of varying site and soil properties (Table 2) was reflected in a range of survival and growth values of the planted species. Elk Run site had the highest survival (51%) and Hobet the lowest (25%). Hobet had a slope of 22%, a pH of 4.5, low EC, and a high soil content of 74%, all of which should be compatible with potential tree and shrub growth. However, Hobet exhibited the worst overall survival and height. Further, Fola had moderate slope, the lowest pH range (<4.0), and the highest EC value of any site in this study, which were less suitable for plant growth. Yet this site had high survival and growth for many of the species including black cherry, choke cherry, common apple, common pear, eastern redbud, Washington hawthorn, black chokeberry, and hazelnut. Soil pH is often a soil parameter indicative of plant growth, but it did not seem to be an important factor here. Fola (low soil pH) and ICG (high soil pH) had similar heights for many species.

Generally, the growth of most of the species was not associated with the silvical characteristics reported here (Table 1) or in the literature (e.g., Burns & Honkala, 1990). For example, blueberry prefers acidic soils and does not thrive in alkaline conditions (Haynes & Swift, 1985). Interestingly, the most acidic site, Fola, had the poorest blueberry survival. Similarly, some of the species that tolerate drier soil conditions should have grown well in this study but grew poorly or moderately well (i.e., eastern redbud). Drought tolerance is often reflected by a conservative growth strategy, where tolerance provides improved survival over less tolerant species, and may be partially responsible for the limited number of height differences among species.

Our objective was to evaluate which species from a list of 20 would perform well when planted on four reclaimed mine sites 7 and 9 years after planting. This study demonstrated a range of survival from 0% to almost 60% for this broad assortment of trees and shrubs. Fourteen of the 20 species grew three to four times over their initial planted seedling height. The results of a study like this provide important information about collective success of planted trees and shrubs on several sites with varying site and soil conditions. Those species that averaged good survival and growth across these four sites provides some confidence that they may be successful in establishing and growing when planted at other reclaimed sites. These results will help reclamation planners select appropriate small trees and shrubs for reforestation projects on reclaimed lands. Further monitoring of survival and growth of these small trees and shrubs here and at other reclaimed reforestation projects will provide more information to refine the selection of species.

4 | SUMMARY AND CONCLUSIONS

The survival of small trees and shrubs on surface mines in this study averaged 40% after 7 and 9 years, which was lower than that of reforestation plantings with commercially valuable trees on reclaimed land (~60%) after 8 years (Wilson-Kokes et al., 2013). Five species (black cherry, Washington hawthorn, black chokeberry, hazelnut, and nannyberry) out of the 20 included in this study had ≥50% survival 7 or 9 years after planting. These species successfully established and persisted in this growing environment and are recommended for future reclamation reforestation plantings. They all produce benefits for wildlife food and habitat. Eleven other species survived from 37% to 47% and could be considered as candidates for reforestation plantings. Four species in this study had poor survival (≤30%) and included two species with ≤10% survival (e.g., pawpaw and flowering dogwood).

In reclamation plantings, mortality of planted seedlings is often very high due to planting stress, harsh soil conditions, and herbivory. But after the first year, seedling mortality rates tend to decrease from that experienced during the first year (Burger et al., 2005). Therefore, selection of high-surviving plants for reforestation projects would provide better success and greater benefits long-term. The results of this study will aid reclamation planners in selecting species for future reforestation plantings. Planting of the better performing species in this study including black cherry, choke cherry, eastern redbud, serviceberry, Washington hawthorn, wild plum, black chokeberry, gray dogwood, hazelnut, highbush cranberry, and nannyberry would potentially encourage and accelerate ecological succession and benefit wildlife. Many of the more successful species were from the *Rosaceae* family that produce food and cover for wildlife. Some species had poor survival after 7 or 9 years on these sites that indicated that planting these species may not be practical and a waste of resources. Additionally, to increase the survival of the species that are more adapted to shade and other more mature soil conditions and to save money, it may be advisable to delay transplanting of these species or to simply wait for natural recruitment and succession after a canopy has been established from the planted trees. Species that prefer moist soil conditions and shade, such as pawpaw, should not be included in these plantings.

ACKNOWLEDGMENTS

Appreciation is expressed to Williams Forestry and Associates including Rick Williams, Jon Pomp, and Michael French who originally planted more than 8,000 seedlings for this study. Jon Pomp and Michael French were responsible for monitoring the survival and growth after the first growing season, and we appreciate them for sharing this data with us. Thanks are also expressed to Kermit Fincham, Scott Perdue, and Cody Cooper of Elk Run; Kenny Daniel of Hobet, Dave Bays of Fola; and Keith O'Dell and Bill Young of ICG for allowing access and help during the sampling. This project was

supported by the USDI Office of Surface Mining Reclamation and Enforcement (OSMRE) Applied Science Program Cooperative Agreement S15AC20022 and by funds appropriated under the Hatch Act at West Virginia University. Scott Eggerud pf OSMRE served as the project officer. This article is #3339 from the West Virginia Agricultural and Forestry Experiment Station, Morgantown, WV.

CONFLICT OF INTEREST

The authors confirm that there is no conflict of interest in this research project.

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How to cite this article: Monteleone A, Skousen J, Shuler J, McDonald L, Williams R, Holaskova I. Survival and growth of 20 species of trees and shrubs on Appalachian surface mines. *Land Degrad Dev*. 2018;29:1683–1693. https://doi.org/10.1002/ldr.2962