THE APPALACHIAN REGIONAL REFORESTATION INITIATIVE (ARRI)

FOREST RECLAMATION ADVISORY

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Establishing Small Tree and Shrub Species on Mined Lands Using the Forestry Reclamation Approach

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Under federal law, coal operators are required to restore the land to a condition capable of supporting the uses which it supported prior to any mining, or to higher or better uses (Surface Mining Control and Reclamation Act of 1977). Reforestation of mined lands aims to produce a sustainable forest similar to the forest that existed prior to disturbance (Zipper et al. 2011). The Appalachian Regional Reforestation Initiative (ARRI) encourages restoration of high-quality forests on reclaimed coal mines in the eastern USA (Angel et al. 2005, FR Advisory #1).

The Forestry Reclamation Approach (FRA) is a five-step process of practices known to successfully establish native forest trees on mined sites, which enables their survival, rapid growth, and development (Burger et al. 2005, FR Advisory #2).

The five steps are:

1. Create a suitable rooting medium for good tree growth that is no less than 4 feet deep and comprised of topsoil, weathered sandstone and/or the best materials.
2. Loosely grade the topsoil or topsoil substitute established in step one to create a non-compacted growth medium.
3. Use ground covers that are compatible with growing trees.
4. Plant early succession trees for wildlife and soil stability, and commercially valuable trees.
5. Use proper tree planting techniques.

Step 4 of the FRA encourages the planting of native early succession trees to provide food and cover for wildlife and to diversify plant communities, along with planting commercially valuable native crop trees. Davis et al. (2012, FR Advisory #9) note that more than 100 tree and shrub species grow in Appalachian forests (Figure 1) and they recommend planting small trees and shrubs in mined land reforestation projects in addition to crop trees. Among the early succession native tree and shrub species suitable for planting are eastern redbud, gray and flowering dogwood, American hazelnut, green hawthorn, common persimmon, and serviceberry.

Figure 1. Understory plants in an Appalachian forest.

When the first three steps of the FRA have been followed during reclamation, additional plant species from surrounding forests invade and colonize the site. However, many foresters acknowledge that planting a diversity of woody species at the start of forest re-establishment will enable more-rapid development of the functional and structural diversity of the ecosystem (Aerts and Honnay 2011; Cardinale et al. 2001). Also, the establishment of early succession woody species that produce fruits and seeds at a young age will attract birds and other wildlife that may bring seeds of plants from the adjacent forest, aiding those species' establishment in the reforested area. The intent of FRA reclamation is to develop a forest plant community that resembles the native forest, and thus to accelerate restoration of the land-use capability and ecosystem services that native forests provide (MacDonald et al. 2015; Zipper et al. 2011). A diverse plant community composed of both early and late succession species enhances the wildlife habitat potential, recreational, aesthetic, and productive value of the reclaimed land (Burger 2011).

Reclamation planners have often focused on planting commercially valuable trees. Traditionally, these include oaks, maples, tulip-poplar, and pines. Less emphasis has been on early succession and understory species. Few reforestation contractors plant multiple species of small trees and shrubs on reclaimed mines.

Since understory tree and shrub species are planted in fewer numbers than crop trees, less is known about their survival and growth. Nurseries may not stock a wide variety of native small trees and shrubs for reforestation plantings, hence, some of these beneficial species may not be available in sufficient numbers for large plantings. Thus, this advisory provides information about small tree and shrub species useful for planting in Appalachian mine lands and gives guidance for selection of early succession woody species to be planted along with commercially valuable crop trees as recommended in Step 4 of the FRA. This information will help planners select suitable candidates for planting and help nurseries know which species to provide for reforestation contractors.

FR Advisory #9 (Davis et al. 2012) includes a list of trees and shrubs which are useful for reforestation. The small trees and shrubs from that advisory are listed in Table 1. While almost all native woody plants provide wildlife benefits (for example, those that produce nuts such as the oaks and hickories), small trees and shrubs are particularly important for other food types and cover. Species such as dogwoods and eastern redbud grow rapidly and provide bird nesting sites as well as fruits and seeds for food. Less frequent species like hazelnut, witch hazel, and persimmon provide important structural diversity and unique fruits for food. Reclaimed forests are often plagued by invasive species such as autumn olive, multiflora rose, or Japanese barberry, aggressive competitors that are detrimental to native plant diversity and that can reduce food availability for wildlife (Wood et al. 2013, FR Advisory #13; Adams et al. 2019, FR Advisory #16). Rapid establishment of canopy cover by woody plants, such as that from early succession small trees and shrubs, can help deter invasions by invasive plants (Zipper et al. 2019, FR Advisory #17). Finally, some small tree and shrub species may aid forest succession processes by providing better habitat for late succession species and by contributing to soil nutrients and development.

How Well Do Small Trees and Shrubs Survive?

To answer this question, we evaluated eight reforestation trials on mined lands that included small trees and shrubs. Summaries of site conditions and survival results are below.

1. In a study in central Appalachia, Monteleone et al. (2018) reported survival and growth of 20 small tree and shrub species at four sites with a wide range of soil and site conditions in southern West Virginia. Slopes varied from rolling to steep and average soil pH ranged from 4.5 on one site to 7.5 on another. All four sites had been reclaimed using standard (non-FRA) techniques with topsoil and moderate compaction tracking, and seeded with aggressive herbaceous species (ground cover competition varied between 20 to 100% at time of transplanting). The woody species were planted after herbaceous vegetation had been established.

Seven years after planting, survival of small tree and shrub species averaged 40% across the four sites, and five species out of the 20 had ≥50% survival (Table 2). The five were black cherry, Washington hawthorn, black chokeberry, hazelnut, and nannyberry (Figure 2).

Survival rates for 11 other species ranged from 37 to 47% (Table 2). Four species in this study had poor survival (≤30%) including elderberry, pawpaw, flowering dogwood, and blueberry. All of these species produced food and habitat benefits for wildlife.

2. In another set of studies, Tyree et al. (2017, 2018) examined 30 native tree and shrub species that were planted at the Flight 93 National Monument in central Pennsylvania (northern Appalachia) from 2012 to 2017. Of the 30 species, 10 were considered understory species. The Flight 93 Memorial site is located on a legacy mine site which had been revegetated with aggressive herbaceous plants during the 1980s. Soil materials were a mix of brown and gray sandstone/shale; soil pH ranged from 5.0 to 6.0. The area supported a moderate stand of herbaceous cover with a few volunteer trees scattered across the site. Mine soils were treated with deep tillage prior to planting (Burger et al. 2013, FR Advisory 11), and trees and shrubs were planted in the trenches created by soil ripping. Trees were measured five to seven years after planting.

Sumac and hawthorn had high survival rates, and both experienced natural regeneration at this site (Table 2). Because of regeneration, actual survival of planted seedlings for these species could not be determined and survival is shown as 100%. Black chokeberry had a 70% survival rate and dogwood had 60%. Ninebark, mountain ash, crabapple, and hazelnut showed 20 to 40% survival, while survival for elderberry was less than 5%. Based on the results of this study, five of the 10 species had greater than 40% survival (black chokeberry, ninebark, sumac, hawthorn, and dogwood).

3. At the Catenary Mine, an active mine reclamation site in southern West Virginia, nine tree species were planted and two were small understory trees (Wilson-Kokes et al. 2013). This site was flat to gently rolling and had 4 feet of non-compacted brown sandstone. Soil pH was 7.5 at the time of planting and decreased to 6.7 after eight years, while vegetative cover ranged from 40 to 70%. Eastern redbud and flowering dogwood had between 43 and 46% survival, respectively, eight years after planting (Table 2).

4. At a legacy mine site in Dickenson County, Virginia, four species survived poorly after four growing seasons (Evans et al. 2013). Eastern redbud survived at 37%, flowering dogwood and red mulberry showed 17% survival, and crabapple survived at a much lower rate of 3%.

5. At a site in Wise County, Virginia, three species were grown in alkaline siltstone with moderate grading and a tree-compatible groundcover (Fields-Johnson et al. 2012). After seven growing seasons, red mulberry and eastern redbud showed 86% and 67% survival, respectively (Table 2). Gray dogwood survived at 50%.

6. At an active mine reclamation site in southern WV, three understory species (eastern redbud, gray dogwood, and green hawthorn) all exhibited ≥80% survival after one growing season (Kropchak et al. 2013).

7. At a southwestern Virginia mine site reclaimed with both weathered sandstone and unweathered siltstone after nine years (Zipper et al. 2012), dogwood species survival was 86% after nine years (Table 2). The nitrogen-fixing shrub bristly locust was also planted; it grew and reproduced prolifically across all site areas, but this shade-intolerant species remained present primarily in areas that had not yet achieved canopy closure, which were mostly those reclaimed using unweathered siltstone.

8. At a reclaimed mine site in southeastern Ohio, a pre-SMCRA forested area (planted 50 years ago) was recently cleared of understory invasive exotic plants (autumn olive, multiflora rose, or barberry) and planted with five native understory species. After one growing season, survival of all planted species exceeded 89%. Persimmon, eastern redbud, black haw, and gray dogwood had a 95% survival rate (R. Swab, unpublished data). Arrowwood survival was slightly lower at 90%. Pre-SMCRA forests may benefit from understory plantings and, due to soil preparation and control of competing vegetation, may have higher survival rates of trees than post-SMCRA sites.

Establishing Understory Woody Species

The Forestry Reclamation Approach Advisories provide guidance on site preparation, mine soil selection and quality, compatible ground covers for reforestation plantings, woody species selection and planting guidelines on mined lands. Some important points are summarized below and these recommendations should be followed for planting of understory shrubs and trees.

1. Select and Place Suitable Soil Material

The Forestry Reclamation Approach specifies selecting the best available soil material. Forest Reclamation Advisory #8 (Skousen et al. 2011) explains that native soils are generally more favorable for tree and shrub growth than mine spoil materials. Plus, the native soils often contain seeds and other propagules of native plants that can establish to create a diverse plant community (Hall et al. 2010). Natural soils can be used alone if quantities are sufficient, or they can be mixed with mine spoils. When native soils are not sufficient or suitable, weathered brown mine spoils are preferred over unweathered gray spoils (Wilson-Kokes et al. 2013).

Soil assessment and testing should be done to help determine soil quality, soil amendments, and tree species selection (Burger et al. 2013, FR Advisory #11). Soil properties important to consider are color, pH, conductivity, and compaction. Planners should extract a soil sample to a depth of 6 inches for every 3 acres of planting area and send samples for soil analysis to a reputable soil testing laboratory (Skousen et al. 2011, FR Advisory #8). Use the recommendations for lime and fertilizer application, loosening the soils by ripping (Sweigard et al. 2007, FR Advisory #4), and removing competing vegetation (Burger et al. 2013, FR Advisory #11).

2. Develop a Planting Plan and Select Appropriate Woody Species

A mixture of small trees and shrubs should be planted based on the guidelines of Davis et al. (2012, FR Advisory #9) and Rathfon et al. (2015, FR Advisory # 13) and the information presented in this advisory. Trees planted using a mixture of compatible woody species with understory trees could be planted between the crop trees. Trees and shrubs should be matched to their appropriate moisture/site type, and complement the post-mining land use.

3. Use Good Planting Stock and Proper Planting Procedures

Bare-root stock are the typical seedling type on most surface mine reforestation projects; proper planting procedures are described in FR Advisory #8 (Davis et al. 2010). For special plantings and where no bare-root seedlings are available for certain species, container seedlings (seedlings grown in pots) may be used. As noted in Zipper et al. (2018, FR Advisory #15), container seedlings are more costly than bare-root seedlings and they require more effort and time to plant because a bigger planting hole is needed. However, when planted correctly and protected, survival is generally higher and growth is more rapid for container seedlings. Herbaceous vegetation should also be established on non-vegetated soils and Burger et al. (2009, FR Advisory #6) describe compatible herbaceous vegetation that should be seeded in reforestation projects.

4. Protect and Maintain the Plantings

Re-establishing trees as bare-root seedlings on areas with pre-existing vegetation requires the competing vegetation be controlled or minimized (Burger et al. 2013, FR Advisory #11). Tree seedling survival and growth will improve as competition from other plants is reduced. Browsing and girdling of tree seedlings by wildlife can destroy tree and shrub plantings, so control measures such as tree tubes or wire cages can be used to protect seedlings until they are old enough to withstand browsing or grow out of the reach of browsers.

Conclusions

Based on the results of studies on understory tree and shrub survival and growth, a variety of small tree and shrub species can be planted along with crop trees during reforestation (Table 2). Many of these species showed >40% survival after five or more years of planting. Small tree and shrub species should be chosen for reforestation plantings based on their tolerance of site conditions, including geographic location, slope and soil type, pH, compaction, and herbaceous competition. Ripping tends to ease initial planting and increase subsequent survival. The understory woody species should make up between 20 to 30% of the planted species. These species should be distributed over the planting area and should be planted in locations where they will have the best chance for survival.

Table 2 lists the survival of small tree and shrub species that have been tested in reforestation

Figure 2. Small tree and understory species successfully growing on reclaimed mine sites in West Virginia. Top row from left to right: red bud, Washington hawthorn, black chokeberry. Bottom row left to right: grey dogwood, hazelnut, cranberry.

studies. Some performed well while others did not. If a species performed poorly in the studies highlighted here, this result alone should not preclude it from being tried and tested on other sites. Many of the species listed in Table 1 (Davis et al. 2012) have not been tested in field studies and are not included in Table 2 where no data were available. The untested species may still be considered for reforestation plantings if bare-root seedlings or containerized plants are available.

As forests age and timber trees overtop smaller species, the amount of small-sized trees and shrubs will decline in the maturing forest interior. Where planting conditions allow, consider planting more small trees in areas likely to become permanent forest edges, such as along infrequently used roads, parking areas, drainages, and along boundaries with open land so that natural reproduction and wildlife habitat enhancement provided by these small trees and shrubs will continue after most of the forest understory becomes too shaded to sustain optimal growth of these species. At these locations, the lasting presence of small trees will noticeably improve the appearance of the reclaimed area from a distance as their flowers, fruits and bright fall colors provide visual diversity and a vivid contrast at the forest edge where more visitors are likely to see them.

Table 1. Small trees and shrubs found in Appalachian forest communities (from Davis et al. 2012) and that can be planted in reforestation projects in Appalachia. Plants are listed in alphabetical order by Latin name. Plant species mentioned in this advisory are also added to the list. Crop trees and conifers have been removed.

Species	**Latin Name**	**Growth Rate**	**Site Type**	**pH Range***	**Wildlife Value**
Allegheny serviceberry	*Amelanchier laevis*	moderate	moist	low-high	soft mast
false indigo bush	*Amorpha fruticosa*	slow	moist	low-high	browse
eastern redbud	*Cercis canadensis*	slow	moist	medium-high	browse
silky dogwood	*Cornus amomum*	moderate	moist	medium	cover
flowering dogwood	*Cornus florida*	moderate	moist	low-high	browse
gray dogwood	*Cornus racemosa*	moderate	all	low-medium	browse
American hazlenut	*Corylus americana*	moderate	moist	medium	hard mast
green hawthorn	*Crataegus viridis*	moderate	all	low-high	browse
common persimmon	*Diospyros virginiana*	slow	all	low-high	soft mast
American witchhazel	*Hamamelis virginiana*	slow	moist	low-medium	soft mast
sweet crab apple	*Malus coronaria*	slow	moist	medium	soft mast
red mulberry	*Morus rubra*	moderate	moist	medium	soft mast
American plum	*Prunus americana*	moderate	moist	medium	soft mast
bristly locust	*Robinia hispida*	rapid	dry	low-high	browse
black elderberry	*Sambucus nigra*	rapid	moist	low-high	soft mast
sassafras	*Sassafras albidum*	moderate	moist	low-high	browse
highbush blueberry	*Vaccinium corymbosum*	moderate	wet	low-high	soft mast
southern arrowwood	*Viburnum dentatum*	slow	all	low-medium	soft mast
Black haw	*Viburnum prunifolium*	slow	all	low-high	soft mast
Kentucky coffeetree	*Gymnocladus dioicus*	slow	Moist	medium-high	cover
Added Species					
black chokeberry	*Aronia melanocarpa*	slow	moist	medium-high	soft mast
pawpaw	*Asimina triloba*	moderate	moist	medium	soft mast
ninebark	*Physocarpus opulifolius*	slow	dry	medium	soft mast
choke cherry	*Prunus virginiana*	rapid	all	medium-high	soft mast
staghorn sumac	*Rhus typhina*	rapid	all	medium-high	soft mast
mountain ash	*Sorbus americana*	slow	all	medium-high	soft mast
nannyberry	*Viburnum lentago*	moderate	moist	medium	soft mast
highbush cranberry	*Viburnum opulus*	moderate	moist	medium	soft mast

*pH range key: low pH <5; medium pH 5-7; high pH >7.

Table 2. Survival results of small trees and shrubs based on field studies in Appalachia. The list of species is divided into good (>40%), moderate (30 to 40%), and poor (<30%) survival. Superscripts next to % survival refer to the reference studies listed in the footnote for each species. All studies were located in central Appalachia, except for Tyree et al. (2018), which was in northern Appalachia.

Species	Latin Name	% Survival
Good Survival		
serviceberry	*Amelanchier laevis*	44[1]
black chokeberry	*Aronia melanocarpa*	56[1], 75[2]
eastern redbud	*Cercis canadensis*	45[1], 42[3], 37[4] 67[5], 81[6]
gray and flowering dogwood	*Cornus spp.*	44[1], 60[2], 46[3], 16[4], 49[5], 80[6], 86[7]
hazelnut	*Corylus americana*	50[1], 30[2]
green hawthorn	*Crataegus viridis*	54[1], 100[2], 85[6]
crabapple	*Malus coronaria*	40[1], 37[2], 3[4]
apple	*Malus pumila*	41[1]
red mulberry	*Morus rubra*	41[1], 17[4], 86[5]
American plum	*Prunus americana*	44[1]
choke cherry	*Prunus virginiana*	44[1]
ninebark	*Physocarpus opulifolius*	40[2]
bristly locust	*Robinia hispida*	100[7]
sumac	*Rhus typhina*	100[2]
cranberry	*Viburnum trilobum*	47[1]
nannyberry	*Viburnum lentago*	52[1]
Moderate Survival		
persimmon	*Diospyros virginiana*	37[1]
pear	*Pyrus communis L.*	37[1]
blueberry	*Vaccinium corymbosum*	30[1]
Poor Survival		
black elderberry	*Sambucus nigra*	27[1], 2[2]
mountain ash	*Sorbus spp.*	25[2]
pawpaw	*Asimina triloba*	9[1]

[1] Monteleone et al. 2018
[2] Tyree et al. 2018
[3] Wilson-Kokes et al. 2013
[4] Evans et al. 2013
[5] Fields-Johnson et al. 2012
[6] Kropchak et al. 2013
[7] Zipper et al. 2012

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All Forest Reclamation Advisories are available on the Appalachian Regional Reforestation Initiative's web page (www.arri.osmre.gov). In addition, a compilation of Advisories 1-12 can be found in *The Forestry Reclamation Approach: Guide to successful reforestation of mined lands*, published by the USDA Forest Service, Northern Research Station, available from https://www.nrs.fs.fed.us/pubs/54344.

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