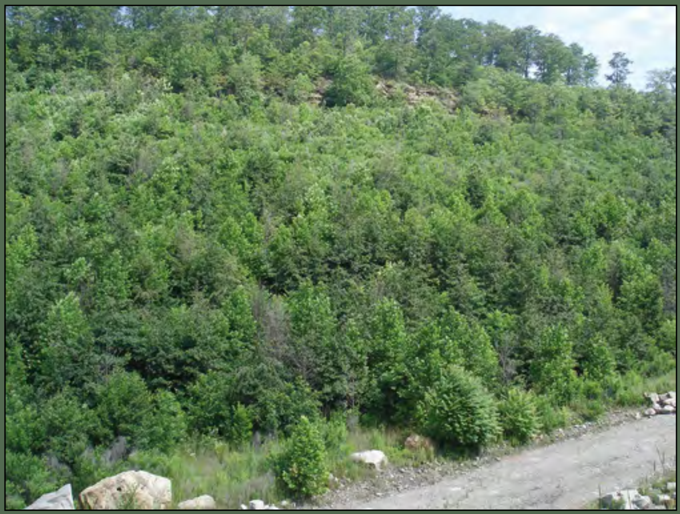
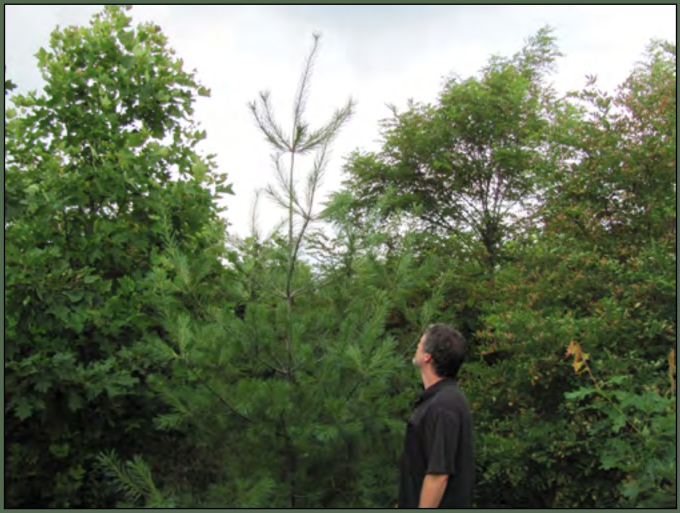
United States Department of Agriculture

The Forestry Reclamation Approach: Guide to Successful Reforestation of Mined Lands





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The Forestry Reclamation Approach: Guide to Successful Reforestation of Mined Lands

Mary Beth Adams, Editor

Cover Photos of Success Stories

These mined sites in West Virginia have been reclaimed to healthy forest with the Forestry Reclamation Approach. Top left: A backfilled outslope in Kanawha County, about 15 years after reclamation by planting minimal ground cover. Top right: A valley fill in Logan County, 12 years after reclamation. Bottom left: Mined site in Monongalia County, 10 years after reclamation by planting tree seedlings into heavy ground cover. Bottom right: Mined site in Nicholas County, about 10 years after reclamation by planting tree seedlings on good mine soil material. Note how much growth has occurred between the top whorl of branches and the second row of branches in the sapling at center. This is the type of growth that can be expected with eastern white pine on a suitable soil medium. Photos by J. Skousen, West Virginia University, used with permission.

U.S. Department of Agriculture Forest Service

Appalachian Regional Reforestation Initiative

Office of Surface Mining Reclamation and Enforcement

ABSTRACT

Appalachian forests are among the most productive and diverse in the world. The land underlying them is also rich in coal, and surface mines operated on more than 2.4 million acres in the region from 1977, when the federal Surface Mining Control and Reclamation Act was passed, through 2015. Many efforts to reclaim mined lands most often resulted in the establishment of grasses, shrubs, and nonnative plants. Research showed that forests could be returned to these mined lands, also restoring the potential for the land to provide forest ecosystem services and goods. Scientists and practitioners developed a set of science-based best management practices for mine reforestation called the Forestry Reclamation Approach (FRA). To help practitioners implement the 5 steps of the FRA and achieve other restoration goals (such as wildlife enhancement), 13 Forest Reclamation Advisories have been written since 2005 and others are underway. The 12 Advisories that are most directly relevant to the Appalachian region are being published here in a single volume for the first time.

These Advisories were originally posted on the Web site of the Appalachian Regional Reforestation Initiative (ARRI), an organization created in 2004 by the U.S. Department of the Interior's Office of Surface Mining Reclamation and Enforcement along with State mining regulatory authorities in the Appalachian region. Members of ARRI come from the coal mining industry, government agencies, and research institutions. The goal of this initiative is to promote forest reclamation and restoration on mine lands through planting of high-value hardwood trees, increasing those trees' survival rates and growth, and speeding the establishment of forest habitat through natural succession. To accomplish these goals, ARRI promotes and encourages use of the FRA by reclamation specialists. The Advisories are intended to serve as easy-to-understand guides to implementing the FRA; they provide specific recommendations as well as illustrations and photos to demonstrate tasks. The reformatted Advisories in this volume contain updated information and the latest additional resources to guide reclamation practitioners and other stakeholders in the reestablishment of healthy, productive forests in the Appalachian region.

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PREFACE

Christopher Barton, Carl Zipper, and James Burger

In 2004, the U.S. Department of the Interior's Office of Surface Mining Reclamation and Enforcement (OSMRE) along with State mining regulatory authorities from coal-producing areas in the Appalachian region created the Appalachian Regional Reforestation Initiative (ARRI) to promote forest reclamation and restoration on active and abandoned mine lands in the eastern United States. Since the passage of the federal Surface Mining Control and Reclamation Act (SMCRA) in 1977 (Public Law 95-87, 30 U.S.C. 1201 and following), through 2015, more than 2.4 million acres of land were mined for coal in the Appalachian region. Efforts to reforest these areas had historically resulted in high seedling mortality, slow growth, and poor production. In a region of the United States that is known for its beautiful mountainous forests, coal mining was dramatically changing the land cover. Where forest once prevailed, grass, shrubs, and nonnative plants were introduced—and began to dominate the landscape—after the mining was complete. The loss of the forest resource due to reclamation with grass and shrub species posed many environmental, ecological, and economic challenges to the region. Not only were soil, water, and air quality affected, but wildlife habitat and food webs were altered. Moreover, this large-scale and systematic land-use conversion compromised future economic opportunities involving timber and nontimber forest products.

Although grassland reclamation became the norm in the Appalachian region after the passage of SMCRA, research showed that forests could be returned to these postmining lands if proper reclamation practices specific for forest reclamation were followed. Several studies had documented that highly compacted soils with chemical characteristics unfavorable to forest trees, and intense competition from seeded herbaceous plants, were impeding the establishment of productive forest trees on surface mines in the Appalachian region. Other obstacles to reforestation of mined lands included poor selection of rooting media, planting of tree species that were not suited to site conditions, improper tree planting techniques, and competition from invasive plants that proliferate and thrive on mined areas.

Drawing on the recommendations generated by decades of surface mine reclamation research, reclamation scientists developed a set of best management practices for mine reforestation called the Forestry Reclamation Approach (FRA). The FRA is based on the research, knowledge, and experience of forest soil scientists, other scientists, and reclamation practitioners.

With the development of the FRA, OSMRE made a commitment to address reforestation shortcomings by regulatory authorities and the mining industry alike through the creation of ARRI. Simply, the goals of this initiative were to promote planting of high-value hardwood trees on surface mines, increase the survival rates and growth rates of those trees, and expedite the establishment of forest habitat through natural succession (the natural changes in plant community composition with time). These goals were to be accomplished by promoting and encouraging use of the FRA by reclamation practitioners, including the coal mining industry.

The organization of ARRI consists of two teams, the Core Team and the Science Team. The Core Team is made up of State mining agency and OSMRE personnel. It facilitates and coordinates the cooperative efforts of many groups: the coal industry; landowners; university researchers; watershed, environmental, and conservation groups; and State and federal government agencies that have an interest in creating productive forest land on reclaimed mined lands. The Core Team also addresses regulatory policies when such policies are found to be hindering effective application of the FRA. The Science Team consists of university, federal agency, and other scientists who are familiar with Appalachian mining and reclamation. The Science Team ensures that the methods ARRI promotes are based on proven science, conducts continued scientific research into forestry reclamation, and communicates effective and science-based reforestation practices to reclamation practitioners, including those who work with industry and agencies.

To this end, the ARRI Science Team prepared a series of Forest Reclamation Advisories that are intended to serve as guidance documents for FRA implementation. The content of the Advisories was based on proven scientific research and field application, but the Advisories were written with the intention of easy understanding by field practitioners. The Advisories provide specific recommendations as well as illustrations and photos to demonstrate how these tasks are implemented. A small group of Science Team members initiates preparation of each Advisory, sometimes at the request of the Core Team, but the full Science Team is involved with developing the Advisory. Each Advisory is reviewed by the full Science Team, and revisions continue until the Science Team members reach consensus that the Advisory is complete. At that point, the Core Team also reviews the Advisory, but with a focus on regulatory issues. If Core Team members think that a recommended practice is not consistent with State or regulatory policy, that issue is addressed with another revision. Once the full Science Team and Core Team agree that the Advisory is ready for publication, the Advisory is posted on the ARRI Web site, and shared with industry and agency practitioners to encourage more effective reforestation of mine sites.

To date, 13 Advisories have been written and are available at no cost on the ARRI Web site (http://arri.osmre.gov/) hosted by OSMRE. The first two Advisories provide specific information on ARRI and describe the FRA. The following seven Advisories (numbers 3 through 9) describe how to implement the five steps of the FRA. The next three Advisories (numbers 10 through 12) document how the FRA can be used for other restoration goals (wildlife enhancement; restoring mined lands that were reclaimed under SMCRA but not reforested, or "legacy mines"; return of the American chestnut). The 13th Advisory deals with mine land reclamation in the Midwest. Other Advisories are under development including planting mixes for forest reclamation outside the Appalachian region and planning for pollinators as a postmining land use.

Many in the coal industry within the Appalachian region have embraced the focused efforts by ARRI and its partners to promote the FRA, and significant changes in reclamation practices have resulted. From ARRI's inception in 2004 through 2015, about 95 million trees were planted on more than 140,000 acres of surface coal mines. ARRI continues to educate and train active mining industry and regulatory personnel about the FRA to promote effective reforestation of new surface mine disturbances. ARRI has also been instrumental in the reforestation of "legacy mines" and abandoned mined lands in the United States. Implementation of the reforestation guidelines for legacy mined land developed by ARRI scientists has resulted in the planting of these lands throughout the Appalachians.

The Forest Reclamation Advisories were instrumental in the success of ARRI and widespread application of the FRA. Both the ARRI Science and Core Teams expressed a desire to compile the Advisories in a single volume that could be distributed to interested parties. Not only would the development of this product be useful for that purpose, but putting it together would provide an opportunity to revisit each Advisory and update it with the most current information.

This volume contains 12 chapters, one for each of the Forest Reclamation Advisories that are directly relevant to the Appalachian region. These Advisories have been reformatted for this publication and are arranged by theme. Our hope is that this volume will continue to aid restoration efforts for one of the region's most valuable assets—the Appalachian forest—and will present ARRI reforestation methods to a wider audience.

CONTENTS

CHAPTER 1
THE APPALACHIAN REGIONAL REFORESTATION INITIATIVE

Patrick Angel, Vic Davis, Jim Burger, Don Graves, and Carl Zipper

INTRODUCTION

The Appalachian Regional Reforestation Initiative (ARRI) is a cooperative effort by the States of the Appalachian region with the U.S. Department of the Interior's Office of Surface Mining Reclamation and Enforcement (OSMRE) to encourage restoration of high-quality forests on reclaimed coal mines in the eastern United States. The goals of ARRI are to communicate and encourage mine reforestation practices that 1) plant more high-value hardwood trees on reclaimed coal-mined lands in the Appalachian region, 2) increase the survival rates and growth rates of planted trees, and 3) expedite the establishment of forest habitat through natural succession. These goals can be achieved when mines are reclaimed by using the Forestry Reclamation Approach (FRA).

The FRA is a method for reclaiming coal-mined land to forest under the federal Surface Mining Control and Reclamation Act of 1977 (SMCRA), and is based on knowledge gained from both scientific research and experience (Chapter 2, this volume). State mining agencies and OSMRE consider the FRA to be an appropriate and desirable method for reclaiming coal-mined land to support forested land uses (Kentucky Department for Surface Mining Reclamation and Enforcement 1997; Ohio Department of Natural Resources 2001; U.S. Office of Surface Mining Reclamation and Enforcement 1999; Virginia Department of Mines, Minerals, and Energy 2001a, 2001b). Seven states (California, Kentucky, Maryland, Ohio, Pennsylvania, Tennessee, and West Virginia) have codified the FRA in their official policy or a memorandum of understanding to signal their adoption of the FRA as a means of reforesting mined sites.

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This chapter is based on Forest Reclamation Advisory No. 1, which originally appeared in December 2005 on the Appalachian Regional Reforestation Initiative's Web site (http://arri.osmre.gov) hosted by the U.S. Department of the Interior's Office of Surface Mining Reclamation and Enforcement. (Note that authors' affiliations were current when the Advisory was originally written.)

When mining and reclamation operations are conducted using the FRA, results can include both cost-effective regulatory compliance by the coal mine operator and productive postmining forests. Productive forests generate value for their owners and provide watershed protection, wildlife habitat, and other environmental services (Fig. 1).

Figure 1.—Thinning and pruning a 17-year-old white pine stand established by an active coal mining operation in Virginia using procedures similar to the Forestry Reclamation Approach. Scientific studies demonstrated that this site's productivity is comparable to that of the area's native forests (Rodrigue and Burger 2004), and that the stand's response to management has created additional economic value for the timber landowner (Burger and others 2003). Photo by J. Burger, Virginia Tech, used with permission.

WHY IS THE APPALACHIAN REGIONAL REFORESTATION INITIATIVE NEEDED?

The roles of ARRI are to coordinate and improve the sharing of information about mined land reforestation, and to promote further research on reclamation and restoration of mine lands across all the Appalachian states. Even though application of SMCRA methods improved the landforms of surface mines compared to pre-SMCRA conditions, the mined land was generally not restored as forest. In contrast with the aftermath of pre-SMCRA mining, the SMCRA approach increased land-surface stability, improved water quality, and enhanced human safety in the Appalachian region. However, implementation of SMCRA has not been accompanied by widespread replacement of forests disturbed by mining. Many mined lands were restored as grasslands, but the owners do not currently use them for hay or pasture. Natural succession will eventually restore native forests on such areas, but this process is slow—centuries may be required.

After passage of SMCRA, regulators focused on stability of landforms created by mining at the expense of restoring forest land capability. They adopted this approach in an attempt to solve the problems caused by pre-SMCRA surface mining, such as severe erosion, sedimentation, landslides, and mass instability. As a result, excessive soil compaction was common on surface mines, and aggressive groundcover species were generally planted. Furthermore, the technical complexities of implementing SMCRA were a challenge to both regulators and mine operators. Consequently, reforestation took a backseat. Last, some of the mine operators' early efforts to reforest under SMCRA proved problematic, in part because they were conducted without the benefit of the scientific knowledge available today. Mine operators and regulators came to believe that postmining land uses such as hayland and pasture were easier and cheaper to achieve than forests. These factors and others contributed to a significant loss of forests due to mining across the Appalachian region. Efforts by the ARRI Science and Core Teams (Preface, this volume) are intended to increase knowledge and change attitudes about planting trees on surface mines.

Forests have been the traditional land use throughout the eastern coalfields and support an established industry; in recent years, resurgence in the hardwood timber and wood-using industries has occurred throughout the region. Furniture, flooring, and paneling are made from many fine hardwood species. Softer woods are used for plywood, oriented strandboard, and wood pulp. Industrial wood-users are seeking "soft hardwoods" such as yellow-poplar (tuliptree), red maple, American sycamore, green ash, and bigtooth aspen—all of which have good potential as reclamation species—along with the traditionally valuable species such as the oaks. (Please see the Appendix starting on p. A-1 for scientific names of species mentioned in this chapter.) Furthermore, forests provide many benefits such as wildlife habitat, watershed control, carbon sequestration, and recreation. Owners of mined lands, who were once content to have their land reclaimed to grassland and shrubland, are becoming more interested in reforestation with commercially valuable hardwoods.

A goal of mined land reclamation under SMCRA is to create land with equal or better postmining land use potential than before mining. Scientific research has demonstrated that reforestation using the FRA is capable of achieving this goal. On many grassland areas created after passage of SMCRA, soil properties are actually less favorable to forests than they were before mining.

WHAT IS A FOREST RECLAMATION ADVISORY?

Reforestation researchers and experts from universities and agencies throughout the region have joined forces with federal and State regulators to form ARRI. One goal of ARRI's Science Team is to generate a series of guidance documents called Forest Reclamation Advisories which describe state-of-the-science procedures for coal mine operators and other mine reforestation practitioners, agency personnel, and owners of mined land. For Web-based access to the Forest Reclamation Advisories, or additional information about the ARRI Science and Core Team members, see the ARRI Web site at http://arri.osmre.gov/.

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CHAPTER 2
THE FORESTRY RECLAMATION APPROACH

Jim Burger, Don Graves, Patrick Angel,
Vic Davis, and Carl Zipper

INTRODUCTION

The Forestry Reclamation Approach (FRA) is a method for reclaiming coal-mined land to forest under the federal Surface Mining Control and Reclamation Act of 1977 (SMCRA). The FRA is based on knowledge gained from both scientific research and experience (Fig. 2-1). The FRA can achieve cost-effective regulatory compliance for mine operators while creating productive forests that generate value for their owners and provide watershed protection, wildlife habitat, and other environmental services.

Forest Reclamation Advisories are guidance documents that describe state-of-the-science procedures for reforestation of mined land. The purpose of this Forest Reclamation Advisory is to describe the FRA. State mining agencies and the U.S. Department of the Interior's Office of Surface Mining Reclamation and Enforcement (OSMRE) consider this approach to be an appropriate and desirable method for reclaiming coal-mined land to support forested land uses under SMCRA (Chapter 1, this volume). Members of the Science Team of the Appalachian Regional Reforestation Initiative (ARRI), which is drawn from universities and other research organizations in nine states (Preface, this volume), and other groups and agencies also support this approach.

THE FIVE STEPS OF THE FORESTRY RECLAMATION APPROACH

The FRA can be summarized in five steps:

1. Create a suitable rooting medium for good tree growth that is no less than 4 feet deep and consists of topsoil, weathered sandstone, or the best available material, or a combination of these materials.
2. Loosely grade the topsoil or topsoil substitutes established in Step 1 to create a noncompacted growth medium.

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Figure 2-1.—A northern red oak stand that grew on a surface mine reclaimed pre-SMCRA in southern Illinois. Observations by reclamation scientists and practitioners of soil and site conditions on reclaimed mines such as this, where reforestation was successful, have contributed to development of the Forestry Reclamation Approach. Photo by J. Burger, Virginia Tech, used with permission.

3. Use groundcover species that are compatible with growing trees.
4. Plant two types of trees: early successional species for wildlife and soil stability, and commercially valuable crop trees.
5. Use proper tree planting techniques.

Step 1. Create a suitable rooting medium

Tree survival and growth can be hindered by highly alkaline or acidic soils. During mining and reclamation, all highly alkaline materials with excessive soluble salts and all highly acidic or toxic material should be covered with the best available rooting medium that will support trees. Place the growth medium on the surface to a depth of at least 4 feet to accommodate the needs of deep-rooted trees.

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 are preferred. However, where such materials are not available, an equilibrium pH as low as 4.5 or as high as 7.5 is acceptable if tree species tolerant of those conditions are used.

Native hardwood diversity and productivity will be best on soils where the pH is between 5.0 and 7.0, and such trees generally grow best in soils with loamy textures, especially sandy loams. Such soils can be formed from overburden materials composed predominantly of weathered brown sandstones, especially if these materials are mixed with natural soils (Fig. 2-2). Use of materials with soluble salt levels less than 1.0 mmhos/cm on the surface is preferred when such materials are available. See Chapter 3 of this volume for further information about FRA Step 1.

Step 2. Loosely grade the topsoil or topsoil substitutes

Excessive soil compaction can severely reduce survival and growth of trees (Fig. 2-3). Even if a soil's chemical properties are ideal, excessive compaction will create a soil that is poorly suited for trees. Use standard engineering practices to place and compact most of the backfill—but not the final surface. The surface layer, which will form the soil for the postmining forest, should be at least 4 feet deep and only lightly graded. Surface grading on longer and steeper slopes should be minimized, provided that doing so does not jeopardize stability.

To reestablish a healthy and productive forest after mining, final grading must minimize surface compaction. This can be achieved by:

Figure 2-2.—A mixture of weathered brown and unweathered gray sandstones, loosely graded to form a soil medium suitable for trees in West Virginia. Photo by J. Burger, Virginia Tech, used with permission.

- Dumping and leveling in separate operations,
- Leveling with the lightest equipment available, using the fewest passes possible, and during dry conditions, and
- Permanently removing all equipment from an area after leveling.

"Tracking-in" operations (Fig. 2-4) compact the soil and hinder tree growth. Avoid these operations unless necessary for slope stability. Rubber-tired equipment should not be used in final grading. See Chapters 4 and 5 of this volume for further information about FRA Step 2.

Figure 2-3.—Photos showing how mine soil properties can have a dramatic effect on tree growth. The eastern white pines in both photos were the same age (8 years old) when the photos were taken; the pines in the left-hand photo grew on compacted alkaline shales; the pines in the right-hand photo grew on a moderately acid sandstone. Photos by J. Burger, Virginia Tech, used with permission.

Figure 2-4.—Soil compaction due to heavy equipment operation on mine soils hinders survival and growth of planted trees. “Tracking-in” operations, such as those shown in the photo, are not recommended for mine sites on which trees will be planted, unless required to stabilize steep slopes. Photo by J. Burger, Virginia Tech, used with permission.

Step 3. Use ground covers that are compatible with growing trees

Groundcover vegetation used in reforestation requires a balance between erosion control and competition for the light, water, and space required by trees. Groundcover species should include grasses and legumes that are slow growing, have sprawling growth forms, and are tolerant of a wide range of soil conditions. Fast-growing and competitive grasses such as Kentucky-31 tall fescue and aggressive legumes such as sericea lespedeza and crownvetch should not be used where trees will be planted. Slower-growing grasses such as red top and perennial ryegrass, and legumes such as bird’s-foot trefoil and white clover, will increase seedling survival when used in a mix with other appropriate species. (Please see the Appendix starting on p. A-1 for scientific names of species mentioned in this chapter.) This slower-growing vegetation will also control erosion over the longer term as the trees and accompanying vegetation mature to form a forest. Apply fertilizer at rates lower in nitrogen than those commonly used to establish pastures, so as to discourage heavy groundcover growth. Rates of phosphorus and potassium should be targeted toward optimal tree growth. See Chapter 6 of this volume for further information about FRA Step 3.

Step 4. Plant the right mix of tree species

To produce a valuable forest that supports multiple uses, plant a mix of native timber species as crop trees. Such species include those that are compatible with the landowner’s postmining forest-management goals, have the potential to grow into healthy trees where they are planted, and are found in the local mature forests. Depending on local conditions, such species might include the oaks, black cherry, sugar maple, and white ash. Reforestation experts recommend that about one-fifth of the seedlings planted should be a mix of species able to survive in the open conditions commonly found on newly reclaimed sites and that support wildlife and soil improvement. Such species might include bristly locust, redbud, dogwood, and crab apple—again, depending on which species are known to do well under local conditions. Mix the selected species when planting them over the site, rather than planting them separately as single-species blocks. When all FRA steps are used, additional native species with seeds that can be carried by wildlife or wind will volunteer and become established on their own, leading to a species mix similar to the surrounding native forests. Mine operators should work with the State regulatory authority to develop reforestation plans that meet State requirements. See Chapter 7 of this volume and Rathfon and others (2015) for further information about FRA Step 4.

Step 5. Use proper tree planting techniques

Poor tree survival is often due to improper handling or planting of seedlings. Tree seedlings should never be allowed to dry out during storage and handling prior to planting, and should be kept dormant until planted. Seedlings should be kept cool, but should not be allowed to freeze, and should be protected from direct sunlight and high temperatures before planting. Plant the seedlings in late winter to early spring at the proper depth and firmly enough to ensure survival (Fig. 2-5). Reputable and experienced crews are recommended for broad-scale, operational tree planting. See Chapter 9 of this volume for further information about FRA Step 5.

Members of the ARRI Science Team have studied and field tested these five steps (Fig. 2-6). They have determined that these steps can be implemented readily and successfully. Plantings on active mine sites by coal mining firms using these techniques have established productive young forests. Additional information on each of these five steps is provided by other Forest Reclamation Advisories (Chapters 3 through 12, this volume).

Figure 2-5.—Planting a seedling at a reforestation project on a reclaimed mine site in Tennessee. Because the soil has not been compacted, a planting hole of the correct depth for the seedling can be opened easily. The seedling is being planted while still dormant, during the late winter season. Photo by R. Williams, Williams Forestry, used with permission.

Figure 2-6.—An emerging hardwood forest established on an active mine in Virginia as a demonstration of the Forestry Reclamation Approach. Photo by J. Burger, Virginia Tech, used with permission.

The FRA is intended to be compatible with mine operators' goal of cost-effective regulatory compliance. Avoidance of soil compaction requires that leveling and grading operations be minimized, which helps the operator control equipment operation costs. The species recommended for forest-compatible ground covers are widely available at a reasonable cost, and are best seeded with fertilization rates lower than those used commonly for grassland establishment.

Avoidance of soil compaction will make it easier for tree planters to plant seedlings firmly and at the proper depth, thereby increasing survival rates. Survival of planted seedlings will also increase if surface materials are selected with chemical and physical properties suitable for trees and if less-competitive ground covers are successfully established. These two steps will allow for recruitment by native tree species from the surrounding forest as well.

HOW DOES THE FORESTRY RECLAMATION APPROACH IMPROVE VALUE, DIVERSITY, AND SUCCESSION OF RECLAIMED FORESTS?

The FRA is designed to restore forest land capability. When these five steps are followed, forest land productivity equal to or better than that which preceded mining can be restored. Furthermore, the FRA accelerates the natural process of forest development by creating conditions similar to those of natural soils where native forests thrive. By limiting compaction during reclamation, the growth medium becomes deep and loose, similar to the best forest soils. Temporary erosion-control ground covers are selected to allow native herbaceous and woody plants to seed in, emerge, and grow. The groundcover species are meant to be sparse and slow growing in the months following seeding, after which they will yield to a more diverse species mix that will control erosion and will be self-sustaining as required by SMCRA. Over the longer term, the herbaceous ground cover will yield to native forest through the process of natural succession (changes in the composition of the plant community with time).

Natural succession is further accelerated by planting late successional, heavy-seeded species such as the oaks, which wind and wildlife do not easily disperse from the native forest. Planting these heavy-seeded species puts them onsite right away, allowing them to emerge with other species that can seed in on their own (Fig. 2-7). When a good growth medium is established, as outlined in Steps 1 and 2 of the FRA, late successional plants will thrive, especially if native soil is used or mixed with suitable overburden materials. Using native forest soils as a part of the growth medium will accelerate native vegetation establishment because vegetation will sprout from those seeds of forest understory and tree species that remain viable. Overall, such reclamation practices create a diverse and valuable forest of native trees that produces wood products and wildlife habitat.

The FRA does not preclude mine operators from establishing tree crops such as biomass plantations, Christmas trees, or nut orchards, if such reclamation satisfies permit requirements and meets landowners' goals. In such cases, all of the five steps apply except that a tree crop is planted instead of a native hardwood mix. Tree crops will benefit from FRA reclamation.

Figure 2-7.—Red oaks established on the Starfire mine in eastern Kentucky using the Forestry Reclamation Approach. Photo by J. Burger, Virginia Tech, used with permission.

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Chapter 3: Selecting Materials for Mine Soil Construction when Establishing Forests on Appalachian Mined Lands

Jeff Skousen, Carl Zipper, Jim Burger, Christopher Barton, and Patrick Angel

INTRODUCTION

The Forestry Reclamation Approach (FRA), a method for reclaiming coal-mined land to forest (Chapter 2, this volume), is based on research, knowledge, and experience of forest soil scientists and reclamation practitioners. Step 1 of the FRA is to create a suitable rooting medium for good tree growth that is no less than 4 feet deep and consists of topsoil, weathered sandstone, or the best available material, or a combination of these materials. Selection and placement of a suitable growth medium are critical for successful reforestation on surface mines. Constructing mine soils using suitable materials enhances and accelerates development of diverse forest ecosystems. This Forest Reclamation Advisory provides guidance on how to execute Step 1 of the FRA and is intended for mine operators seeking to reestablish native forest as a postmining land use with pre-mining capability on surface mines.

BACKGROUND

Soil is a mixture of weathered rocks, organic material, water, air, and living creatures. Its properties provide the structural support and other resources necessary for plant and animal life in a forest. The soil is the foundation of a forest ecosystem. Indeed, the health and productivity of a forest are largely determined by the nature and properties of the soil.

The Appalachian Mountains are among the world's most ancient landscapes. The region's soils have developed over long time periods from the rocks that form this landscape, and they reflect the local climate, plants and animals, and landscape position (Jenny 1941). In turn, diverse plant communities throughout the Appalachians have evolved over millennia on these weathered rock and soil materials (Fig. 3-1).

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Figure 3-1.—A forest in the Appalachian Mountains. The Mixed Mesophytic Forest of the Appalachians is a diverse assemblage of more than 40 tree species that depend on native soil properties and other environmental factors. Photo by J. Burger, Virginia Tech, used with permission.

Weathering is the process of changing rocks into soil-like materials. During surface mining, unweathered rocks are often placed on the surface as a growth medium. These rocks react with air and water and break down physically and chemically, releasing soluble salts and changing mineral forms (Sencindiver and Ammons 2000). Plants can become established and grow in these presoil materials, producing organic matter to aid soil development and making the growth medium more favorable for colonization by microorganisms and other plants (Johnson and Skousen 1995). These processes are well known, occur naturally, and can be accelerated by reclamation activities such as fertilizing and seeding. When starting with unweathered rocks, however, very long time periods are required to produce a soil that can support a plant community like the one that existed before mining (Fig. 3-2).

Although unweathered gray rock materials brought to the surface during mining will eventually weather into soils, they are generally not suitable for restoring pre-mining forest capability. Forest development can be accelerated by using the natural soil, weathered brown rock materials, or a combination, to reconstruct the land surface (Fig. 3-3). Salvaged soils and weathered rocks are superior to unweathered gray rocks as soil substitutes because they supply nutrients, air, and water to plants (Figs. 3-4 through 3-7). Hardwood trees and other plants that are native to Appalachian landscapes have evolved to grow in the region's soils and near-surface weathered rocks (Smith 1983, Torbert and Burger 2000). (Please see the Appendix starting on p. A-1 for scientific names of species mentioned in this chapter.)

Figure 3-2.—Native soils of the Appalachian region (A) develop over long time periods and have properties that are well suited to supporting (B) native forest ecosystems. Photos by J. Burger, Virginia Tech, used with permission.

Figure 3-3.—Overburden consisting of weathered brown sandstone over unweathered gray sandstone and siltstone. The native soil has been stripped off the surface before blasting and mining. A native plant community is growing on native soils in the background. Photo by J. Skousen, West Virginia University, used with permission.

Figure 3-4.—Weathered brown sandstone on a West Virginia mine site 2 years after reclamation. The sandstone has formed a mine soil that supports good tree growth and promotes colonization by native plants. Mine soil pH is 6.0. The experimental areas on this mine site were not seeded with ground cover. Photo by J. Skousen, West Virginia University, used with permission.

Figure 3-5.—Unweathered gray sandstone on the same West Virginia mine site as in Figure 3-4 after 2 years showing some weathering into smaller particles, but generally poor tree growth and poor colonization by native plants. The pH is above 8.0. Photo by J. Skousen, West Virginia University, used with permission.

Figure 3-6.—The same mine site as in Figure 3-4, with weathered brown sandstone, 6 years after planting with native hardwood trees. Good growth by trees and herbaceous plants is evident. Photo by J. Skousen, West Virginia University, used with permission.

Figure 3-7.—The same mine site as in Figure 3-5, with unweathered gray sandstone, 6 years after planting with native hardwood trees. Although planted trees are surviving, growth is poor. Soil pH remains above 7.5. Photo by J. Skousen, West Virginia University, used with permission.

THE SURFACE MINING CONTROL AND RECLAMATION ACT

The federal Surface Mining Control and Reclamation Act of 1977 (SMCRA) requires that reclamation practices shall "restore the land affected to a condition capable of supporting the uses which it was capable of supporting prior to any mining, or higher or better uses of which there is reasonable likelihood …" (30 CFR Sec. 515 (b) (2)). The guidelines recommended here are consistent with SMCRA and promote the placement of soil materials that will create conditions suitable for forest reestablishment.

Forested land requires deep soil for productive tree growth (Andrews and others 1998, Torbert and others 1988). Regulations under SMCRA require removal and replacement of "topsoil" unless a variance from that requirement is obtained. Under SMCRA, the term "topsoil" is often used to describe the upper soil horizons, or the upper 6 inches of soil. Salvaging and respreading only the upper few inches of soil is unlikely to restore pre-mining capability unless additional materials suitable for reforestation are added. Federal regulations state that "selected overburden materials may be substituted for, or used as a supplement to topsoil if the operator demonstrates to the regulatory authority that the resulting soil medium is equal to, or more suitable for sustaining vegetation than the existing topsoil, and the resulting soil medium is the best available in the permit area to support revegetation" (30 CFR 816.22). This Advisory provides guidance for practices that may be used to satisfy that requirement when restoring mined land as forest.

GUIDELINES

1. Salvage and respread soil (except where the operation would compromise machine operators' safety)

The term "soil," as used here, refers to all surface soil material to a depth of broken bedrock that can be removed with a dozer. Soil includes the O, A, E, B, C, and R soil horizons. Soil to be salvaged for respreading should include soil organic matter and plant materials such as tree stumps, roots, branches, and leaves remaining from harvested trees, and rocks found within the soil profile. The best soil materials for reforestation are those with the most organic materials—that is, generally those which occur closest to the surface.

Soils from forested areas contain materials that aid plant community development on reclaimed mines. Three properties of soil make it especially valuable for reclamation when reestablishing forests. First, viable seeds and propagules contained in the soil (called a seedbank) enable restoration of native forest species (Hall and others 2010). Second, organic matter in the native soil contains nitrogen (N) and phosphorus (P), soil nutrients essential for plant growth that are not readily available to plants growing in unweathered mine spoils. Third, soil-dwelling animals and micro-organisms in the forest soil aid in providing and cycling nutrients for plants, create channels for air and water movement, and promote favorable hydrologic properties.

Soil should be considered a "living resource" and respread immediately when possible to maintain living soil animals, micro-organisms, roots, and seeds. When soil is obtained from forested areas before mining, the salvage operation should take stumps, roots, and woody debris left on the site, transport them to the reclaimed area, and respread them with the soil.

Even if salvageable soil is not available in quantities sufficient to produce an adequate depth over the entire reclamation area, replacement of fresh soil over portions of the reclamation area or mixing salvaged soil with other overburden materials, or a combination of these measures, will aid reestablishment of a native forest plant community. It will also aid restoration of essential ecosystem processes on the reclaimed mine land.

If graded to a smooth surface, and especially if lacking rocks and organic debris, salvaged soil may be more prone to erosion initially than the rocky spoils used in some reclamation practices today. Thus, when a slow-growing tree-compatible ground cover is used, some soil erosion may occur during the first year or two as the seeded and volunteer vegetation becomes established (Chapter 6, this volume). However, a surface that is loose, is rough with small depressions, and contains forest-floor rocks and organic debris enhances water infiltration, reducing runoff and surface erosion.

When both salvaged native soils and other materials are being used for mine soil construction, "mixing" is accomplished by hauling and dumping materials, and then by lightly grading the surface (Fig. 3-8) or with the use of other equipment to level the surface (Fig. 3-9) (Chapter 4, this volume). It is essential that spreading be done in a manner that avoids soil compaction. Additional equipment operation to mix these materials more thoroughly should be avoided to reduce the potential for compaction of the surface layers.

Figure 3-8.—Mixing of soil materials. Materials can be transported to the site, dumped in adjacent piles, and then lightly graded. Photo by J. Skousen, West Virginia University, used with permission.

Figure 3-9.—Excavator leveling dumped topsoil piles. An excavator can be used to level soil piles without causing compaction and can be useful when the dumped soil piles contain stumps, logs, and other coarse woody debris. Photo by J. Burger, Virginia Tech, used with permission.

2. Salvage and respread weathered spoil materials, and especially sandstones, where available and of suitable quality, to supplement soil materials

Weathered materials can be easily recognized on most mine sites by their brownish colors (Fig. 3-10). They are found just below the surface, usually within the upper 10 to 30 feet. Weathered sandstones, if available, will generally be superior as a reforestation growth medium to weathered siltstones and shales. Weathered sandstone will generally have a pH of 4.5 to 6.0.

Weathered rocks are not suitable as a growth medium if they are extremely acidic or contain pyritic materials that will cause water quality problems if used on the surface (Isabell and Skousen 2001). If soil pH is less than 4.0, the soil probably contains acid-producing minerals and should not be used. Some weathered sandstones are low in essential plant nutrients, and mixing these materials with weathered siltstone or shale may improve soil fertility (Showalter and others 2010). Soil tests can predict available nutrient levels in these materials.

Figure 3-10.—Weathered overburden above unweathered materials. Weathered overburden can be found immediately below the soil and often extends to about 30 feet beneath the surface—although it may be deeper. The weathered overburden, which has been affected by surface processes, is better material to place on the surface for forestry land uses than unweathered gray materials. Photo by C. Zipper, Virginia Tech, used with permission.

3. When soil and weathered brown sandstone are not available in adequate quantities, select unweathered overburden materials with suitable properties for use as supplemental materials

Just as a brown color can distinguish the weathering status of overburden, white and gray colors often indicate unweathered materials. Generally these materials when used alone will not support either rapid tree growth or rapid recolonization by native plants (Fig. 3-7) (Angel and others 2008, Emerson and others 2009). On remining sites, however, very little topsoil or weathered materials may be found. On these areas, almost exclusive use of unweathered materials as the growth medium may be unavoidable. In such cases, base selection of the best available material on physical and chemical tests that indicate likely suitability for trees. Unweathered overburdens that contain no pyritic minerals, are composed of rocks that break down to form soil-like materials when exposed to air and water, have relatively low levels of soluble salts, and weather to generate soil pH between 4.5 and 7 will form a better growth medium for forest trees than other unweathered spoil materials.

If soil and weathered materials are available but not abundant, selected unweathered materials of primarily sandstone with small amounts of shale and siltstone can be used (Burger and others 2007, Conrad 2002). We have documented mine sites where soils composed of weathered overburden support tree growth comparable to unmined forests (see Box 3-1), but we are not aware of mines reclaimed with only unweathered spoils that have achieved pre-mining productivity levels.

4. Avoid surface placement of materials that are unsuitable as a growth medium for native forest trees

Properties of spoil materials that make them unsuitable for reforestation are:

a) Content of coarse fragments (larger than 2-mm-diameter particles) of greater than 60 percent by mass that will not break down rapidly into smaller particles, such as materials typically used as durable rock (Daniels and Amos 1984, Haering and others 1993, Sencindiver and Ammons 2000).

b) High pH (more than 7.5).

c) Content of pyritic minerals sufficient to produce soils with pH less than 4, and to generate acids and excess salts, thereby elevating total dissolved solids (TDS) in runoff waters. Generally, materials with greater than 0.1 percent sulfur contents will be unsuitable.

d) Minerals that will produce high levels of soluble salts. Selected materials should achieve electrical conductivities of less than 1,000 µS/cm, as measured by methods commonly applied in soil analysis[1], when trees are planted. Generally, raw spoils with electrical conductivities more than 1,000 µS/cm, as measured using a method applied to raw spoils[2], will be unsuitable.

e) Carbonaceous rocks such as “black shales.” These rocks are usually unsuitable.

Avoid materials with these properties when constructing growth media for reforestation of coal surface mines. For a discussion of the scientific basis for these material selection guidelines, refer to Box 3-1.

Some mine sites, such as remining sites in areas where pyritic materials and shales are common, may lack materials suitable for reforestation to achieve pre-mining productivity. Operators on such sites should obtain expert assistance in selecting the best available materials. This Advisory does not address material selection for reforestation on such sites.

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[1]Measured after mixing soil-sized fragments with deionized water at a 1:5 soil:water ratio, following Rhoades (1982).

[2]Crush raw spoils to less than 0.5 cm and mix with deionized water at a 1:1 ratio; allow the mixture to sit for 30 minutes, then measure the water’s conductivity after filtration.

Box 3-1. Scientific Background for Material Selection Guidelines

Research and practice have shown that the FRA, when applied correctly and completely, will restore forest vegetation on mine sites. Numerous studies show that Step 1 of the FRA—selecting and properly placing good soil materials—is critical for reestablishment of productive, diverse forests.

The native soil is an excellent material for mine soil construction. Use of fresh soils as plant growth media can aid plant diversity by giving rise to living plants from seeds and propagules (Hall and others 2010, Showalter and others 2010, Skousen and others 2006, Wade 1989, Wade and Thompson 1993). Further, soil contains mycorrhizal fungi, important to plant growth and mine soil development (Miller and Jastrow 1992), along with organic nutrients and soil biota for nutrient cycling. Native forest soils have organic matter pools which can supply essential nutrients, including N and P, unlike raw spoils (Howard and others 1988, Li and Daniels 1994), and also increase soil water-holding and cation exchange capacities.

As reviewed by Skousen and colleagues (2011), other research has found that weathered rocks, especially sandstones, produce excellent soil materials. Casselman and others (2007) reported excellent tree growth on mine sites constructed from deep, uncompacted soil and weathered rock mixtures. Working on experimental plots in southwestern Virginia, Torbert and others (1990) found weathered sandstone to support greater growth of pitch × loblolly hybrid pine than unweathered siltstone spoil materials. Studying native hardwoods on an active mine site in southern West Virginia, Emerson and others (2009) recorded more rapid growth on weathered than on unweathered sandstone materials (Figs. 3-4 through 3-7). Working with four native hardwoods in eastern Kentucky, Angel and others (2008) found that weathered sandstone spoils supported faster tree growth and more rapid colonization by native plants than either unweathered sandstones or a mixture of the two spoil materials.

Several studies found that soil properties occurring in soils and weathered spoils, including low soluble salts and moderately acidic pH, are associated with good growth by forest trees on coal surface mines (Andrews and others 1998, Jones and others 2005, Rodrigue and Burger 2004, Showalter and others 2007, Torbert and others 1988).

SUMMARY

When native forest reestablishment is the postmining land use and reclamation goal, the FRA guidelines for creating a suitable rooting medium (Table 3-1) can aid mine operators in ensuring that mine soils, applied at a minimum of 4 feet in thickness, will restore land capability and support forest growth and diversity at pre-mining levels. An ability to restore native forests on mined lands after mining will be an asset to the Appalachian coal industry as it seeks to demonstrate its capability to mine coal in this region while protecting and restoring environmental quality. By following these guidelines, mine operators can help to restore productive and diverse native forests after mining.

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Table 3-1.—Summary of material types and guidelines for constructing forestry mine soils on Appalachian coal surface mines

Type	Description	Use
1. Soil	Pre-mining forest soil; includes mineral horizons, rocks, stumps, roots, and seedbank as well as soil-dwelling animals and micro-organisms	Use if available; usually the best available material.
2. Weathered rock	Brown rocks that lie beneath the soil prior to mining	Mix with (1) if necessary to achieve adequate quantity for ≥4-foot depth; sandstones are best.
3. Selected unweathered rock	Rock below weathered strata, usually gray, that weathers within a few years to pH 4.5-7.0, has relatively low soluble salts, and breaks down to form soil-like material	If (1) and (2) are not available in adequate quantities to produce a mine soil of ≥4-foot depth, (3) may be mixed at up to 2:1 ratio with (1) or (2), or a combination.
4. Unweathered rock to avoid	Has pyritic minerals, high pH, or high soluble salts, or a combination of these properties; or is durable rock or black shale	Avoid use for forestry mine soils, either alone or in significant quantities within mixes.

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Chapter 4: Low Compaction Grading to Enhance Reforestation Success on Coal Surface Mines

R. Sweigard, J. Burger, C. Zipper, J. Skousen,
C. Barton, and P. Angel

INTRODUCTION

This Forest Reclamation Advisory describes final-grading techniques for reclaiming coal surface mines to forest postmining land uses. Final grading that leaves a loose soil and a rough surface increases survival of planted seedlings and forest productivity. Such practices are often less costly than traditional "smooth grading" while meeting the requirements of the federal Surface Mining Control and Reclamation Act of 1977 (SMCRA).

LOW COMPACTION GRADING IS SMART RECLAMATION

Avoiding compaction during reclamation to forest makes good economic sense. It costs money to operate a dozer. Smooth surfaces do not contribute to postmining land use success and are not required under SMCRA. Therefore, grading with multiple passes to create smooth surfaces on reforestation sites is an unnecessary expense. The practice of covering the land surface with dozer track and cleat marks—often called walking-in or tracking-in—is also unnecessary and hinders reforestation success.

Leaving surface soils loose and uncompacted helps planted trees survive and grow:

- By helping planters get trees planted correctly: The planting hole must be large enough to hold the entire root system without requiring planters to bend or fold the roots. Generally, planting holes should be at least 8 to 10 inches deep. Planters will usually insert the planting tool to open the hole just one time. A seedling whose roots have been chopped short or folded to fit a shallow hole will be less likely to survive than a seedling that has been planted correctly with a full root system in an adequate hole. Leaving the soil loose makes it easier for the planters to get the tree's roots into the ground correctly.
- By allowing rainwater to infiltrate the soil: Soil surfaces that are loosely graded with rough configurations, or are left ungraded, allow

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more water to infiltrate than the smooth, tight surfaces produced by conventional grading. Increased infiltration means more water is available in the soil for the planted trees.

- By allowing the soil to hold more water and air: Spaces between soil particles hold and store water and air. Soil compaction compresses soil particles, making those spaces smaller. Thus, compacted soils will provide less water to growing trees between rainfalls, and will be less able to provide the air exchange that tree roots and soil organisms need.
- By allowing roots to grow more freely: The tree's roots are essential to its survival and growth. A loose, uncompacted soil allows roots to grow freely; in contrast, compacted soils limit root growth. A tree with a larger root mass will be able to reach a larger soil volume for water and nutrients, will have a greater chance of survival in the short run, and will grow bigger and faster in the long run.

Many scientific studies have found that soil compaction hinders survival and growth of planted trees. In eastern Kentucky, Torbert and Burger (1992) found that reducing soil compaction increased survival and growth of hardwood species and reduced soil erosion. Jones and others (2005) found that soil density on Virginia and West Virginia mine sites had a greater effect on eastern white pine growth than any other measured soil property. (Please refer to the Appendix starting on p. A-1 for scientific names of species mentioned in this chapter.) Seedlings planted in loosely graded experimental plots on eastern Kentucky's Starfire mine demonstrated excellent survival and growth, relative to trees planted in conventionally graded plots (Angel and others 2006). Emerson and Skousen (2006) reported greater than 80-percent survival of hardwood trees planted into end-dumped spoils that were graded with only one or two passes in southern West Virginia. Rodrigue and Burger (2004) found that pre-SMCRA mine soils with favorable chemical properties made excellent forest sites for both hardwood and softwood species—but only if the soils were left loose and uncompacted. Many other studies have had similar findings.

LOW COMPACTION GRADING PRACTICES

The Forestry Reclamation Approach (FRA) is a way of reclaiming active surface mines to maximize reforestation success (Chapter 2, this volume); Step 2 of the FRA is to loosely grade the topsoil or topsoil substitutes to create a noncompacted growth medium. This practice can be used on any type of surface mine. Techniques for low compaction grading are described next for various landforms.

Flat and Gently Rolling Surfaces on Mountaintop, Area, and Contour Mines

On surface mines where the final configuration will be flat or gently rolling, place the subsurface backfill using standard practices—whatever is required by the permit, including any compaction necessary for stability. When the postmining land use is forest, however, the surface material should be at least 4 feet deep and only lightly graded, if at all. To accomplish this where trucks are used to deliver the surface material, a process called end-dumping, tail-dumping, or loose-dumping is used (Fig. 4-1). The trucks dump the surface material into tightly spaced piles that abut one another across the reclamation area. Then, a light dozer can grade the spoil piles and level the area with one or, at most, two passes (Fig. 4-2). When this practice is used, it is essential that the piles be dumped close together so that the final surface thickness is 4 feet or more.

Level the loose-dumped materials with the lightest equipment available and using the fewest passes possible. If possible, grading should be done with just one pass of a low ground pressure (LGP) dozer. Equipment with rubber tires should not be used for final grading because rubber-tired equipment concentrates its weight on a smaller "footprint" and creates more surface compaction than tracked equipment.

Figure 4-1.—Loose-dumping a topsoil substitute over a compacted subsurface on a West Virginia surface mine. The topsoil-substitute material is being dumped in closely spaced piles and will be graded using only a single dozer pass. The final surface will be revegetated with a tree-compatible ground cover and trees will be planted in the loose topsoil-substitute materials. Photo by J. Skousen, West Virginia University, used with permission.

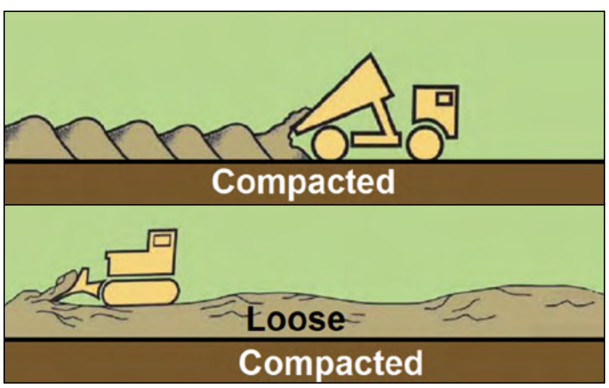

Figure 4-2.—Diagram of end-dumping and final grading on a truck-and-haul surface mine. Subsurface materials have been placed as described in the permit and have been compacted by equipment operations. Surface materials are dumped over the compacted subsurface to a depth of 4 to 6 feet (upper) and are graded only lightly so that they remain loose and uncompacted (lower).

Note the example of loose-dumped surface materials in Figure 4-3. Grading of these materials with a single pass of a track dozer during dry conditions would create soil conditions suitable for trees. Depending on State program policies and on material properties, it may be possible to plant trees in loose-dumped spoils such as those in Figure 4-3 with no further grading or leveling. This method is especially applicable if the material will drain water easily and weather to create a more level surface over time. If such piles are left on a sloped area, placing them in an alternating pattern that does not create linear downward channels can help prevent erosion.

Where a dragline is used, the spoil material can be cast and shaped in a manner that reduces the amount of final grading needed by tracked equipment. As with end-dumping, place the final surface in piles or ridges that tightly abut one another across the entire area. Then grade the spoil material with a single pass, or, at most, two passes (Fig. 4-4).

Another method of moving spoils to create a final surface suitable for trees is called dozer push-up (Fig. 4-5). This method can be used where spoils are moved only a short distance, so that the dozer is a more cost-effective way of moving the material than hauling in trucks. The materials are

Figure 4-3.—Loose-dumped soils on the surface at an Ohio mine site. Photo by M. Hiscar, OSMRE.

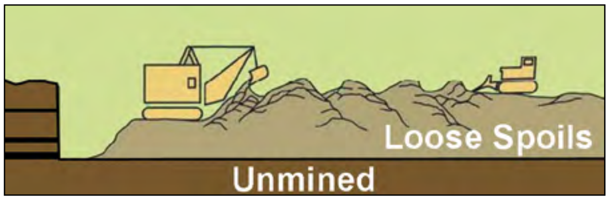

Figure 4-4.—Diagram of final grading on spoils placed by a dragline on a mountaintop or area mine.

Figure 4-5.—Diagram illustrating the "dozer push-up" method. This method can be used to prepare uncompacted surfaces that are suitable for reforestation where materials for surface placement are moved over a short distance. Depending on the situation and State program policies, it may be possible to use the "dozer push-up" surface for reforestation without a final strike-off grading. Otherwise, the push-up piles should be struck off with one or, at most, two passes with a light dozer.

pushed into long parallel ridges and are kept loose during each push. The dozer starts on one edge of an area with the material and pushes the first pile of the first ridge into place and then backs up and moves over one blade-width to push the next pile of the first ridge into place. Then the dozer returns to the starting edge and repeats the process for the next ridge. When viewed from above, the final grade surface looks like an old-fashioned washboard. In some situations and depending on State program policies, mine operators may have the option of leaving the dozer push-up ridges as the final surface for tree planting. Otherwise, strike off the surface by using a light dozer under dry conditions with only one or two passes, leaving a material depth of at least 4 feet.

Reconstructing Slopes

Practices for achieving an uncompacted growth medium on sloped backfills will vary from operation to operation. Backfill construction, however, should not vary much from what would be done normally—except that grading of the final surface is minimized. If the backfill materials are suitable and approved for use as a topsoil substitute, place those materials to construct the backfill using the usual practices. When all materials are in place, the dozers shape the fill to its final form—but they do not smooth and track-in the surface (Fig. 4-6). Do all grading moving downslope; confine upslope tramming to roads or tramways, which avoids tracking over and compacting materials that have already been shaped.

If the backfill requires compaction for stability, place all materials except the surface and compact as needed to construct a stable backfill using normal practices (Fig. 4-7). Dump topsoil or topsoil-substitute materials as needed to cover the outer surface of the compacted fill with 4 to 6 feet of loose, uncompacted material. Place the material from the outer edge of each lift, or construct an access road to enable the entire fill's surface to be dumped over from the top. If necessary, strike off the dumped spoil to shape the final landform. Again, do all dozing moving downslope and only as needed to shape the fill; confine upslope tramming to roadways or the like, which avoids tracking back over and compacting the shaped materials. It is essential to leave the outer surface of the underlying compacted materials in a rough configuration so as to assure a good interface with the uncompacted surface. Leaving a smooth surface on the compacted base of a steeply sloped fill can create a slide plane, making the surface material vulnerable to instability.

The mine operator is responsible for assuring that approximate original contour and backfill stability are achieved, as in any other SMCRA-regulated operation. Place and stabilize areas that will support final drainage ditches and waterways as in normal practice.

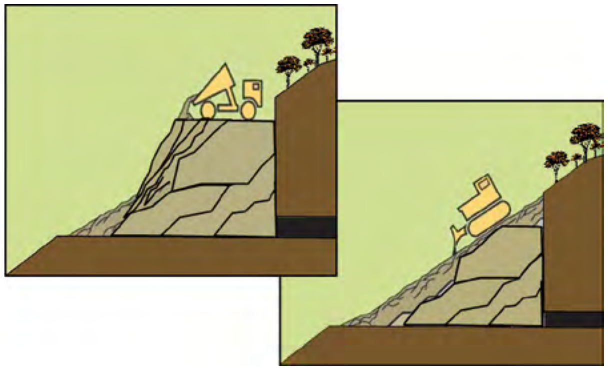

Figure 4-6.—Diagram of soil placement and final grading on a steep-slope contour mine where the backfill is constructed of approved topsoil substitute material and does not require compaction to maintain stability. The material is dumped in place (left) as per normal practice and then struck off to shape the backfill (right) but not graded smoothly. The dozer grades moving downward and trams back up on roads or defined tramways so as to minimize tracking back over materials that have already been shaped.

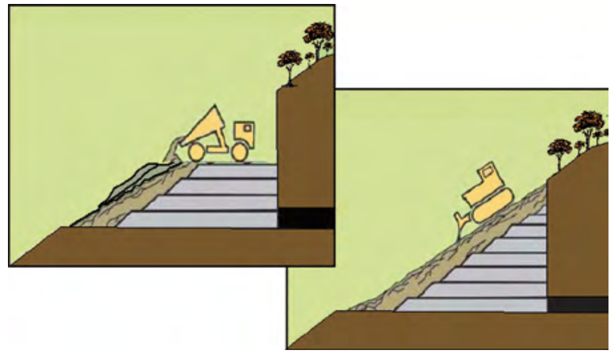

Figure 4-7.—Diagram depicting spoil placement and final grading to achieve stability on a steep-slope contour mine where backfill compaction is specified by the permit. The backfill materials are placed and compacted by using standard procedures as required for stability. Then loose materials suitable for surface placement are dumped over the compacted spoil material (left) and graded only lightly (right) and only if necessary to shape the final surface. The surface materials can be placed over the compacted backfill as each lift is completed, or they can all be dumped from the top lift.

Leaving a Rough Soil Surface

On any surface mine, low compaction grading techniques that create excellent forest soils will leave rough surfaces. Mine sites being prepared for reforestation can be left with rough surfaces similar to natural forests. Grading practices that leave small depressions and rocks on the surface will be an aid to successful reforestation (Fig. 4-8). Such surfaces absorb rainwater more easily than the smoothly graded surfaces that are used in reclamation for hayland, pasture, and other agricultural postmining land uses. The surface depressions and void spaces that occur on such sites can capture and germinate seeds that are carried to the site by wind or animals, and the rough surface increases water infiltration. Any water that infiltrates cannot cause erosion by running off the surface. If the surface materials contain old stumps or other organic debris from the pre-mining forest, these materials can also be left on the surface to aid reforestation.

Figure 4-8.—A topsoil-substitute material that has been prepared for revegetation by using the low-compaction grading technique on a coal surface mine. The materials have been left in a loose condition. The rocky, rough surface will aid water infiltration and will not hinder the forest postmining land use that is being established on this site. Photo by J. Skousen, West Virginia University, used with permission.

Final Grading

Do final grading only when surface materials are dry. This will help to reduce compaction and will be more cost-effective than grading moist materials. When spoil materials are damp or moist, the pressures exerted by the dozer can pack the soil particles together more tightly than would occur under dry conditions. If the surface materials are wet, damp, or moist, delay final grading until they dry.

Keeping Traffic off the Final Surface

Once the final surface has been graded, exclude all equipment traffic from the area. If it becomes necessary for heavy equipment to travel over some portion of the graded area, use deep ripping to restore that area's suitability for trees (Chapter 5, this volume).

FREQUENTLY ASKED QUESTIONS ABOUT LOW COMPACTION GRADING

What about site stability?

Regulations under SMCRA require that reclaimed mine sites be stable. Therefore, handle and place all below-surface spoils as needed to ensure stability as described in the permit; only the top 4 to 6 feet must remain loose and uncompacted for successful reforestation.

What about backfill settlement?

Successful postmining forests require that compaction be avoided only on the top 4 to 6 feet; therefore, place most of the backfill material using procedures that would normally be used to prevent settlement and highwall exposure. Any settling that occurs because the top 4 to 6 feet has been left loose will be minimal. Operators can overfill the top of the highwall using the same amount of loose spoil that they would otherwise compact—but without the added expense of compacting this final lift of material.

If the site is not graded smoothly, will that be "ugly reclamation"?

Each loose-graded site will look different, with some rougher and some smoother. Some sites will have many rocks on the surface while others will not. But whether or not these sites should be considered "ugly reclamation" is in the eye of the beholder. To a person who can envision a productive natural forest with diverse vegetation and wildlife emerging from the mine site, such reclamation can be beautiful. Many natural, unmined forests in the Appalachian region have rough and rocky soil surfaces.

If the surface is not compacted to "hold it in place," will soils erode more rapidly?

Scientific research (Torbert and Burger 1992) and onsite observations demonstrate that compacting soil surfaces accelerates soil erosion. Soils erode when rainfall fails to infiltrate the soil and runs off the surface. Surface compaction prevents rainfall infiltration, encouraging erosion. Mine soils reclaimed with low compaction grading allow water to infiltrate the surface, which prevents erosion. Mine operators who switch from conventional to low compaction grading often observe that sediment-pond cleanouts are needed less frequently.

If gullies develop in the uncompacted materials, should they be regraded?

Because low compaction grading encourages infiltration of rainfall, gullies are less likely to form when low compaction grading is used. If small gullies form in the final surface, they should not be regraded. When regrading occurs, it compacts the soil surface. If regrading occurs after the site has been planted with trees, those trees within the regraded area are destroyed. The maximum allowable gully size that does not require regrading varies with State program policies. Generally, the States allow stabilized gullies to remain in place on forested mine sites if they are not large enough to hinder the operation of forestry equipment.

Will the mine inspector like it?

Most inspectors will approve low compaction grading without problem or difficulty because the FRA is allowed under SMCRA. The U.S. Department of the Interior's Office of Surface Mining Reclamation and Enforcement (OSMRE) and the States that participate in the Appalachian Regional Reforestation Initiative (ARRI) have issued directives to that effect (Chapter 1, this volume). Both federal and State inspection personnel in those States have been informed of this "new" way of reclaiming mine sites for forests, which includes low compaction grading. OSMRE and the mining agency for each State in the Appalachian region have assigned one or more people to encourage use of FRA practices in permits and in the field, and to ensure that FRA practices are accepted as means of achieving bond release.

If a mining firm is concerned that its inspector will not favor low compaction grading, it should state in the mining permit that low compaction grading practices will be used. If the company is not certain that its inspector will approve low compaction grading, a mine supervisor can ask the inspector for an onsite meeting. Carrying a copy of this volume or other ARRI publications (available at http://arri.osmre.gov/Publications/Publications.shtm#FRAs) to the meeting can help communication with the inspector. If such a meeting were to be unsuccessful, a call to that State's ARRI liaison, or to any member of the Core or Science Teams, could be the next step. FRA practices—including low compaction grading—are allowed under SMCRA when the postmining land use is forest, and are encouraged by both OSMRE and State agencies.

SUMMARY

Since SMCRA's early years, equipment operators and inspectors have taken pride in the clean and smooth "golf course" look produced by fine grading. Scientific research has made it clear, however, that such practices compact soils and hinder development of planted trees.

To reestablish a healthy and productive forest after mining, surface compaction should be minimized by placing surface spoils using techniques that leave them loose, leveling with the lightest equipment available with the fewest passes possible during dry conditions, and permanently removing all equipment from the area after leveling.

The low compaction grading techniques described in this Advisory are less costly than conventional smooth-grading and tracking-in practices that have been common since SMCRA went into effect. Low compaction grading for forestry postmining land uses is consistent with SMCRA and with federal and State regulations. Low compaction grading will aid seedling survival, reduce the need for replanting, increase the likelihood of prompt bond release, and allow the planted trees to grow into a productive forest.

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CHAPTER 5: LOOSENING COMPACTED SOILS ON MINED LANDS

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INTRODUCTION

Successful surface coal mining businesses must move earth materials efficiently, so mining operations today depend on large and heavy equipment (Fig. 5-1). Track dozers and haul trucks used for mining can weigh more than 100 tons each. Wheel loaders and loaded haul trucks often exceed 200 tons. The mining industry has learned that successful reforestation of reclaimed sites requires loose and uncompacted surface materials, but some areas become compacted due to the machinery operation, traffic, and storage that are necessary for the mining business to be successful.

Trees require deep, loose mine soils to survive and grow into healthy, productive forests. Such forests can support viable forest products businesses, protect the watershed, store carbon, and serve as wildlife habitat. This Forest Reclamation Advisory describes how to loosen soils that have become compacted by mining equipment; these procedures can be used to restore land capability for forests.

Figure 5-1.—Haul trucks, which can weigh 50 to 100 tons or more even when empty. This weight exerts force where tires meet the land surface, causing severe compaction of mine soils. When operated on surface soils, loaders, dozers, and other heavy mining equipment also cause compaction that hinders tree growth. Photo by J. Skousen, West Virginia University, used with permission.

AVOIDING SOIL COMPACTION

The best way to deal with compaction on mine sites is to avoid compacting the soil in the first

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place. Uncompacted conditions suitable for trees can be created by using techniques that cost less than traditional smooth-surface “tracked-in” reclamation. Loose dumping of surface materials, combined with the minimum grading necessary to shape the land, creates loose soils and rough surfaces, increases rainwater infiltration, and increases trees’ survival and growth. Throughout the Appalachian region, mine operators are finding these techniques to be a cost-effective successful method for establishing forests and achieving timely bond release when used with the Forestry Reclamation Approach (FRA) (Chapter 2, this volume).

Mine operators can minimize equipment use on the final surface, but there will often be areas that become compacted. These areas are generally the flatter areas and sites used for storing equipment. Many Appalachian and midwestern mine sites reclaimed under the federal Surface Mining Control and Reclamation Act of 1977 (SMCRA) have become compacted due to excessive equipment operation (Chapter 1, this volume). In order for such lands to support a forested postmining land use, soils must be loosened before reforestation.

WHAT CAN BE DONE TO LOOSEN COMPACTED SOIL?

Deep tillage or ripping of the soil with a deep plow or ripper blade attached to a dozer can alleviate most soil compaction effects on mine sites (Fig. 5-2). Subsurface ripping was first used for reclamation on prime farmlands disturbed by mining in the Midwest. In the years immediately following the passage of SMCRA, rubber-tired equipment was often used to replace the subsoil and topsoil on these sites. Such practices compacted soils and created lands that could not produce the required crop yields. Various deep plows were developed and used to overcome compaction in prime farmland reclamation, and research studies have shown that their use helps to restore soil productivity (Dunker and others 1995, 2000). More recently, similar methods have been used to alleviate soil compaction on post-SMCRA mine sites (Conrad and others 2002).

The choice of ripping device and procedure depends on site conditions. Available ripping devices include single-, double-, and triple-shank rippers, with and without plow attachments. In areas where topsoil is lacking and surface spoils contain large boulders, a single-shank ripper (Fig. 5-3) will generally produce the best results. As the shank encounters boulders, it lifts and

Figure 5-2.—A dozer ripping to loosen soils and produce soil conditions favorable to successful reforestation in a former roadway. Photo by P. Angel, OSMRE.

Figure 5-3.—A single-shank ripper attached to a dozer. This type of ripper is capable of ripping the soil to a depth suitable for forest trees when attached to a large dozer. Photo by P. Angel, OSMRE.

rotates them; this action has the effect of loosening the material around and above the boulders (Fig. 5-4), which increases the operation's effectiveness. With this type of ripper in rocky soil, it is usually adequate to rip in only one direction.

When ripping is done on mined land with thick soil that is relatively free of boulders, a deep plow will do a better job of loosening the soil than a straight-shank ripper. In this case the plow's shape is important because, without boulders to be pulled up, the subsurface blade must lift and fracture the soil. A plow-like attachment has been used successfully on a single-shank ripper blade (Fig. 5-5). Such a device cannot withstand the stresses of moving large boulders and is not recommended where boulders are present.

If soils have a high clay content, ripping in two perpendicular directions ("cross-ripping") is recommended, as ripping in only one direction in clayey soils tends to cut a narrow trench without shattering the surrounding soil. Roots of trees tend to grow only in the direction of the trenches, which makes them susceptible to being blown over after they develop a crown.

Most forest trees require at least 4 feet of uncompacted rooting medium to achieve their growth potential, so compacted mined land being prepared for trees should be ripped to at least that depth. Although 4 feet will be an effective ripping depth on most sites, deeper is better. In order to rip a compacted mine site to 4 feet, a dozer equivalent to a Cat® D-9 (Caterpillar Inc., Peoria, IL) or larger is generally required. Use of shorter (less than 4 feet) rippers can be beneficial in areas where surface soils have been compacted but deeper soils remain loose. If using a shorter single-shank ripper (less than 4 feet), cross-rip the entire area to ensure adequate loosening of the surface. Using a triple-shank ripper should eliminate the need to cross-rip because it loosens most of the total surface area. Unless a very large dozer is used, however, a triple-shank ripper may not reach as great a depth as a single-shank ripper.

Figure 5-4.—Large boulders brought to the surface by a ripping operation on an Appalachian surface mine. This operation loosens the surrounding soil materials. Note also that the ripping has reduced groundcover density near the ripped channel, which will help tree seedlings planted over that channel to survive and become established. Photo by P. Angel, OSMRE.

Figure 5-5.—A ripper with a plow attachment, which can be used to loosen soils that do not contain large rocks and boulders. The "wings" on the ripper blades will loosen soils located next to the ripping trench. Photo by D. Graves, University of Kentucky, used with permission.

When ripping is done on nearly level ground, the direction of ripping is not critical. However, when ripping is done on slopes, it is advisable to rip along the contour to minimize erosion. In all cases, it is best to rip when the ground is dry because dry soils fracture much better than damp or moist soils; this is especially important for clayey mine soils. Ripping operations during late summer or fall take advantage of the relatively dry seasonal conditions while allowing soil settling for tree planting in early spring.

IS RIPPING NEEDED?

On Appalachian surface mines it is common for relatively flat areas to be more compacted than steeper slopes, especially if those areas have been used for equipment storage, maintenance, and operations. Such heavily compacted soils will require ripping to produce commercially valuable trees. In contrast, soils on steeper slopes often remain relatively loose because they are not affected by equipment operations after grading.

It is relatively easy to determine whether soils have been compacted to an extent which makes ripping necessary for satisfactory tree growth. Use a common hand spade or a drain spade shovel (Fig. 5-6) to estimate the extent of compaction by putting a modest amount of foot pressure (50 pounds) on the spade while rocking its tip to bypass coarse fragments. (If a rock big enough to block the spade is encountered, move to another spot.) The depth of spade penetration will be affected by the degree of compaction and is an indicator of forest site quality (Table 5-1). For example, a highly compacted soil could be penetrated with a spade to a depth of 1 to 3 inches. Without ripping, the site would

Figure 5-6.—A long-nosed drain spade being inserted into mine spoil. A spade can be used to estimate mine soil density and the need for ripping. Depth of penetration when applying foot pressure and a rocking motion is an indicator of a soil's capability to support trees that will survive and grow into commercial products (see Table 5-1). This spade was able to penetrate spoil easily; this area is expected to be able to grow trees successfully without being ripped. Photo by C. Zipper, Virginia Tech, used with permission.

Table 5-1.—The relationship among degree of compaction, spade penetration depth, forest site quality (an indicator of the soil's ability to support growing trees), and relative return on a forestry investment (after Burger and others 1998, 2002; Probert 1999).

Soil density condition	Very dense	Dense	Moderately compacted	Slightly compacted	Loose
Spade penetration	0–1 inches	1–3 inches	3–6 inches	6–9 inches	9–12 inches
Site quality class	V (poor)	IV (fair)	III (medium)	II (good)	I (excellent)
Oak site index[a]	40	50	60	70	80
Use for wood products	None	Firewood	Railroad ties	Sawtimber	Veneer
$/1,000 board ft stumpage value[b]	$0	Less than $100	$200	$500	$2,000
Relative return on investment	-2%	0%	2%	4%	8%

[a] Approximate height in feet of a white oak or northern red oak growing at age 50. These ratings assume that all factors other than soil density (for example, other mine soil properties, ground cover, seedling quality) affecting productivity are optimum.

[b] Source: Hayek (2007).

be classified as “fair” and would be capable of growing oaks only 50 feet tall at age 50. Trees growing at this rate would have little value except as firewood so the land would have little or no value as a forest-products investment. Ripping the site would improve the soil by one to three site-quality classes, depending on the type and quality of the ripping practice. (This assumes other soil properties are suitable for growing trees, and good forestry practices are applied after the area is ripped.) Note that return on investment doubles when site quality is improved by one class.

Relationships between soil compaction, soil physical properties, and tree growth (Table 5-1) have been worked out in research studies. The term “bulk density” refers to a technical measure of soil density that is often used in such studies. A low bulk density indicates a loose soil that allows rainfall to infiltrate easily—which helps to prevent erosion—and that will not impede root extension by growing trees. Bulk density can be measured in different ways including specialized field sampling methods. Research has found that, in rocky spoil, dry bulk density should be less than 100 pounds per cubic foot at a depth of 2 inches, which correlates with relatively deep shovel penetration. Another way of evaluating soil density conditions is with a cone penetrometer (Fig. 5-7), a common geotechnical testing device that drives a steel cone into the ground with a hydraulic ram. To ensure good tree growth in rocky spoil, the cone should be able to penetrate at least 1 foot into the ground. This is an average value that can vary with soil type and rock content.

HAS RIPPING BEEN EFFECTIVE?

Our experience shows that a deep and thorough ripping of very dense mine soils can improve the soil by as many as three or four site quality classes (Table 5-1). Even a moderately compacted site can be greatly improved because the economic value of trees increases disproportionately on the high end of the site-quality gradient due to improved

Figure 5-7.—A tractor-mounted cone penetrometer being used to evaluate soil density on a Kentucky surface mine. Photo by OSMRE.

wood product class (for example, veneer has a much greater value than sawtimber; Table 5-1) as well as faster growth rates.

IS RIPPING COST-EFFECTIVE?

Ripping should be considered a practice of last resort. It is far less expensive to avoid compaction during reclamation than to correct it once it has occurred. Loose grading costs less than the excessive grading needed for compacted soils because loose grading requires less dozer time—and loose-graded sites can grow trees successfully without the expense of ripping. Nonetheless, it is difficult to avoid all surface compaction on an active mine site; the pre-mining capability to grow trees cannot be restored on areas that have been compacted by repetitive equipment traffic unless such areas are ripped before planting.

Experience has shown that it takes about 1 hour to rip 1 acre with a D-9 dozer or equivalent with a single-shank ripper. Costs, using contract equipment, range from about $150 to $200 per acre (2016 estimates; B. Strahm, personal communication). The type of ripper used will also affect the per-acre cost. For example, a triple-shank ripper would require a larger tractor and more time.

SUMMARY

The FRA is a way of reclaiming active surface mines to maximize reforestation potentials (Chapter 2, this volume). A noncompacted growth medium is essential to FRA reclamation. Soil conditions suitable for trees can be created by placing materials on the surface loosely, and minimizing surface grading. On areas that do become compacted, soil conditions suitable for trees can be restored through deep ripping. Although ripping may not produce land that is as desirable as land that has been loosely graded from the outset, it can alleviate soil compaction so that reforestation can be successful and land capability can be restored to pre-mining levels.

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Chapter 6: Tree-Compatible Ground Covers for Reforestation and Erosion Control

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INTRODUCTION

Productive native forests create economic value for landowners, produce raw materials for wood-based products, and provide benefits such as watershed control, water quality protection, carbon storage, wildlife habitat, and native plant diversity. Owners of lands mined for coal in the Appalachian region are increasingly interested in assuring that productive forests are restored after mining.

Sediment control is essential to coal mine reclamation under the federal Surface Mining Control and Reclamation Act of 1977 (SMCRA). This Forest Reclamation Advisory describes how mining firms can achieve good tree survival and restore forest productivity by using tree-compatible ground covers, when necessary, to control erosion and meet groundcover standards.

THE FORESTRY RECLAMATION APPROACH

The Forestry Reclamation Approach (FRA) is a method for reclaiming mined land to forest under SMCRA (Chapters 1 and 2, this volume). The FRA differs from past reclamation practices that used agricultural grasses and legumes such as Kentucky-31 tall fescue and red clover to create dense vegetative cover. (Please see the Appendix starting on p. A-1 for scientific names of species mentioned in this chapter.) Thick, vigorous agricultural grasses and legumes are necessary for postmining land uses such as hayland and pasture. But when lands are being reclaimed for forestry, grasses and legumes are used only as needed for erosion control. For forestry, native herbaceous and woody ground cover is preferred because it

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seldom hinders tree survival and growth (Burger and Zipper 2011).

The FRA has five steps:

1. Create a suitable rooting medium for good tree growth that is no less than 4 feet deep and consists of topsoil, weathered sandstone, or the best available material, or a combination of these materials.
2. Loosely grade the topsoil or topsoil substitutes established in Step 1 to create a noncompacted growth medium.
3. Use groundcover species that are compatible with growing trees.
4. Plant two types of trees: early successional species for wildlife and soil stability, and commercially valuable crop trees.
5. Use proper tree planting techniques.

This Advisory deals with Step 3 of the FRA: use of ground covers that are compatible with growing trees. It describes methods for establishing groundcover vegetation to control erosion without hindering survival and growth of planted trees. Those methods include establishing soil conditions to encourage native, volunteer ground cover, and, when necessary, seeding grasses and legumes that will provide minimal competition with growing trees.

THE FORESTRY RECLAMATION APPROACH CONTROLS EROSION

Steps 1 and 2 of the FRA—selection and placement procedures for mine soils to promote tree survival and growth—reduce the need for sowing agricultural grasses and legumes for erosion control. Mine soils with good chemical and physical properties for native trees are also good for native herbaceous plants, microbes, and soil animals.

When suitable mine soil is used, a variety of native plants often become established and provide nearly complete ground coverage within several years (Angel and others 2006). High diversity often occurs when native topsoil is included in the mine soil (Hall and others 2009, Holl and others 2001, Wade 1989). On an eastern Kentucky area with three types of mine soils planted with trees but not sown with ground cover, Angel and others[1] found that after 4 years, brown weathered sandstone had 79-percent cover made up of 69 volunteer species including 16 tree species, whereas gray unweathered sandstone had 4-percent cover made up of 18 volunteer species including only 1 tree species—black locust. This example shows how native vegetation responds to different topsoil substitutes, and how little or no agricultural grasses and legumes are needed for ground cover when the FRA is used on favorable materials.

Step 2 of the FRA leaves the surface soil looser and rougher than conventional grading (Chapter 4, this volume). Loose spoil allows more water infiltration, so more rainwater enters the soil, where it can be used by growing plants. Less rainfall runs off the surface, limiting the amount of eroded soil. The soil that is carried by rainfall runoff often moves only short distances into depressions in the rough surfaces. Thus, when the soil surface is left rough and uncompacted, erosion can often be controlled without establishing dense groundcover vegetation.

Natural processes can establish ground cover readily when soil conditions are favorable for reforestation. Favorable conditions are uncompacted soil with a rough surface, constructed from topsoil or weathered brown sandstones, or a combination, either mixed with overburden or alone; and a soil pH between 5.5 and 6.5. Even when using the FRA, grasses and legumes will need to be sown on steep slopes, on areas far from native seed sources within large mining operations, and in states with specific groundcover standards.

[1] Unpublished data on file with P. Angel.

NEW GROUNDCOVER REGULATIONS

Although each State has different regulations, federal regulations do not require establishment of ground cover where trees are planted using the FRA if tree establishment is successful, the postmining land use is achieved, and erosion and offsite sedimentation are controlled (Federal Register 2007). Tennessee and Virginia have modified their groundcover requirements for FRA reclamation from set standards (80 percent and 90 percent cover, respectively) to ground cover as needed to control erosion. These changes recognize that FRA reclamation reduces runoff and erosion on most mine sites, compared to traditional reclamation practices that compact the soil, and that aggressive ground covers inhibit tree seedling survival and forest productivity.

TREE-COMPATIBLE GROUND COVER

Using tree-compatible ground cover with the FRA differs from the "grassland reclamation approach" used in past years to establish hayland and pasture as well as unmanaged forest. The grassland reclamation approach uses fast-growing agricultural grasses and legumes to achieve rapid and complete coverage of the ground. In contrast, FRA reclamation uses "tree-compatible" ground cover to minimize competition with tree seedlings. To establish tree-compatible ground cover:

- Use less-competitive groundcover species,
- Use lower seeding rates,
- Use less nitrogen (N) fertilizer, and
- Accept a less-dense herbaceous ground cover in the first few years after seeding.

The result will be a lower-growing, less vigorous, sparse ground cover that allows planted tree seedlings to survive and grow, and allows more recruitment of volunteer plants (Fig. 6-1). Use of tree-compatible ground cover will achieve timely bond release on soils that are properly prepared for reforestation (Burger and others 2010). FRA seeding and fertilizer rates are presented as general guidance in Table 6-1. Because climate, soil conditions, and regulatory policies vary

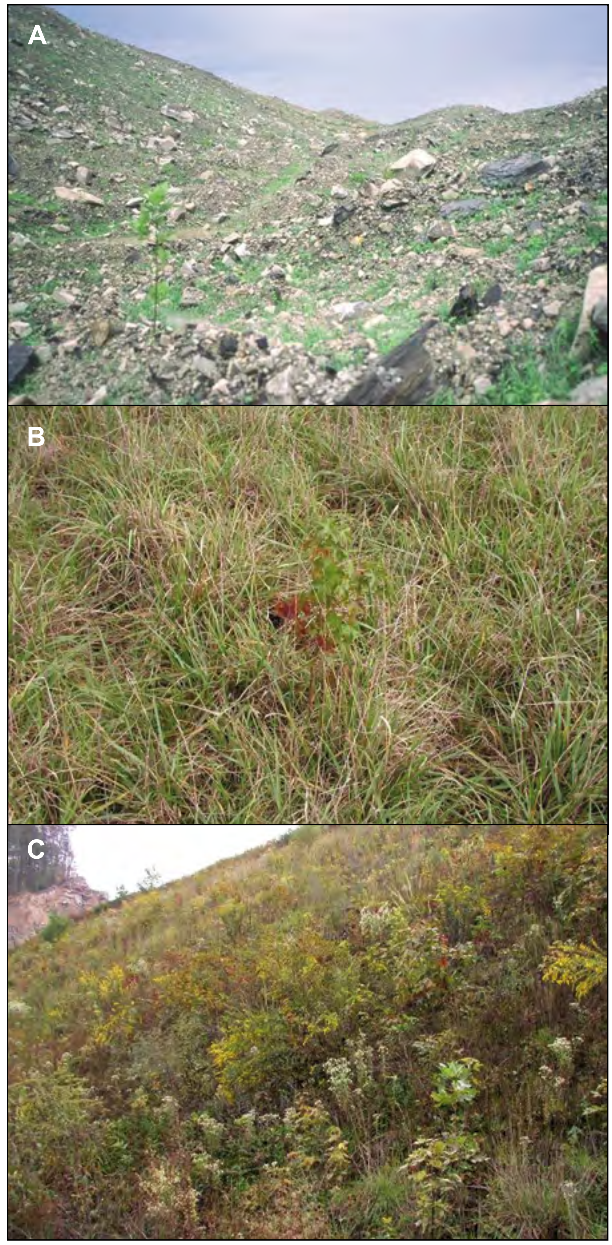

Figure 6-1.—Groundcover vegetation on coal mine sites. (A) A tree-compatible ground cover in mid-summer, about 3 months after planting. The cover is sparse, but planted trees are able to survive and grow, and native plants can seed in and become established. (B) A grass-dominated ground cover that is typical of conventional grassland reclamation, 3 years after planting. The site is fully covered, but the tree is growing at less than half its potential and is exposed to predation. (C) A tree-compatible ground cover, 3 years after planting. At least half the cover on this site is made up of native plants, including trees that seeded in via wind and wildlife. Trees are growing faster because the cover is less competitive. Photo A by C. Zipper, Virginia Tech, used with permission; photos B and C by J. Burger, Virginia Tech, used with permission.

Table 6-1.—Example of a seeding and fertilizer application for FRA reclamation on mine sites where soil conditions are favorable for forest vegetation (pH between 5.0 and 6.5)†

Species††	Rate (lbs per acre)
Perennial grasses:	
Perennial ryegrass	10
Orchardgrass (steep slopes only)	5
Timothy	5
Annual grasses:	
Annual ryegrass, or	5
foxtail millet§	10
Legumes (with inoculant):	
Bird's-foot trefoil (steep slopes only)	5
Ladino or white clover	3
Fertilizer§§:	
Nitrogen (N)	50-75
Phosphorus (as P)	80-100
(as P_2O_5)	180-230

† These rates are intended to achieve >80-percent ground cover after 2 years, although species and rates may differ based on local conditions. Before seeding, mining firms are encouraged to check with the SMCRA regulatory authority.

†† For more detail on each species, see Skousen and Zipper (2009).

§ Foxtail millet can substitute for annual ryegrass in late spring/early summer seedings.

§§ Can be achieved by applying 400 lbs/acre di-ammonium phosphate, by blending 200 lbs/acre concentrated super phosphate (0-60-0) with 300 lbs/acre 19-19-19 fertilizer, or with other fertilizer blends.

among states, and because State and federal regulatory policies change with time, the rates of Table 6-1 should not be considered a rigid recipe or prescription. We encourage mining firms to consider the guidance of Table 6-1, site conditions, and local regulatory policies when deciding on groundcover seeding rates.

Instead of the high N and low phosphorus (P) used for grassland reclamation, FRA reclamation uses low N to reduce the vigor of early-growing grasses and high P to nourish trees for the long term. The fertilizer rate in Table 6-1 is adequate to establish seeded ground covers; as the legumes mature, they convert N from the atmosphere to plant-available forms. Generally, the three perennial grasses and both legumes listed in Table 6-1 would be seeded, along with one of the annual grasses. Because foxtail millet produces more organic material than annual ryegrass, some agencies and companies may prefer it to annual ryegrass, especially on steep slopes. Foxtail millet, however, is considered to be an invasive species and is not recommended for Tennessee (Tennessee Exotic Pest Plant Council 2008). Another disadvantage of foxtail millet, relative to annual ryegrass, is its production of large amounts of vegetative cover that can inhibit native vegetation recruitment during its first year. It also produces seed grains and cover that can attract animals such as rodents and deer, which can damage the tree seedlings.

We have found the rates of Table 6-1 to be adequate for establishing FRA ground cover on a wide range of mine spoil materials where pH is greater than 5, but other seeding strategies are also possible. For example, in Tennessee groundcover mixes have been seeded that rely on native warm-season grasses to establish perennial cover. These species take 2 years to become established, so they are seeded with an annual such as annual ryegrass or millet. Species of shorter height (Table 6-2) are recommended for this use, as tall species such as switchgrass can be expected to compete with the tree seedlings (Rizza and others 2007).

Table 6-2.—Short-statured native warm-season grasses (NWSG) that have been seeded† with annual grasses and hydromulch to establish tree-compatible ground cover successfully in Tennessee

Common name	Scientific name
little bluestem	*Schizachyrium scoparium*
side oats grama	*Bouteloua curtipendula*
eastern gamagrass	*Tripsacum dactyloides*
broomsedge bluestem	*Andropogon virginicus*
Indian grass	*Sorghastrum nutans*

† Typical rates: 8-10 lbs. total NWSG seed/acre

Using tree-compatible ground cover helps establish forested postmining land uses in several ways:

- The lower-growing tree-compatible species allow more sunlight to reach the tree seedlings.
- Tree-compatible species withdraw water and nutrients from the soil more slowly than faster-growing grasses and legumes, leaving more of these essential resources for the planted trees.
- Tree-compatible species do not cover the ground as rapidly or completely, allowing more of the seeds that are carried to the site by wind and wildlife to land on the soil surface, germinate, and become established. In Appalachian mining areas, most of these seeds are generally of native forest species.
- Tree-compatible ground cover allows rapid establishment and growth of native trees, thereby minimizing the invasion of troublesome exotic species such as multiflora rose and autumn-olive.
- Tree-compatible species are less attractive to animals such as deer and rodents, which may damage tree seedlings through browsing or other means.

Revegetation using the FRA is typically done in two steps: 1) planting bare-root tree seedlings, and 2) hydroseeding groundcover seeds, fertilizer, mulch, and lime if needed. Because herbaceous ground cover often competes with the trees, reducing their survival and growth, we recommend that whenever possible the trees should be planted first in late winter, followed by hydroseeding the next spring or even the following fall if allowed by the regulatory authority. Hydroseeding over planted seedlings in the spring should be done before leaf formation by the trees. Fall hydroseeding over planted seedlings should be delayed until after tree leaves change color so as to avoid the possibility of seedling damage. Planting trees in established ground cover can reduce seedling survival, especially in drought conditions.

If an area is ready for reclamation after the tree planting period ends in mid-spring and the regulatory authority or mining firm believes ground cover is needed before the next tree-planting season, the best option for reforestation is to seed an annual grass such as annual ryegrass or foxtail millet on that area. This annual vegetation will become a dead standing crop by the next tree-planting season and will not interfere with the planted trees. In fact, these dead plant materials can be an asset to reforestation as they will aid recycling of fertilizer nutrients and help protect the soil surface from erosion. Having this plant material onsite in the fall will also aid in "catching" wind-blown seeds from surrounding areas. If soil conditions are favorable and good natural recruitment of native plants occurs, such sites may be able to meet regulatory groundcover requirements without overseeding. If using this strategy, confer with the regulatory authority to determine the need for overseeding and its timing. In some cases, only spot overseeding on steeper slopes may be necessary. When allowed by regulatory authorities, avoid fall seeding followed by tree planting during that winter, as this practice will usually produce ground cover that is too competitive the following spring.

SHOULD THE MINE SITE BE FERTILIZED?

Growing trees require essential nutrients in adequate quantities. Weathering overburden releases calcium, magnesium, potassium, sulfur, and many micronutrients, but N and P are often lacking in mine overburden. Successful mine reforestation requires that N and P be supplied in sufficient quantities to support tree growth.

If the mine soil used for reforestation incorporates native topsoil in amounts similar to the unmined forests, that topsoil will usually carry sufficient N and P to support tree growth. The term "topsoil," as used here, means all soil materials that can be removed easily by a dozer, including stumps, roots, and woody debris left behind after timber removal. If topsoil is used as a substitute for fertilization, it is essential that organic materials from the forest soil surface be included because the surface is the most nutrient-rich portion of the forest topsoil. The surface materials also include viable seed, so use of fresh topsoil for reclamation will encourage natural revegetation.

If topsoil is not used to restore the surface of a mine site where the mine operator is relying on natural processes for ground cover, fertilize the site using the rates in Table 6-1. Apply such fertilizer with a hydroseeder either just before planting seedlings or after planting when the seedlings are dormant. Alternatively, broadcast as pelletized forms during any season. Consult the regulatory authority when making decisions about fertilization.

SHOULD A SOIL TEST BE PERFORMED?

If regulators require a soil test or if soil chemistry is not known, a soil test should be performed. However, when reclaiming lands for forestry, be wary of soil test results not targeted for mining and forestry. Most soil testing recommendations are well suited for farms, golf courses, and homeowners that use plants with nutrient needs that are different from those of planted trees. Such soil test N recommendations will generally exceed desirable levels for FRA ground cover. Although P recommendations may be adequate for short-lived crops, they will often be inadequate for forest trees' long-term nutrition needs. The fertilizer rates in Table 6-1 are tailored to FRA groundcover and tree requirements and are suitable for most mine sites.

Unless acid-forming materials are present, liming is generally not needed for FRA reclamation. Soil test lime recommendations are intended to achieve the near-neutral pH values preferred by crops and grasses. But FRA groundcover species do well in the pH range of 5.5 to 6.5, which most Appalachian hardwood trees prefer. If soil pH is expected to stabilize at less than 5, apply lime to adjust pH to between 5.5 and 6.5.

RECLAMATION WITH THE FORESTRY RECLAMATION APPROACH ENCOURAGES ECOLOGICAL SUCCESSION

"Succession" is a term used to describe natural changes in plant community composition over time (Chapter 8, this volume). During FRA reclamation four vegetation types are established, but they grow at different rates and flourish, or dominate, at different times (Fig. 6-2).

Vegetation established by FRA reclamation is a combination of planted and volunteer herbaceous species, nurse and wildlife trees, and crop trees. As represented by "total cover" in Figure 6-2, FRA reclamation is designed to provide at least 80-percent cover by the end of the second growing season and to approach 100-percent cover by the fifth growing season.

Four stages of cover development occur (Fig. 6-2):

- Stage 1. Grasses dominate and provide most of the cover. The slow-growing, bunch-forming grasses of Table 6-1 will be sparse at first but will produce more ground cover during the second and third years. When most of the fertilizer N has been utilized, the grasses thin, creating openings for native plants that are carried onto the site as seed by birds, other wildlife, and wind.
- Stage 2. Legumes and native plants dominate and provide most of the cover. The legumes add N to the soil and are less competitive than grasses. The herbaceous legumes persist until they are shaded out by the trees.
- Stage 3. Fast-growing nurse and wildlife trees make up 10 to 20 percent of the total trees planted in the FRA. Some of these trees fix N from the atmosphere and all provide habitat for wildlife and canopy cover for erosion control. Those nurse trees that grow edible fruits and

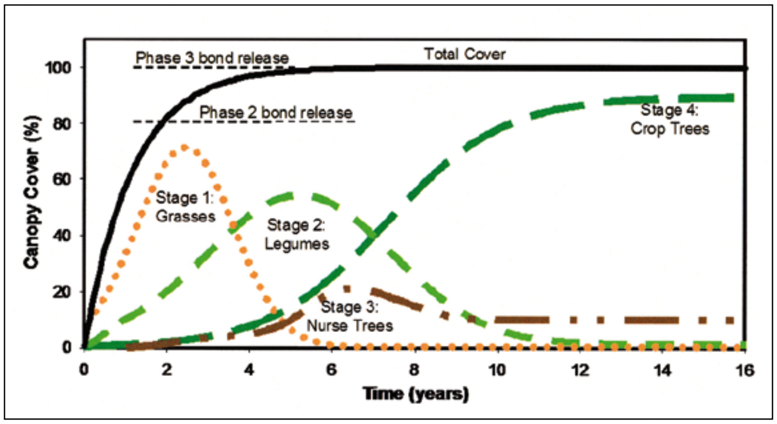

Figure 6-2.—Representation of how vegetative cover changes through time when FRA reclamation is used. All four vegetation types are sown or planted during reclamation, but each type is dominant at a different stage.

seeds attract seed-carrying birds and other wildlife, thus aiding establishment of plant species from unmined areas.

- Stage 4. By the time the trees close canopy (i.e., when the tree tops grow together), the crop trees dominate and provide most of the cover. Fallen leaves and other organic litter accumulate and begin to decompose, providing additional nutrients for the trees. Because much of the ground is shaded by trees, the nontree vegetation closer to the ground ("understory") remains sparse.

Because the hydroseeded ground cover remains sparse during the first few years, native plants including forest trees are able to seed in, germinate, and emerge. Thus, the plant community is composed of many species in addition to those seeded and planted by the mining firm. Rapid canopy closure by native species reduces invasion of troublesome exotic species such as multiflora rose and autumn-olive. Over time, the plant community develops naturally to become more like the region's native forest.

The guidelines of Table 6-1 are intended to establish vegetation that will promote succession to a productive forest. Following these recommendations can help to control erosion, allow recruitment by native plant species for increased diversity, fix N from the atmosphere, create wildlife habitat, minimize invasion of exotic species, and develop into a productive forest dominated by native hardwoods. Experience has shown that many native tree species volunteer by growing from seeds brought in by wind and wildlife, which can help the mining firm satisfy regulatory requirements if the permit specifies those species as components of the postmining land use.

HOW GROUND COVER USING THE FORESTRY RECLAMATION APPROACH LOOKS AND WORKS

"Tree-compatible" FRA ground over (Table 6-1) is designed to be less competitive than ground cover for reclamation to grassland. The FRA ground cover looks short and sparse on a rough-graded surface, especially during its first year (Fig. 6-1A). This is by design. Some miners and inspectors who are more familiar with grassland reclamation may have trouble, at first, accepting the "look" of the FRA reclamation. What is important, however, is not the look but how it works. Use of native cover or sown, tree-compatible ground cover within the FRA allows operators to establish a productive forest while meeting regulatory standards.

When reforesting sites that have not been mined, foresters usually kill competitive grasses and weeds with herbicides as a standard practice before planting trees. Traditional mine reclamation has taken the opposite approach, sowing competitive grasses and legumes to the detriment of the planted trees. Reclamation procedures for establishing forests differ from those for establishing hayland, pasture, and other uses that require agricultural grasses. The two reclamation approaches look different because they are intended to achieve different purposes.

SUMMARY

The FRA is becoming more popular with mine operators and landowners as a way of reducing reclamation costs while improving the postmining land's value as productive forest. The FRA uses a slow-growing, noncompetitive, tree-compatible ground cover. This ground cover will look sparse for the first several years. When used within the FRA, however, such ground cover controls erosion while encouraging recruitment by native forest species and allowing planted trees to survive and grow. Because State regulations vary, mine operators are encouraged to confer with regulatory authorities when developing groundcover seeding plans.

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Chapter 7: Selecting Tree Species for Reforestation of Appalachian Mined Lands

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INTRODUCTION

The Forestry Reclamation Approach (FRA) is a method for reclaiming coal-mined land to forested postmining land uses under the federal Surface Mining Control and Reclamation Act of 1977 (SMCRA) (Chapter 2, this volume). Step 4 of the FRA is to plant native trees for commercial timber value, wildlife habitat, soil stability, watershed protection, and other environmental benefits. This Forest Reclamation Advisory provides guidance for selecting native tree species to plant on mine sites that are reclaimed by using the FRA in the Appalachian region.

Favorable soil properties and noncompetitive ground cover are essential features on mine sites intended for reforestation. Use of the FRA will provide these features for planted trees while also providing conditions suitable for natural seeding of plants from nearby forests.

SELECTING TREE SPECIES

More than 100 native tree species and numerous native shrub species grow within Appalachian forests. This diversity reflects the many site conditions found across the region. Forest site conditions are affected by many factors including sunlight, moisture, soil properties, proximity to native seed sources, and competition among species. The native trees most likely to produce healthy, productive forests on mine sites are those well suited to the site's growing conditions (Fig. 7-1). When selecting trees, also consider:

- Permitting and bond release requirements under SMCRA and
- The location of the mine relative to species' native ranges.

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Figure 7-1.—Northern red oak seedling. This seedling will have an excellent chance of surviving, growing, and contributing to the development of a forest because it was planted on an FRA-compliant mine site. Photo by V. Davis, OSMRE.

SITE TYPES FOR TREE SPECIES SELECTION

Selection of suitable species for any portion of a mine site depends on an understanding of the location of the site on the landscape, because landscape position influences availability of soil moisture and sunlight. Site type is a reflection of landscape position, which is a combination of the direction that a slope faces (or "aspect") and topography. Aspect, slope steepness, and location on the slope are the primary factors to consider when selecting tree species for planting (Fig. 7-2).

Slope aspect affects the amount and timing of sunlight that a slope receives. Slopes facing south receive more solar radiation than north-facing slopes. Even though east-facing and west-facing slopes receive similar amounts of sunlight, the west-facing slopes receive sunlight during the hottest part of the day—mid-afternoon and late afternoon. As a result, slopes with southern and western aspects have drier soils than those that face north and east. Northeast- and east-facing slopes are generally most favorable for tree growth because of higher levels of soil moisture. Southwestern slopes are generally least favorable because of their dryness (Fig. 7-3).

Topography describes the surface shape, relief or terrain, and elevation of a site's position on the land surface. Topography will influence availability of soil moisture. Steep slopes are drier than more gentle slopes because they shed more rainfall as runoff, allowing less water to infiltrate the soil. Large, uncompacted, flat areas on mine sites can provide moist soil conditions and good growth potential. Landscape channels, depressions, and streambanks will have wetter soil conditions.

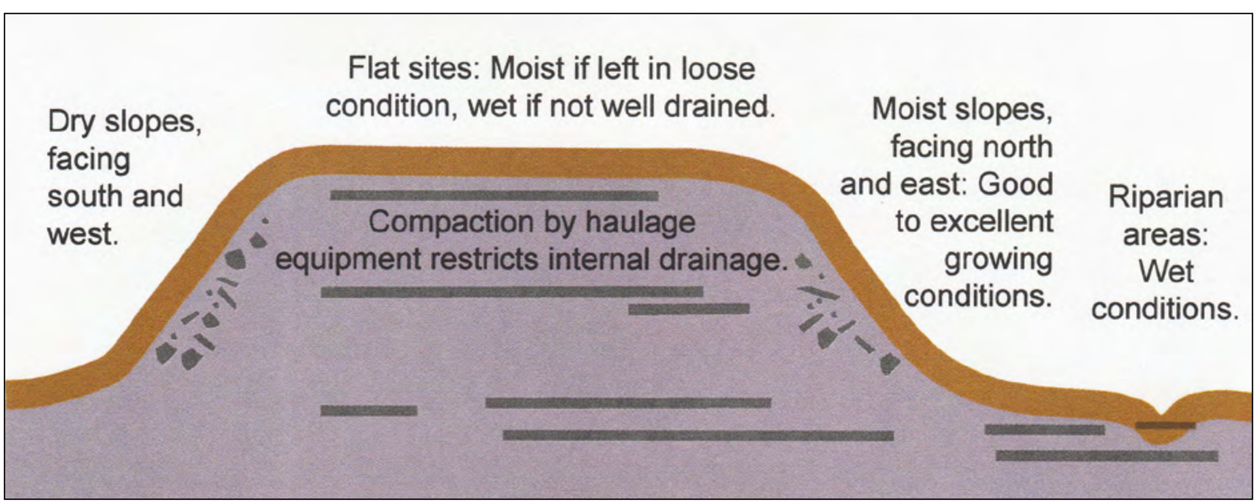

Figure 7-2.—Four site types that commonly occur on coal surface mines and influence tree species.

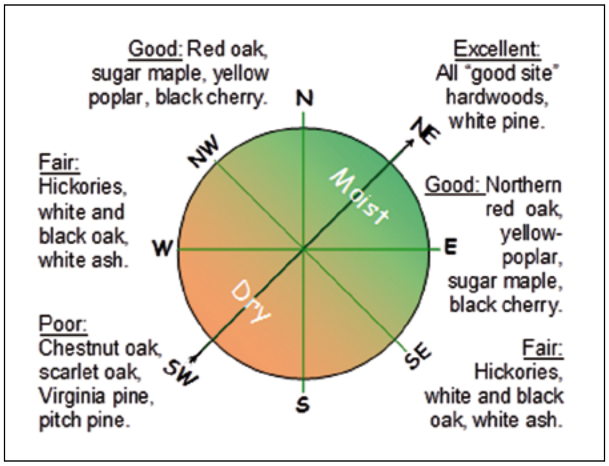

Figure 7-3.—Diagram showing tree-growth potential based on the direction that a slope faces (aspect), which influences availability of soil moisture and sunlight and should be considered in tree species selection. Aspect is rated as having excellent, good, fair, or poor tree-growth potential. "Good site" hardwoods are those prescribed for sites with good growth potential in the diagram.

Figure 7-4.—North- and south-facing slopes, flats, and riparian areas, for which different tree prescriptions or species mixes can be used. The south-facing slope in the foreground was reclaimed by using the FRA and planted with dry-slope species including white oak. Several rows of riparian species planted along the reconstructed stream channel will aid reestablishment of functional aquatic communities. Photo by V. Davis, OSMRE.

Four general landscape positions, or site types, that can be applied to mined landscapes when selecting tree species for planting (Fig. 7-2) are:

- Dry slopes: Slopes facing south and west; areas with dry growing conditions (Fig. 7-4)
- Moist slopes: Slopes facing north and east; areas with moist growing conditions and well-drained soils
- Flat sites: Flat and rolling areas with moist growing conditions if soils are left in a loose condition and with enough landscape relief to allow water to drain easily, or that are wet, if not well-drained.
- Wet sites: Areas within and adjacent to channels and surface depressions, including reconstructed streams and wetlands; these areas have wet soils caused by landscape position or poor internal drainage.

TREE PRESCRIPTIONS

A tree prescription is a list of species to be planted, with planting rates, for any portion of a mine or the entire area. We recommend that tree prescriptions be developed for the major site types that occur within each area to be planted. Most large mines will have several site types, each of which can be targeted for planting with its own tree prescription.

Tree prescriptions that can be applied on Appalachian mined lands (Table 7-1) are provided for each of the four primary site types (Fig. 7-2). The example prescriptions are for mines where the reclamation goal is native forest land that will produce commercial timber and environmental services.

Mine operators can change these prescriptions as needed. Table 7-2 includes information for other tree species, and range maps for most native trees can be found on the Internet. For instance, refer to Silvics of North America (Burns and Honkala 1990a, 1990b), or the PLANTS database (Natural Resources Conservation Service 2016).

Table 7-1.—Example tree species prescriptions (stems per acre). Use species native to the planting area, and those that are suited to the landscape position of the mine site. If State regulations require more than 450 surviving stems per acre, increased planting numbers are advised.

Dry Slopes (south, west)		**Flat Sites** (and rolling)		**Moist Slopes** (north, east)		**Wet Sites** (riparian)	
Crop trees		*Crop trees*		*Crop trees*		*Crop trees*	
white oak	200	white oak	100	white oak	100	pin oak/river birch†	200
scarlet or post oak	100	northern red oak	100	northern red oak	200	American sycamore	200
black oak	100	sugar maple	100	sugar maple	100	sweetgum	200
chestnut oak	100	yellow-poplar	100	yellow-poplar	100	*Nitrogen-fixing tree*	
Virginia pine	100	black cherry	100	black cherry	100	alder	25
Nitrogen-fixing tree		black walnut	100	*Nitrogen-fixing tree*		*Wildlife trees*	
black locust	25	*Nitrogen-fixing tree*		bristly locust	25	black willow	25
Wildlife trees		bristly locust	20	*Wildlife trees*		silky dogwood	25
common persimmon	25	*Wildlife trees*		eastern white pine	25	elderberry	25
eastern redbud	25	flowering dogwood	20	shagbark hickory	25		
mockernut hickory	25	bitternut hickory	20	green hawthorn			
		eastern white pine	20	or gray dogwood	25		
		American hazelnut	20				

† Select either species, considering native range.

Table 7-2.—Suitable woody species for Appalachian mine site reclamation.

Species	Scientific name	Leaf type[1]	Site type	Potential crop tree?[2]	Growth rate[3]	N-fixer?	pH range[4]	Cli-mate[5]
boxelder	*Acer negundo*	d	wet		rapid		M-H	
red maple	*Acer rubrum*	d	all	see note	rapid		L-M-H	
sugar maple	*Acer saccharum*	d	moist, flat	yes	slow		L-M-H	C
gray alder	*Alnus incana*	d	wet		rapid	M	M	
speckled alder	*Alnus incana* ssp. *rugosa*	d	wet		mod.	L	L-M-H	
hazel alder	*Alnus serrulata*	d	wet		rapid	M	M	
mountain alder	*Alnus viridis* ssp. *crispa*	d	wet		mod.	L	L-M-H	
Allegheny serviceberry	*Amelanchier laevis*	d	moist, flat		mod.		L-M-H	
false indigo bush	*Amorpha fruticosa*	d	moist		slow	M	L-M-H	
yellow birch	*Betula alleghaniensis*	d	moist, flat		slow		L-M-H	C
sweet birch	*Betula lenta*	d	moist, flat		mod.		L-M	
river birch	*Betula nigra*	d	wet	yes	rapid		L-M	W
bitternut hickory	*Carya cordiformis*	d	moist, flat	see note	slow		L-M-H	
pignut hickory	*Carya glabra*	d	dry	see note	slow		L-M-H	
shellbark hickory	*Carya laciniosa*	d	moist, flat	see note	slow		M	
shagbark hickory	*Carya ovata*	d	moist, flat	see note	slow		L-M-H	
mockernut hickory	*Carya tomentosa*	d	dry	see note	slow		L-M	
American chestnut	*Castanea dentata*	d	dry, moist	see note	rapid		L	
northern catalpa	*Catalpa speciosa*	d	moist, flat		rapid	L	M	
New Jersey tea	*Ceanothus americanus*	d	dry, moist		slow	L	L-M	
common hackberry	*Celtis occidentalis*	d	moist, flat		rapid		M-H	
common buttonbush	*Cephalanthus occidentalis*	d	moist, wet		mod.		L-M-H	
eastern redbud	*Cercis canadensis*	d	moist, flat		slow		M-H	
silky dogwood	*Cornus amomum*	d	moist, flat		mod.		M	
flowering dogwood	*Cornus florida*	d	moist, flat		mod.		L-M-H	
gray dogwood	*Cornus racemosa*	d	all		mod.		L-M	
American hazelnut	*Corylus americana*	d	moist, flat		mod.		M	
green hawthorn	*Crataegus viridis*	d	moist, flat, wet		mod.		L-M-H	
common persimmon	*Diospyros virginiana*	d	moist, wet		slow		L-M-H	
American beech	*Fagus grandifolia*	d	moist, flat	see note	slow		L-M-H	
white ash	*Fraxinus americana*	d	moist, flat	see note	mod.		L-M-H	
green ash	*Fraxinus pennsylvanica*	d	moist, flat, wet		rapid		L-M-H	

(continued on next page)

Table 7-2 (continued).—Suitable woody species for Appalachian mine site reclamation.

Species	Scientific name	Leaf type[1]	Site type	Potential crop tree?[2]	Growth rate[3]	N-fixer?	pH range[4]	Climate[5]
water locust	*Gleditsia aquatica*	d	wet		mod.	L	M-H	
honeylocust	*Gleditsia triacanthos*	d	moist, wet		rapid		L-M-H	
Kentucky coffeetree	*Gymnocladus dioicus*	d	moist, flat		slow	L	M-H	
American witchhazel	*Hamamelis virginiana*	d	moist, flat		slow		L-M	
American holly	*Ilex opaca*	e	moist, flat		slow		L-M-H	
common winterberry	*Ilex verticillata*	d	all		mod.		L-M-H	
black walnut	*Juglans nigra*	d	moist, flat	see note	rapid		L-M-H	
eastern redcedar	*Juniperus virginiana*	e	moist, flat		slow		L-M-H	
sweetgum	*Liquidambar styraciflua*	d	moist, wet	yes	rapid		L-M-H	
yellow-poplar (tuliptree)	*Liriodendron tulipifera*	d	moist, flat, wet	yes	rapid		L-M	
sweet crab apple	*Malus coronaria*	d	moist, flat		slow		M	
red mulberry	*Morus rubra*	d	moist, flat		mod.		M	
hophornbeam	*Ostrya virginiana*	d	moist, flat		slow		L-M-H	
sourwood	*Oxydendrum arboreum*	d	dry, flat		slow		L-M	
red spruce	*Picea rubens*	e	moist, flat	yes	mod.		L-M	C
shortleaf pine	*Pinus echinata*	e	moist, flat	yes	rapid		L-M	W
pitch pine	*Pinus rigida*	e	dry		rapid		L	
eastern white pine	*Pinus strobus*	e	moist, flat	yes	rapid		L-M	
loblolly pine	*Pinus taeda*	e	dry	yes	rapid		L-M-H	W
Virginia pine	*Pinus virginiana*	e	dry		rapid		L-M-H	
American sycamore	*Platanus occidentalis*	d	moist, flat, wet	yes	rapid		L-M	
eastern cottonwood	*Populus deltoides*	d	moist, wet	yes	rapid		L-M	
bigtooth aspen	*Populus grandidentata*	d	moist, flat, wet		rapid		L-M	C
American plum	*Prunus americana*	d	moist, flat		mod.		M	
pin cherry	*Prunus pensylvanica*	d	moist, flat		rapid		L-M-H	
black cherry	*Prunus serotina*	d	moist, flat	yes	rapid		L-M-H	C
white oak	*Quercus alba*	d	dry, moist, flat	yes	slow		L-M	
scarlet oak	*Quercus coccinea*	d	dry	yes	rapid		L-M	
southern red oak	*Quercus falcata*	d	dry, flat	yes	mod.		L-M-H	W
bur oak	*Quercus macrocarpa*	d	dry, moist, flat	yes	mod.			
chestnut oak	*Quercus montana*	d	dry	yes	slow		L-M	
chinkapin oak	*Quercus muehlenbergii*	d	dry	yes	mod.		M-H	
pin oak	*Quercus palustris*	d	moist, wet	yes	rapid		L-M	
northern red oak	*Quercus rubra*	d	moist, flat	yes	mod.		L-M-H	
Shumard oak	*Quercus shumardii*	d	dry, flat	yes	mod.		M-H	W
post oak	*Quercus stellata*	d	dry	yes	slow		L-M	
black oak	*Quercus velutina*	d	dry	yes	mod.		L-M	
bristly locust	*Robinia hispida*	d	dry, moist, flat		rapid	M	L-M-H	
black locust	*Robinia pseudoacacia*	d	all		rapid	M	L-M-H	
black willow	*Salix nigra*	d	wet		rapid		L-M-H	
American black elderberry	*Sambucus nigra* ssp. *canadensis*	d	moist, flat, wet		rapid		L-M-H	
sassafras	*Sassafras albidum*	d	moist, flat		mod.		L-M-H	
American basswood	*Tilia americana*	d	moist, flat	yes	mod.		L-M-H	
American elm	*Ulmus americana*	d	moist, flat	see note	rapid		M-H	
slippery elm	*Ulmus rubra*	d	moist, flat		rapid		M-H	
highbush blueberry	*Vaccinium corymbosum*	d	wet		mod.		L-M-H	
southern arrowwood	*Viburnum dentatum*	d	all		slow		L-M	
blackhaw	*Viburnum prunifolium*	d	dry, moist		slow		L-M-H	

[1] Leaf type: d = deciduous, e = evergreen.
[2] Notes concerning crop trees: Hickories, American beech, and black walnut have growth forms that are well suited for crop trees, but consistent success in planting these species on coal surface mines has not been demonstrated. Red maple is not recommended for planting because it volunteers readily. American chestnut, white ash, and American elm are well suited as crop trees when healthy but are subject to special considerations due to their susceptibility to pests as described in text.
[3] Growth rate: mod. = moderate.
[4] Soil pH range: Trees are grouped by soil pH suitable for the species. L = low (pH < 5); M = medium (pH 5–7); H = high (pH > 7).
[5] Climate suitability. C = does well in cool climates, including the northern Appalachian region, and at higher elevations (>3,000 ft) in central and southern Appalachia; W = does well in warm climates, including Appalachia's southern region and parts of central Appalachia. If neither C nor W is specified, the species does well throughout the region.

Some mines contain only one primary site type. For example, a contour mine on a southern slope would be a dry slope over most of its area, so prescribing dry-slope species for the entire site would be an effective strategy. However, other mines include extensive areas of several site types. For example, a mountaintop mine reclaimed to approximate original contour could be planted with dry-slope species on its south- and west-facing slopes, moist-slope species on north- and east-facing slopes, and wet-site species along drainage channels and ponds.

For all tree prescriptions, plant species as a diverse mix across the landscape, not as single-species rows or blocks. One way to plant a diverse mix is for each of two planters to carry half of the prescribed species and mix them as they plant. The person planting the adjacent row will be planting different species so that all prescribed species are mixed into two adjacent rows.

TREE PRESCRIPTION ADVICE AND GUIDANCE

Select Species Suited to Site Conditions

Species should be prescribed by a person who is knowledgeable about local tree species, mine site conditions, and landowner and reclamation goals. If this expertise is not available, the Table 7-1 example may be used. If using Table 7-1, check that the native range of each prescribed species includes the planting area. If the planting area is outside the prescribed species' range, use this Advisory to select substitutes that are native to the area and suited to site conditions (Table 7-2).

Plant Enough Seedlings to Get the Job Done

On mines with bond release requirements of 450 surviving stems or fewer, we recommend planting 700 trees per acre—equivalent to 8-foot × 8-foot spacing. Assuming that survival rates on mine sites often average about 70 percent, the result would be 490 surviving trees per acre (70 percent of 700 planted). If a larger number of surviving stems is required, the number of planted trees should be increased accordingly. It is important to work closely with the State regulatory authority to identify and establish the tree stocking standards that will be applied at bond release, and to plant enough trees to provide a margin of safety to ensure compliance with bond release standards.

Plant and Mix Multiple Species

Native forests of the Appalachian region are diverse. It is common to find 40 or more tree and shrub species per acre in these forests. Mine sites often have a variety of soil and site conditions. The presence of multiple species can help a plant community persist if a pest or pathogen severely affects one or several of its species. For these reasons, we recommend planting multiple species.

Wet-site species are often planted as several rows along streambanks, ponds, or wetland borders (Figs. 7-4 and 7-5). Flowing waters will attract wildlife, thus creating opportunities for recruitment of unplanted species. Most flat site types will be on large-area or mountaintop mines far from forest seed sources, so that prescription includes more species than for other site types.

Figure 7-5.—Reclaimed mine site, showing how several rows of wet-site species planted along water channels can accelerate restoration of streamside vegetation. Riparian woody vegetation aids functioning aquatic communities in reconstructed streams by shading the channel and producing organic matter that enters the stream. Photo by J. Burger, Virginia Tech, used with permission.

Plant Crop Trees, Wildlife Trees, and Nitrogen-fixing Trees

For most mine areas, we recommend prescribing three types of species for planting:

- Crop trees that will form a forest canopy,
- Tree species selected for wildlife benefits, and
- Tree species that will fix atmospheric nitrogen (N), improving soil quality.

Crop trees are species such as black cherry, yellow-poplar (tuliptree), sugar maple, and oaks that can produce economic value for the landowner and form the forest canopy.

Some crop-tree species have heavy seeds that are slow to disperse. For example, oaks and hickories are major forest components throughout much of the Appalachian region, but their heavy seeds will not travel far without the help of animals. To promote the presence of these species on reclaimed mine land, our prescriptions emphasize heavy-seeded crop-tree species that are important components of the region's natural forests, especially the oaks.

Although many crop tree species provide wildlife benefits, some tree and shrub species have less commercial value but are important to wildlife. These species also occur in natural forests. Thus, prescribe other tree and shrub species in addition to crop trees for improving wildlife habitat in the FRA planting.

Species such as flowering dogwood and eastern redbud become established and grow rapidly, producing early canopy structure used by birds for cover and nesting, and fruits and seeds that serve as wildlife food. Attracting wildlife aids natural succession and forest development. Mammals and birds consume fruits and seeds in unmined habitats and then move through the reclaimed mine, where seeds passing through them are deposited. If site conditions are favorable, such seeds may germinate to produce live seedlings.

Some tree species occurring in natural forests at relatively low densities, such as common persimmon and black walnut, produce large fruits and seeds. These species' large seeds make them especially valuable as wildlife food sources but also limit their spread into the reclaimed mine landscape by wind and animals. Planting heavy-seeded species as seedlings is usually necessary to establish them on reclaimed mines.

Certain species produce physical structures that will aid habitat development as they mature. For example, native pines planted at low densities will provide winter cover for wildlife species such as white-tailed deer. As another example, shagbark hickory and white oak have exfoliating bark that can provide shelter for bat species, including the endangered Indiana bat. Most crop tree species also provide wildlife benefits. For example, oaks produce acorns, an important winter food source for species such as white-tailed deer. As we use the term here, wildlife trees are those planted in addition to crop trees for providing additional wildlife benefits.

Nitrogen-fixing trees remove N from the air, transforming it to organic forms that enrich the soil. Unless constructed from salvaged forest soils that contain surface organic material (Chapter 3, this volume), mine soils will generally be low in N, an essential plant nutrient. If not taken up by plants, the N applied as fertilizer will remain in the soil to support forest development only for the first few years. Thus, we recommend planting at least one tree species that is able to "fix" N from the atmosphere.

Encourage Natural Succession

The term "natural succession" describes the natural progression of plants becoming established and replacing other plants over time on disturbed areas. The FRA is designed to create a tree growth environment that will support natural succession to develop a diverse forest plant community (Fig. 7-6) (Chapter 8, this volume).

Figure 7-6.—South-facing slope on a Tennessee mine site, photographed during its seventh growing season. This site was reclaimed with the FRA and planted with oaks, green ash, yellow-poplar, and eastern white pine. Volunteer species including sweet birch, red maple, blackgum, and black cherry also became established. Photo by V. Davis, OSMRE.

Early successional trees are often referred to as "pioneer plants" because they colonize open areas, need full sunlight to germinate (they are not shade-tolerant), grow very fast, and are short-lived. Mid-successional trees replace the pioneer species over time, have intermediate shade tolerance, and are also fast growing; but they are longer-lived than the pioneer species. Late successional species make up most of the trees in the mature forest; they can grow and become established well in full shade (they are shade-tolerant). Late successional species such as sugar maple, American beech, and shagbark hickory establish and grow more slowly than early and mid-successional species but are long-lived and will eventually replace them in the developing forests, especially on moist sites. On dry sites, the oaks will persist.

We recommend prescribing a compatible mix of early, mid-, and late successional tree species that will shorten the period of time from bare ground to a diverse, valuable, mature forest. This can be accomplished by planting a mix of crop trees and wildlife trees.

SPECIES-SPECIFIC CONSIDERATIONS

Hickories and black walnut are heavy-seeded late successional species. Unfortunately, efforts to plant them on surface mines are often unsuccessful. Because of their importance as crop trees and wildlife habitat, include a small percentage of hickories and black walnut in tree prescriptions as an effort to ensure future seed sources. Hickories are important to wildlife, providing both mast and habitat on dry and moist slopes and flat areas. Black walnut can be prescribed for moist sites that have been reconstructed by using salvaged soils (Chapter 3, this volume).

White and green ash have been used in mine reclamation plantings with good success. We have not included ash species in Table 7-1 because an invasive insect pest, the emerald ash borer, is highly destructive to ash trees. Although the ash borer is not a current threat within most of the Appalachian coalfield, its range is expanding rapidly. Hence, many nurseries have ceased their production of ash seedlings.

Historically, American chestnut was a dominant forest species throughout the Appalachian region. However, most American chestnut have succumbed to invasive pests: a pathogenic fungus commonly known as the chestnut blight and the water mold Phytophthora root rot. Efforts are underway to develop blight- and root-rot resistant hybrids of American chestnut that grow well on mine sites (Chapter 12, this volume).

American elm is another native tree species that is being affected by a fungal pest. Like American chestnut, blight-resistant American elm hybrids are being developed.

SITE-SPECIFIC CONSIDERATIONS

Although site type (Fig. 7-2) is the major consideration for selecting tree species, other site conditions can also influence species selection. Soil properties, climate, distance to seed sources, and drainage patterns are other factors to consider.

Tree Growth Medium

The replaced mine soil must be able to provide growing trees with moisture, nutrients, and a drained and aerated soil condition if those trees are to survive and grow well. Soils selected and replaced using FRA practices will support most native species, but some soil conditions will limit selection of species (Chapter 3, this volume).

Most native tree species grow well in moderately acidic soils, that is, soils with pH in the range of 5.0 to 6.5. Alkaline soils, that is, soils with pH levels greater than 7.0, are often found in mine soils constructed with unweathered spoils and will limit tree species selection. Step 1 of the FRA prescribes soil construction using topsoil, weathered sandstone, or the best available material, or a combination of these materials. On most mine lands, materials will be available to enable construction of moderately acidic soils. This is fortunate because only a few of the species available for planting are able to tolerate highly alkaline or highly acidic soil. Bur oak and Shumard oak can tolerate soil pH greater than 7.5. A few species, including pin oak, can tolerate soil pH less than 4.0.

Soil compaction will also limit species selection. A few native species such as green ash and American sycamore can survive in compacted soils, but most species will not survive. If a mine site is compacted, future forest productivity will be significantly diminished. Step 2 of the FRA recommends leaving soils loose and uncompacted. Where equipment traffic causes soil compaction, rip soils to produce loose conditions before planting (Chapter 5, this volume).

Climate

Many hardwood species such as northern red oak and white oak occur throughout the Appalachian region and can be planted widely, but some species should be restricted only to certain climatic conditions. Species such as sugar maple, bigtooth aspen, and red spruce are adapted to cool climates and will be more successful in northern areas and at elevations above 3,000 feet in the central Appalachians. In contrast, species such as southern red oak are adapted to the warmer climates of southern areas and lower elevations. Table 7-2 includes information on species' climate suitability.

Proximity to Seed Sources

Some tree species, such as red maple, yellow-poplar, and American sycamore, have wind-blown seed that can travel great distances, and they establish readily on mine sites with favorable soils. If an adequate seed source exists near the mine site, then there is no need to plant these species.

How "Flats" and "Moist Slopes" Differ

Large flat areas on mine sites often have poor internal drainage, meaning they lack subsurface channels to carry infiltrating water and air into the rooting zone. Poor internal drainage is a problem for planted trees because such soils retain excessive moisture and restrict access by plant roots to soil air. Although we generally recommend species for flat and rolling areas similar to those used on moist slopes, large flats with little surface relief will often have sufficient soil moisture to support wet-site species.

Wet-site species, however, will rarely do well on slopes because slopes have better internal drainage. Step 2 of the FRA recommends that soils be kept loose, but this is often accomplished more readily on slopes. More importantly, gravity helps subsurface water move within the planted trees' rooting zone on sloped sites.

STANDARDS FOR SUCCESS

Federal law (SMCRA) requires coal mining operations to restore the land's pre-mining capability. Many mining operations are conducted on lands that were forested prior to mining. Proper use of the FRA should produce a healthy forest that satisfies that SMCRA mandate. Selecting and planting tree species that are well suited to site conditions is essential to successful reforestation with the FRA.

Planted trees of many species will survive and grow well if the land is reclaimed by using the FRA. Placing trees on soil and landscape conditions for which they are well suited will increase their survival and growth, improving prospects for prompt and trouble-free bond release. Proper use of the FRA will also allow volunteers of certain species to become established, increasing the diversity and land use capability of the restored forest. Select tree species for planting based on both their suitability for the soil and landscape conditions on the mine site, and an understanding that the resulting composition of the forest will be a mix of planted and volunteer species.

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Chapter 8: Mine Reclamation Practices to Enhance Forest Development through Natural Succession

J. Groninger, J. Skousen, P. Angel, C. Barton,
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INTRODUCTION

"Natural succession" is a term used to describe natural changes in plant community composition over time. In the forested Appalachian region, disturbances from storms, fire, logging, or mining can disrupt or destroy established forests. Natural processes that lead to restoration of the forest vegetation following such a disturbance usually begin quickly and result in development of another forest. On reclaimed mine sites, the quality of that forest and the speed with which it develops depend upon the conditions created by the mining and reclamation process (Fig. 8-1).

Figure 8-1.—Reclaimed mine site in eastern Tennessee 47 years after reforestation. This site was reforested with various pine species and black locust in 1959 on uncompacted spoil with no planted ground cover. Succession and colonization have occurred over the years. The pine forest has been replaced with vegetation similar to the nearby native forest: yellow-poplar dominant in the overstory; red maple, sassafras, and northern red oak in the mid-story; and blueberries, groundpine, Virginia creeper, and ferns in the understory. Photo by Vic Davis, OSMRE.

Conventional surface mine reclamation as practiced from the late 1970s until recently under the federal Surface Mine Control and Reclamation Act of 1977 (SMCRA) commonly featured smooth grading of topsoil or topsoil-substitute material followed by establishment of grasses and legumes

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that grow rapidly to form a thick ground cover. These compacted mine soils and the competitive grasses hinder tree establishment and growth and delay the process of succession to forest cover.

In contrast, reclamation practices known as the Forestry Reclamation Approach (FRA) are intended to encourage succession in a manner that helps the mine operator satisfy regulatory requirements cost effectively and achieve prompt bond release (see Box 8-1). This Forest Reclamation Advisory describes the ways in which these reclamation methods can encourage rapid succession and accelerate development of high-quality postmining forests.

SUCCESSION: FROM BARE GROUND TO FOREST

When land is disturbed in a way that removes all vegetation, including seeds and plant material capable of resprouting, and nothing is done to revegetate, succession occurs slowly. At first, "pioneer" plant species including grasses, other herbs such as goldenrods and ragweed, vines, and shrubs such as raspberry and blackberry colonize and dominate the site. Depending on soil and site conditions, this plant community type may continue to dominate for many years, or it may be replaced sooner by other kinds of plant communities, including forest trees. (Please see the Appendix starting on p. A-1 for scientific names of species mentioned in this chapter.)

When soil and vegetation conditions are favorable for trees, fast-growing short-lived (early successional) trees such as black locust, sassafras, Virginia pine, and hawthorn overgrow the shrubs. In time, these early successional trees make the site more habitable for slower-growing but longer-lived (later successional) trees such as oaks, hickories, cherry, sugar maple, and ash. As succession proceeds, the open spaces between trees continue to decrease. When the tree tops (or "canopy") of the emerging forest grow together so that very little light reaches the ground, a phase of succession called canopy closure occurs, often 15 to 20 years after the initial disturbance. After canopy closure, lower-growing vegetation beneath the forest canopy (called the understory) declines in response to decreased sunlight until another disturbance opens up the forest.

HOW LONG DOES IT TAKE FOR A FOREST TO MATURE?

When succession occurs under good conditions, some fast-growing timber trees may grow to a size that can be harvested as soon as 30 to 40 years after disturbance; slower-growing hardwoods may require 50 to 60 years or longer (Fig. 8-4). Other sites may still be in the grass-herb-shrub stage with only scattered trees for several decades after a disturbance because soil conditions are not suitable or the understory vegetation is too competitive for tree recruitment. This is called "arrested succession," which is a failure of later

Figure 8-4.—Fifty-five-year-old black walnut trees that were planted and grew on spoil banks in southwestern Indiana. Photo by R. Rathfon, Purdue University, used with permission.

Box 8-1. Can the Forestry Reclamation Approach Achieve the Rapid Succession of Natural Forests?

After harvest in natural forests, most regenerating hardwood trees grow as sprouts from well-established root systems. This type of regrowth cannot occur on reclaimed mines because those rooting systems have been removed. Unless native forest soils are used in reclamation, mine sites lack the seedbanks and budbanks (live seeds on or in the forest floor and buds that can produce sprouts) of native forests, so the vegetation immediately following reclamation is unlikely to be as diverse.

In some cases, mine sites that have been reclaimed using the FRA (Chapter 2, this volume) will undergo succession more rapidly than natural forest sites following timber harvest. After an initial planting of saplings at 6-foot × 6-foot spacing on an ungraded eastern Kentucky mine site (Fig. 8-2), canopy closure occurred within about 7 years. The dense planting of early and later successional tree species kept competing weeds at a minimum, which allowed rapid colonization by 27 forest tree species that were growing nearby. In addition, the number of naturally recruited forest species (trees and other vegetation types) was 10 times greater on loose-dumped spoils than on those spoils that were graded using conventional reclamation practices. The loose-dumped spoils allowed natural succession to occur, as indicated by a far higher number of recruited stems per acre (475) compared to the conventionally graded spoil (49 stems per acre) (Fig. 8-3). Tree canopy occupied more than half the area on the loose-dumped spoils. In contrast, canopy cover was only 5 percent in the conventionally graded areas of the mine site.

As the FRA is used on more reclaimed mines, researchers will have the opportunity to improve these techniques and further increase the value of reclaimed lands for future generations.

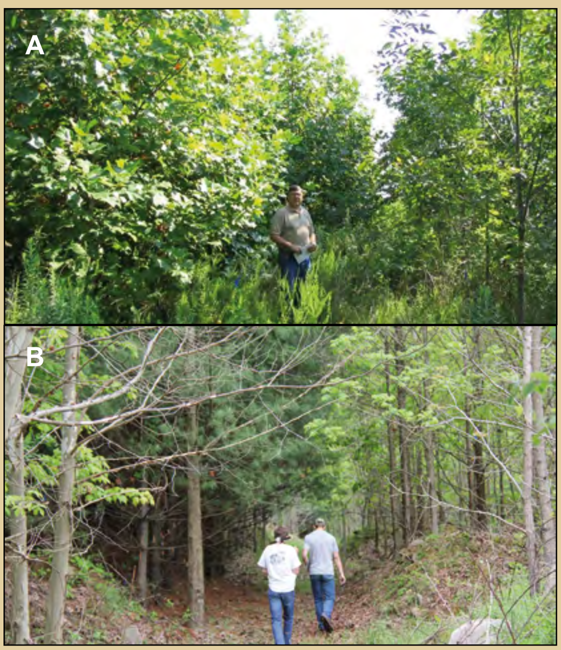

Figure 8-2.—Reforested mine site in southeastern Kentucky (A) 8 years and (B) 18 years after reforestation. White oak, white ash, eastern white pine, northern red oak, black walnut, and yellow-poplar were planted. The loose-dumped, uncompacted mine spoils allowed planted seedlings to achieve greater survival and faster growth while allowing more colonization by nonplanted forest species, compared to an adjacent mine site that was graded by using conventional practices. The closed canopy forest with abundant native plants remaining in the understory was achieved in the 10 years between the photos, indicating how rapidly forests can develop on a high-quality growth medium. Photos by OSMRE.

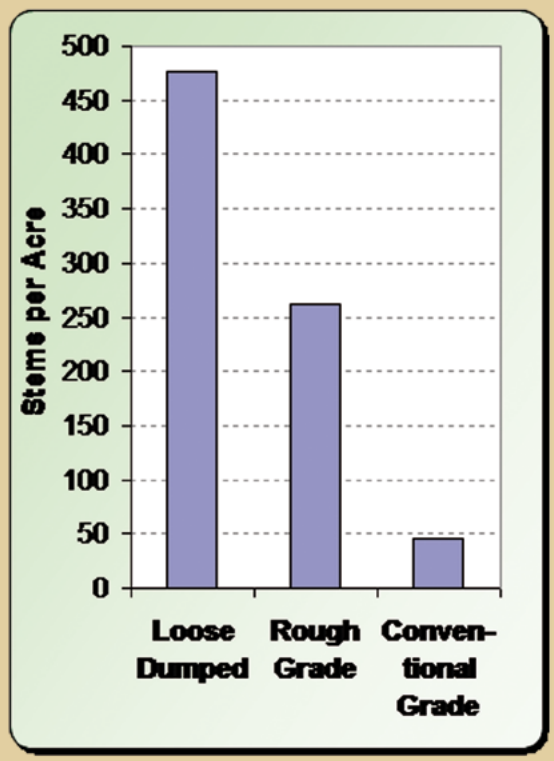

Figure 8-3.—Number of stems per acre of naturally seeded forest species after 8 years in loose-dumped, rough-graded, and conventionally graded areas of the southeastern Kentucky surface mine shown in Figure 8-2 (data from Barton and others, in press.).

successional species to become established and eventually dominate a site (see Box 8-2). Arrested succession also occurs in areas where large populations of deer or rodents consume or destroy tree seedlings.

Box 8-2. "Arrested Succession"

A condition known as "arrested succession"—a failure of later successional species to colonize a site—can occur after reclamation if principles of natural succession are ignored (Fig. 8-5).

For decades, a common reclamation practice consisted of seeding fast-growing grasses such as tall fescue and sericea lespedeza to rapidly revegetate mine sites. Often, black locust seed was added to the groundcover seeding mix. This practice produced thick vegetation that easily satisfied the bond release requirements of those times. But within 10 years after planting, most black locust trees become infested with a tiny insect known as the locust borer beetle. This pest causes the trees to lose vigor, and they break down to a shrub-like form. In this form, their sparse canopy and nitrogen-fixing capability allow the groundcover grasses to persist, so the thick herbaceous cover under the black locust remains intact, preventing the recruitment of other trees and forest vegetation. Because other native tree species are not present to replace the black locust, tall fescue and companion species such as sericea lespedeza can dominate such sites for decades.

Figure 8-5.—Reclaimed surface mine in western Maryland. Black locust and grass vegetation were planted 16 years earlier. As a result, the development of a natural forest community through natural succession has been delayed, a condition known as "arrested succession." Photo by OSMRE.

WHAT FACTORS AFFECT SUCCESSION ON A MINE SITE?

Quality of the Rooting Medium

If soil replacement results in a rooting medium that is shallow or has been compacted, the site will be prone to drought and plant nutrition problems. Mine soil pH that is too high (pH more than 7) or too low (pH less than 5) and mine soils that have high levels of soluble salts can also cause plant nutrition problems. Seeds of unplanted forest species that are carried to the mine site by wind or wildlife will not germinate and grow if the soil surface is compacted or has chemical properties that are not well suited to their needs. Those grass and shrub species that are able to become established and grow on such soils will dominate on such sites, and forest succession will progress slowly. In contrast, a deep and loose growth medium that contains plant nutrients encourages colonization and canopy development by species from the native forest. These soil properties promote a diversity of trees and other vegetation and are productive for timber and wildlife.

Groundcover Vegetation

Where tall, aggressive grasses are established on the site through reclamation, or where herbs, shrubs, and vines become established in dense thickets, new tree establishment is hindered and young trees become stunted. Because a sparser ground cover allows sunlight to reach the soil surface, planted seedlings can grow and seeds from the surrounding area carried in by wind and wildlife can become established more easily. Tall, thick ground covers also remove water and nutrients from the soil rapidly, leaving fewer of these essential resources for the slower-growing trees. These ground covers also attract deer, which can consume the tree seedlings; and they provide cover for small rodents, which can gnaw on planted seedlings.

The Mixture of Tree Species

Natural forests in the Appalachian region consist of a mixture of tree species. Some become dominant soon after disturbance and play an important role in establishing the full range of forest plant species. In time, these typically short-lived species die, decline, or are harvested as the longer-lived tree species take over. A mature, closed forest canopy then results. Mine operators can shorten the time it takes nature to produce a valuable forest by preparing the site with loose, good-quality mine soils that encourage establishment of volunteer early-successional species, and by planting a mixture of early and later successional tree species, such as those described next.

- Early successional trees are fast-growing species such as pines, sweet birch, sourwood, red maple, and bigtooth aspen that provide habitat for birds and other seed-moving animals and help suppress grasses, thus allowing native forest plant species to become established. Early successional species such as dogwoods and redbud produce fruit and may further contribute to forest development by attracting seed-carrying birds and other wildlife.
- Later successional tree species are those which typically dominate a site later in the natural succession process. These include many of the commercially valuable hardwoods—such as the oaks, hickories, walnut, and cherry—that are characteristic of mature Appalachian and midwestern forests. Many of these species have relatively large and heavy seeds that are not moved quickly over long distances by natural forces. Planting later successional species on a mine site can help these species become established more rapidly than through unassisted natural succession.

To maximize forest value where reclamation has produced soil, groundcover vegetation, and other conditions favorable to reforestation (FRA conditions), planted trees should be compatible for growth in mixed stands. High-value later successional species capable of living for at least several decades should be favored for planting. On such productive sites, plant early successional trees and shrubs in significant numbers if they will help improve the growth and value, and further aid the colonization, of longer-lived and more valuable trees.

Other Factors

Other soil and site factors will also influence the speed of natural succession on mine sites. For example, use of excavated soils that contain living seeds and roots from the native forest in reclamation areas can accelerate natural succession. Mined areas that are close to unmined native forest will be colonized by native forest species more rapidly than sites farther from unmined forests (see Box 8-3).

WHAT RECLAMATION PRACTICES AID ESTABLISHMENT OF FORESTS BY ACCELERATING NATURAL SUCCESSION?

Reforestation researchers have developed the FRA, which, when implemented properly, can accelerate natural succession on reclaimed mine sites, aiding formation of healthy, diverse hardwood forests (Chapter 2, this volume). The FRA can be summarized in five steps:

1. Create a suitable rooting medium for good tree growth that is no less than 4 feet deep and consists of topsoil, weathered sandstone, or the best available material, or a combination of these materials.
2. Loosely grade the topsoil or topsoil substitutes established in Step 1 to create a noncompacted growth medium.
3. Use groundcover species that are compatible with growing trees.
4. Plant two types of trees: early successional species for wildlife and soil stability, and commercially valuable crop trees.
5. Use proper tree planting techniques.

Box 8-3. Making Post-reclamation Vegetation More Diverse

Natural Appalachian forests contain hundreds of plant species. Replacing all of these species through replanting and seeding is virtually impossible. Natural colonization and replacing topsoils are two mechanisms that can increase plant diversity of reclaimed sites.

Reclaimed mine sites are naturally colonized by native vegetation

In Virginia, researchers studied vegetation change on mine sites over time (Holl 2002, Holl and others 2001). In 1992, and again in 1999, they documented the species present on contour mine sites of three different age classes—reclaimed in 1967-1972, 1972-1977, and 1980-1987 using techniques typical for those times—and in the adjacent natural forests. Succession was clearly evident because many more species were present on reclaimed sites than had been originally planted, and many of the unplanted species also occurred in the adjacent forests.

However, natural succession occurs slowly when conventional reclamation practices are applied. On the 1972-1977 sites, which had been reclaimed with aggressive ground covers, grass-like herbaceous vegetation was still dominant 15 to 20 years after the initial reclamation. By 1999, the herbaceous cover was finally beginning to yield to woody species, including red maple and sweet birch, that have small seeds which can be carried by wind and birds. But even though most native forest species were present by 1999, some understory species such as trillium, wintergreen, and serviceberry were not found on any of the reclaimed mines despite the proximity of most of these sites to undisturbed forest (within a few hundred yards' distance).

In another study established in 2005 in Kentucky, FRA reforestation plots of loose-dumped brown weathered sandstone were planted with four native hardwood species, but no ground cover was applied (Sena and others 2014). In 2013 seedling survival was high (86 percent) and vegetation completely covered the ground. The total number of colonizing species on the plots was 57, and 68 percent of those were native to the region. There were 26 naturally colonized tree and shrub species. Under the conditions of this experiment, the physical and chemical makeup of the mine spoil, linked with available seed sources, led to the development of a diverse forest community.

Accelerating succession by spreading forest soils

In some areas, soils salvaged from the pre-mining forest floor can be recycled to produce a plant-growth medium after mining. In these cases, seeds or roots contained in the soil can sprout, establishing species not typically spread by wind or wildlife or where potential seed sources are far away (Wade 1989). For example, at a mine site in Kentucky that was reclaimed by using topsoils from the adjacent natural forest, 63 species from the natural forest donor site were found on the reclaimed mine site within 1 year after the soils were spread (Hall 2009). Some important points to consider when implementing this treatment are:

- Native forest soil aids succession most effectively when moved directly from the mining area to the reclamation area. Storage of soil before respreading causes seeds and roots to lose viability, with longer storage periods causing greater losses.
- Fast-growing agricultural grasses and legumes are incompatible with most native forest vegetation. As a result, spreading native topsoil is most effective as a reforestation practice when other ground covers, especially agricultural grasses and legumes, are not seeded.
- Moved topsoil must be free of invasive plant species such as multiflora rose, oriental bittersweet, and Japanese honeysuckle for this treatment to provide a long-term benefit to forest development. Carefully inspect the source site prior to mining and keep soil-moving machinery clean as precautions to prevent spread of these species through topsoil replacement. Spreading soils from areas with undesirable species during reclamation can lead to establishment of those species on the mine site, causing "arrested succession."

Use of the FRA practices can accelerate natural succession by creating conditions similar to those where native forests thrive.

SUMMARY

Landowners and mine operators are increasingly choosing forest as the postmining land use. Compared to conventional reclamation practices, reclamation using the FRA allows more planted seedlings to survive and more species from the surrounding forest to colonize the reclaimed mine site. Agencies in the Appalachian Regional Reforestation Initiative states allow both planted trees that survive and tree recruits that are compatible with the postmining land use to be counted toward the tree-stocking standard for reclamation success. Reclamation practices that encourage natural succession can help mine operators meet regulatory requirements and achieve prompt bond release while restoring native forests.

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Chapter 9: Planting Hardwood Tree Seedlings on Reclaimed Mine Land in the Appalachian Region

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INTRODUCTION

The Forestry Reclamation Approach (FRA) is a method of reclaiming surface coal mines to forested postmining land use (Chapter 2, this volume). "Use proper tree planting techniques" is Step 5 of the FRA; when used with the other FRA steps, proper tree planting can help to ensure successful reforestation.

Proper care and planting of tree seedlings is essential to any reforestation effort. Appalachian coal mines reclaimed by using the FRA will often be rough, rocky, and on steep terrain. Thus, hand planting is the usual method for planting hardwood tree seedlings. Professional tree planting companies with experience in hand-planting reclaimed mines can provide excellent results. Most of these companies offer a complete service that includes obtaining, handling, and planting hardwood tree seedlings. State forestry departments and consulting foresters can also provide valuable assistance.

Any tree planting process on mined land entails several steps, each of which must be executed competently to assure a successful reforestation project. They are:

- Selecting and ordering seedlings
- Site preparation
- Proper handling and storage of seedlings
- Preparing seedlings for planting
- Planting tree seedlings
- Post-planting care and assessment.

The next six sections discuss these steps, and additional resources are listed in Box 9-1.

SELECTING AND ORDERING SEEDLINGS

Nurseries produce seedlings as either bare-root or containerized stock. Bare-root seedlings grown in nursery beds (Fig. 9-1) are relatively inexpensive when purchased in bulk. Less-common species are produced in smaller quantities, usually

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Box 9-1. Additional Resources

Burger, J.A.; Zipper, C.E. 2009. **How to restore forests on surface-mined land.** Virginia Cooperative Extension Publication 460-123. Blacksburg, VA: Virginia Polytechnic Institute and State University. Available at http://www.cses.vt.edu/PRP/VCE_Pubs.html (accessed November 4, 2016).

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Pijut, P.M. 2003. **Planting and care of fine hardwood seedlings: planting hardwood seedlings in the Central Hardwood Region.** FNR-210. West Lafayette, IN: Purdue University, Department of Forestry and Natural Resources. 8 p. Available at www.treesearch.fs.fed.us/pubs/12877 (accessed November 4, 2016).

South Carolina Forestry Commission. [N.d.]. **Tree planting guide.** http://www.state.sc.us/forest/refplant.htm (accessed November 4, 2016).

Figure 9-1.—Hardwood seedlings growing in a nursery. Many State- and privately owned nurseries have increased production in response to recent demand for high-quality hardwood seedlings. Photo by V. Davis, OSMRE.

in containers, and are delivered in soil-filled containers or with a plug of soil surrounding the roots. Most hardwood seedlings for reforestation are purchased as bare-root stock grown in a nursery for 1 year and are referred to as 1-0 seedlings. Bare-root hardwood 1-0 seedlings should have a vigorous root system.

Mine operators and reclamation practitioners are encouraged to review the reforestation plan in the approved permit during the summer and calculate the number of trees required for the upcoming tree-planting season. Advance placement of tree orders in late summer or fall, 4 to 6 months before the planned planting date, will reserve the desired number and species of tree seedlings. If large numbers of seedlings or uncommon species are needed, coordination with the nursery a year or more in advance may be required.

Use of seedlings grown from seed collected from the same geographic region where they will be planted will increase the long-term reforestation success. Seed origin should be as close in latitude as possible to the planting site and within the same USDA hardiness zone (map available from http://www.usna.usda.gov/Hardzone/). Distance in an east-west direction is less important. Ask the nursery manager for information about seed origin.

SITE PREPARATION

The FRA includes construction of a growth medium with favorable properties, suitable placement, and minimal grading of that material while avoiding compaction, and the use of tree-compatible ground cover (Chapters 2, 4, and 6, this volume). On active mines reclaimed using the FRA, additional site preparation will not be required. Plant trees directly into the surface materials. In areas of high soil compaction such as temporary roads or equipment work areas, or on mines that were reclaimed years ago by using methods that compacted the soil, dozer ripping can be used to loosen soils (Chapter 5, this volume). On older sites, thick and vigorous ground covers may be temporarily controlled by ripping, disking, or herbicide so that young tree seedlings have a better chance to compete. On active mines, plant tree seedlings in winter before seeding the ground cover the next spring, or plant tree seedlings shortly after seeding the ground cover.

Native hardwoods normally grow at a soil pH in the range of 4.5 to 7.0; most species prefer a pH of 5.0 to 6.5. Where reclamation has established mine soils favorable for trees, fertilize the site as recommended in Chapter 6 of this volume. Soil samples should be taken to a soil testing laboratory that is experienced and capable of providing recommendations for mine soils; specify that forestry is the land use so as to receive proper lime and fertilizer recommendations. Lime is generally not recommended on reforestation sites unless acid-producing materials are present or soil pH is less than 5.0. Mine soils are commonly deficient in phosphorus (P), so apply fertilizer that contains sufficient P to support tree establishment and long-term growth but relatively low rates of nitrogen (N) to avoid stimulating herbaceous competition that will depress planted seedlings' survival and growth.

Figure 9-2.—Tree seedlings in cold storage. Seedlings should be kept in cold storage with bags unopened until just before planting. Photo by M. French, Green Forests Work, used with permission.

PROPER HANDLING AND STORAGE OF SEEDLINGS

Bare-root tree seedlings are lifted from the nursery after the seedlings enter winter dormancy. Depending on the nursery location, seedlings are generally available for distribution by late December through the end of March. Tree seedlings are living organisms, so limit the level of stress between lifting and planting to increase the vigor and survival rate of planted seedlings. Inspect nursery seedling bags upon delivery; mend any holes with tape. If possible, arrange with the nursery to lift and ship seedlings immediately before planting. If seedlings arrive more than a day or two before they will be planted, place the bags in regulated cold storage (33 to 40 °F with humidity above 80 percent) until planting (Fig. 9-2). Protect seedling bags from freezing and never place them in direct sunlight.

If cold storage is not available, keep the seedling bags cool and moist, with temperature below 40 °F but above freezing. Higher temperatures may cause seedlings to break dormancy, increasing transpiration and drying out the roots. Storage for more than 10 days is not recommended. If seedlings must be stored for an extended period in cold storage, inspect bags at least once a week to check that roots appear wet. Water roots with a fine mist if needed, but do not let standing water in the bottom of the bag be more than a half-inch deep. Any time you open the bag, reseal it with tape to prevent water loss. Ensuring cool temperatures and moist roots will reduce losses during storage and after planting.

PREPARING SEEDLINGS FOR PLANTING

Again, cool temperatures and moist roots are the keys to success. During transportation, leave tree seedlings in the bags and protect them from wind and sunlight in an enclosed vehicle or covered with a tarp. In the field, cover the nursery bags and planting bags with light-reflecting tarps so they are not exposed to sun and wind. Planting a mixture of tree species will require opening the individual nursery bags, separating the seedlings, and mixing the various species together in the tree planting bags; perform this operation in the staging area, in the shade.

Commercially available tree planting bags are designed for easy use and help to protect the seedling roots from drying. Placing wet mulch in the planting bag, or dipping the seedling roots in a hydrating gel, can provide extra protection (Fig. 9-3). Mulch that is not saturated with water will wick moisture away from the roots. If planting bags are not available, use 5-gallon plastic buckets containing 1 to 2 inches of water; cover the buckets loosely with a plastic bag.

Soil or hydrating gel clinging to the roots is beneficial and should not be shaken or rinsed off, so be careful when adding water to the planting bags. Once the seedlings are placed in the planting

Figure 9-3.—Preparing seedlings in the field: (A) Seedlings are separated carefully; roots are dipped in a hydrating gel, then (B) immediately placed in a planting bag to reduce root drying. Photos by K. Schmidt, University of Kentucky, used with permission.

bag, plant them as soon as possible. If the roots dry out for even a few minutes, seedling mortality will increase significantly, so it is important to work quickly and keep the roots moist at all times. Any seedlings that are not immediately used should remain in the nursery bag; after adding a fine mist of water if necessary to keep the seedlings moist, keep the bag tightly closed. Return unused bags to cold storage to reduce the chance of seedling damage.

Some pruning of the root system occurs at the nursery while processing tree seedlings for distribution. Because carbohydrates stored in the seedling's roots are used for initial shoot development, do not do additional pruning of the roots in the field. Keeping as much of the root system intact as possible will increase both the initial survival rates and early growth rates of the planted seedlings. The best way to plant a hardwood seedling with an extra-large root system is to dig a bigger hole.

PLANTING TREE SEEDLINGS

Desirable planting dates in the Appalachian region range from December to mid-April depending on the latitude and elevation of the planting site (check with your State forestry department or consulting forester). Planting trees early in the planting season will allow development of the root system before the drier weather arrives. The best planting days are overcast with temperatures below 50 °F when the soil is moist but not frozen. A staging area, protected from wind and direct sunlight, should be located on the planting site and used to distribute the seedlings from the nursery bags to the planting bags.

Most reforestation plans prescribe the desired tree spacing. However, if the spacing location falls in an area of heavy ground cover or surface rock, seedling survival will be increased by moving the planting spot a few feet to a place where there is less ground cover or surface rock. Common grid patterns for planting tree seedlings are listed in Table 9-1. Tree spacing depends largely on what is required for stocking by each State mining agency, so check the State regulations and the revegetation plan in the mining firm's permits for the required tree spacing and number of trees per acre. Planting plans are often developed assuming that 70 percent of the planted seedlings will survive. But actual survival may be greater or less depending on soil conditions, weather, planting practices, and similar factors.

Table 9-1.—Trees per acre planted and surviving assuming 70-percent survival rate for common grid patterns for planting tree seedlings

Spacing (feet)	Trees per acre: Planted	Trees per acre: Surviving
7 × 7	889	622
7 × 8	778	544
8 × 8	681	476
8 × 9	605	423
9 × 9	538	376
9 × 10	484	338
10 × 10	436	305

The most common tree planting tools on mine sites in the Appalachian region are the hoedad, the KBC planting bar, the sharpshooter spade, and the dibble bar (Fig. 9-4). Most planting contractors prefer the hoedad because the wooden handle

Figure 9-4.—Tree-planting tools commonly used on mine sites. From left to right: hoedad, KBC planting bar, sharpshooter spade, and dibble bar.

absorbs some of the impact shock encountered when planting in rocky soil, and it is easier to use on steep slopes (Fig. 9-5). Both the KBC planting bar and the sharpshooter spade have long pointed blades that can make a hole deep enough for 1-0 hardwood seedling roots in rocky soils (Fig. 9-6). The shorter, blunt dibble bar blade works better for planting pine seedlings with smaller root systems.

Regardless of the tool, the planting procedure is basically the same. The hardwood seedlings' root system is generally larger than that of pine seedlings of the same age, so extra time may be required to make a hole to accommodate the 1-0 hardwood roots. Generally, the planting hole should be vertical or near vertical so that planted seedlings can stand straight up when planted.

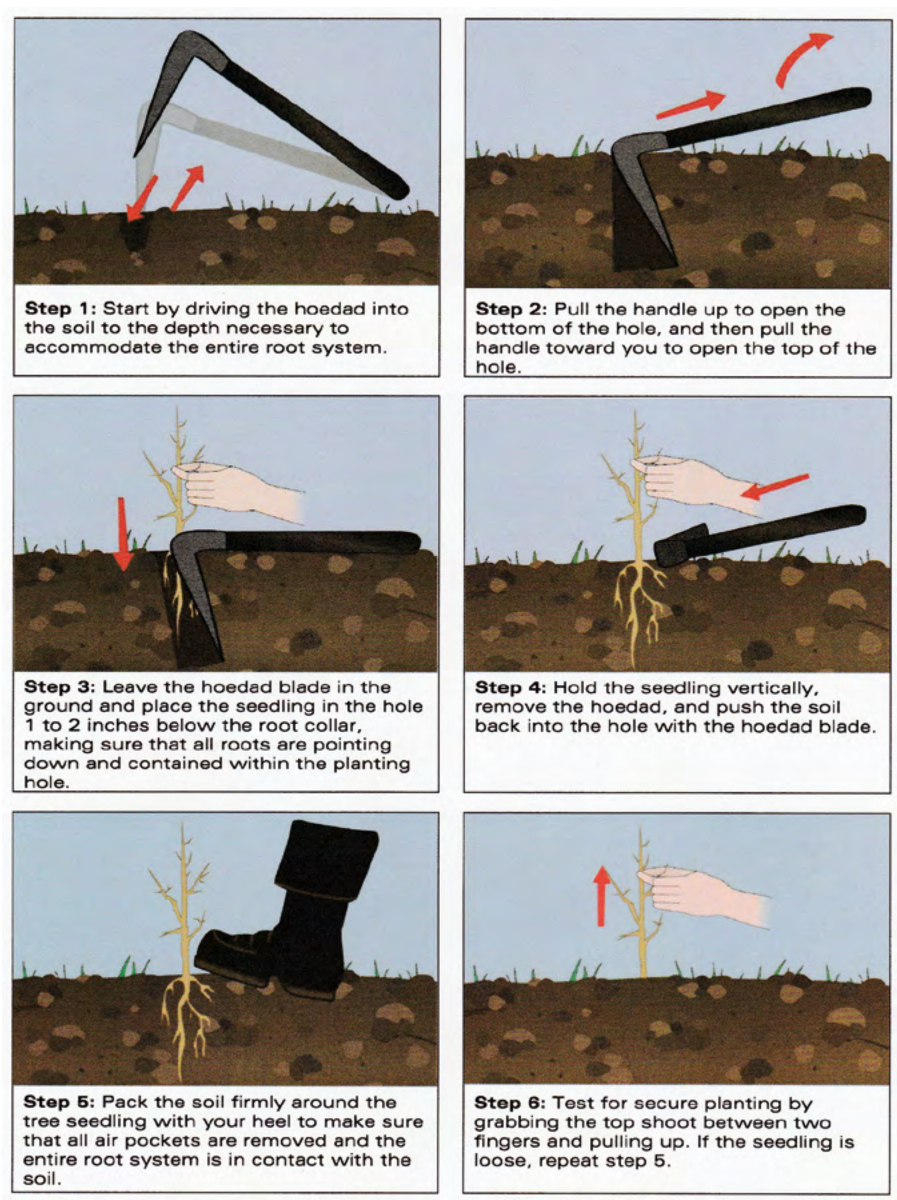

Figure 9-5.—Tree planting using a hoedad.

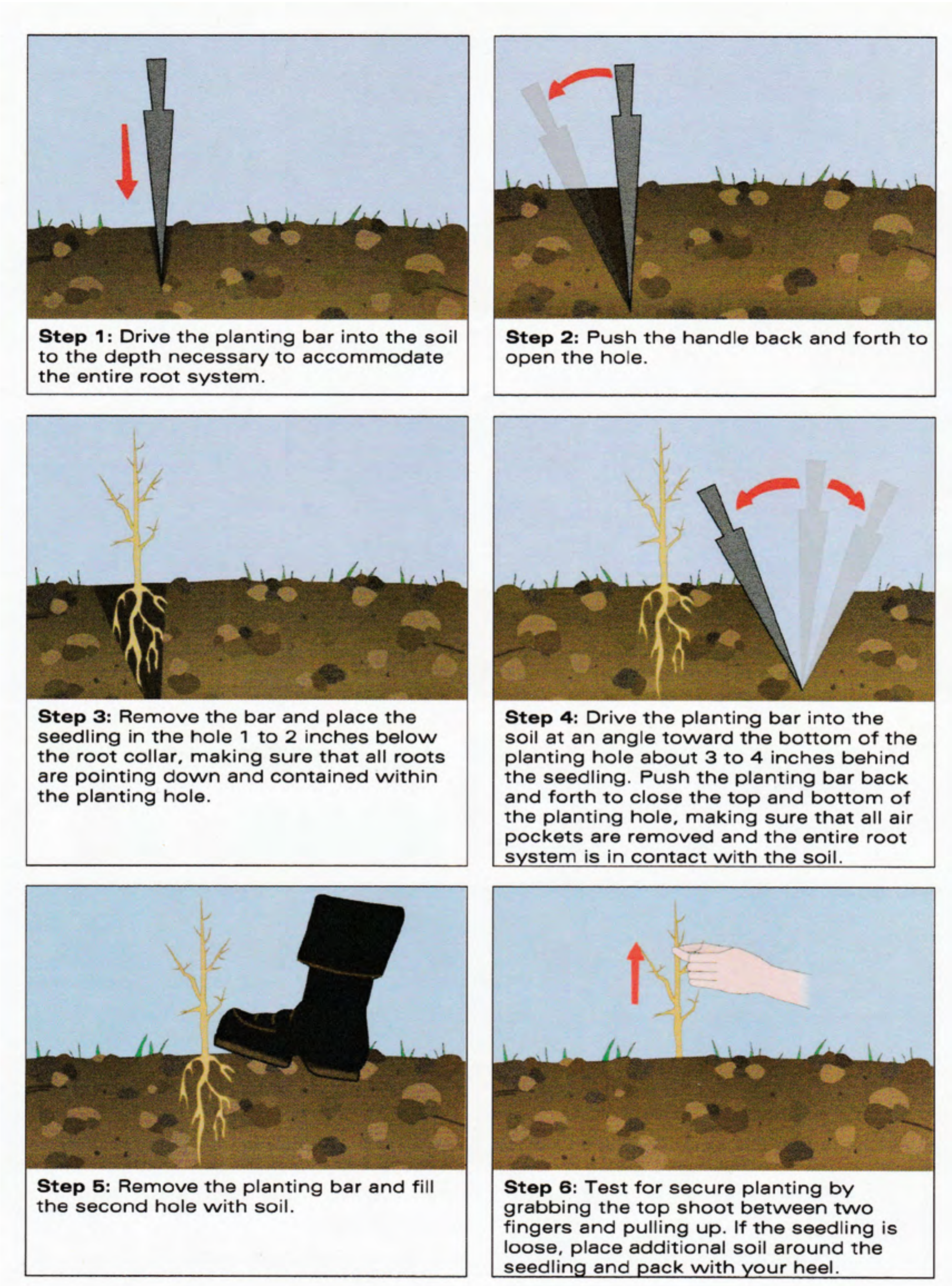

Figure 9-6.—Tree planting using a KBC bar, sharp-shooter spade, or dibble bar.

Seedlings must be planted at the proper depth, or initial survival and long-term growth will be compromised. The seedling root collar is the transition zone between the root system and the stem (Fig. 9-7). Plant hardwood seedlings 1 to 2 inches below the top of the root collar, which will allow for some soil settlement without exposing the roots. Take care to ensure that all roots are pointing down and contained within the planting hole. When planting, remove only one seedling at a time from the planting bag. Seedling roots should not be forced or twisted into the planting hole, as this practice will cause bent or broken roots and impair new root development, and may eventually cause the tree to die. Plant the seedling in a vertical position with the soil packed firmly around the roots so that all air pockets are removed and the entire root system is in contact with the soil. On steep slopes, the hole may be oriented slightly away from the vertical position if necessary to ensure that the seedling will remain stable and roots can contact deeper soil layers. Keep all seedlings, except the one being planted, in the planting bag, where they are protected from drying out.

Test for secure planting by grabbing the seedling's top shoot between two fingers and pulling up. If the seedling is loose, place additional soil around the seedling and pack firmly (Fig. 9-8).

Personnel from the mining firm should be present during the planting operation to ensure that seedlings are handled and planted using proper procedures. Close supervision of the planting crew and inspection of planted trees will help to control quality and provide consistent results.

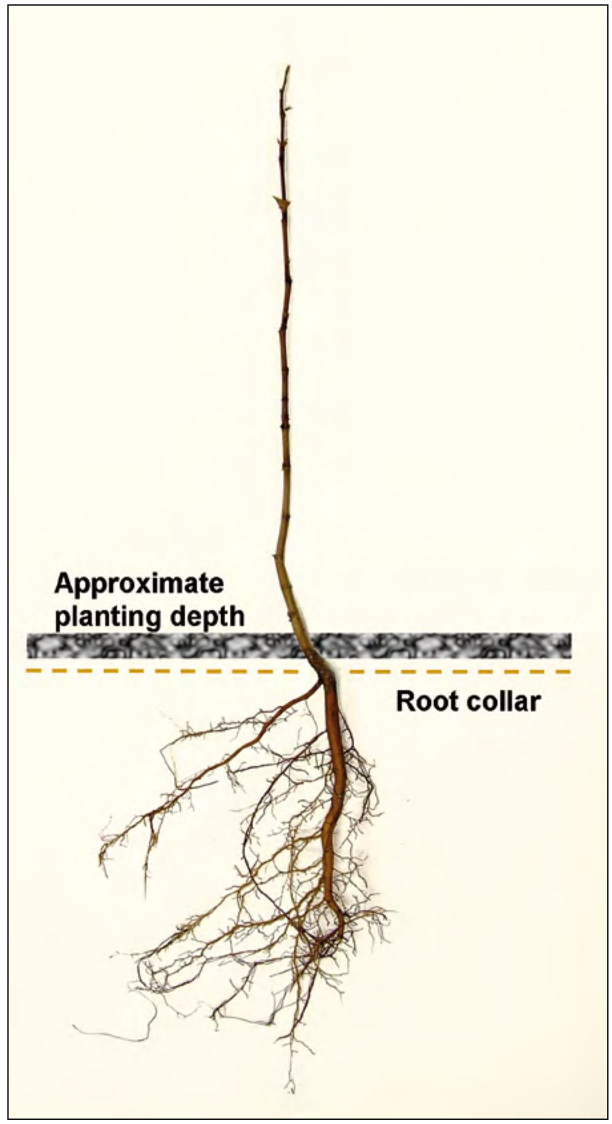

Figure 9-7.—A bare-root hardwood tree seedling before planting. The "root collar" is an area where the stem meets the roots, and is thicker than the stem above. The seedling should be planted 1 or 2 inches below the root collar, well above the highest root.

Figure 9-8.—Tree planting with a hoedad, using the steps illustrated in Figure 9-5. (A and B) Tree seedlings should be planted by making a planting hole deep enough to accommodate the entire root system. (C) The seedling is placed so that all roots are contained within the hole without forcing, bending, or twisting the roots. (D) The soil is packed firmly around the tree seedling's roots to ensure that all air pockets are eliminated and the entire root system is in contact with the soil. (E) The top shoot of the seedling is grasped between two fingers and pulled to make sure it has been securely planted. Photos by K. Schmidt, University of Kentucky, used with permission.

POST-PLANTING CARE AND ASSESSMENT

Post-planting survival assessment is essential to any reforestation project. The mine operator should conduct a survival assessment during the second growing season, before leaf fall. If survival appears adequate for performance bond release, no further action is required. The vast majority of planted trees that live into the second growing season can be expected to survive for the long term. If survival is not adequate, make arrangements for replanting during the upcoming winter season. On active mines, prompt identification and remediation of survival problems can help to achieve prompt bond release. Experience has shown that when FRA reclamation and reforestation procedures are fully employed, replanting is rarely needed.

Research has shown that hardwood tree survival in the range of 70 to 80 percent can usually be achieved when the FRA is fully implemented. In the first year after planting, most hardwood species invest the majority of their energy in the development of the root system and do not show exceptional shoot growth. During times of extreme drought or stress, hardwood seedlings may shed leaves and appear dead, but the following spring new shoots can sprout from living roots. During the third growing season, after roots are established, the shoot growth will begin to accelerate and the development of a healthy and productive forest begins.

ACKNOWLEDGMENTS

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CHAPTER 10: ESTABLISHING NATIVE TREES ON LEGACY SURFACE MINES

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J.G. Skousen, C.D. Barton, and S. Eggerud

INTRODUCTION

More than 1 million acres have been surface mined for coal in the Appalachian region. Today, much of this land is unmanaged, unproductive, and covered with nonnative plants. Establishing productive forests on such lands will aid restoration of ecosystem services provided by forests—services such as watershed protection, water quality enhancement, carbon storage, and native wildlife habitat—and will enable mined lands to produce valued products such as commercial timber.

This Forest Reclamation Advisory describes practices for establishing native forest trees on lands that were surface mined for coal and reclaimed to meet legal standards under the federal Surface Mining Control and Reclamation Act of 1977 (SMCRA), and where the mine operator no longer has any legal responsibilities ("legacy surface mines"; Fig. 10-1). These lands often differ from their pre-mining condition with respect to topography, soils, water resource influences, and vegetation.

Figure 10-1.—A legacy surface mine. The land is covered with nonforest vegetation even 15 years after reclamation in the late 1990s. Photo by N. Hall, Green Forests Work, used with permission.

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Successful establishment of native forest trees on legacy mines typically requires a sequence of steps or procedures over several years. Here, we describe those steps as the “four Ps”: Plan, Prepare, Plant, and Protect. All four steps are needed to ensure success. Some project managers may desire more technical detail than we have provided here. Hence, we refer to other Forest Reclamation Advisories that provide detail and suggest that reforestation experts be consulted if necessary.

PLAN: Assess the Site and Develop a Plan

The first step is to develop a reforestation plan or strategy by assessing site conditions. Preparing a written plan will aid the reforestation process.

Survey existing vegetation

Herbaceous plants and woody shrubs, including nonnative and invasive species, often dominate legacy surface mines. Herbaceous plants that are common on mine sites, such as nonnative grasses and sericea lespedeza, will outcompete young planted trees if not controlled. (Please see the Appendix starting on p. A-1 for scientific names of species mentioned in this chapter.) Nonnative invasive woody plants also require control because they often grow rapidly and, if present, will outcompete native tree seedlings.

First, visit the site, assess vegetation and site conditions, and develop a vegetation management strategy that will enable planted trees to survive. A site map or aerial photo will help with this task. On the map, delineate and mark areas with 1) different types and amounts of vegetation (for example, good growth of native trees, dominance of invasive species, complete herbaceous cover, extensive bare soil), 2) land slope, 3) aspect (direction the slopes are facing), 4) soil sampling locations, 5) property lines, 6) roads and access, and other information that will aid planning.

Areas with a thick cover of nonnative shrubs and trees will require clearing before replanting. Because the nonnative shrubs and trees that proliferate on Appalachian coal mines—including autumn-olive, tree of heaven, and paulownia—will resprout from living roots even if their tops are cut, they should be killed with a herbicide.

When mine sites are dominated by nonnative herbaceous species such as tall fescue and sericea lespedeza, we also advise killing them with a herbicide. This control will be temporary as seeds in the soil will germinate. But this temporary control will allow tree seedlings to get a good growing start before competing plants emerge from the soil seedbank. Successful reforestation requires control of competing vegetation until planted trees grow and become established.

Assess physical properties of mine soils

Surface soils on many sites have been compacted by mining equipment, and most mine soils have become dense over time. A dense soil restricts growth of tree roots and limits water and air movement. Therefore, loosening such soils will improve survival and growth of planted trees. Dense mine soils can be loosened by using deep tillage, a process commonly known as “soil ripping” (Chapter 5, this volume). A site survey before reforestation can determine where deep tillage can be applied. Slopes up to 30 percent can be ripped with a dozer. Slopes up to 40 percent can be ripped by using a tracked excavator with a ripping bar mounted on the end of the arm.

In our experience, almost all legacy mine sites have dense soils and will become more favorable to reforestation if loosened with deep tillage. Growth of established trees, digging of soil pits, use of soil penetrometers if spoil materials are not too rocky, and other procedures can be used to evaluate soil compaction and the need for deep tillage. The presence of wetland vegetation on upland sites may also indicate compacted areas. Ripping all areas with slopes of 30 percent or less is recommended on legacy surface mines. Flat areas are especially prone to physical settling and compaction. Steeper slopes (greater than 30 percent) may or may not require ripping.

Designate areas that are suitable for soil ripping (not steeply sloped) on a site map similar to that used for the vegetation survey. The area designated for ripping can be used to estimate the cost.

Assess chemical properties of mine soils

Many legacy mine sites have soil chemical properties that are adequate for trees (Zipper and others 2011), but it is prudent to check soil properties. This can be accomplished by obtaining soil samples while walking the site. Collect a soil sample from each area expected to have a different type of soil, or with differing vegetation that indicates possible soil differences. In areas with only sparse vegetation, the soil may be strongly acidic (pH less than 5) or have other major problems. Vegetation which is yellow or otherwise discolored can indicate poor soil quality, lack of adequate soil nutrients, or soil moisture problems. Sample those areas separately.

Procedures for obtaining a soil sample are described in publications of soil testing laboratories. Sampling procedures recommended for natural soils can also be applied to mine soils. Record the location for each sample taken, and the area it is intended to represent, on the site map. The soil sample can be sent to a soil testing laboratory for analysis. If the soil testing lab provides special tests for mine soils, request those tests. When sampling mine soils, be aware that mine operators may have applied a layer of topsoil, subsoil, or soil substitute material on the surface to serve as the growth medium. Soil ripping may pull up subsurface mine soils that are different from the surface layer. If possible, check the mining and reclamation history of the site or dig several test pits down to 2 or 3 feet as needed to check subsoil materials.

Common soil testing procedures are intended for garden or agricultural soils, which are quite different from mine soils. Hence, much of the information provided by the soil testing lab will not apply and can be ignored. Essential soil test results for mine soils are:

- **Soil pH**—If pH is between 5.5 and 6.5, soil chemical properties are likely to be suitable for native hardwood trees. If soil pH is less than 5.0, apply lime as recommended by the soil test report to raise soil pH to the 5.5 to 6.5 range, or plant acid-tolerant trees such as pines and selected hardwoods. If pH is less than 4.0 or if you suspect acid-producing minerals are present, conduct more detailed soil investigations. If soil pH is 7.0 or higher (highly alkaline), the tree-planting prescription should use species that can tolerate high-pH soils.
- **Salinity**—On the surface of mine soils that have been in place for at least 5 years, soluble salts should be similar to the range that is typical for natural soils in the area. If soluble salt levels at the surface remain significantly above what is typical for natural soils, a more detailed soil investigation is advised.
- **Minor nutrients**—If the soil test shows low levels of one or more micronutrients, include a micronutrient mix in the fertilizer application. Standard soil tests for nitrogen (N) and phosphorus (P) are unreliable when applied to mine soils constructed from rock spoils. Fertilizer with N and P should always be applied because most mine spoils contain little of these nutrients in plant-available forms. Other essential macronutrients—calcium (Ca), magnesium (Mg), potassium (K), and sulfur (S)—are usually present in mine soils in adequate quantities.

If the site is so acidic or alkaline that very little vegetation is growing, the soils are likely to contain problematic minerals. For such lands, more detailed soil investigations are advised. The guidelines of this Advisory may not be an appropriate treatment for such lands. Similarly, use alternative procedures if highly acidic mine spoils underlie a thin capping of soil-like surface material.

Plan for tree planting

An essential planning step is to select the types of trees to be planted. The landowner's intended use for the site will influence this choice. In most cases, mined land will be suitable for mixed Appalachian hardwoods. Consult Chapter 7 of this volume for assistance with tree species selection and planting design. If the landowner intends to produce woody biomass, fast-growing species can be planted. Tree selection can also consider habitat needs for rare species such as the Indiana bat (Chapter 11, this volume). Landowners may consult a forester who has experience with mined land for advice on selecting tree species.

Make tree-planting arrangements in the summer or fall prior to planting. As explained in Chapter 9 of this volume, you may order seedlings from private sources or from State nurseries. If a contractor will do the planting, the contractor may also be willing to order and provide the seedlings.

Figure 10-2.—A legacy surface mine where the dominant plant species is sericea lespedeza. Successful reestablishment of forest trees planted as young seedlings will require temporary suppression of this species. Photo by N. Hall, Green Forests Work, used with permission.

PREPARE the Mined Site for Planting

Control competing vegetation

It is essential that preexisting vegetation be controlled because otherwise it will compete with planted trees for sunlight, water, and nutrients (Fig. 10-2). Herbaceous vegetation can be killed during the growing season with a tractor- or ATV-mounted herbicide application. Mowing thick herbaceous vegetation with a bush-hog and then allowing it to grow back for a week or two before spraying can improve contact of the herbicide with actively growing leaves and therefore increase chances of mortality. Apply the herbicide in the summer prior to deep tillage and tree planting. If herbaceous vegetation is not killed before tree planting, it is still possible for the planted trees to be successful if post-planting vegetation control is applied (as described next).

We recommend killing nonnative woody plants with herbicide prior to tree planting. This can be accomplished by an aerial application during the growing season if the site is remote and if the woody vegetation is dense. Otherwise, it must be accomplished manually. If nonnative woody plants are small, they can be killed by applying herbicide to the leaves with a backpack sprayer during the growing season. If they are too large for that, an application to the lower stem, using a basal-bark application approved for the herbicide, will often kill the plant. Another method is to cut the tree and apply herbicide to the stump immediately after the cutting (Fig. 10-3). Basal-bark and cut-stump applications typically require a stronger mix of herbicide than leaf application, but these methods work well in late summer, fall, and early winter when leaf applications are not effective.

Consider the type of vegetation present when selecting a herbicide and the season of application. Sericea lespedeza, for example, will not respond to certain herbicides intended to control grasses and is difficult to kill late in the growing season. Only herbicides intended to control woody vegetation will be effective for that purpose. Detailed herbicide recommendations are available in publications such as Miller and others (2010). For all herbicide applications, follow label directions

Figure 10-3.—A nonnative invasive shrub being cut down. Nonnative invasive trees and shrubs should be removed before reforesting legacy mine sites. Shortly after the plant is cut, roots should be killed by applying a concentrated herbicide to the upper surface of the cut stem. Photo by P. Angel, OSMRE.

and assure applicator safety by using appropriate safety procedures and equipment.

Loosen the soil

When mine soils have become dense, loosening is needed to allow root growth, water infiltration, soil drainage, and air movement for growing trees. Use a deep tillage device ("soil ripper") to loosen the soil to a depth of 3 feet or more before tree planting on most mine sites (Fig. 10-4). Application of deep tillage to active mines is described in Chapter 5 of this volume; these practices can also be used on legacy mines.

The most common method of soil loosening is to use a stout single-shank ripping tooth on the back end of a large dozer, bigger than a Cat® D-8 (Caterpillar Inc., Peoria, IL). Generally, single rips should be oriented across slopes to minimize soil erosion and potential gullying. On steeper slopes, a tracked excavator with a ripping tooth mounted on the end of the arm can be used (Fig. 10-5).

Figure 10-4.—Ripping tooth on the back of a dozer. The ripping tooth can be inserted into and pulled through the ground to loosen the dense mine soil, improving its physical properties and ability to support planted trees. Photo by N. Hall, Green Forests Work, used with permission.

Ripping should occur when the mine soil is relatively dry, usually in the late summer or fall prior to planting. When compacted mine soils are dry, they are loosened more effectively by the ripping tool. When soils are wet, the dozer will compact the soil where it tracks, making tillage less effective.

When sites are heavily compacted, this initial ripping operation can be followed by ripping another set of parallel rows in a direction perpendicular to the initial rips ("cross-rips").

Figure 10-5.—An excavator outfitted with a ripping tooth. This equipment can loosen compacted soils on slopes that are too steep for a dozer. Photo by N. Hall, Green Forests Work, used with permission.

Cross-ripping is desirable because planted trees tend to extend roots preferentially along the ripped channel. Cross-ripped sites will give the planted trees greater stability and capability to resist windthrow than a single-directional rip.

When cross-ripping slopes, operating the ripper in the up-down slope dimension first, followed by a second rip running either across the slope (along the contours) or at an angle to the slope (creating a pattern called diamond rips) will help to stabilize the surface and to hinder the waters from gullying in the up-down slope channels. It is also desirable to break up the soil surface by using smaller shanks on either side of the main ripping tooth, especially if the site is not cross-ripped. The loosened surface aids growth of planted trees' lateral feeder roots.

Use of coulter wheels to create a "mound" of soil over the rip is also recommended (Fig. 10-6). This treatment is especially desirable on near-level sites where water is unable to drain freely. Planting trees on the mound can aid tree survival if mine soils are poorly drained, and also makes it easy to locate seedlings for post-planting herbicide treatments and assessments. Mounding soil over the rip makes it easy to plant the tree, orients the tree directly above the rip for the best rooting opportunity, and provides a stable surface for the new seedling. Use of coulters is especially beneficial in fine-textured mine soils with few rocks, as such soil materials tend to restrict water drainage. In contrast, use of coulters in rocky mine soils can be problematic given the tendency of coulters to ride up over the rocks.

Figure 10-6.—Coulter wheels on the back of a dozer, with ripping tooth inserted into the soil. The coulter wheels pile loosened soil into a mound, allowing seedlings to be planted at a slightly elevated position above the land surface. Use of coulter wheels is advised for mine soils with poor water drainage and few large rocks. Photo by J. Burger, Virginia Tech, used with permission.

Design the ripping or tillage operation with spacing to accommodate the tree planting plan, as trees should be planted on or near the deep rips. Ripping at spacings of 8 to 10 feet will accommodate plantings of 600 to 700 trees per acre (Chapter 7, this volume).

In rocky mine soils, the dozer operator should attempt to pull the rocks up or twist them around for greater soil fragmentation. The operator should not lift the ripping shank to ride over the rocks unless the rock is so large that it cannot be moved. The ripped area may have rocks pulled up to the surface, creating a rocky, rough appearance.

If the soil ripping operation is expected to create disturbance with potential to allow soil movement offsite, apply best management practices (BMPs) to limit soil erosion and losses. Most States have manuals that describe BMPs for erosion prevention and sediment control (for example, see Kentucky Department of Water 2007). In our experience, soil ripping operations in Appalachian mine soils rarely cause or allow extensive soil movement.

Improve soil chemical properties

Soil nutrients—especially N and P—are essential to tree growth. Adequate plant-available nutrients will enable quick growth of planted seedlings. This is desirable because planted trees' likelihood of survival is improved once they become "free to grow" by overtopping their competition. Over the longer term, soil nutrients are essential to forest productivity.

Most unmanaged mine soils are low in plant-available N and P. Therefore, apply fertilizers with these nutrients. Soil pH affects plant availability of soil P, so apply lime if soils are strongly acidic (pH less than 5).

If soil pH is less than 5.0, apply lime according to the soil test recommendations to raise soil pH to between 5.5 and 6.5. Lime can be broadcast over the site prior to tillage using agricultural methods such as truck- or tractor-mounted spreaders.

Apply fertilizers in a manner that confines availability to planted trees. Fertilizers should not be broadcast over the entire area, as that will stimulate rapid growth of competing vegetation (Evans and others 2013, Sloan and Jacobs 2013). If possible, apply fertilizer in narrow bands over the tree-planting row produced by soil ripping. On most mined lands, application of 50 to 75 lbs N, 100 lbs P (230 lbs P_2O_5), and 40 lbs K (48 lbs K_2O) per acre will be adequate.

A way to stimulate early tree growth on nutrient-deficient mine sites is to use fertilizer pellets or tablets. Place the pellets below the surface and about 2 to 4 inches from each planted seedling. Fertilizer pellets contain sufficient nutrients to help the seedlings become established but not enough nutrients to support long-term growth.

Fertilizer can be applied by a dispenser mounted on the front of the tillage dozer, allowing the fertilizer to be incorporated into the soil by the tillage operation. If this method or other mechanical methods of application are not possible, apply fertilizer by hand to the soil surface near each planted tree. Spread about one 16-ounce cup of di-ammonium phosphate fertilizer (18-46-0) in a circle around the stem of each tree, keeping it about 12 inches from the stem and spreading it evenly. If fertilizer is applied at planting as pellets, an additional application around the stem is also advised as a means of ensuring adequate nutrients for long-term growth. If the site survey or soil test reveals a likelihood of micronutrient deficiency, use fertilizers with micronutrients.

Use of controlled-release fertilizers, which dissolve and release nutrients slowly over time, has been found to provide good results in mine reforestation plantings (Sloan and Jacobs 2013). Organic amendments, such as manures and composts, have been applied to improve soil properties on many mine sites. The precautions for using such materials on farmlands also apply to legacy mines. Additional precautions are in order for high-nutrient organic materials, such as fresh manures, given the sensitivity of Appalachian native trees to soil properties.

PLANT Native Trees

Hand-plant seedlings on or along the deep rips to enable tap roots to penetrate the soil easily. We recommend that trees be planted at rates of 600 to 700 per acre.

On mine lands with little surface relief, plant trees in a manner that places them in high ground, either over or adjacent to the ripped channel. On sites that are cross-ripped, plant trees near where the rips intersect to enable the lateral roots to extend easily in all four directions. On sites that are sloped and able to drain water easily, plant the trees in a position that is close to the natural ground surface. When possible, plant trees in soil that has been loosened by the ripping operation. See Chapter 9 of this volume for a description of how to plant trees on mine sites.

Many legacy mine plantings use bare-root seedlings with no protective devices installed (Fig 10-7). For large-area plantings with thousands of seedlings, this practice can result in successful reforestation if most of the planted seedlings survive and grow. However, survival prospects can be improved by installing protective devices such as tree tubes, weed mats, or both for individual seedlings.

Tree shelters (plastic cylinders that are placed around seedlings to create moist microenvironments) have been shown to both protect seedlings from browsing animals and increase tree growth (Fig. 10-8). Fabric mats are another option for improving tree growth. Seedlings are placed in the center of a fabric mat (about 18 inches × 18 inches in size), and the edges of the mat are staked into the ground. These

Figure 10-7.—Volunteers planting tree seedlings on a legacy surface mine that has been prepared for reforestation by using the guidelines described in this chapter. If adequate finances are available, professional firms can be engaged to plant trees. Photo by P. Angel, OSMRE.

Figure 10-8.—Tree tubes in use on a legacy mine site with the intent of increasing survival and growth of high-value seedlings. Photo by P. Angel, OSMRE.

mats allow rainfall infiltration but prevent growth by competing plants in soil close to the seedling. The best protection is provided by protective devices that combine tree tubes with weed mats. When cost prevents use of protective devices for the entire job, they can be installed to improve success in high-visibility areas or for high-value seedlings.

PROTECT Planted Trees

Control competing vegetation

Because young trees are vulnerable, they should be protected. A primary threat is competing vegetation that prevents seedlings from reaching sunlight, water, and soil nutrients. Rodents may be attracted and sheltered by heavy herbaceous competition; they can kill the trees by girdling or debarking them as a winter food source. Control of competing vegetation will be essential on virtually all reforested legacy mines.

Immediately after planting while seedlings are still dormant, a preemergent herbicide can be applied to reduce emergence of herbaceous plants from seeds. This application can occur in a circle around each seedling or, if applied using a tractor or ATV, in bands over the tree rows.

In late spring or early summer, a post-emergent herbicide can be applied by "spot spraying" a circle around each planted tree, using tree shields or other means to ensure that no herbicide contacts tree leaves (Fig. 10-8). Herbicide applicators should be trained to recognize any problematic invasive shrubs and trees (Table 10-1), especially species present prior to clearing or along site borders. Spray these plants when they appear. Herbicides should be applied only under calm atmospheric conditions, following label directions, and by applicators wearing protective gear. Repeat spring preemergent and summer post-emergent herbicide applications in subsequent years until most of the trees have grown so they are above the herbaceous competition. Here, we have not specified herbicide types. The herbicide should be selected after determining the types of plant species that require control and consulting a reference such as Miller and others (2010).

Apply additional protection if needed

Apply additional common-sense protective measures as well. Once the site is planted, it faces threats from livestock and wildlife browsing, insects, humans, and invasive plants. Occasional browse will slow the growth of young hardwood tree seedlings but usually will not kill them. Repeated browse, however, will be more

Table 10-1.—Partial list of invasive species that are problematic on legacy mine sites and are capable of interfering with successful reforestation if not controlled. For photographs of these species, see Natural Resources Conservation Service (2016), the Southeast Exotic Plant Pests Council (2013), or State conservation agency Web sites.

Common name	Scientific name	Plant type
silktree (mimosa)	*Albizia julibrissin*	Tree
tree of heaven (ailanthus)	*Ailanthus altissima*	Tree
Russian-olive	*Elaeagnus angustifolia*	Tree
autumn-olive	*Elaeagnus umbellata*	Shrub
Japanese knotweed	*Fallopia japonica*	Shrubby forb
shrubby lespedeza	*Lespedeza bicolor*	Shrub
sericea lespedeza	*Lespedeza cuneata*	Forb, legume
Japanese honeysuckle	*Lonicera japonica*	Shrub/woody vine
bush honeysuckle	*Lonicera maackii*	Shrub
white sweet clover	*Melilotus alba*	Forb
Japanese stiltgrass	*Microstegium vimineum*	Grass
Chinese silver grass	*Miscanthus sinensis*	Grass
paulownia (princesstree)	*Paulownia tomentosa*	Tree
mile-a-minute vine	*Polygonum perfoliatum*	Vine
kudzu	*Pueraria montana*	Woody vine
multiflora rose	*Rosa multiflora*	Shrub
tall fescue*	*Schedonorus* spp.	Grass
johnsongrass	*Sorghum halepense*	Grass

* Also known as *Schedonorus phoenix*.

damaging. Fencing can exclude grazing animals and prevent emerging vegetation from being damaged or destroyed by vehicles (for example, ATVs, tractors, 4×4s). Signage can be used to mark the planting boundaries if fencing is not used. Maintaining locked gates at critical access points can help limit uncontrolled human access and guard against these hazards.

Assess survival and replant if needed

The money and effort invested in the site should also be protected by assessing survival after the first growing season, generally in September or October, after stressful mid-summer conditions have passed but while living trees retain their leaves. Survival can be assessed by sampling or counting living trees within areas selected to represent the rest of the site. It is not necessary to count all surviving trees over the entire site.

A common method of survival assessment is to establish circular sampling plots at random locations and to count surviving trees within those plots. To define the plots, place a stake at the center point and use a rope of fixed length or tape to measure distances from the center point (Fig. 10-9). For example: to assess survival within a 1/20th-acre sampling plot, count every surviving tree within a circular area up to 26 feet 4 inches of a center point.

Sampling plots should be distributed evenly but located randomly over the site. This can be done by determining in advance how many plots are needed, then defining straight-line transects over the site and locating the plots at predefined distances along those transects. For example, if 10 plots are needed within a site that is long and rectangular, two transects could be defined

Figure 10-9.—Personnel preparing to assess survival and growth of planted tree seedlings on a legacy surface mine. Photo by N. Hall, Green Forests Work, used with permission.

along the site's long dimension with 5 plots located along each transect. Plot center points can be located along the transect while distance is estimated by counting paces. It is essential that plots be located using a predetermined method that considers the planted area's configuration and size; plots should not be located by walking over the site, seeing what is out there, and on that basis deciding that "this looks like a good spot."

The number of plots that should be established is a matter of judgment. The sampling plots are intended to represent the entire site. More sampling plots, when appropriately placed, will provide a more accurate survival estimate than fewer plots. The following rule of thumb can be followed: For mine sites with fairly uniform soils and topography, a 5-percent sample or one 1/20th-acre plot per acre should be adequate; for areas with highly variable soils and topography, or mine sites for which irregular survival across the site is suspected for any reason, a 10-percent sample, or two 1/20th-acre plots per acre should be measured.

Count the number of living trees within each 1/20th-acre circular plot and multiply that number by 20 to estimate the number of trees per acre. Record this per-acre number for each plot for a per-acre estimate for that particular area. Estimate the overall per-acre number for the entire site by averaging the per-acre estimates for all 1/20th-acre plots. Also record the species of each surviving tree.

Where weeds have been controlled successfully and the summer has not been unusually hot and dry, average survival should be higher than 70 percent after the first year—490 trees per acre if 700 trees per acre were planted. If stocking is below this level, the site manager should determine the cause, working with the tree planter if a contractor was employed. If poor survival was due to poor seedling quality or improper planting, the manager can determine who is responsible and seek to engage that party in remedial replanting. If first-year survival is not satisfactory, "holes" left by nonsurviving trees should be replanted during the next winter.

By the end of the third, fourth, or fifth growing season, most planted trees should be above the competing herbaceous vegetation (Fig. 10-10). Make a final survival assessment after the third or fourth growing season using the same assessment procedures just described. At this time, a minimum of 400 well-distributed healthy trees per acre will ensure reforestation success. During the site surveys, visually assess the presence of invasive

Figure 10-10.—Oak seedling released from herbaceous competition by herbicide application. Photo by C. Zipper, Virginia Tech, used with permission.

species with potential to outgrow and outcompete planted seedlings. When possible, control or remove such species if they are present at densities sufficient to interfere with planted seedlings' survival within certain areas.

EXPECTED OUTCOME

Reestablishing native Appalachian forests on legacy surface mines that are not being managed for other purposes can produce marketable timber and environmental benefits such as watershed protection, carbon sequestration, and improved wildlife habitat. Until recently with the adoption of the Forestry Reclamation Approach (Chapter 2, this volume), common coal-mine reclamation practices under SMCRA often created conditions unfavorable to reforestation. When the guidelines described in this Advisory are applied, productive Appalachian forests can be restored on such mined lands (Fig. 10-11).

SUMMARY: STEP-BY-STEP GUIDANCE

A step-by-step summary and timeline for the recommended procedures is found in Table 10-2 (see next page). Depending on site conditions, all treatments may not be needed.

ACKNOWLEDGMENTS

Thanks to personnel with Green Forests Work (GFW) for their assistance in developing this Advisory. GFW personnel can provide technical and other types of assistance to parties who are attempting to reestablish Appalachian forest vegetation on legacy surface mines.

Figure 10-11.—Appalachian hardwood trees emerging from herbaceous vegetation on a legacy surface mine during the third growing season after using methods described in this chapter. Photo by C. Zipper, Virginia Tech, used with permission.

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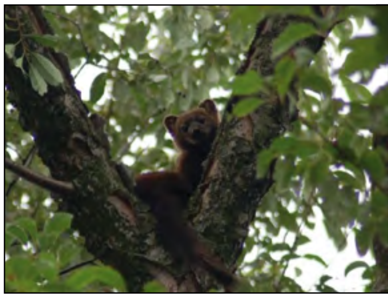
Table 10-2.—Step-by-step summary of the guidelines presented in this chapter

Month	Year	Task	Task detail
		PLAN	
Prior to July	1	Survey vegetation, assess soil properties	Survey the area to assess vegetation; test soil physical and chemical properties. Use information to develop a reforestation plan for the site.
Summer or fall	1	Determine species to plant, order trees	If the site is to be planted by a contractor, that contract should be put in place. The contractor may be able to provide seedlings.
		PREPARE	
July	1	Remove and control existing vegetation	Broadcast-spray herbicide to control vegetation. If large invasive shrubs and trees are present, control via aerial herbicide or manual removal. Be sure to kill invasive shrubs and trees with capability to resprout from living roots.
Aug.-Sept.	1	Apply lime, if needed	Apply lime if needed and as needed to raise pH to between 5.5 and 6.5.
Sept.-Oct.	1	Deep-till and fertilize	Loosen soil with a deep-tillage tool, ripping with 8- to 10-foot spacing between rows. Band-apply fertilizer along the rows.
		PLANT	
Jan.-March*	2	Plant trees	Plant tree seedlings correctly (recommended planting rate: 600 to 700 per acre).
		PROTECT	
Feb.-March*	2	Weed control	Band-spray a preemergent herbicide over the tree rows.
May-June	2	Weed control	Spot-spray herbicide around each tree seedling, using tree-shields to protect seedlings from herbicide drift. Apply herbicide to emergent invasive shrubs and trees if present.
Sept.-Oct.	2	Assess tree survival	Survey tree survival; determine if replanting is needed.
Jan.-March*	3	Replant if needed	If the tree survival assessment reveals inadequate survival in any area, replant to fill in between surviving trees as needed to assure adequate stocking.
Feb.-March*	3	Weed control	Repeat the preemergent herbicide.
May-June	3	Weed control	Repeat the spot-spray herbicide.
May-June	4	Assess vegetation	Walk the site to determine if the majority of planted trees have grown so uppermost leaves are above herbaceous competition.
May-June	4	Weed control	Repeat the spot-spray herbicide (if needed).
Sept.-Oct.	4	Final survey	Survey tree stocking. Look for a minimum of 400 planted trees per acre.

* Tree planting and preemergent herbicide application can be extended through April in the northern Appalachian region.



Chapter 11: Reforestation to Enhance Appalachian Mined Lands as Habitat for Terrestrial Wildlife

Petra Wood, Jeff Larkin, Jeremy Mizel, Carl Zipper, and Patrick Angel

INTRODUCTION

Surface mining is widespread throughout the Appalachian coalfields, a region with extensive forests that are rich in wildlife. Game species for hunting, nongame wildlife species, and other organisms are important contributors to sustainable and productive ecosystems. Although small breaks in the forest canopy are important to wildlife diversity, most native Appalachian wildlife species require primarily forested habitats (Wickham and others 2013). This Forest Reclamation Advisory provides guidance on reforestation practices to provide high-quality habitat for native forest wildlife on Appalachian coal mines.

Mined lands reclaimed under the federal Surface Mining Control and Reclamation Act of 1977 (SMCRA) with conventional methods—smooth-grading mine spoil and seeding fast-growing ground covers—are used by a few wildlife species and can increase species diversity. But expansive areas of these lands have little habitat value to most native wildlife species in the Appalachian region. Conventional reclamation also inhibits forest succession (a term used to describe natural changes in plant community composition over time) and causes most native plant species to have poor colonization, growth, and survival. As a result, high-quality wildlife habitat rarely develops away from the forest–mine edge on surface mines reclaimed with conventional methods. Even popular game species often observed on conventionally reclaimed mined lands such as deer, elk, bear, and wild turkey are rarely seen far from the forest edge. (Please see the Appendix starting on p. A-1 for scientific names of species mentioned in this chapter.) However, improved wildlife habitat is a postmining goal for many landowners and is achievable through application of the Forestry Reclamation Approach (FRA) to enhance natural succession (Chapter 8, this volume) on active mines (Chapter 2, this volume),

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and through soil mitigation and planting of trees and shrubs on older mine sites that were reclaimed by using conventional methods years ago ("legacy mines") (Chapter 10, this volume).

APPALACHIAN FOREST AND MINED LAND HABITATS

Appalachian hardwood forests are some of the most biologically diverse temperate forests in the world (Hinkle and others 1993). They provide habitat for numerous wildlife species that require young forest conditions, as well as those that require mature forest.

Many wildlife species (amphibians, reptiles, birds, and mammals) that depend on young forests for foraging, cover, or breeding (Gilbart 2012) are declining in population (Litvaitis 1993). Native young forest communities consist of dense herb, vine, sapling, and shrub growth that exists for a relatively short time (12 years or less). Therefore, patches of young forest must be continuously created and dispersed across the landscape to ensure long-term viability of the many species dependent on these habitats. Wildlife agencies in every state of the Appalachian coalfields list young forest communities as high-priority habitats.

More than 1 million acres of mined lands have been reclaimed in the eastern United States (Zipper and others 2011) and additional mined lands are being created. Reforestation of mined lands has the potential to provide extensive areas of young forest habitat interspersed among unmined mature forests. Through succession, these young forests will become mature forests. A regional, landscape-scale effort to reforest mined lands has great potential to benefit wildlife species dependent on young and mature forest habitats.

Golden-winged warbler, brown thrasher, and eastern whip-poor-will are a few of the nongame bird species that breed in young forests and are undergoing long-term population declines in the Appalachian region (Sauer and others 2014). Like many species that are young-forest specialists, these birds require habitat with dense patches of native shrubs interspersed with trees of varying size and herbaceous cover. Patches of young forest also provide important foraging habitat and cover for several Appalachian game species including cottontail, black bear, white-tailed deer, elk, ruffed grouse, northern bobwhite, and American woodcock (Fig. 11-1). Within most surface mines reclaimed under SMCRA by using non-FRA methods, nonnative shrub and grass species predominate and areas of dense native woody vegetation are typically absent or restricted to forest–mine edges.

In contrast, forest reclamation can create a dense undergrowth of native shrubs, saplings, and forbs that species such as cottontail require for protective cover from predators. These patches of dense woody and herbaceous cover provide abundant forage for game and nongame species in the form of insects, mast, seeds, buds, foliage, and fruits from vines and shrubs. Young forest habitat adjacent to mature forest also may benefit fisher, a forest-dependent predator that has been reintroduced to several Appalachian states (Fig. 11-2). Many mammal and bird species that are preyed upon by fisher and other carnivores use areas where young forest next to mature forest creates structurally diverse habitat (Litvaitis 1993).

Figure 11-1.—American woodcock. This species of high conservation concern inhabits moist, young forest habitats. Photo by A. Newman, Eastern Kentucky University, used with permission.

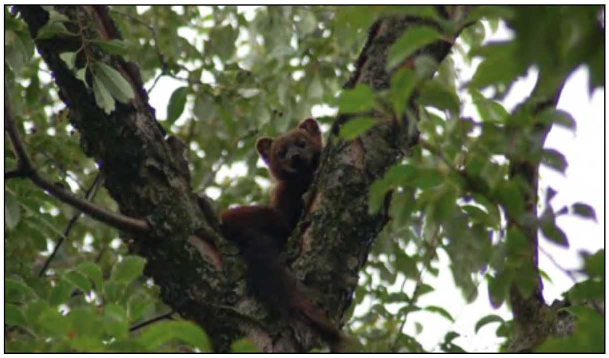

Figure 11-2.—A fisher. This forest-dependent carnivore is colonizing many Appalachian states after reintroductions in West Virginia, Tennessee, and Pennsylvania. Young forest along mature-forest edges provides habitat for many of the fisher's favorite prey. Photo by J. Larkin, Indiana University of Pennsylvania, used with permission.

Ultimately, surface mines that persist as nonforest cover lead to forest fragmentation and reduced forest cover on the landscape, which negatively affect wildlife species that require large, continuous blocks of forest (Wood and Williams 2013, Wood and others 2006). One such species is the cerulean warbler (Fig. 11-3), a declining forest songbird (Sauer and others 2014) with a breeding range that has considerable overlap with the Appalachian coalfields (Fig. 11-4). Cerulean warblers, and probably other mature forest songbirds as well, are less abundant near the abrupt edges created by surface mines reclaimed to grassland (Wood and others 2006). For some species of woodland salamander, grassland patches act as barriers to movement between forest patches (Rittenhouse and Semlitsch 2006). Thus, reforestation of surface mines may benefit mature-forest wildlife in the short term by creating more transitional forest–mine edges (feathered edges) and reducing forest fragmentation, and in the long term by compensating for the loss of mature forest habitat.

Figure 11-3.—Male cerulean warbler. Photo by M. Shumar, Ohio State University, used with permission.

GUIDELINES FOR WILDLIFE HABITAT ENHANCEMENT ON MINED LANDS

1. Increase Structural Complexity of the Soil Surface; Avoid or Remediate Soil Compaction

Structurally complex forest floors are important habitat features for many types of wildlife, such as small mammals, snakes, and salamanders (Fig. 11-5). Forested rock outcrops are unique

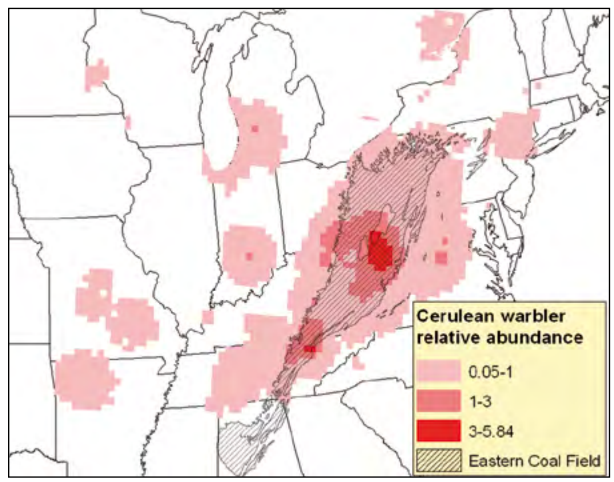

Figure 11-4.—The Appalachian coalfield and the breeding range of cerulean warbler (derived from Breeding Bird Survey counts, Sauer and others 2011).

Figure 11-5.—A red eft, the terrestrial life stage of the eastern newt. Photo by K. Aldinger, West Virginia University, used with permission.

habitats important to many species of Appalachian wildlife, particularly the Allegheny woodrat and green salamander. However, because rock outcrops are usually located along ridgetops or upper side slopes, mining often removes these habitat features. Conventional reclamation generally fails to restore these important, structurally and biologically diverse components of eastern forests.

On sites with active reclamation, avoid excessive smoothing and compacting of soil. A rough-graded soil surface with loose-soil conditions, exposed rocks, and surface relief provides a more structurally diverse habitat than conventional smooth grading.

On legacy mines, compacted spoil can be loosened by a dozer equipped with a ripper tooth (Chapter 5, this volume). Ripping compacted spoil not only improves water infiltration and rooting conditions for trees and shrubs, but it also benefits burrowing species such as salamanders, earthworms (which are food for American woodcock and other wildlife), and small mammals. These animals need loose, moist soil to burrow and forage. Small mammals and salamanders occur in greater abundance where spoil is not compacted (Larkin and others 2008, Wood and Williams 2013). These animals in turn are a food source for many predator species.

Incorporating rocks on the surface (Figs. 11-6 and 11-7) can provide additional structure and cover for ground-dwelling and burrowing species. After young forest and some tree canopy develop, large boulder piles (Fig. 11-7) may provide habitat for Allegheny woodrat (Chamblin and others 2004) and many other species that use wooded rock outcrops, particularly if they are close to nearby forested areas that contain rock outcrops. One study found that reintroduced fishers in Pennsylvania occasionally rested in ground dens within rock outcrops, including an area of large boulders along a forest-reclaimed mine edge (Gess and others 2013).

Figure 11-6.—A rock exposed by ripping of compacted mine soils. Ripping reduces compaction and increases structural complexity of the surface by exposing large rocks. Such features provide habitat for small mammals, amphibians, and reptiles. Photo by P. Wood, U.S. Geological Survey.

Figure 11-7.—Boulders on a reclaimed mine site in eastern Kentucky. After trees become established, piles of boulders can provide habitat needed by wildlife that use wooded rock outcrops, such as Allegheny woodrat, bobcat, and bear. Photo by P. Wood, U.S. Geological Survey.

2. Apply Native Forest Soils with Organic Debris or High-quality Substitutes During Reclamation

Salvaging and reapplying topsoil on active mines or bringing in topsoil for reclamation on legacy mines can accelerate development of high-quality young forest habitat (Chapter 3, this volume). Native topsoil can contribute a seedbank of plant species such as river birch, blackberry, yellow-poplar (tuliptree), grapevine, and many others that contractors do not commonly plant during reclamation. Occasionally, oaks and hickories will sprout from seeds present in topsoil (Hall and others 2010). These volunteer species provide food sources and increase structural complexity of vegetation on reclaimed mines (Fig. 11-8), often enabling greater wildlife diversity. Blackberry, for example, provides fruit for many wildlife species including seed predators, provides preferred nest patches for young forest songbirds such as golden-winged warbler, and serves as cover for cottontail and other wildlife species. Salvaging native soils, with their organic matter and living creatures, may increase abundance of soil invertebrates (Richards and others 1993), which are prey for woodland salamanders, songbirds, and small mammals. One study found American woodcock using reclaimed mines, where better soil conditions resulted in complex vegetative structure and higher biomass of earthworms (Gregg and others 2000). Salvaging native soils would help produce these conditions.

Figure 11-8.—Young forest on a West Virginia surface mine with a dense undergrowth of volunteer shrubs. Mine operators salvaged and reapplied the topsoil, used reduced grading, and planted native hardwoods including white, chestnut, black, and northern red oaks. Trees are 10 years old in this photo. Photo by J. Mizel, National Park Service.

When a limited amount of topsoil is available, distribute it across the mine surface, either by mixing it with mine spoil intended for surface construction (Chapter 3, this volume) or by dumping piles across the mine-site surface (Hall and others 2010), particularly away from edges on large mines. These seedbank patches could yield dense shrubby vegetation in areas where forest seed sources are distant and plant colonization is limited. Soil also is an important inoculation source for mycorrhizal fungi, which most woody species need to grow and thrive.

Native trees and shrubs also can colonize and grow rapidly when favorable mine spoil materials are used as a topsoil substitute (Chapter 3, this volume). After 1 to 2 years post-planting, young-forest bird species such as indigo bunting and common yellowthroat (Fig. 11-9) had colonized the interior of a surface mine that was reclaimed by using FRA methods and salvaged topsoil (Fig. 11-10).

Figure 11-9.—Male common yellowthroat. Photo by D. Becker, West Virginia University, used with permission.

Figure 11-10.—An Ohio surface mine reclaimed by using the Forestry Reclamation Approach. Herbaceous plants and shrubs rapidly developed 1 to 2 years after planting. Photo by J. Mizel, National Park Service.

Figure 11-11.—Native vegetation sprouting from root wads that were left on a reclaimed mine surface. Incorporating woody residues benefits ground-dwelling and burrowing species by providing surface cover and increasing surface complexity. Photo by OSMRE.

3. Add Coarse Woody Debris to Further Promote Surface Complexity and Provide Cover for Wildlife

Incorporating woody residues (for example, roots, stumps, logs, and branches) on and into mine surfaces accelerates forest development by improving water infiltration, decreasing soil temperature, increasing the soil water-holding capacity, and increasing soil colonization by nutrient-cycling micro-organisms (Chapter 3, this volume). The addition of coarse woody debris (Fig. 11-11) also benefits ground-dwelling wildlife by providing surface cover and greater overall surface complexity. Decomposition of woody residues incorporated into the growth medium creates subsurface channels which burrowing species can use as retreats (Carrozzino and others 2011). Through the addition of woody residues, moisture-limited species such as salamanders and earthworms benefit from increased organic matter and water-holding capacity in soils.

4. Locate Reforestation Efforts Where They Maximize Benefits for Wildlife

If an entire mine site cannot be planted to trees and shrubs, select areas to reforest that maximize benefits for wildlife. Greatest benefits for wildlife include reducing forest fragmentation, reducing the amount of forest–grassland edge, and connecting remnant forest patches.

Changes in microclimate caused by forest loss can penetrate from edges into mature forests (Matlack 1993). These changes, such as increased wind, light, and ambient temperatures, can negatively affect ground-foraging species by reducing litter depth and densities of litter-dwelling arthropods near forest edges (Ortega and Capen 1999). Some mature forest-dependent species such as the cerulean warbler reach their highest densities in large tracts of mature forest and away from abrupt edges (Wood and others 2006). Conversely, species that depend on young forest, such as the golden-winged warbler, establish breeding territories in young-forest transition zones (Fig. 11-12) but generally within 150 feet of the mature forest edge (Patton and others 2010). Therefore, reforestation that extends from the

Figure 11-12.—A young forest transition zone between reclaimed mine land (foreground) and unmined mature forest (background). When the resources needed to reforest entire legacy mine sites are not available, establishing such transition zones can improve habitat. Photo by S. Bosworth, West Virginia University, used with permission.

forest–mine edge and creates a transitional, feathered edge (Figs. 11-12 and 11-13) can reduce edge effects for cerulean warblers and other mature-forest species while also providing young forest habitat for shrubland-dependent species. If the development of cerulean warbler habitat is a postmining goal, reforestation efforts should also target ridgetops and north- and east-facing slopes, where cerulean warblers are most abundant in the Appalachian Mountains (Wood and others 2006).

Small mammal and woodland salamander species can move only short distances to reach suitable habitat (Waldrick 1997), and grassland patches are barriers to such movement (Rittenhouse and Semlitsch 2006). Therefore, reforesting areas that extend from the forest–mine edge, that interconnect mature forest patches, or that connect

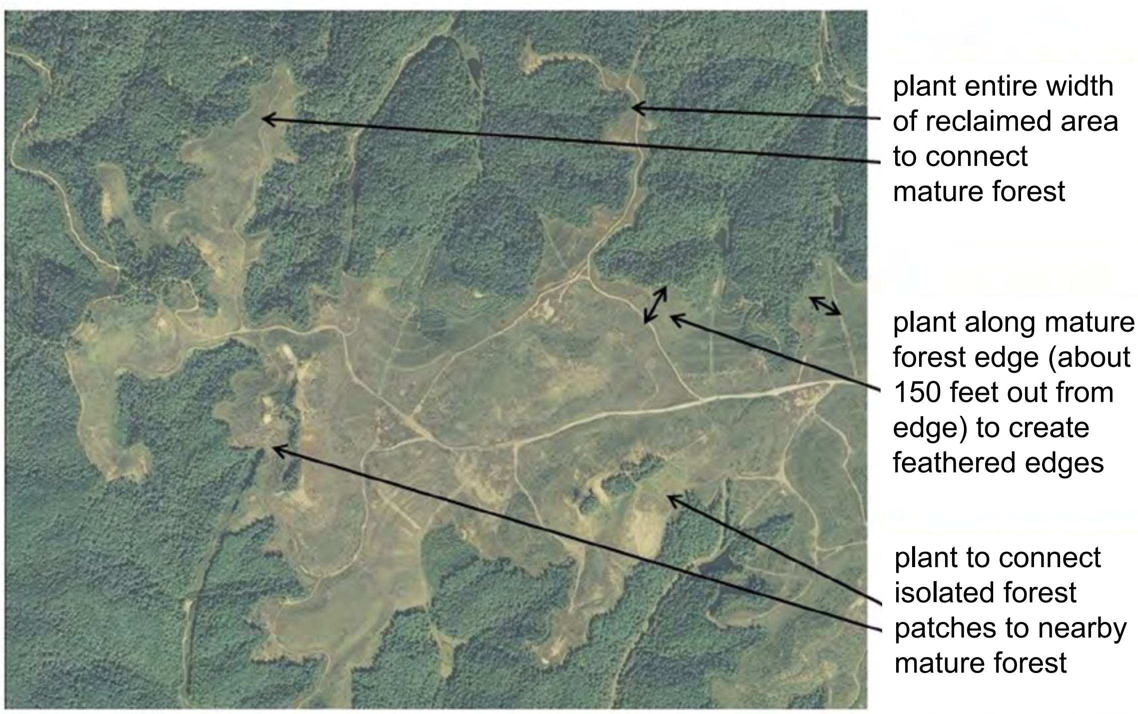

Figure 11-13.—Aerial photograph indicating areas on legacy mine lands where reforestation efforts could be focused. When the resources needed to reforest entire legacy mine sites are not available, focus reforestation efforts on areas adjacent to mature forest to create young-forest transitions (see Figure 11-12) and on areas that interconnect mature forest or that connect isolated forest patches to nearby mature forest. This will increase forest patch size and decrease edge effects, improving habitat for mature-forest wildlife. It also creates transitions between forest and reclaimed mine sites which are beneficial for young-forest species. Photo by Google® Earth.

isolated forest patches to intact forest (Fig. 11-13) will expand habitat for woodland salamanders and small mammals. Reforestation in these locations also benefits many forest wildlife species by increasing forest patch size. Further, planting native trees and shrubs within extensive areas of reclaimed grasslands can benefit elk as this species rarely uses open habitats farther than 1,000 feet from a forest edge (Skovlin and others 2002).

5. Plant a Variety of Native Trees and Shrubs, Particularly Heavy-seeded (Hard Mast-producing) Tree Species

Many of the plant species that become established readily as volunteers on mined lands have small seeds that are spread relatively easily by wind and birds. Heavy-seeded species such as oaks and hickories are less easily dispersed and rarely colonize the interior of large mining complexes unless planted. Reestablishing heavy-seeded native tree species provides an important food source for wildlife, a seed source to maintain habitat diversity, and habitat for the many wildlife species that depend on these tree species.

Some forest songbirds prefer to forage and nest in hickory and white oak species, but they avoid red oak species and red maples (Wood and others 2013). Oaks are hosts for large populations of many leaf insect species in their canopies (Summerville and Crist 2008), and those insects are a food source for forest songbirds. Oak-hickory forests have deeper leaf litter because their leaves decompose slowly, and thus have greater abundance of litter-foraging species, such as ovenbird, than do forests dominated by red maple and yellow-poplar (Mizel 2011). The mast (hard-shelled seeds) from oaks and hickories is an important part of the diet for gamebirds, deer, black bear, and many other wildlife species. Planting tree species that develop exfoliating bark such as white oak, hickory, and black locust provides future roost trees for bats. Several bat species, including the endangered Indiana bat, are dependent on mature trees of these and other species for roosting and maternity sites. Where the Indiana bat is found pre-mining, federal regulations require forestry postmining land use.

American chestnut, a consistent and prolific producer of hard mast, once provided food for numerous bird and mammal species. The American Chestnut Foundation has developed potentially blight-resistant chestnut varieties, and surface mines are now being used for reintroduction of American chestnut to eastern forests. These chestnut varieties have shown excellent survival on mined lands reclaimed by using the FRA (Chapter 12, this volume) and on previously compacted mined lands that were prepared by using deep soil ripping (McCarthy and others 2010). Establishing mined land forests with blight-resistant American chestnut would have substantial value for Appalachian wildlife.

Native mast-producing shrubs are important wildlife food sources. Pin cherry and shrubs such as blackberry and raspberry, for example, have high numbers of caterpillars and were selected as foraging sites by golden-winged warblers (Bellush 2012). American hazelnut, black chokeberry, common chokecherry, common elderberry, mapleleaf viburnum, gray dogwood, serviceberry, blackhaw, and hawthorns are just some of the native shrub species that can be included in the tree planting mix. Plant them singly among tree seedlings or in groups to help create patchy habitat structure. When planting shrubs in patches, we suggest patches no larger than 24 feet × 24 feet. To select which specific tree and shrub species to plant, follow the guidelines in Chapter 7 of this volume and plant native species that provide hard mast or soft mast (fleshy, perishable fruit) as recommended by Apsley and Gehrt (2006). Planting a variety of native trees and shrubs in their native range will provide habitat for a diverse wildlife community. Control competing nonnative vegetation to increase survival of planted trees. In high elevation areas within the native range of red spruce, planting red spruce will provide a critical component of habitat for northern flying squirrel.

SUMMARY

When operators of active mines follow FRA reclamation guidelines (Chapter 2, this volume), they create lands where forest development can occur more rapidly. On legacy mines, ripping when needed to loosen compacted soil, planting native trees and shrubs, and controlling competing vegetation as needed for planted trees' survival will facilitate ecological succession (Burger and others 2013). Thus, forest reclamation can produce habitat that has the structural and compositional features needed by young-forest wildlife in the short term. Over longer time periods, the mature forest that results from these efforts will benefit mature-forest wildlife by reducing forest fragmentation and helping to compensate for habitat loss caused by mining. Surface mine reforestation is an opportunity for landowners and mine operators to conduct reclamation that provides direct and far-reaching benefits by aiding conservation of Appalachian wildlife.

Summary of Reforestation Guidelines on Mined Lands to Enhance Habitat for Appalachian Wildlife

Burrowing and ground-dwelling species (for example, salamanders, earthworms, small mammals)

- Create loose, moist soil for burrowing by end-dumping or ripping
- Include single boulders or clusters of boulders on the surface for protective cover
- Incorporate woody residues for surface complexity, aboveground cover, and subsurface retreats
- Apply native soils with organic matter to increase invertebrate prey
- Treat sites and plant native trees and shrubs in areas that connect to mature forest to promote colonization by wildlife species.

Young-forest species (for example, cottontail, blue-winged warbler, golden-winged warbler, ruffed grouse)

- Use native soils, which provide seedbanks to quickly increase structural and compositional diversity of vegetation
- Use tree-compatible groundcover species that will enable colonization by native plants
- Plant a variety of native shrubs and trees
- On legacy mines where reforestation resources are limited, treat and plant areas that connect to mature forest for increased habitat complexity across the landscape.

Mature-forest species (for example, cerulean warbler, fisher, woodland salamanders)

- On legacy mines, treat and plant areas that connect to mature forest (especially isolated patches in mine interiors) to reduce edge effects and forest fragmentation and to increase forest patch size
- On active mines, reforest the complete mining disturbance, when possible
- Plant heavy-seeded (hard mast-producing) tree species (for example, American chestnut, oaks, and hickories) throughout the reclaimed area to provide food resources for many species (for example, bear, deer), preferred nest sites for forest songbirds, and roost trees for bats
- Reforest mines near areas with high density of cerulean warbler.

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Chapter 12: Reestablishing American Chestnut on Mined Lands in the Appalachian Coalfields

Michael French, Chris Barton, Brian McCarthy, Carolyn Keiffer, Jeff Skousen, Carl Zipper, and Patrick Angel

INTRODUCTION

American chestnut was formerly a major component of forests throughout the Appalachian coalfields and beyond. Chestnut's strong, lightweight wood was naturally rot-resistant, making it a preferred timber tree for many purposes. Unlike many nut-producing trees that flower early in the year, American chestnuts flower in June and July, so they were less susceptible to a late freeze or frost that could damage the flowers. Due in part to its late flowering, American chestnuts produced a reliable and abundant nut crop that was an important source of nutrition for wildlife, livestock, and humans.

However, American chestnut has suffered severe decline throughout the United States; today, few living and mature American chestnut trees remain. This Forest Reclamation Advisory discusses efforts to develop new American chestnut varieties, and describes reclamation and planting techniques for chestnut on mined lands.

American Chestnut's Demise and Restoration

Beginning in the early 1900s, an introduced fungus known as the chestnut blight devastated chestnut populations. (Please see the Appendix starting on p. A-1 for scientific names of species mentioned in this chapter.) American chestnut was virtually eliminated as a canopy tree throughout its native range by the 1950s.

Early attempts at breeding disease-resistant trees that could restore chestnuts to the forest failed to produce a tree with sufficient disease resistance and the ability to compete against other hardwoods. In 1983, The American Chestnut

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Foundation (TACF) was founded with the mission to restore American chestnut to eastern forests to benefit the environment, wildlife, and society. The foundation focused on a breeding strategy to create a population of chestnuts that would incorporate the disease resistance of Chinese chestnut and retain the form and functional characteristics of American chestnut (Fig. 12-1). This strategy crosses Chinese chestnuts and American chestnuts, then takes those offspring

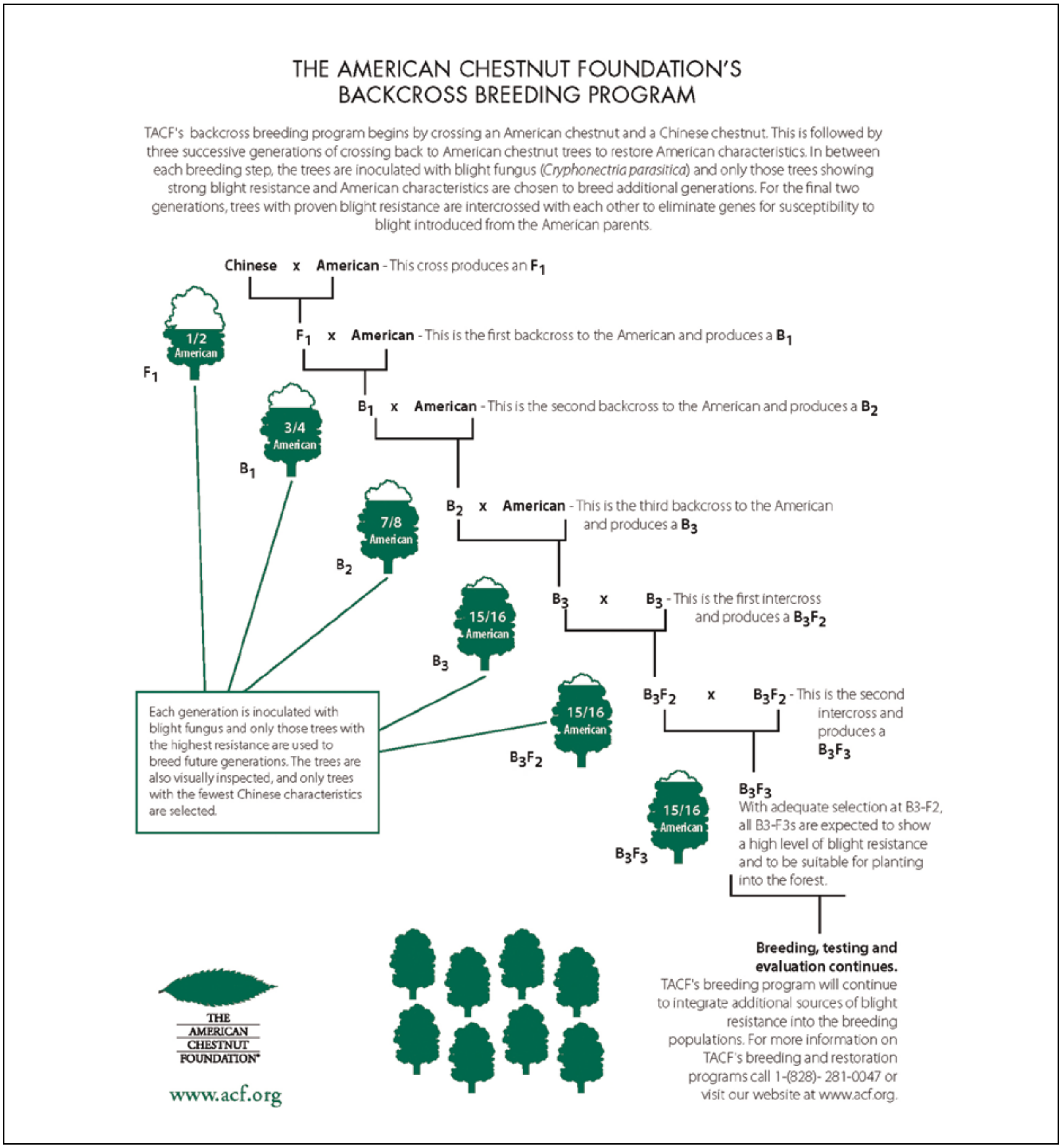

Figure 12-1.—The American Chestnut Foundation's breeding strategy to develop a population of chestnuts that will display the growth and form characteristics of American chestnut while retaining the blight resistance of Chinese chestnuts. (Courtesy of The American Chestnut Foundation.)

through a series of backcrosses and intercrosses to create trees with American traits and high levels of disease resistance.

At each step of the process, trees are intentionally infected with the disease so that only trees with high levels of disease resistance and American characteristics are used for further breeding. In 2005, TACF began producing trees that are about 15/16 American chestnut, 1/16 Chinese chestnut in character and expected to have a high level of disease resistance (specifically, the B_3 F_3 generation). TACF is calling this generation "Restoration Chestnuts 1.0," which implies that breeding efforts are expected to continue to improve both disease resistance and American characteristics into the future. The foundation is now testing Restoration Chestnuts 1.0 for their disease resistance and other characteristics.

AMERICAN CHESTNUT'S ECOLOGY, DISTRIBUTION, AND ABUNDANCE

Historical literature and examination of sprouts and remnants of older trees indicate that American chestnut preferred rich, noncalcareous, well-drained, acidic to slightly acidic soils (pH about 4 to 6); it was a dominant component of slopes and ridgetops throughout the Appalachian region but grew poorly in wet soils (Abrams and McCay 1996, Abrams and Ruffner 1995, Braun 1950, Burke 2011, Frothingham 1912, Paillet 2002, Russell 1987, Wang and others 2013). Chestnut's abundance on the landscape varied with many factors including land use history, but it reportedly accounted for about 25 percent of the virgin timber in the southern Appalachian Mountains and more than 50 percent of the timber in some second-growth forests (Braun 1950, Buttrick 1915, Frothingham 1912).

By all accounts, American chestnut's sheer dominance in many stands made it eastern North America's most important nut producer and one of the most important timber producers. The loss of American chestnut from our forests is often described as the greatest ecological disaster of the 20th century.

THE FORESTRY RECLAMATION APPROACH FOR CHESTNUT RESTORATION

During the early 2000s in anticipation of disease-resistant chestnuts, cooperators and researchers with the Appalachian Regional Reforestation Initiative (ARRI) began testing the suitability of mined lands reclaimed with the Forestry Reclamation Approach (FRA) for chestnut introduction. Cooperators and researchers have planted and monitored pure American chestnuts and backcross chestnuts on FRA-reclaimed lands throughout the Appalachians. Once chestnut varieties with disease resistance and American characteristics become widely available, mine operators will be able to plant those seedlings along with other Appalachian hardwoods and reclamation species on mine sites.

The TACF strategy for chestnut restoration includes early establishment of small populations throughout the chestnut's former range. These initial groups of trees ("founder populations") are intended to serve as seed sources and to aid natural dissemination to other areas.

Establishing founder populations of chestnuts on mined lands has been of interest to TACF researchers for many reasons. The first is the overlap of American chestnut's native range and the Appalachian coalfields (Fig. 12-2). Furthermore, many mining disturbances occur on upper slopes and ridgetops where chestnuts were formerly a dominant component of the forest, potentially making former surface mines ideal locations for chestnut introduction. In addition, research has demonstrated that chestnut can be successful when planted on mines that have been reclaimed by using the FRA. Mining disturbances reclaimed with the FRA may also limit the establishment of root-rot pathogens, such as the water mold Phytophthora, which have hindered TACF's breeding efforts in the southern Appalachians (James 2011). Phytophthora is a water mold that favors wet soils or those with a high water-holding capacity; the well-drained soils

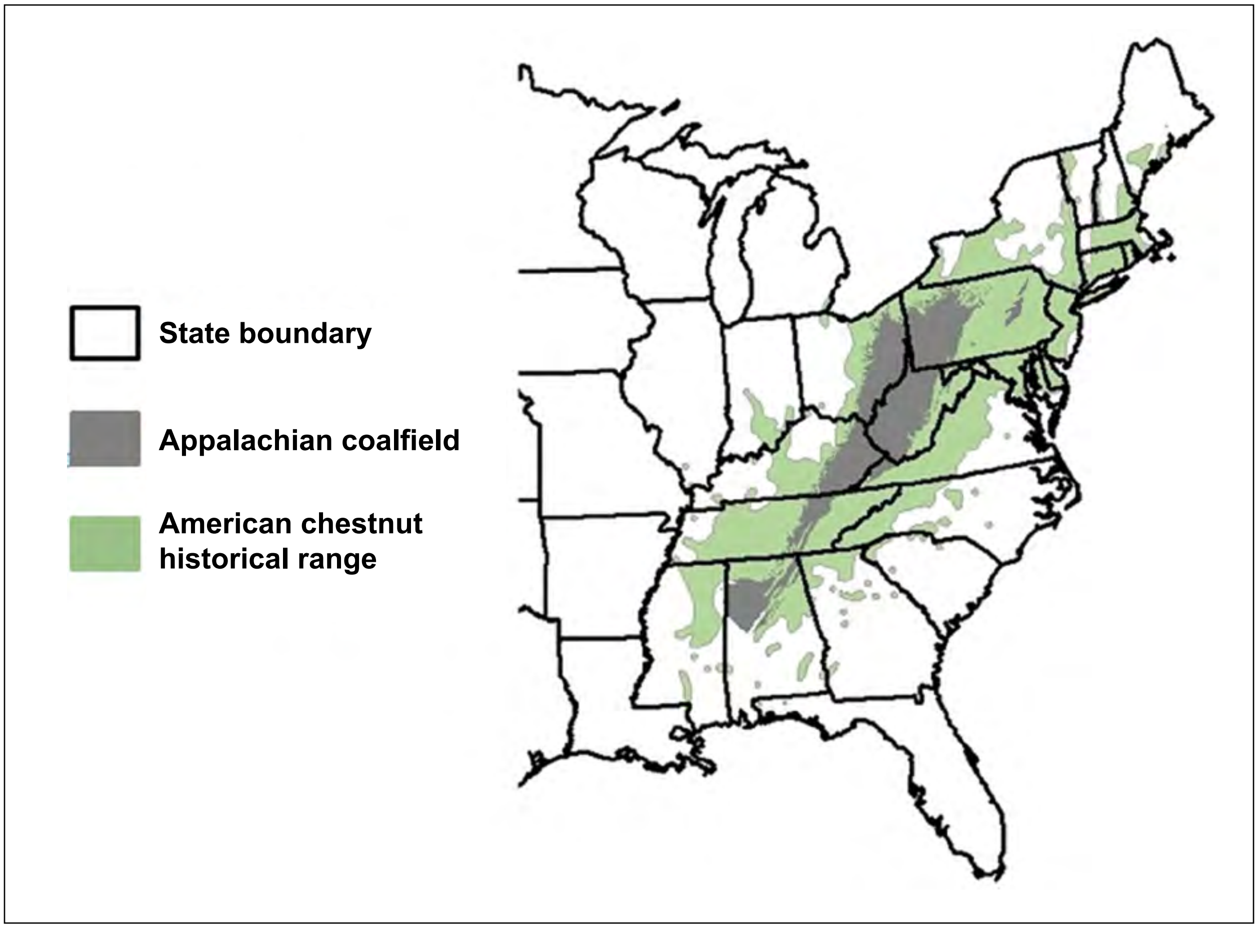

Figure 12-2.—The native range of American chestnut (Little 1977) overlaid on the Appalachian coalfields. (Map prepared by P. Donovan, Virginia Tech.)

created by the FRA may limit its establishment. Last, surface mines reclaimed with the FRA are essentially "blank slates," where conditions benefiting chestnut establishment can be created. Vegetative competition for nutrients, sunlight, and water can be reduced through the proper implementation of Step 3 of the FRA (Chapter 6, this volume). In contrast, chestnuts planted in existing forests and old fields face competition from established vegetation.

PRIOR RESEARCH AND WORK

Studies of the growth and survival of early backcross chestnut (B_1 F_3, B_2 F_3, and B_3 F_2) on sites that implemented FRA techniques as a part of active mining operations have offered encouraging results. Two studies in West Virginia found survival rates of 40 to 70 percent for backcross chestnuts planted as seed ("direct-seeded") after four growing seasons; the authors noted that the survival for the total chestnut stock fell within the survival range of other hardwoods in similar planting trials (Skousen and others 2013). A study in eastern Kentucky found survival rates from 41 to 60 percent for sheltered, direct-seeded backcross chestnuts after five growing seasons (Barton and others 2013). Similar trials on FRA sites in Ohio, Pennsylvania, and Tennessee exhibited similar survival rates (more than 40-percent average survival for backcrosses after five growing seasons) (Bizzari 2013). A study comparing groundcover effects on backcross chestnut survival on an FRA site in southwestern Virginia showed 48- to 73-percent survival after two growing seasons and showed that bare-root seedlings initially performed better than chestnuts that were direct-seeded (Fields-Johnson and others 2012). Bare-root seedlings also performed better than chestnut seeds in an Ohio study (McCarthy and others 2010). Several planting methods have been shown to give adequate initial survival, including potted seedlings, direct seeding, and bare-root plantings; all of these methods are suitable for introducing chestnuts to mined lands (Fields-Johnson and others 2012, French and others 2007, Skousen and others 2013). A Tennessee study found dense ground cover of annual ryegrass inhibited chestnut growth (Klobucar 2010).

Legacy surface mines (those reclaimed by using conventional reclamation methods under the federal Surface Mining Control and Reclamation Act of 1977 [SMCRA] and not reforested with native trees) and abandoned mine lands are also potential launching points for blight-resistant chestnut introduction, although less work has been done to identify establishment methods that are most suitable for such sites. Restoration Chestnut 1.0 (B_3F_3) plantings on abandoned mine sites in 2012 and 2013 used a limited quantity of seed and seedlings and early success varied from 32- to 100-percent survival after one season.[1] Bauman and others (2013a) found that a cross-ripped legacy site in Ohio had 73-percent survival of bare-root chestnuts after six growing seasons and that the chestnuts began producing nuts in the fourth growing season. The authors and collaborators from ARRI have observed similar chestnut seed production by the fourth or fifth growing season (Fig. 12-3) on active FRA sites in Ohio, Kentucky, Tennessee, and West Virginia. Mitigation of compaction on a legacy mine in Ohio enabled greater colonization of chestnut root-tips by beneficial mycorrhizal fungi, which probably led to higher survival and growth rates when compared to the untreated controls (Bauman and others 2013b).

Figure 12-3.—A 5-year-old backcross chestnut on a reclaimed mine in West Virginia. Many of the trees on this site were producing male and female flowers. Photo by M. French, The American Chestnut Foundation, used with permission.

TACF is currently creating mixed hardwood/American chestnut forests on mined lands that implement the FRA as a part of a Conservation Innovation Grant (CIG) awarded to TACF by the U.S. Natural Resources Conservation Service in 2011. Each of the 12 CIG plantings is about 30 acres in size and has a mixed hardwood component with Restoration Chestnuts 1.0 planted randomly throughout. The Restoration Chestnuts 1.0 are planted at 20 per acre as 1-year old (1-0) bare-root seedlings in a mix with other 1-0 bare-root hardwoods for a total of 680 trees per acre. This will demonstrate how Restoration Chestnuts 1.0 compete against other commonly used native

[1] Unpublished data on file with TACF, Asheville, NC.

hardwoods in a mixed hardwood reforestation planting. A direct-seeded, 1-acre progeny test to examine varying degrees of blight resistance in the Restoration Chestnut 1.0 population is also a component of each of these plantings. Several of these plantings have had greater than 80-percent germination and survival for direct-seeded chestnuts and greater than 90-percent survival for bare-root planted chestnuts after one growing season.[2]

BIOTIC AND ABIOTIC CONSIDERATIONS FOR ESTABLISHING CHESTNUTS ON MINED LANDS

Many active mine sites that implement the five steps of the FRA (Chapter 2, this volume) meet the criteria of American chestnut's site requirements in historical accounts. Although every step of the FRA is important, pay particular attention to avoiding compaction on areas to be reforested with chestnuts. Compacted soils are often poorly drained, and chestnuts are known to perform poorly in wet soils (Rhoades and others 2003). Phytophthora root rot on American chestnut seedlings was found to be greater in soils with higher moisture content (Rhoades and others 2003).

Additionally, soil pH varies greatly on mined lands and should be tested before planting to ensure that it is near chestnut's preferred range (pH of about 4 to 6). These soil pH levels can usually be achieved through use of salvaged soil, weathered overburden, or a combination for soil reconstruction, following FRA recommendations (Chapter 3, this volume). New mine soils constructed of unweathered overburden usually will not be suitable for American chestnut plantings due to high soil pH, high salinity, or both.

[2] Unpublished data on file with TACF, Asheville, NC.

Take into account microsite factors when planting as well. Gilland and McCarthy (2012) found that chestnut seedlings planted near the edge of existing forest (within about 16 feet) showed significantly lower growth and survival than seedlings planted away from the forest edge (75 to 150 feet). They also found that chestnuts fared better when some ground cover was present, and that seedlings survived better when planted on the sides of end-dumped FRA piles than when planted on the tops of the piles.

When planting bare-root chestnuts, no special handling is necessary. ARRI recommendations for preparing, handling, storing, and planting hardwoods are sufficient for chestnuts (Chapter 9, this volume). Chestnuts are known to be fast-growing and 1-0 seedlings are generally of adequate size to be vigorous. However, take care to obtain seedlings from nurseries that do not have Phytophthora, if such assurance can be obtained.

When direct-seeding chestnuts, use 18- to 24-inch tree shelters to prevent unacceptable losses from rodent predation and to avoid the problems associated with the use of tall tree shelters (Fig. 12-4) (McCarthy and others 2010, Sena and others 2014, Skousen and others 2013). Deer, rodents, and other herbivores are known to consume chestnut foliage, bark, and seeds. In areas with dense deer or elk populations, it may be necessary to construct fencing or wire cages around seedlings to prevent browsing and seedling losses. In Tennessee, fertilizer application at the time of planting was found to increase growth rates in the first 2 years (de Lima and others 2011, Miller and others 2011).

For establishing chestnut plantings on legacy mines, refer to recommendations in Chapter 10 of this volume. Again, soil pH should be tested before planting; apply soil amendments if necessary. Control competition from existing vegetation.

Figure 12-4.—A Restoration Chestnut 1.0 planted as seed emerging from a 24-inch-tall tree shelter after 3 months on an active mine in Ohio. Photo by M. French, The American Chestnut Foundation, used with permission.

SUMMARY AND FUTURE WORK

Many field planting trials have shown that Appalachian mined lands reclaimed with the FRA provide an opportunity for introducing blight-resistant chestnuts into eastern U.S. forests. The level of disease resistance in TACF's population of backcross chestnuts will not be known for several years, so continued monitoring will be necessary. However, TACF will continue increasing blight resistance in the chestnut seedlings that it is distributing for planting. Research has found that mine reclamation sites can be planted to establish founder populations of blight-resistant chestnuts that could then spread by natural processes into surrounding forests (Jacobs 2007). There is still much to be learned about establishing chestnuts as a part of a mixed hardwood forest on mined lands; research is ongoing.

The lessons learned from these trials may also play a role in reestablishing other native tree species that are being threatened by nonnative pests and diseases. For example, mined lands are currently being tested to reintroduce American elms that are resistant to Dutch elm disease.

Assisting ARRI and other organizations such as Green Forests Work in creating productive and biodiverse forests on active mining operations, legacy mines, and abandoned mine lands is a high priority for TACF.

As more Restoration Chestnuts 1.0 are produced, TACF intends to contribute more of these chestnuts for reclamation projects. However, demand for blight-resistant chestnuts will outpace supply for many years to come. Full implementation of the FRA will be important to TACF decisions concerning allocation of blight-resistant chestnut stock for mine reclamation plantings.

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Thanks to Patricia Donovan, Virginia Tech, for preparing the map in Figure 12-2.

Photo of chestnut tree on p. 12-1 is courtesy of Michael French, The American Chestnut Foundation.

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APPENDIX: COMMON AND SCIENTIFIC NAMES OF SPECIES MENTIONED IN THIS VOLUME

FLORA

Common name	Scientific name
ash:	*Fraxinus*
green	*pennsylvanica*
white	*americana*
aspen, bigtooth	*Populus grandidentata*
autumn-olive	*Elaeagnus umbellata*
beech, American	*Fagus grandifolia*
birch:	*Betula*
river	*nigra*
sweet	*lenta*
bird's-foot trefoil	*Lotus corniculatus*
blackberry	*Rubus* spp.
blackhaw	*Virburnum prunifolium*
blueberry	*Vaccinium* spp.
cherry:	*Prunus*
black	*serotina*
chestnut:	*Castanea*
American	*dentata*
Chinese	*millissima*
chokecherry:	
black	*Aronia melanocarpa*
common	*Prunus virginiana*
clover:	*Trifolium*
ladino or white	*repens*
red	*pratense*
crownvetch	*Coronilla* spp.
dogwood:	*Cornus* spp.
gray	*racemosa*
elderberry, common	*Sambucus canadensis*
foxtail millet	*Setaria italica*
goldenrods	*Solidago* spp.
grapevine	*Vitis* spp.
groundpine	*Lycopodium dendroideum*
hawthorn	*Craetagus* spp.
hazelnut, American	*Corylus americana*
hickory:	*Carya*
shagbark	*ovata*
Japanese honeysuckle	*Lonicera japonica*
Kentucky-31 tall fescue	*Lolium arundinaceum*
locust:	*Robinia*
black	*pseudoacacia*
bristly	*hispida*

Common name	Scientific name
maple:	*Acer*
red	*rubrum*
sugar	*saccharum*
multiflora rose	*Rosa multiflora*
oak:	*Quercus*
black	*velutina*
chestnut	*montana*
northern red	*rubra*
southern red	*falcata*
white	*alba*
orchardgrass	*Dactylis glomerata*
oriental bittersweet	*Celastrus orbiculatus*
paulownia (princesstree)	*Paulownia tomentosa*
pine:	*Pinus*
eastern white	*strobus*
pitch x loblolly	*rigidaxtaeda*
ragweed	*Ambrosia* spp.
raspberry	*Rubus* spp.
red top	*Agrostis gigantea*
redbud	*Cercis* spp.
ryegrass:	*Lolium*
annual	*multiflorum*
perennial	*perenne*
sassafras	*Sassafras albidum*
sericea lespedeza	*Lespedeza cuneata*
serviceberry	*Amelanchier* spp.
sourwood	*Oxydendrum* spp.
spruce, red	*Picea rubens*
sycamore, American	*Platanus occidentalis*
tall fescue	*Schedonorus* spp. *or* *Schedonorus phoenix*
timothy	*Phleum pratense*
tree of heaven (ailanthus)	*Ailanthus altissima*
trillium	*Trillium* spp.
viburnum, mapleleaf	*Viburnum acerifolium*
Virginia creeper	*Parthenocissus quinquefolia*
walnut:	*Juglans*
black	*nigra*
wintergreen	*Pyrola* spp.
yellow-poplar (tuliptree)	*Liriodendron tulipifera*

Source: Natural Resources Conservation Service. 2016. The PLANTS database. Greensboro, NC: U.S. Department of Agriculture, Natural Resources Conservation Service, National Plant Data Team. www.plants.usda.gov/ (accessed November 17, 2016).
Photo of Appalachian forest courtesy of J. Burger, Virginia Tech.

FAUNA

Common name	Scientific name
Allegheny woodrat	*Neotoma magister*
American woodcock	*Philohela minor*
bear:	*Ursus*
black	*americana*
bobcat	*Lynx rufus*
brown thrasher	*Toxostoma rufum*
common yellowthroat	*Geothlypis trichas*
cottontail	*Sylvilagus floridanus*
deer:	*Odocoileus* spp.
white-tailed	*virginianus*
earthworm:	*Dendrobaena octaedra*
	Lumbricus
	rubellus
	terrestris
eastern whip-poor-will	*Antrostomus vociferus*
elk	*Cervus elaphus*
emerald ash borer	*Agrilus planipennis*
fisher	*Marten pennanti*
Indiana bat	*Myotis sodalis*
indigo bunting	*Passerina cyanea*
locust borer beetle	*Megacyllene robiniae*
northern bobwhite	*Colinus virginianus*
northern flying squirrel	*Glaucomys sabrinus*
red eft	*Notophthalmus viridescens*
rodent	Order Rodentia
ruffed grouse	*Bonasa umbellus*
salamander:	
green	*Aneidas aeneus*
woodland	*Plethodontidae* family
snake	Suborder Serpentes
warbler:	
blue-winged	*Vermivora cyanoptera*
cerulean	*Dendroica cerulea*
golden-winged	*Vermivora chrysoptera*
wild turkey	*Meleagris gallopavo*

PATHOGENS

Common name	Scientific name
chestnut blight	*Cryphonectria parasitica*
Dutch elm disease	*Ophiostoma Novo-ulmi*
root rot	*Phytophthera* spp.

Adams, Mary Beth, ed. 2017. **The Forestry Reclamation Approach: guide to successful reforestation of mined lands.** Gen. Tech. Rep. NRS-169. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station: 128 p. https://doi.org/10.2737/NRS-GTR-169.

Appalachian forests are among the most productive and diverse in the world. The land underlying them is also rich in coal, and surface mines operated on more than 2.4 million acres in the region from 1977, when the federal Surface Mining Control and Reclamation Act was passed, through 2015. Many efforts to reclaim mined lands most often resulted in the establishment of grasses, shrubs, and nonnative plants. Research showed that forests could be returned to these mined lands, also restoring the potential for the land to provide forest ecosystem services and goods. Scientists and practitioners developed a set of science-based best management practices for mine reforestation called the Forestry Reclamation Approach (FRA). To help practitioners implement the 5 steps of the FRA and achieve other restoration goals (such as wildlife enhancement), 13 Forest Reclamation Advisories have been written since 2005 and others are underway. The 12 Advisories that are most directly relevant to the Appalachian region are being published here in a single volume for the first time.

These Advisories were originally posted on the Web site of the Appalachian Regional Reforestation Initiative (ARRI), an organization created in 2004 by the U.S. Department of the Interior's Office of Surface Mining Reclamation and Enforcement along with State mining regulatory authorities in the Appalachian region. Members of ARRI come from the coal mining industry, government agencies, and research institutions. The goal of this initiative is to promote forest reclamation and restoration on mine lands through planting of high-value hardwood trees, increasing those trees' survival rates and growth, and speeding the establishment of forest habitat through natural succession. To accomplish these goals, ARRI promotes and encourages use of the FRA by reclamation specialists. The Advisories are intended to serve as easy-to-understand guides to implementing the FRA; they provide specific recommendations as well as illustrations and photos to demonstrate tasks. The reformatted Advisories in this volume contain updated information and the latest additional resources to guide reclamation practitioners and other stakeholders in the reestablishment of healthy, productive forests in the Appalachian region.

KEY WORDS: mineland reclamation, reforestation research, Forest Reclamation Advisory, Appalachian Regional Reforestation Initiative, Appalachia, Office of Surface Mining Reclamation and Enforcement