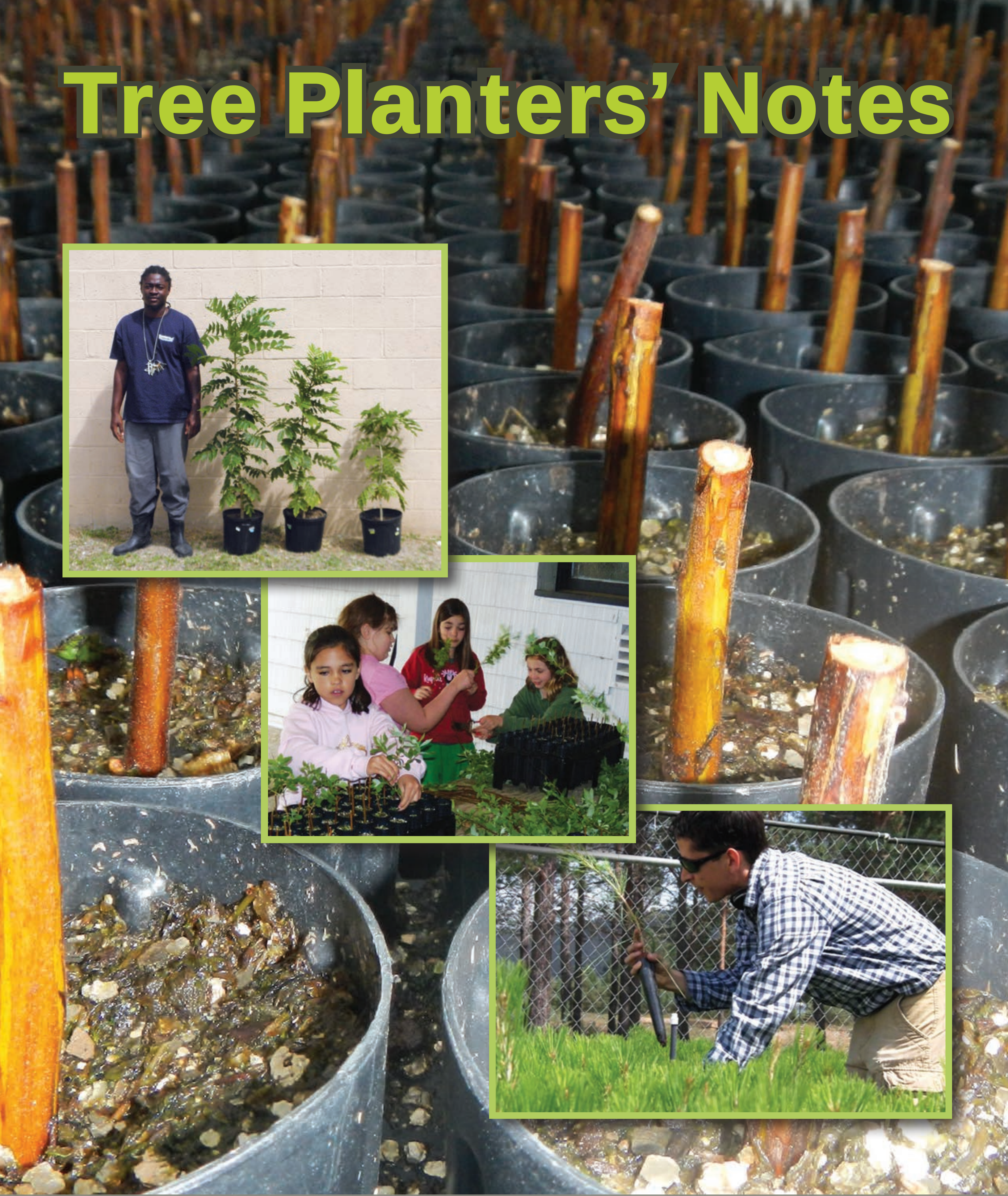
Tree Planters' Notes



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Tree Planters' Notes **(TPN) is dedicated to technology transfer and publication of information relating to nursery production and outplanting of trees and shrubs for reforestation, restoration, and conservation.**

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Dear TPN Reader

This is my fourth year as your editor for *Tree Planters' Notes*. Although it is a time-consuming endeavor, I find it very rewarding to work with authors who share a passion for working with plants, to learn more about reforestation and restoration projects around the world, and to receive positive feedback from subscribers. I have especially enjoyed TPN's ongoing series to highlight tree planting activities in every State. So far, 18 States have been profiled, including 2 in this issue (New Mexico, page 4, and Michigan, page 13). Recruiting authors for these papers can be challenging, however. I intend to include all 50 States and the U.S. territories before I retire! If you would like to volunteer to write the paper for your State (or to nominate someone), please contact me.

Also, in this issue, Williams and Dumroese (page 21) provide an overview of assisted migration strategies in response to climate change and how this approach will affect nursery and reforestation programs; Arbab and colleagues (page 27) report on a 20-year study to establish ponderosa pine seedlings in heavily grazed forest stands on the Navajo forest; Barnett (page 35) gives a history of efforts to reforest southern pines with direct seeding, including techniques and considerations for using this method today; Morgan and Zimmerman (page 49) describe a study to evaluate the potential of native tree species for landscaping in the Caribbean based on their required irrigation frequency; and Heckeroth (page 61) reports on an innovative cooperative effort in northwest Oregon to produce planting stock for forest and riparian restoration.

I'm always looking for more articles to fill future issues of Tree Planters' Notes. Please consider submitting your paper for publication. You can also send suggestions for topics or authors you would like to see included in TPN. Guidelines for authors can be found at the end of this issue as well as online at http://www.rngr.net/publications/tpn

May you all have a wonderful spring and summer. Here's an apt quote for the passion we all share:

The creation of a thousand forests is in one acorn. ~ Ralph Waldo Emerson

Kind Regards,

Diane L. Haase

Contents

SEE PAGE 19

SEE PAGE 41

Forestry and Tree Planting in New Mexico

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Abstract

New Mexico's varied climate and geography, coupled with its deep sociocultural background provide a rich and dramatic backstory to its present day position in the forest industry. Resource extraction during the mid-19th century negatively impacted forests and woodlands near settlements in response to growing railroads, mining operations, and ranches. In the 1940s, fire suppression efforts were established to protect the ever-growing timber industry that was feeding the post World War (WW) II housing boom. With these suppression efforts, fuel densities have reached extremely hazardous conditions in many of New Mexico's forests. Combined with severe drought conditions, these dense forests have been burning at catastrophic levels in recent years. In response to both harvest activities and fire restoration efforts, reforestation became a new focus in New Mexico in the 1970s. The John T. Harrington Forestry Research Center, an Agricultural Experimental Station of New Mexico State University, opened in 1972 as part of a State legislative act to improve forest productivity and reforestation success. In 1995, the listing of a federally endangered species, the Mexican spotted owl (*Strix occidentalis*), halted timber production and thus redirected reforestation efforts to that of post-fire restoration. Pressures from tourism, recreation, drought, and increasingly large wildland fires place new demands on the New Mexico landscape. Looking to the future, reforestation and restoration efforts will provide new challenges for New Mexico's nurseries, while increasing forest densities beg the question whether an economically viable timber industry will make a comeback.

Climatic and Geographic Variation

New Mexico varies widely in climate and geography. The highest point, Wheeler Peak at 13,159 ft (4,011 m) above sea level, is located in northern New Mexico's Sangre de Cristo Range, at the southern end of the Rocky Mountains. The lowest point in New Mexico, 2,841 ft (866 m), is at the northern end of the Red Bluff Reservoir on the Pecos River. The mean elevation of the State is 5,698 ft (1,737 m) above sea level, ranking New Mexico as the fourth highest elevation State in the United States (New Mexico Base and Elevation Maps 2013). The dominant soil order across the State is aridisol, although entisols and mollisols are common as well (Soil Survey 2013).

The climate of New Mexico is dry, continental (Sheppard and others 1999, New Mexico Climate Center 2008), with cold, dry winters, and warm, moist summers. Temperatures can vary from 20 to 50 °F (11 to 28 °C) during a day. Western mountain slopes and the northwestern New Mexico area tend to get greater precipitation than eastern portions of the State that are in the rain shadows of mountain ranges. Higher elevations across the State tend to receive more precipitation than do lower elevation areas (figure 1). Winter storms bring snow pack to the mountains, which most people in the Southwest depend on for their water. Winter and spring storms provide the moisture that is most used by woody vegetation in New Mexico (Williams and Ehleringer 2000, West and others 2008);

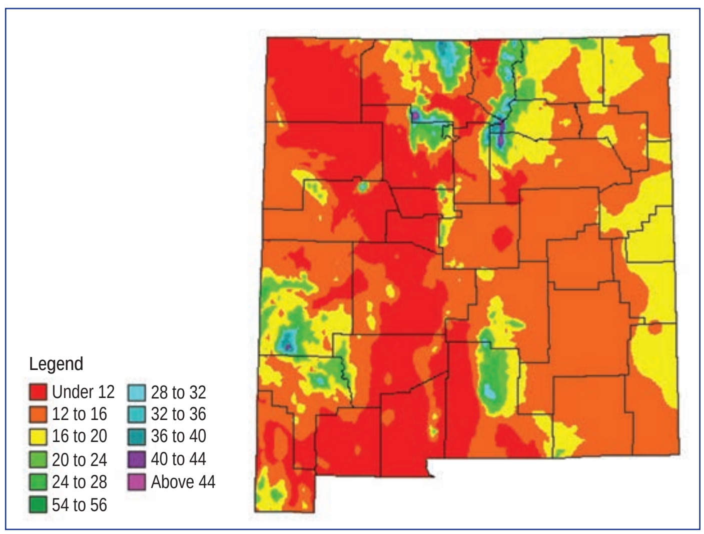

Figure 1. New Mexico annual precipitation in inches per year (1961–1990). (Adapted from Weisburg 1997)

however, late summer monsoon moisture is also important. The greatest proportion of annual precipitation occurs during the monsoon period (early July through mid-September) in high-intensity downpours from thunderstorms (Williams and Ehleringer 2000, New Mexico Climate Center 2008). Solar radiation is intense, especially in the summer; each year, many more days are sunny than have overcast weather throughout the State.

Droughts are common in semiarid New Mexico, and the State often has significantly greater evaporative demand than precipitation. The driest time of the year, based on greatest evaporative demand, is in May and June at the end of the relatively droughty winter and spring seasons. A long dry period developed between 1943 and 1971 resulting in a severe drought in the mid-1950s. Drought is a selective pressure that affects some species more than others (McDowell and others 2008). The 1950s drought resulted in extensive die-off of many vegetation types (Betancourt and others 1993) and increased the lower elevation limit of ponderosa pine (*Pinus ponderosa* Dougl. ex Laws) in Bandelier National Monument (Allen and Breshears 1998). Pinyon pine (*P. edulis* Engelm.) and juniper (*Juniperus* spp.) dieoff was marked over the landscape during the 1950s drought as well (Potter 1957, Betancourt and others 1993). A new drought is causing widespread mortality at the lower elevation limits of tree ranges and in relatively high-density stands.

Land Area and Ownership

New Mexico is the fifth largest State in the Union at approximately 77.5 million ac (31.4 million ha). Of this total land area, 21 percent is covered by forest lands defined as areas in which 10 percent or more of that land is occupied by tree species. Forest lands can be further broken down into woodlands (e.g., pinyon pine, Gambel oak [*Quercus gambelii* Nutt.], and juniper) and timberlands (e.g., ponderosa pine and Douglas-fir [*Psuedotsuga menziesii* (Mirb.) Franco]), occupying 15 and 6 percent of New Mexico's total land area, respectively. The largest ownership of forest lands in New Mexico is the U.S. Department of Agriculture (USDA), Forest Service, which administers approximately 48 percent of all forest lands. Private landowners, which include tribal trust lands, are the second largest with 38 percent forest land ownership. The remaining forest lands are owned and managed by U.S. Department of the Interior (USDI), Bureau of Land Management (BLM) (7 percent); the State of New Mexico (5 percent); and other public sources (2 percent). Across all ownership types, approximately 10 percent of forest lands are in reserve status, which includes wilderness areas and national parks (O'Brien 2003).

Forest Types

Forest lands of New Mexico are classified by forest types based on the predominant tree species in a stand (figure 2). O'Brien (2003) describes in detail the distribution of forest types throughout the State. Distribution of forest types is primarily a function of precipitation and evaporative demand. At the lower elevations, approximately 53 percent of forest lands are classified as pinyon-juniper. A rise in elevation (6,000 to 8,500 ft [1,830 to 2,590 m]) results in a forest type shift to ponderosa pine that makes up 17 percent of the total forest lands. In this forest type, ponderosa pine is the predominant species but Douglas-fir, Gambel oak, and pinyon pine also occur. Douglas-fir is the next forest type at an elevation range of 8,000 to 9,500 ft (2,438 to 2,895 m) and includes Douglas-fir, ponderosa pine, white fir (*Abies concolor* (Gord. & Glend.) Lindl. ex Hildebr), and aspen (*Populus tremuloides* Michx.), all of which make up 6 percent of the total forest lands. In the elevation range of 8,000 to 11,000 ft (2,438 to 3,350 m), the white fir forest type (3 percent of forest lands) exists in association with Douglas-fir, aspen, and ponderosa pine. At the highest elevation ranges (above 9,000 ft [2,743 m] to timberline), Engelmann spruce (*Picea engelmannii* Parry ex Engelm.) and subalpine fir (*A. lasiocarpa* (Hook.) Nutt.) dominate the spruce-fir forest type (2 percent of forest lands). The spruce-fir forest type typically has a longer life span (500 to 600 years) compared with the lower elevation forest types because of fewer natural disturbances, such as fire (Battaglia and Shepperd 2007).

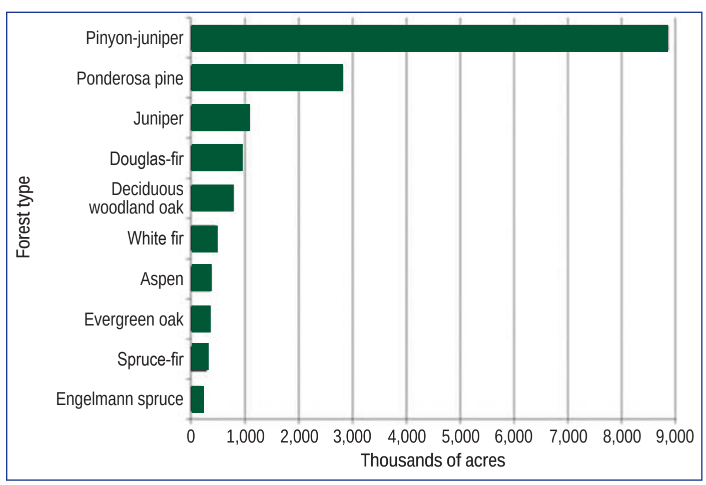

Figure 2. Area of land by forest type. (Adapted from O'Brien 2003)

History of New Mexico's Forests

The first contact between Europeans and New Mexico was the Coronado Expedition in 1540. Colonists introduced horses, burros, cattle, sheep, and goats as well as new crops (Scurlock 1998). New Mexico became a U.S. territory in 1850 after a military takeover in 1846 during the Mexican-American War. The increase in trade with the United States via the Santa Fe Trail and later the railroads (1872) brought new technologies that greatly improved efficiency in resource extraction. Large-diameter trees could be efficiently felled and bucked with cross-cut steel saws, and steam engines powered lumber mills and increased access to wider markets by railroad. Railroad grades for timber extraction were built through the Sacramento and Jemez Mountains. Extensive areas of forest lands near settlements and railroad lines were harvested for both fuelwood and construction materials. Timber stands were high graded, leaving a few unhealthy or defective trees to regenerate stands. Harvested sites were thereafter grazed and browsed by livestock. Large populations of livestock on open ranges overused grasslands, shrublands, woodlands, and forest lands, which resulted in extensive erosion and shifts of grasslands to shrublands and woodlands (Dick-Peddie 1993). New Mexico became a State in 1912 and national forests were created in 1915. National forests brought a scientific, inventory perspective to timber usage and silviculture, which was originally devised for distant and more productive ecosystems. Transportation and saws powered by internal combustion engines expanded roads and timber harvests into new, remote areas. Upon recognition that wildlands were disappearing, Congress created the first designated wilderness area, the Gila in southwest New Mexico. The conversion of common lands, traditionally used by Indian and Hispanic villagers, to Federal control remains controversial to some to this day.

The Forest Conservation Commission was established in 1957 to address fire protection on State and private land. The commission later became the New Mexico State Forestry Division (hereafter, the Forestry Division), which is now part of the Energy, Minerals, and Natural Resources Department. The Forestry Division's mission has expanded to include timber management and conservation efforts. The Forestry Division's role includes technical forestry assistance to private and State landowners, conservation of forest lands through easements, encouragement of forest industries, inmate forestry work programs, heritage of native plants, and many other programs that support healthy ecosystems in New Mexico. The Forestry Division places the importance of proper watershed management as a top priority to achieve overall ecosystem health. To achieve this goal, the Forestry Division has taken a leadership role in crafting collaborative efforts with local, State, Federal, and tribal agencies, as well as private landowners, businesses, and nongovernmental organizations (Tudor, personal communication 2013).

Fire Suppression and Fire Ecology in New Mexico

In light of antifire feelings fueled by World War II, a campaign (Cooperative Forest Fire Prevention Campaign) was launched to reduce wildland fire risk, part of which was to urge people to be more careful with fire. In 1944, Walt Disney allowed the Fire Prevention Campaign to use Bambi on one of its posters for 1 year. After Bambi's reign on the poster, the campaign chose Smokey Bear as the national symbol for fire prevention. The first Smokey Bear poster appeared in 1944, and since then Smokey has become a national symbol (Thomas and McAlpine 2010). The living symbol of Smokey Bear was an American black bear cub that was caught in the Capitan Gap fire in 1950, which burned 17,000 ac (6,979 ha) in the Capitan Mountains of New Mexico on the Lincoln National Forest. Smokey had climbed a tree to escape the blaze, but his paws and hind legs had been burned. He was rescued by firefighters and was rehabilitated, becoming the living legend of Smokey. The two icons, Bambi and, particularly, Smokey Bear, have saved timber worth more than $17 billion in the National Park System alone (Ling and Storer 1990).

Smokey's message is as relevant as ever; nonetheless, fire ecologists have urged managers and the public to understand the importance of fire as a critical ecological process. Particularly in the ponderosa pine forests of New Mexico and the Southwestern United States, fire suppression has led to increased fuel densities (Covington and Moore 1994). Forests that would have been historically cleared by frequent, low-severity surface fires are now overcrowded and contain high levels of hazardous fuels that contribute to catastrophic fire events (figure 3). Like most of the United States, New Mexico has seen an increase in the area burned in wildland fire during the past 10 years. The State experienced wildfire on approximately 73,000 ac (29,542 ha) per year from 1990 to 2000. From 2002 through 2012, New Mexico burned an average of 416,000 ac (168,349 ha) (NIFC 2013); this fivefold increase occurred in only two decades. In 2011 alone, 1,286,487 ac (520,622 ha) of New Mexico burned; contained in that acreage was the Las Conchas fire (156,293 ac [63,249 ha]), now the second largest fire in the history of New Mexico, surpassed only by the White Water Baldy Fire (297,845 ac [120,533 ha]) of 2012.

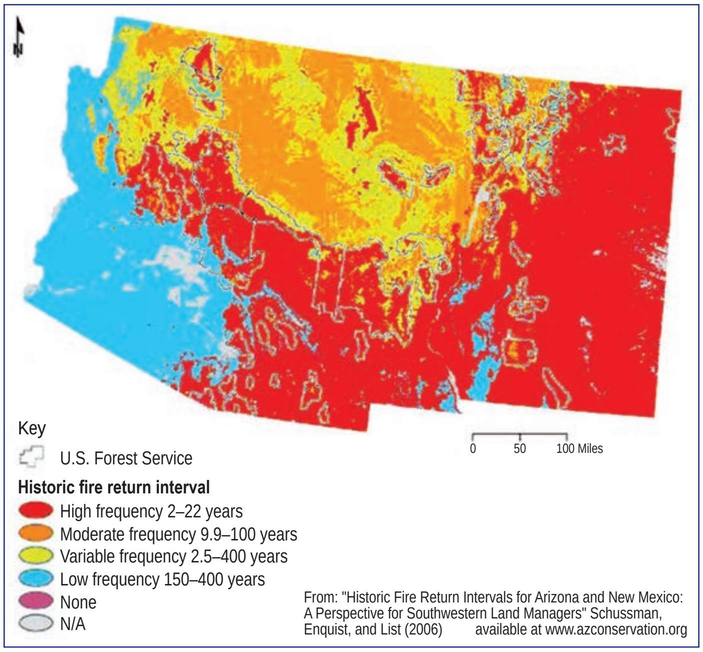

Figure 3. Historical fire frequency for Arizona and New Mexico. Most of New Mexico's forests were historically cleared out by very frequent, low-severity surface fires. This low-severity fire regime has been replaced by catastrophic fire events. (Schussman et al. 2006)

Current State of New Mexico's Forests

New Mexico's forests currently have increasing demands placed on them from recreation, tourism, and scattered urban and rural development. The population of the Southwest has grown tremendously during the past few decades, placing greater demands on recreational opportunities. Since 1965, the USDA Forest Service system lands have seen a fourfold increase in recreation-visitor-days (Dahms and Geils 1997). With the expanded growth in human population, water requirements continue to strap an already limited resource. Other significant forest demands are because of grazing and mining interests. New Mexico's forests experienced light grazing pressure in the 1800s and severe pressure in the first few decades of the twentieth century. Attempts are being made to balance number of livestock with the land's grazing capacity. The number of range cattle and sheep in New Mexico peaked during or shortly after World War I and have since declined. Around 1920, range cattle numbered approximately 1.6 million in New Mexico and have since dropped to 1.2 million head. Sheep populations have also experienced a decline from 2.3 million head to 0.2 million (Dahms and Geils 1997). Scattered urban development divides forest and woodlands into small parcels under diverse management paradigms. Homesteads increase the complexities and difficulties in managing wildfires.

After WWII, strong housing markets and public policy increased timber harvests on national forests lands. Timber harvest in New Mexico increased from about 150 million board feet (MMBF) annually to a peak of nearly 300 MMBF in the late 1960s. Harvest dropped in the 1970s and 1980s, with the late 1980s averaging about 190 MMBF annually. Since the late 1980s, New Mexico's timber harvest has declined dramatically. The greatest decline in timber harvesting has been on private and tribal lands (-53 MMBF Scribner). Further declines have been caused largely by decreases in harvests from national forests. New Mexico's national forest timber harvest has followed a pattern similar to that of many Western States. Harvest levels on national forest lands declined in the early 1990s, because of a combination of pressures related to threatened and endangered species and appeals and litigation directed at Federal timber sales (Keegan and others 1995a, 1995b; Keegan and others 1997; Warren 1999). In New Mexico, the listing of the Mexican spotted owl (*Strix occidentalis*) had a profound downward impact on national forest timber harvest levels. The Mexican spotted owl was listed as threatened by the U.S. Fish and Wildlife Service in March 1993. In August 1995, a Federal judge prohibited the logging of new timber sales on national forests in New Mexico pending development of a recovery plan for the owl (*Silver* v. *Babbitt* 1995). This injunction remained in place until December 1996. The lifting of the injunction resulted in small increases in national forest timber harvests in subsequent years. Overall timber harvests in 1997, 2002, and 2007 were 97, 74, and 39 MMBF Scribner, respectively. Most current harvests are for sawlogs. In 2007, ponderosa pine and Douglas-fir accounted for 47 and 25 percent, respectively, of the State's timber harvest. Value of timber products from New Mexico in 2007 was $25.6 million.

Forest Regeneration and Nurseries

Before 1995, most tree planting programs in New Mexico were aimed to reforest areas harvested for timber on public and private (mainly tribal) lands with an additional focus on fire restoration. After the listing of the Mexican spotted owl as a threatened and endangered species, however, timber harvests on national forests in the Southwest nearly halted (Kosek 2006). Many forest industry operations, such as the Vallecitos mill owned by Duke City Lumber, closed down in response to the significant decrease in wood supply (Forrest 2001). Because of the lack of industry, the current state of tree planting has shifted away from reforestation efforts and toward restoring those forest lands severely damaged from catastrophic wildfires (figure 4). Burned sites that are not quickly revegetated are vulnerable to significant issues with flooding and erosion.

Figure 4. Las Conchas fire of 2011 burning 156,593 ac (63,371 ha) in New Mexico, the second largest forest fire in the State's history. (Photo by Tammy Parsons, New Mexico State University 2011)

Early reforestation programs (until the 1970s) in New Mexico acquired bareroot seedlings from out of State. Seed source was not an ecological concern at that time, which in combination with long-distance shipping, hindered much of the reforestation efforts. This hindrance quickly changed with the introduction of the first forest nursery and research center in Mora, NM. New Mexico State University (NMSU) opened the Agricultural Research Station in Mora in 1972 as part of a State legislative act to improve forest productivity and reforestation success, principally on State and private lands. The mission of the station was to conduct research on tree improvement, nursery operations, forest regeneration, and other areas of forestry. The greenhouse nursery was constructed in 1976 and began producing seedlings in Spencer-Lemaire "root trainers" containers. Container types have changed multiple times in response to research developments and new technology. Since the spring of 1980, more than 2.5 million seedlings have been produced generating approximately $1.3 million in sales. Ponderosa pine and Douglas-fir are the dominant species produced at the Mora nursery. The Mora nursery currently grows more than 125,000 seedlings annually of more than 25 different species, both conifers and hardwoods, in Ray Leach SC10 containers (figure 5). Seedlings are sold via large contracts to forestry division and tribal lands. Use of local seed sources and improved nursery and outplanting techniques has resulted in dramatically improved survival of distributed conifer seedlings from 15 to 80 percent (Fisher, personal communication 2013). In 1993, the Mora program was placed in the hands of Dr. John Harrington and new directions were followed as research opportunities surfaced. His innovative progress as a researcher, professor, and station superintendent distinguished his career. After his death in 2011, the Mora Research Center was renamed the "John T. Harrington Forestry Research Center" to honor his contributions.

The second forest nursery to open in New Mexico was operated by the USDA Forest Service in Albuquerque from 1977 to 1990. It was primarily a bareroot nursery with production rates up to 3 million seedlings per year. In addition to the bareroot seedling production, a greenhouse facility existed on site capable of producing approximately 20,000 containerized seedlings. The nursery also featured a seed extractory and a large seed storage freezer where all the USDA Forest Service Southwestern Region seedbank was stored. Most seedlings produced were ponderosa pine with a minor component of Engelmann spruce and Douglas-fir. These seedlings mainly went to Federal restoration and reforestation efforts within the region. Poor site conditions and technical problems (such as high soil pH and lime-induced chlorosis) greatly hampered production and Federal customers began to purchase containerized seedlings from private sources. In addition, demands from national forests in the Southwestern Region were much lower than originally estimated. As a result of these issues, the nursery closed in 1990 and the remaining seed from the seedbank was moved to the USDA Forest Service Lucky Peak Nursery in Boise, ID, where it remains today (Hinz, personal communication 2013). In addition to the closing of these two nurseries, a few private and tribal nurseries have come and gone since the Mora nursery was established. The most notable nurseries that are currently, or were very recently, in operation include Riparian Restoration Technologies (subsidiary of Plant Propagation Technologies in Las Cruces, NM), Johnson Enterprises (Cuervo, NM), Mescalero Apache Tribe (Mescalero, NM), and the Pueblo of Zuni (Zuni, NM).

Seedlings produced by tribal lands are typically used only on their own land for fire restoration, reforestation, and riparian restoration. A large portion of the seedlings produced from NMSU's Mora nursery are sold to tribal communities to supplement the seedlings that they have either grown in their own nursery or acquired from other nurseries. The Mora nursery also produces most of the seedlings for the New Mexico State Forestry Conservation Seedling Program, which offers low-cost seedlings to landowners for a variety of purposes including reforestation, fire restoration, erosion control, windbreaks, and Christmas tree plantations. In addition, the program purchases bareroot seedlings from the Colorado State Nursery (Fort Collins, CO) and containerized seedlings from Riparian Restoration Technologies and Johnson Enterprises.

Figure 5. Ponderosa pine seedlings grown in Ray Leach SC10 containers at the John T Harrington Forestry Research Center in Mora, NM. (Photo by Jane Moorman, New Mexico State University 2012)

Tree Improvement Program

In 1977, the New Mexico Cooperative Tree Improvement Program was approved by the USDA Forest Service Southwestern Region to implement the tree improvement and forestation plan submitted by New Mexico State Forestry. In 1978, the State of New Mexico tasked both the New Mexico Forestry Division and NMSU's Forestry Research Center in Mora to implement the Tree Improvement Program (Harrington and others 1996). The overall goal of this program was to partially address the decline in forest industry and productivity observed on New Mexico's State and private lands over previous decades. Owing to overexploitation and fire, more than 100,000 ac (40,468 ha) of forest land were considered unstocked or understocked in 1978, often with natural regeneration dependent upon remnant inferior seed trees because of high-grading logging practices.

A specific program goal was to develop genetically improved seed and planting stock for three main species (ponderosa pine, Douglas-fir, and Engelmann spruce) for both State and private lands. Traits targeted for improvement included survival, growth rate, and tree form. Other native conifer and hardwood species are open for consideration to be included in the tree improvement program, although they are not specifically addressed. Progress to date includes identifying stands with superior trees, collecting seed from these superior trees, establishing multiple progeny and provenance tests, conducting research on drought tolerance, and establishing the first seed orchards in the State (figure 6).

Future Directions

Looking to a future of changing climatic conditions and potentially more catastrophic fires, restoration and reforestation efforts will need to address new and increasing challenges. The federally funded Burned Area Emergency Response (BAER) program is designed to address large fire effects through implementing emergency treatments on Federal

Figure 6. Seed orchard converted from a progeny test of ponderosa pine planted in 1979 in Mora, NM. (Photo by Robert Heyduck, New Mexico State University 2013)

lands to minimize threats to life or property or to stabilize and prevent unacceptable degradation to natural and cultural resources. Some of the more common post-fire stabilization techniques that BAER teams recommend are reseeding of ground cover with quick-growing or native species (USDA 2013). The BAER team that treated the Las Conchas fire area on the Santa Fe National Forest seeded 5,200 ac (2,104 ha) with native grass seed (approximately 33 lb per ac [37 kg per ha]) and used aerial mulching techniques on another 1,100 ac (445 ha) (InciWeb 2013). Nearly 500,000 Douglas-fir seedlings were also planted on approximately 2,000 ac (809 ha) near popular recreation areas (Los Alamos Daily Post 2013).

Most current tree planting efforts in the State are aimed to restore areas after severe forest fires, which produce a harsh, dry, and nutrient poor environment for planting seedlings (Harrington and others 1996). Thus, a new direction for the Tree Improvement program will be to focus research efforts on heat and drought tolerance given the issues with survival on these harsh site conditions. In addition, it will be important to establish more accurate seed zones for primary tree species to be used for creating seed transfer guidelines. Based on the combination of improved seed source selections and seed zones, a seed bank will be established to conserve these specific genotypes for moderately long-term storage.

With the ever-increasing forest densities of New Mexico's ponderosa pine forests, it is critical to find an economical means to thin these forests to protect them from catastrophic fire events. A new forest industry must emerge to capture these small diameter resources. Many monetary and political obstacles need to be overcome to reestablish the forest industry in New Mexico. Most of the forest lands in need of thinning, however, are owned by the USDA Forest Service; timber harvests on Federal lands have been significantly limited because of changes in management strategies and environmental litigation. If the Federal Government opens more harvesting options in New Mexico, it may attract forest product businesses to the State and promote healthy forests and a strong forest industry.

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Forestry and Tree Planting in Michigan

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Abstract

At the start of the 20th century, the pine forests of northern Michigan were largely depleted. In their place were large areas that had been devastated by years of forest fires and attempts to farm the poor soils. With the advent of the State Forestry Commission, the U.S. Department of Agriculture (USDA), Forest Service, and research at Michigan Agricultural College (now Michigan State University) planting on these cutover lands began in the early 1900s. At about the same time, the first forest tree seedling nurseries were established to provide seedlings for these planting projects. The planting of burned, cutover, and tax-reverted lands and the establishment of new seedling nurseries were accelerated by the work of the Civilian Conservation Corps in the 1930s. Today, the Forest Resources Division of the Michigan Department of Natural Resource and the USDA Forest Service, along with commercial and private forest landowners, continue the management and reforestation efforts of Michigan forests.

Introduction

Michigan is unique among all the States because it is composed of two peninsulas surrounded by four of the five Great Lakes. The State of Michigan covers 56,809 mi^2 (147,134 km^2) of land and 40,001 mi^2 (103,602 km^2) of water, of which 38,192 mi^2 (98,917 km^2) is part of the four Great Lakes that border Michigan. The geography of Michigan is quite varied. The eastern Upper Peninsula and the eastern Lower Peninsula are relatively flat, the western Lower Peninsula is somewhat rolling, and the northwestern Upper Peninsula is mountainous. The State elevations range from a low of 571 ft (174 m) at Lake Erie in the southeast Lower Peninsula to a high of 1,979 ft (174 m) at Mount Arvon in the western Upper Peninsula. The climate of Michigan is also quite varied. The southern one-third of the State has hot summers and cold winters and the northern two-thirds of the State have short, mild summers and cold to very cold winters. Some areas of northern Michigan average nearly 200 in (508 cm) of snow per year (State of Michigan 2013).

Most of the pre-European settlement land was forested, with portions of the southern Lower Peninsula in prairie and oak savanna. Today, about 50 percent of the State's land is covered with 19.3 million ac (7.8 million ha) of forest, of which 18.6 million ac (7.53 million ha) are considered capable of producing commercial timber (Pugh and others 2012). Most of the commercial timberland is in the northern two-thirds of the State, while agriculture and urban development dominate the southern one-third. Michigan's forest-related industries, recreation, and tourism supports 200,000 jobs statewide and annually contributes $121 billion to the State's economy (Michigan State University Extension 2013).

Recreation and tourism in particular are a vital part of the economy of Michigan. Michigan is a national leader in the number of licensed deer hunters and registered snowmobiles and boats. The Michigan Department of Natural Resources and the U.S. Department of Agriculture (USDA), Forest Service maintains an extensive system of hiking, skiing, snowmobile, and off-road vehicle trails. Both agencies also provide rustic and modern campgrounds throughout the State. In addition, two national lakeshores, six national wildlife refuges, and three national parks are in Michigan.

Michigan's Forests

Michigan's forests, as well as the ownership of the forest lands, are quite diverse. The forests range from those species normally associated with the central hardwoods: oak (*Quercus* spp.), elm (*Ulmus* spp.), ash (*Fraxinus* spp.), hickory (*Carya* spp.), and pine (*Pinus* spp.) in the south to more northern boreal species such as spruce (*Picea* spp.), fir (*Abies* spp.), and birch (*Betula* spp.) in the north (figure 1). The ownership of these forest lands also varies within the geographical area of the State with the southern one-third of the State being almost completely in private ownership, and the northern two-thirds in public and corporate ownership (figures 2 and 3).

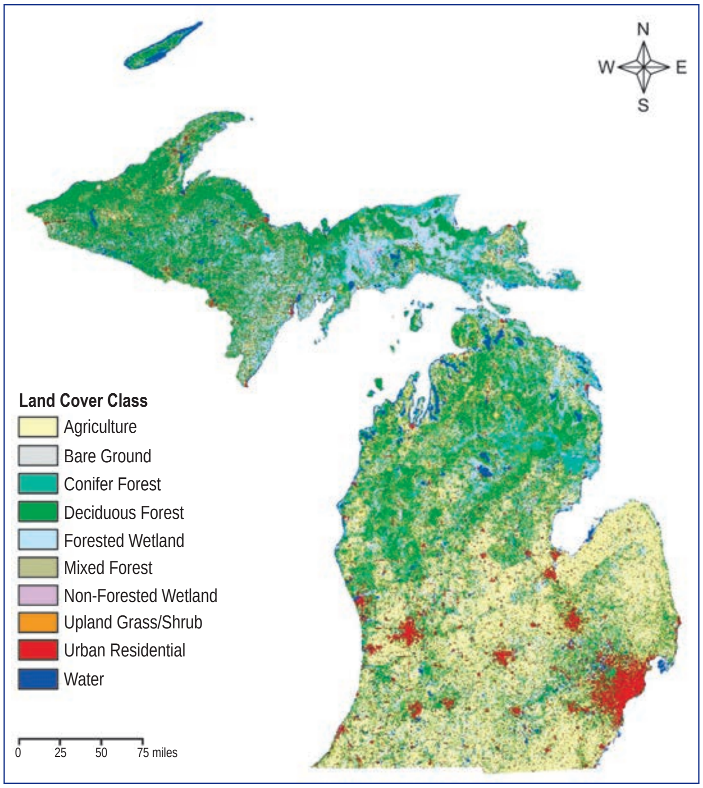

Figure 1. Michigan land cover, circa 2000. (Source: Michigan Department of Natural Resources)

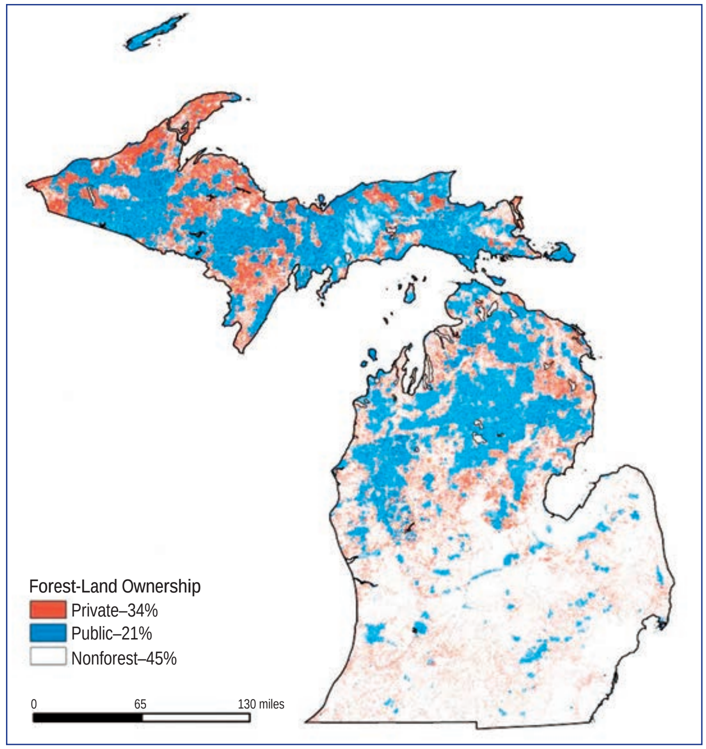

Figure 2. Forest land ownership in Michigan. (Source: Michigan Geographic Library 2010)

Forest Types

In Michigan, 14 main forest types are classified by the USDA Forest Service Forest Inventory and Analysis (FIA) program data (table 1). The most abundant is the northern hardwood type, with about 71 tree species associated with it. Sugar maple (*Acer saccharum* Marsh.) is the major species in the northern hardwood type; other major components are red maple (*Acer rubrum* L.), beech (*Fagus grandifolia* Ehrh.), yellow birch (*Betula alleghaniensis* Britton), eastern hemlock (*Tsuga canadensis* L.), and black cherry (*Prunus virginiana* L.). Elm (*Ulmus* spp.), at one time, was also a major component of this type but was virtually eliminated by the Dutch elm disease in the mid- to late 1900s. Nearly all of this forest type is regenerated by natural reproduction (Barnes and Wagner 1981).

The second most prevalent forest type is aspen. This forest type consists mainly of two species of aspen: quaking aspen (*Populus tremuloides* Michx.) and bigtooth aspen (*P. grandidentata* Michx.). Also associated with this forest type is paper birch (*Betula papyrifera* Marsh.), balsam fir (*Abies balsamea* L.), and eastern white pine (*Pinus strobus* L.). This forest type is regenerated by clearcutting and allowing the shoots to develop along the roots of the parent tree in a process known as suckering.

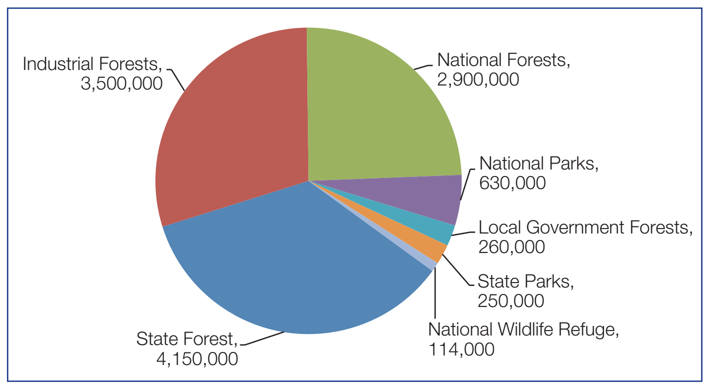

Figure 3. Forest ownership in Michigan by owner and acreage. (Source: Michigan Department of Natural Resources 2013)

Table 1. Michigan's forest types.

Forest type	Number of tree species	Acreage
Northern hardwoods	71	7,161,000
Oak/hickory	63	1,982,000
Swamp hardwoods	57	1,627,000
Aspen	50	2,676,000
Red pine	40	897,000
Northern white cedar	36	1,349,000
Paper birch	35	292,000
Balsam fir	32	563,000
White pine	32	234,000
Balm-of-Gilead	27	190,000
Jack pine	26	846,000
White spruce	25	147,000
Black spruce	22	465,000
Tamarack	22	149,000

Source: Pugh and others 2012

The two forest types that are most commonly regenerated by artificial methods are jack pine (*Pinus banksiana* Lamb.) and red pine (*P. resinosa* Ait.). In Michigan, most of the forest tree planting by acreage is of these two species. Clearcut stands of these two species are scarified and direct seeded, disc trenched and hand planted, or machine planted. For both species, the planting stock used is either a greenhouse container grown plug or a 2- to 3-year-old bareroot seedling.

History of Michigan Forests

Michigan has a long history of human interaction with its abundant natural resources. Humans first settled in the area about 10,000 years ago. When the first European explorers arrived in the early 1600s, about eight native tribes were scattered throughout the State with most being in the Lower Peninsula. Most of the native settlements were along rivers and the shores of the Great Lakes, because these waterways were the natives' major means of transportation. The first Europeans in the region were predominantly fur trappers and traders who were primarily interested in the lucrative beaver pelt trade with Europe. Exploitation of the forest resources did not begin to any large extent until the opening of the Erie Canal and the extensive settlement of Europeans in the early 1800s. The southern one-third of the State, which has the best agricultural soils and growing conditions, was deforested and settled by the middle of the 1800s. This area is still the main agricultural area. By 1880, Michigan became the leading timber producer in the country; the vast tracts of pine from the northern two-thirds of the State supplied lumber for the rapidly growing cities of the Midwest (Michigan Forest Products Council 2013).

Early Lumbering Era

Logging of eastern white pine began in Michigan in the 1850s and reached its culmination in 1890 with lumber production of 5.5 billion board feet. By 1910, eastern white pine had been mostly depleted. Lumber production dropped to a low of less than one-half billion board feet in the 1950s. This tremendous boom in timber production lasted about 100 years and is now known as the "Early Lumbering Era."

The prevailing wisdom of the Early Lumbering Era was that 'The plow will follow the axe,' meaning that the clearing of the forests also cleared the way for farming on what was anticipated to be highly productive land. Some of it was highly productive, but most did not prove to be suitable for farming. During the Early Lumbering Era, farmers tackled the task of clearing slash from cutover lands to put them into crop production. Some timber was found to be suitable for construction of homes, barns, fences, and other farm structures; the rest was burned. The practice of slash burning by farmers led to unthinkable conflagrations that destroyed homes and towns and cost the lives of many farmers and farm families. Three notable years were: (1) 1871 when 2 million ac (809,370 ha) burned and more than 200 lives were lost, (2) 1881 when 1 million ac (404,685 ha) and 282 lives were lost, and (3) 1908 when 2.4 million ac (974,245 ha) burned and 29 lives were lost (Botti and Moore 2006).

The Michigan landscape became more prairie-like than forest. As a result, prairie wildlife moved in and found a home. Prairie chickens, sharptail grouse, and coyotes were some of the species that found the new landscape to their liking. At the same time, fires continued to sweep the land, thwarting any efforts at forest regeneration, either natural or artificial. Much of northern Michigan became stump-filled grassland.

Early Reforestation Efforts

The Michigan Forestry Commission, established in 1887, conducted surveys of pine regeneration in the 1890s and found that ample numbers of young white pines were sprouting, but were inevitably wiped out by uncontrolled fires. A method of fire control was needed if reforestation efforts were to be successful.

In 1903, the Michigan Legislature dedicated about 34,000 ac (13,800 ha) of tax-reverted land as the first State forest in Michigan. The location was the area around Higgins and Houghton Lakes, in the north central Lower Peninsula. That area forms the headwaters of three major Michigan Rivers: the AuSable, the Manistee, and the Muskegon. A nursery was established at Higgins Lake. In the same year, plans began for restoring the State forest land to a productive condition. Soon after, several other State forests were dedicated throughout the northern two-thirds of the State.

The first order of business to restore the land was figuring out how to control the fires. Fire trucks and double-moldboard fireplows did not exist at this time. The answer to the fire problem was a system of fire lines that were 12 ft (3.7 m) wide, made with a horse and plow, and exposed bare sand, which is about as fireproof as anything can be. The lines were spaced 0.25 mi (0.4 km) apart in a grid pattern forming 40-ac squares (16.2 ha total) inside the grid. When a fire broke out, it would burn up to a plow line and stop. Thus, the fires were brought under control on the State forests and reforestation began. Later, lookout towers were established and specialized fire-fighting equipment was developed at the Forest Fire Experiment Station at Roscommon, near Higgins and Houghton Lakes (Mitchell and Robson 1950).

Early reforestation on State lands focused on restoration of the pine ecosystem. Early plantings took place on the old stump fields, first using hand-planting crews with the Civilian Conservation Corps (CCC) or local labor sources, and later, in the 1950s, with planting machines developed at the nearby Forest Fire Experiment Station (figure 4). Much of the land in the stump fields had become locked into heavy quack grass (*Elymus repens* L.) sod that was serious competition for young pine seedlings. The new planting machines addressed the sod issue with a double moldboard that flipped the sod both right and left as the machine was pulled through the ground. That left a strip 8 to 10 in (20 to 25 cm) wide that was sod free and allowed newly planted pine seedlings to become established before the sod moved back in.

The new planting machines created another problem, however, because the quack grass harbored thousands of white grubs, the larvae of June bugs. These grubs crawled along the slit in the ground made by the planting machine and were very efficient at eating the pine seedling roots. It was common to see flocks of blackbirds walking the furrows behind the planting machines eating the grubs that were turned up. But the birds didn't come close to getting them all; that was the next hurdle to overcome.

In the 1950s and 1960s, the insecticide Aldrin was used to control the grub damage. Spray nozzles were added to the planting machines in such a way that the planter could tap a foot pedal and deliver a squirt of Aldrin on the roots of each seedling as it was planted. This approach was effective but was discontinued by the mid-1970s when the public became concerned about the effects of persistent pesticide use.

State forest planting peaked during the CCC years, 1933 to 1942, during which time nearly 485 million trees were planted on cut-and-burned land in Michigan (Symon 1983), an incredible average of nearly 48 million trees per year. Focus was still on restoring pine to the land where it had grown so well. Planting continued in this restoration mode until about 1975, when only about 300,000 trees were planted on State lands. The pine stump fields were pretty well planted up by then, but that did not mean a need for planting no longer existed.

Recent and Current Reforestation in Michigan

State foresters had experimented with direct seeding and natural regeneration of jack pine through the 1960s and early 1970s with mixed results. Strip clearcuts initially showed promise, but insect problems, most notably jack pine budworm, prevented the young trees from growing up. Clearcutting seemed to be the most practical and effective method of regenerating jack pine. Some areas had sufficient moisture to allow for direct seeding success; other areas needed to be planted to assure success. A new era in Michigan reforestation was dawning. The State had moved from a focus on restoration to one of maintenance.

By 1970, the openings resulting from the 19th century fires were back in production and attention was turned to keeping up with the harvesting of jack pine and red pine. New

Figure 4. Tree planting in Michigan in 1955 (left) and 1962 (right) with machines developed at the Forest Fire Experiment Station. (Photos from MDNR files)

equipment was needed to plant through fresh stumps and slash. A combination of Whitfield Forestland Planters and FESCO®/Mathis Plow Company lift type v-Plows mounted on John Deere 550 bulldozers filled the bill, and the reforestation of pine lands could keep up with the harvest level. This machine-planting configuration began around 1980 and served well for about 10 years (figure 5).

In the late 1980s, foresters began to have difficulty finding part-time help to operate the rented bulldozers. So, rather than risk serious injury to planters, a transition was made to contract hand-planting crews. That planting method has proven to be reliable and effective and is still in use today.

The development and use of refrigerated vans to haul trees from the nursery and store them on the planting site allowed for better survival rates and longer planting seasons. Mead Paper Company of Escanaba led the way on this effort. The company found that they could buy used vans after a change in Wisconsin law allowed longer trailers on their highways. The older, shorter, vans could be purchased for a fraction of the price of a new van. Michigan eventually purchased seven of these used refrigerated vans for a total of about $35,000—a cost equivalent to the price of one new one. Seedlings were thus delivered to the planting site in good condition and were kept under refrigeration until the day they were planted. The result was increased survival and extension of the planting season by 3 or 4 weeks.

After a century of reforestation, both natural and artificial, Michigan's forests have rebounded from the exploitation and fires of the late 19th century. The prairie chickens have disappeared altogether, and only a few remnant flocks of sharptail grouse remain. The coyote, however, will likely be here forever. Many birds and mammals of the mature forest have returned—eagles, osprey, various warblers, fisher, pine martens, and timber wolves are finding homes in Michigan's forests once again. It's a great story of resilience and recovery of the forest resource accomplished over a century with a little help from mankind.

Tree Seedling Production in Michigan

Private Nurseries

Compared with other States, Michigan has always had a large number of private tree seedling nurseries. The major markets for these nurseries have been seedlings for the Christmas tree industry and reforestation. Over the years, the number of these nurseries has varied because of the cyclic nature of the Christmas tree market. Today, about 25 private tree seedling nurseries are in Michigan producing about 10 million seedlings per year. A large percentage of these seedlings are sold for Christmas tree production and the rest are sold for reforestation or for transplanting to grow into larger nursery stock. With 54,000 ac (22,000 ha) on 830 farms currently producing 3 million Christmas trees annually, Michigan is ranked fourth in the Nation in production. Michigan Christmas tree growers grow more species for Christmas trees than any other State. More than a dozen species of trees are currently sold for Christmas trees. Scotch pine (*Pinus sylvestris* L.) historically has been the most widely planted species. In recent years, the trend has been toward production of more true firs (*Abies* spp.); Fraser fir (*A. fraseri* Pursh), concolor fir (*A. concolor* [Gord. & Glend.]), Korean fir (*A. koreana* E.H. Wilson) and Cannan fir (*A. balsamea* var. *phaneroepis*), are now widely planted. Although true firs take longer to grow than many of the pine and spruce species, they produce a higher value product.

Figure 5. Whitfield planting machines (left and right) mounted on John Deere bulldozers were used for several years, circa 1980. (Photos from MDNR files)

Federal Nursery

The USDA Forest Service, Ottawa National Forest, operates the J.W. Toumey Nursery in Watersmeet, MI. The nursery was named after James Toumey who was a forester with the Division of Forestry (predecessor of the USDA Forest Service) and the second dean of the Yale School of Forestry. The nursery was established in 1935, and is currently the only USDA Forest Service nursery in the USDA Forest Service Eastern Region. The nursery encompasses 110 ac (44.5 ha) with 66 ac (26.7 ha) currently in production. Current annual production is approximately 4 million bareroot tree seedlings, with a total inventory of about 8 million. In addition to the bareroot seedlings, the J.W. Toumey Nursery also produces 500,000 containerized seedlings annually using two greenhouses, and also produces native grass, forb, and shrub species for distribution to the national forests in the Lakes States area. The nursery is home to the Eastern Region seed bank and provides seed cleaning, storage, and tracking for national forests in the USDA Forest Service Eastern Region.

State Nursery

The Forest Resources Division of the Michigan Department of Natural Resources (MDNR) operates the Wyman Nursery in Manistique, MI. The nursery was named for Thomas B. Wyman who trained foresters at the Wyman School of the Woods in Munising, MI, from 1908 to 1918. The USDA Forest Service constructed the nursery using CCC members in the early 1930s. The USDA Forest Service operated the nursery until 1943, when it was closed because of a lack of labor force during World War II. One of the last crops the USDA Forest Service grew at the Wyman Nursery was 23.0 ac (9.3 ha) of kok-saghyz, (*Taraxacum kok-saghyz* L.E. Rodin) commonly known as Russian or rubber dandelion. That species was grown as part of a national experiment to find domestic sources of latex for rubber for the war effort (Barnett 2005). The USDA Forest Service never reopened the nursery; they were able to meet their planting stock needs from their other two nurseries, Chittenden Nursery near Wellston, MI, and the J.W. Toumey Nursery at Watersmeet, MI.

The Michigan Department of Natural Resources acquired the Wyman Nursery in 1950 and began producing tree seedlings for planting on 4.1 million ac (1.7 million ha) of State forest lands. Since 1950, the Wyman Nursery has produced 237 million seedlings. At various times the Michigan Department of Natural Resources operated four State forest nurseries. Today, the Wyman Nursery is the only operational State forest nursery in Michigan. The Wyman Nursery currently produces from 5.0 to 7.5 million bareroot seedlings per year on about 70 ac (28.3 ha) of nursery beds (figure 6). All of the

Figure 6. Two-year-old jack pine seedlings growing at Michigan's Wyman Nursery. (Photo from MDNR file 2010)

seedlings are grown for planting on State forests, State game areas, and State parks. The main species grown at the nursery are jack pine, red pine, eastern white pine, and northern red oak (*Quercus rubra* L.) (Michigan Department of Natural Resources 1989).

Kirtland's Warbler

One of the most successful and innovative tree planting programs in Michigan during the past 40 years has been the dedication and restoration of nesting habitat for the endangered Kirtland's warbler (*Dendroica kirtlandii* S.F. Baird) (figure 7). The Kirtland's warbler is one of the rarest of the wood warbler family (Parulidae). Its nesting range is in a few areas in Wisconsin, northern Ontario, and northern Michigan. The largest nesting concentration is in a few counties in the north central Lower Peninsula. This warbler is unique in that it nests on the ground only in large dense blocks of 5- to 20-year-old jack pine. About 150,000 ac (61,000 ha) are currently on public land dedicated for Kirtland's warbler habitat in the core nesting areas. Of this acreage, 38,000 ac (15,000 ha) are intensely managed on a 50-year rotation to provide continuous nesting habitat. The Michigan Department of Natural Resources, USDA Forest Service, and the U.S. Fish and Wildlife Service plant 3 to 5 million jack pine seedlings annually to maintain this habitat. Since the Kirtland's warbler is territorial, the best way to estimate its population is by an annual singing male census, where biologists count the number of singing males in the nesting areas. Because of this intensive regeneration work in the jack pine habitat, the annual singing male census in the core nesting area has increased from fewer than 200 in 1971 to more than 1,800 male warblers in 2011 (Michigan Department of Natural Resources 2013).

Figure 7. Tree planting programs in Michigan have been dedicated to restoring habitat for the rare Kirtland's warbler. (Photo from David Kenyon, MDNR 2006)

Forest Pests and Diseases

Much of Michigan's public forest land was acquired by tax reversion. Most of this land was originally old growth red and white pine which had been clearcut to meet a burgeoning demand for lumber for projects such as rebuilding Chicago after the fire of 1871. The resulting slash fueled great fires, which reportedly burned from the shores of Lake Michigan to Lake Huron. As a result, lichens replaced the organics in many of the light soils that supported pure conifer forests. These lichens rob the soils of much of the moisture provided by low to moderate rainfalls. Thus, regenerating such sites was a challenge in doughty years. White pine blister rust spurred the CCC to hand-pull hundreds of acres of *Ribes*.

Insects like the redheaded pine sawfly took advantage of these insect stresses and stresses from vegetative completion to build damaging populations. The Saratoga spittlebug damaged both young red and jack pine where sweet-fern was associated. Where winter snow accumulation in Michigan's Upper Peninsula often exceeds 4 ft, Scleroderris canker sets both red and jack pine back until they can attain a height of 6 ft. These challenges still exist today. New challenges include Diplodia shoot blight, which prevents using natural regeneration systems for red pine. On the hardwood front, both the Emerald Ash Borer and Beech Bark Disease have greatly impacted the forests of Michigan. The diseases have led to the loss of mature ash and beech; both of these species continue to send up sprouts that have little chance of maturing. Many of these sites will require planting to increase tree species diversity and to capture the productivity of the sites once again.

Future

Exactly like the past, when Michigan residents overcame many challenges to restore the productivity of the forests, future forest productivity in Michigan faces many problems. Climate change, exotic insect and disease pests, urban expansion, and forest fragmentation are only a few of the challenges that will engage foresters and nursery managers of today and tomorrow. With dedicated university research, proper land management, continuing education, and an appreciation and knowledge of past practices, these professionals will ensure that the forests of Michigan will continue to provide timber resources, recreational opportunities, wildlife habitat, and a quality of life for all citizens of Michigan.

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Assisted Migration: What It Means to Nursery Managers and Tree Planters

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Abstract

Projections indicate that natural plant adaptation and migration may not keep pace with climate changes. This mismatch in rates will pose significant challenges for practitioners that select, grow, and outplant native tree species. Populations of native tree species planted today must be able to meet the climatic challenges they will face during this century. One strategy to meet this challenge is assisted migration, the intentional movement of plant materials in response to climate change to maximize survival and curtail maladaptation. For successful assisted migration, climate changes will need to be met by changes in ethical, legal, political, and economical paradigms, as well as with the way foresters view seed transfer guidelines. We review and explore assisted migration as an adaptation strategy, discuss the role of nurseries, present some working examples, and provide tools and resources for consultation.

Introduction

Although climate is always changing, and ecosystems have been adjusting to those changes (Davis 1990, Huntley 1991, Jansen and others 2007), the climate is now expected to change faster than trees can adapt or migrate naturally in some regions (Zhu and others 2012, Gray and Hamann 2013). As a consequence, foresters may need to assist tree species in their migration to new locations to ensure the resilience and sustainability of ecosystem services (e.g., wildlife habitat, timber production, recreation, and water and air quality) (Aubin and others 2011). Assisted migration is a complex topic rife with ethical, economical, legal, political, and ecological issues (Schwartz and others 2012); it disrupts widely held conservation objectives and paradigms (McLachlan and others 2007). Even so, assisted migration can be a viable option for some tree species and populations that are at risk of decline or extirpation under rapid changes in climate (figure 1). For a more indepth discussion, see the review by Williams and Dumroese (2013).

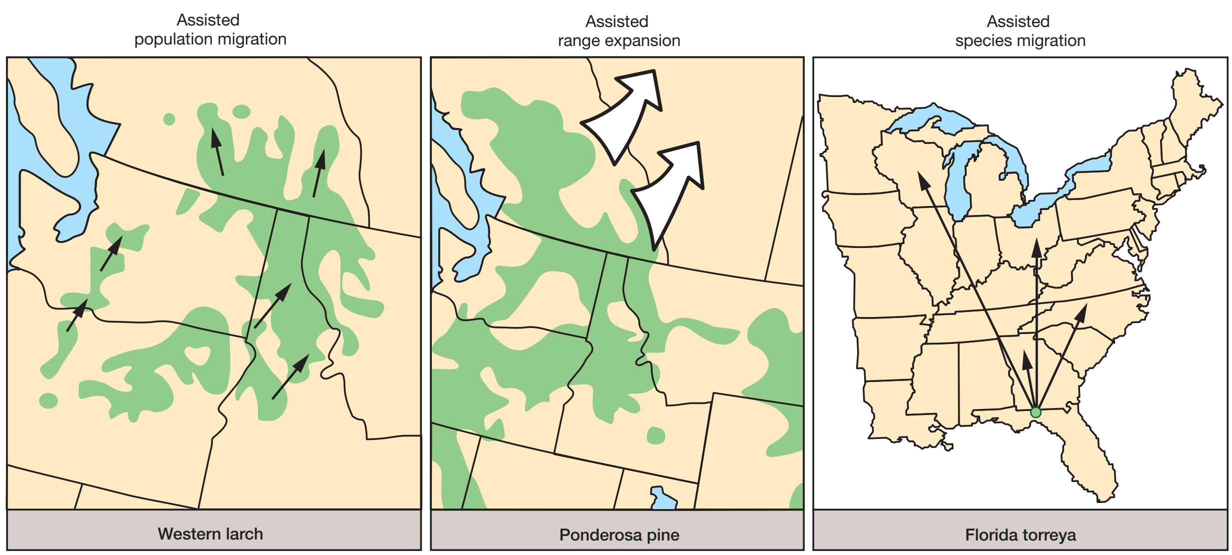

Figure 1. Seed migration can occur as assisted population migration in which seed sources are moved climatically or geographically within their current ranges (green), even across seed transfer zones; e.g., moving western larch 125 mi (200 km) north within its current range, (left). Seed sources can also be moved climatically or geographically from current ranges to suitable areas just outside the range to assist range expansion, such as moving seed sources of ponderosa pine into Alberta, Canada, (middle). For assisted species migration, species could be moved far outside current ranges to prevent extinction, such as planting Florida torreya in States north of Florida (Torreya Guardians 2008), (right). (Terms were reused from Ste-Marie and others 2011 and Winder and others 2011; distribution maps were adapted from Petrides and Petrides 1998 and Torreya Guardians 2008.)

Humans have been moving plants for a long time, and, as foresters, we have been properly moving trees by using seed transfer guidelines. Taking this process one step further, assisted migration is the intentional movement of species and populations to facilitate natural range expansion in a direct management response to climate change (figure 1) (Vitt and others 2010). Assisted migration does not necessarily mean moving plants far distances, but rather helping genotypes, seed sources, and tree populations move with suitable climatic conditions to avoid maladaptation (Williams and Dumroese 2013), which will probably entail moving seed across current seed-zone boundaries or beyond transfer guidelines (Ledig and Kitzmiller 1992). Thus, seed transfer guidelines will need to factor in climate change because using current guidelines and zones will likely result in native trees or their populations facing unfavorable growing conditions by the end of this century.

What Is the Role of Nurseries?

Nursery managers have an important role in the assisted migration process. It is unfortunate that most State and commercial nurseries in the United States have not yet explored how changes in climate will impact their operations (Tepe and Meretsky 2011). As part of the target plant concept (Landis and others 2010), however, nursery managers should see themselves in partnerships with land managers, foresters, and restorationists, and work with stakeholders to provide appropriate plant materials (i.e., seed, nursery stock, or genetic material). The matching of existing plant materials with future ecosystems that will have different climate conditions is a formidable component of assisted migration (Pedlar and others 2011, Potter and Hargrove 2012). Foresters and nursery managers will need to rethink the selection, production, and outplanting of native trees in a dynamic context. That is, they will need to reevaluate the practice of restricting tree movement to environments similar to the tree's source, a long-held practice in forest management (Langlet 1971). Nurseries can work with geneticists to explore genotypes that may be resilient to extreme temperature and moisture conditions. Using disturbed areas as outplanting sites to test assisted migration is a perfect opportunity to also evaluate genotypes, seed mix diversity, and age classes (Spittlehouse and Stewart 2003, Millar and others 2007, Jones and Monaco 2009).

Many existing provenance and common garden studies can be transformed with little modification to look at adaptation and response to climatic conditions (Matyas 1994), thereby shifting our focus to producing plant materials that grow and survive well in changing climates. Information such as where the plant comes from, where it is planted geographically, and how it performs (growth, survival, reproduction, etc.) can guide forestry practices to increase the proportion of species that thrive under new climatic conditions (McKay and others 2005, Millar and others 2007, Hebda 2008). Changing policies will require collaboration and discussion of how predicted conditions will affect forests, how nurseries can plan for the future, and how clients can be encouraged to plant trees adapted to future conditions, such as warmer temperatures and variable precipitation patterns (Tepe and Meretsky 2011). It is fortunate that many State and commercial nurseries, especially in the eastern half of the United States, already carry tree species and seed sources collected from sites farther south (often beyond State borders) than the anticipated outplanting sites, which suggests that plant materials being planted now may be adapted to warmer conditions.

Assisted Migration in Action

Assisted migration will be best implemented where seed transfer guidelines and zones are currently in place and most successful if based on anticipated climate conditions (McKenney and others 2009) because these data can be used to ensure that trees being established today will be adapted to future climates (Pedlar and others 2012). Researchers are working to better understand how to use assisted migration. One project is the Assisted Migration Adaptation Trial that consists of several long-term experiments being conducted by the British Columbia (B.C.) Ministry of Forests, the USDA Forest Service, timber companies, and other partners. The experiments test assisted migration, climate change, and tree performance in B.C. and the Pacific Northwest region (table 1) (Marris 2009). Douglas-fir (*Pseudotsuga menziesii* Mirb. Franco) has also been planted around the Pacific Northwest region to evaluate its growth response to climatic variation (Erickson and others 2012). To test species range limits in Quebec, Canada, northern sites are being planted with a mixture of seed sources from the southern portion of the province.

Preliminary research on most commercial tree species in Canada demonstrates that target migration distances would be short, occurring within current ranges of those species (O'Neill and others 2008, Gray and others 2011). For some tree species, target migration distances are less than 125 mi (less than 200 km) north or less than 328 ft (less than 100 m) up in elevation during the next 20 to 50 years (Beaulieu and Rainville 2005, O'Neill and others 2008, Pedlar and others 2012, Gray and Hamann 2013). Several Canadian provinces subsequently have modified seed transfer policies to be more dynamic and in conjunction with climate change. Alberta has extended current seed transfer guidelines northward by 2° latitude and upslope by 656 ft (200 m) (NRC 2013) and new guidelines for some species were revised upslope by 656 ft (200 m) in B.C. (O'Neill and others 2008). Also in B.C., western larch (*Larix occidentalis* Nutt.) may now be moved to suitable climatic locations just outside its current range (NRC 2013). In a similar vein, foresters in the Southern United States have been moving seed sources of southern pines one seed zone north to take advantage of changes in climate (Schmidtling 2001). Assisted species migration is being used to save Florida torreya (*Torreya taxifolia* Arn.), a rare Southeastern United States evergreen conifer, from extinction (McLachlan and others 2007, Barlow 2011).

Table 1. Resources related to forest management, native plant transfer guidelines, climate change, and assisted migration for the United States and Canada. Most programs are easily located by searching their names in common Web browsers. All URLs were valid as of October 15, 2013. Reprinted from Williams and Dumroese (2013).

Resource or program	Description	Authorship
Assisted Migration Adaptation Trial http://www.for.gov.bc.ca/hre/forgen/interior/AMAT.htm	Large, long-term project to evaluate the response of 15 tree species to climate change and assisted migration	Ministry of Forest and Range, British Columbia
Center for Forest Provenance Data http://cenforgen.forestry.oregonstate.edu/index.php	Online database where public users can submit and retrieve tree provenance and genecological data	Oregon State University and USDA Forest Service
Centre for Forest Conservation Genetics http://www.genetics.forestry.ubc.ca/cfcg/	Portal for forest genetics and climate change research conducted in British Columbia, Canada	The University of British Columbia
Climate Change Response Framework http://climateframework.org/	Collaborative framework among scientists, managers, and landowners to incorporate climate change into management	Northern Institute of Applied Climate Science
Climate Change Tree Atlas http://www.nrs.fs.fed.us/atlas/tree/tree_atlas.html	An interactive database that maps current (2000) and potential status (2100) of Eastern U.S. tree species under different climate change scenarios	USDA Forest Service
Forest Seedling Network http://www.forestseedlingnetwork.com	Interactive Web site connecting forest landowners with seedling providers and forest management services and contractors; includes seed zone maps	Forest Seedling Network
Forest Tree Genetic Risk Assessment System (ForGRAS) http://www.forestthreats.org/research/projects/project-summaries/assessing-forest-tree-risk	Tool to identify tree species risk of genetic degradation in the Pacific Northwest and Southeast Regions	North Carolina State University and USDA Forest Service
MaxEnt (Maximum Entropy) http://www.cs.princeton.edu/~schapire/maxent/	Software that uses species occurrences and environmental and climate data to map potential habitat; can be used to develop seed collection areas	Phillips and others (2006)
Native Seed Network http://www.nativeseednetwork.org/	Interactive database of native plant and seed information and guidelines for restoration, native plant propagation, and native seed procurement by ecoregion	Institute for Applied Ecology
Seed Zone Mapper http://www.fs.fed.us/wwetac/threat_map/SeedZones_Intro.html	An interactive seed zone map of western North America that displays political and agency boundaries, topography, relief, streets, threats, and resource layers and where user selects areas to identify provisional and empirical seed zones for grasses, forbs, shrubs, and conifers	USDA Forest Service
Seedlot Selection Tool http://sst.forestry.oregonstate.edu/index.html	An interactive mapping tool to help forest managers match seedlots with outplanting sites based on current climate or future climate change scenarios; maps current or future climates defined by temperature and precipitation	Oregon State University and USDA Forest Service
SeedWhere https://glfc.cfsnet.nfis.org/mapserver/seedwhere/seedwhere-about.php?lang=e	GIS tool to assist nursery stock and seed transfer decisions for forest restoration projects in Canada and the Great Lakes region; can identify geographic similarities between seed sources and outplanting sites	Natural Resources Canada, Canadian Forest Service
System for Assessing Species Vulnerability (SAVS) http://www.fs.fed.us/rm/grassland-shrubland-desert/products/species-vulnerability/	Software that identifies the relative vulnerability or resilience of vertebrate species to climate change; provides a framework for integrating new information into climate change assessments	USDA Forest Service

GIS = geographic information system. USDA = U.S. Department of Agriculture.

New Tools for Determining Proper Seed Transfer

Target migration distances are needed for short- and long-term planning efforts and will require adjustments as new climate change information comes to light. To guide seed movement under climate change, methods using transfer functions and provenance data have been developed (e.g., Beaulieu and Rainville 2005, Wang and others 2006, Crowe and Parker 2008; Thomson and others 2010, Ukrainetz and others 2011). Projected seed zones have been developed for a variety of trees, including commercial species such as quaking aspen (*Populus tremuloides* Michx.) (Gray and others 2011); lodgepole pine (*Pinus contorta* [Douglas ex Loudon]) (Wang and others 2006), longleaf pine (*P. palustris* Mill.) (Potter and Hargrove 2012), and whitebark pine (*P. albicaulis* Engelm.) (McLane and Aitken 2012); western larch (Rehfeldt and Jaquish 2010); and noncommercial species such as flowering dogwood (*Cornus florida* L.) (Potter and Hargrove 2012).

Canada and the United States have online tools to assist forest managers and researchers in making decisions about matching seedlots with outplanting sites. For Quebec, Optisource (Beaulieu 2009) and BioSim (Regniere and Saint-Amant 2008) are useful tools. In Ontario, SeedWhere can map potential seed collection or outplanting sites based on climatic similarity of chosen sites to a region of interest (McKenney and others 1999). In the United States, the Seedlot Selection Tool (Howe and others 2009) is a mapping tool that matches seedlots with outplanting sites based on current or future climates for tree species such as Douglas-fir and ponderosa pine (*Pinus ponderosa* Lawson & C. Lawson). Because of the lack of seed transfer guidelines and zones for noncommercial tree species, the best we can do currently is consult provisional seed zones (e.g., Seed Zone Mapper—table 1) developed from temperature and precipitation data and Omernik level III and IV ecoregion boundaries (Omernik 1987).

Final Remarks

Climate change poses a substantial challenge for foresters, but given their long history of selecting and growing trees, the forestry profession has the knowledge, skills, and tools to test and implement assisted migration. Researchers, foresters, and nursery managers can work together to begin discussing and implementing climate change adaptation strategies, such as assisted migration, and hopefully curtail significant social, economic, and ecological losses associated with impacts from a rapidly changing climate. Whatever the chosen adaptive strategies may entail, forest and conservation nurseries need to be included in the dialogue for climate change planning because this collaboration is key to successfully producing native trees to sustain future ecosystems (McKay and others 2005).

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Strategies for Establishing Ponderosa Pine Seedlings in a Repeatedly Grazed Area of the Navajo Forest in Arizona—20-Year Results

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Abstract

Reforestation in some areas of the Navajo forest is challenging because of intense grazing and vegetative competition. A study was initiated in 1989 to determine if disking the site to alleviate competition, planting ponderosa pine seedlings, and installing fencing for 10 years to exclude livestock would result in acceptable stocking. After 20 years, 36 percent of trees had survived and were growing at an acceptable rate for the low-moisture site conditions. This approach met the goal of establishing an understory stand before harvesting the overmature overstory trees. Furthermore, exclusion of livestock allowed for seedlings to become tall enough to reduce the risk of grazing damage when the area was reopened to grazing. In fact, reintroduction of livestock after 10 years resulted in reduced vegetative competition with no apparent effect on seedling growth or survival.

Introduction

The Navajo forest is located in the Chuska Mountains and on the Defiance Plateau of the Navajo Nation along the Arizona—New Mexico border (Navajo Forestry Department 2005). Nearly all (95 percent) of the Navajo forest is ponderosa pine (*Pinus ponderosa* Lawson & C. Lawson). Annual precipitation averages 20 to 25 in (50 to 64 cm) and occurs as rain in July, August, and September and snow from December through March (Navajo Forestry Department 1982).

Forest regeneration on the Navajo forest can be severely hampered by grazing. Grazing, particularly by sheep, leaves a near continuous impact on the landscape (Shepperd and others 2006). Sheep husbandry is a means of subsistence for some local people who are granted grazing permits by the U.S. Department of the Interior, Bureau of Indian Affairs (Weisiger and Cronon 2011). The permit holder is thus entitled to the grazing use of a certain area. The boundaries of the use area, however, are not always rigidly regulated or adhered to; as a result, more livestock are often grazing in some forested areas than were originally permitted, making the grazing pressure on the land very severe.

Grazing damage to planted and naturally regenerated seedlings can be reduced if reductions are made both in the number of sheep and in the length of the grazing season (Pearson 1933); but the pattern of relentless grazing in some areas of the Navajo forest has led to destruction of natural regeneration for decades. Conifer seedlings can be frail, brittle, and watery after germination (Baker 1950). Even if an occasional seedling starts to get established in a favorable spot, the sheep and goats graze it to the ground in its most vulnerable stage after germination.

Sheep should be excluded from areas on which it is desired to secure reproduction until the seedlings have become firmly established and are out of danger from browsing (Pearson 1910). Mexal and others (2008) recorded the major cause of mortality to conifer seedlings to be goats in unprotected plantations. Removing sheep from the area, however, does not set well with the people, and attempts at livestock reduction on the Navajo Reservation have always met with resistance (Roessel and Johnson 1974). Livestock operations particularly those of sheep in the Navajo forest will continue. Both market and subsistence value are involved in these operations; sheep are used for food, for ceremonies, to pay healers, and for wool (Iverson 2002).

In addition to grazing pressure, competing vegetation is a challenge to successful forest regeneration (Pearson 1942, Heidmann 2008). In many areas, seed from overstory trees cannot reach mineral soil to get established because of a thick cover of Mountain muhly (*Muhlenbergia montana* [Nutt.] Hitchc.), a grass with low palatability that develops into a sod-like mat. We have observed germinated seedlings with long exposed roots lying in the grass and ultimately drying in place. Macdonald and Fiddler (1989) point out that, competing vegetation causes a lack of initial resources available to conifer seedlings, low food production, decreased exploitation of soil, poor growth and, in many cases, death. Proper site preparation can increase the success of direct seeding and planting (Shepperd and Battaglia 2002). Planting success has been best on areas receiving complete site preparation

(Schubert and Adams 1971). Tree planting on sites where competing vegetation has not been killed or removed is not recommended (Heidmann 2008). Several researchers have noted increased survival and growth of pine following control of plant competition (Derr and Mann 1971, Malac and Brightwell 1973).

Because of grazing and competing vegetation, foresters are concerned that some stands in the Navajo forest might not regenerate in the foreseeable future. This condition has been observed elsewhere, where cutover stands failed to restock adequately after 50 or more years (Schubert and Adams 1971). The goal of our project was to restock the understory of a particularly vulnerable stand with ponderosa pine seedlings by planting and fencing the area off for 10 years, after which the plantation would be reopened to grazing by removing the fence.

Materials and Methods

Site Description

This study was conducted on 140 ac (57 ha) in stand 31 of compartment 19 in the Navajo forest, located on the Defiance Plateau, near the community of Sawmill, AZ. Stand 31 is on the east side of the compartment and is part of a 2,200-ac (890-ha) area that has been regenerated by planting because of inadequate natural regeneration. The stand was park like with an overstory of ponderosa pine and no natural reproduction in the understory with the exception of three small (less than 1.0 ac [0.4 ha] each), widely dispersed patches of natural reproduction. The ponderosa pines, both overmature and younger trees, existed primarily as a single story (figure 1). Such park-like stands have been reported in the Southwestern United States by several authors (Woolsey 1911, Pearson 1950, Heidmann 2008). The site index of the stand is 82 (Minor 1964).

The stand was harvested in the 1950s and again in 1987 using the shelterwood seed-cut method. Sheep, goats, and other domestic livestock heavily grazed the stand for several decades. Several sheep camps and stock ponds are in compartment 19; grazing is continuous for 8 months of the year. Stand 31 is very close to the sheep camps and, like other adjacent stands, is consequently more heavily grazed by sheep and goats on their way to, and from, livestock corrals. One family had 300 sheep grazing the area in the 1960s (personal communication with local land users), although the numbers are considerably less at the present time. Natural regeneration has not occurred to restock the stand since the 1950s, in spite of several mild cone crops.

Figure 1. Overmature trees like those pictured here dominated the stand in a park-like setting before planting. (Photo by Amanullah K. Arbab and Leonard C. Lansing)

The predominant ground cover in the stand was Mountain muhly (figure 2). Livestock grazing tends to shift plant species composition in the understory to those of lower palatability (Houston 1954). The next grass of significant quantity is Arizona fescue (*Festuca arizonica* Vasey), which seems to be more palatable as evidenced by its heavier use by livestock. Other plants in the stand are big sagebrush (*Artemisia tridentata* Nutt.), blue grama (*Bouteloua gracilis* [Willd. ex Kunth] Lag. ex Griffiths), pine dropseed (*Blepharoneuron tricholepis* [Torr.] Nash), paintbrush (*Castilleja austromontana* Standl. & Blumer), larkspur (*Delphinium nuttallianum* Pritz. ex Walp.), squirreltail (*Elymus elymoides* [Raf.] Swezey), wild buckwheat (*Eriogonum alatum* Torr.), snakeweed (*Gutierrezia sarothrae* [Pursh.] Britton & Rusby), pingue rubberweed (*Hymenoxys richardsonii* [Hook.] Cockerell), one-seeded juniper (*Juniperus monosperma* [Engelm.] Sarg.), lupine (*Lupinus argenteus* Pursh), aster (*Machaeranthera canescens* [Pursh] A. Gray), creeping barberry (*Mahonia repens* [Lindl.] G. Don), Navajo tea (*Thelesperma subnudum* A. Gray), owl's-clover (*Orthocarpus purpureoalbus A. Gray ex S. Watson*), pinyon pine (*Pinus edulis* Engelm.), muttongrass (*Poa fendleriana* [Steud.] Vasey), and deathcamas (*Zigadenus elegans* Pursh).

Site Preparation

Logging slash was piled and removed. In the fall of 1989, the entire stand was disked with a Towner off-set disk pulled by a D-7 Caterpillar crawler tractor. The disk had two rows of six notched blades, each 38.0 in (96.5 cm) in diameter and 0.63 in (1.6 cm) thick. Disking with the offset disk can control most grasses, forbs, and nonsprouting shrubs (Stevens and Monsen 2004). Mountain muhly and other vegetation were uprooted and the mineral soil was exposed. Disking penetrated the soil to a depth of 10 to 18 in (25 to 46 cm) resulting in most seed of competing vegetation buried too far below the surface to be available for immediate germination. Approximately 70 percent of the ground was disked at a cost of $34 per ac ($84 per ha).

Fencing To Protect Planted Seedlings

Fencing of the study area after planting seemed a desirable alternative provided that people using the area agreed to it. As Weisiger and Cronon (2011) caution: "Without listening to those who are most affected and live in intimate contact with the land, things can go wrong." The grazing permit holders

Figure 2. Mountain muhly forms a sod-like ground cover. (Photo by Amanullah K. Arbab and Leonard C. Lansing)

of stand 31 were contacted and the need for setting aside the land for reforestation was explained to them. Through this contact, we were able to obtain their written consent for the project. A five-strand, barbed wire fence was constructed around the stand at a cost of $1,800 per mi ($1,118 per km).

Livestock owners tend not to reduce herd size or discontinue grazing without compensation of some kind (Maroney 2006). An agreement was made with the land users that they would be compensated with hay for as long as the fence was up and livestock access to the stand disallowed. Compensation was based on one-half of the 176 lb per ac (197 kg per ha) of palatable forage that the land produced. Based on the proper use of "leave half, use half" for 6 months, livestock owners were compensated with 6,778 lb (3,070 kg) of hay per year for the entire stand. Compensation continued for 10 years, at which time the fence was dismantled and the area was reopened for livestock grazing.

Planting Seedlings

Ponderosa pine seedlings were grown in the Navajo greenhouses from a local seed source for 14 weeks in 21.5-in^3 (350-cm^3) Spencer-Lemaire Rootrainer® containers and then moved to the lath house to harden off and overwinter. Seedlings were outplanted on the fenced and disked stand April 4 through May 7, 1990. At the time of planting, the average seedling was 5 in (13 cm) tall with a root collar diameter of 0.19 in (4.8 mm) and a dormant bud.

Seedlings were shovel planted at a density of 524 seedlings per ac (1,294 seedlings per ha). The planting cost was $135 per ac ($333 per ha), not including the cost of seedlings. Planting was accomplished by digging a 10-in (25-cm) deep hole, placing the seedling in the hole, putting moist soil back in the hole up to the root collar, and tamping the soil around the seedlings. Planters attempted to stay as close to 9 ft by 9 ft (2.7 m by 2.7 m) spacing as possible. Most of the uprooted and ripped vegetation was dead and dry at the time of planting.

Measurements

After planting, 140 permanent circular plots were installed for monitoring growth, survival, animal and insect damage, and causes of mortality. Each plot was 1/100 ac (40.5 m^2). Diagrams of permanent plots were drawn and locations of planted seedlings on each plot were marked on a plot sheet. Survival and growth measurements were conducted 8 times beginning in 1991 and ending in 2010. Heights were measured from ground level to the top of the uppermost bud. Root collar diameters were measured as close to the ground as possible. Height and diameter measurements were taken regardless of whether the seedlings were intact or damaged. Only seven survival data are reported here. Growth for the 10th year (after which fencing was removed) was not recorded but was estimated based on the average of the previous 9 years.

Results And Discussion

Competing Vegetation

Mountain muhly and other vegetation started colonizing the stand during the year after planting. Six years after planting, the Mountain muhly cover was nearly as thick as it had been before disking. Pinedrop seed, rarely observed before disking, became more prevalent. The squirreltail population also had a marked increase. Buckbrush (*Ceanothus fendleri* A. Gray), goldenrod (*Solidago* spp.), and stickseed (*Lappula* spp.) came into the site as new invaders in the flora and gradually declined with time.

After 10 years, during which time planted seedlings were not subject to damage by sheep, seedlings averaged 3.5-ft (1.1-m) tall and survival was 42 percent (table 1). When the fence was removed, the rest period had resulted in the volume of grass cover and other vegetation being greater than the adjoining untreated stands. The fence removal had the obvious effect of attracting more livestock to the plantation and resulted in reducing vegetative competition to the planted seedlings without any apparent harm to the reforestation effort.

Table 1. Percent survival of planted seedlings over time.

Year	Percent survival
1991	77
1992	63
1994	52
1999	42
2008	36
2009	36
2010	36

Seedling Survival

Survival after the first year was high, gradually declining until stabilizing at 36 percent when the seedlings were 18 years old (table 1). Because sheep, goats, and other livestock were completely excluded from the plantation for 10 years, the 64 percent mortality on the site was caused by other factors. Drought and unknown causes were the major factors (59.4 percent mortality). Drought has been recognized as the major cause of mortality of planted containerized ponderosa pine seedlings (Heidmann and Haase 1989). The unknown causes may include improper planting, planting on undisked sites, or planting where too much competition exists. Rabbits damaged 44 seedlings, 23 of which ultimately died (contributing 3.1 percent of the mortality). Rabbits cut the seedlings and left them in place without consuming them for food. Trees that were damaged by rabbits but survived were shorter and less vigorous. Porcupine damaged 42 seedlings, 12 of which died (accounting for 1.6 percent of the mortality). Porcupine-damaged trees that survived had various deformities (figure 3). Damage by porcupine occurred in the first 4 to 5 years when the understory of planted seedlings was getting established and ceased later on. No porcupine damage is currently reported.

No more trees were lost to drought or rodents after year 18, although minor tip moth damage was observed. In the stand are 187 surviving trees per acre in various stages of development. Visually the distribution of planted trees, interspersed between the overmature trees of the overstory looks relatively uniform (figure 4).

Seedling Growth

Average heights and root collar diameter of 265 surviving seedlings on 140 permanent plots are shown in figure 5. Considerable variation exists in the height and root collar diameter of individual trees on the plots (figure 6). Nearly 70 percent of the planted seedlings had root collar diameters between 1.8 and 4.8 in (4.5 and 12.1 cm) and heights between 3 and 16 ft (0.9 and 4.9 m), while 23 percent had root collar diameters between 5 and 7 in (12.7 and 17.8 cm) and heights between 9.0 and 17.7 ft (2.7 and 5.4 m) and 8 percent have root collar diameters between 0.5 and 1.5 in (1.3 and 3.8 cm) and heights between 1 and 4 ft (0.3 and 1.2 m). Overall

Figure 3. Most porcupine-damaged trees had a pronounced crook at the point of injury above which the tree ultimately resumed normal growth (top). Some porcupine damage resulted in two stems developing on the tree (bottom). (Photos by Amanullah K. Arbab and Leonard C. Lansing)

Figure 4. After 20 years, the plantation is evenly stocked with ponderosa pine saplings (top), some of which have established beneath overmature trees (bottom). (Photos by Amanullah K. Arbab and Leonard C. Lansing)

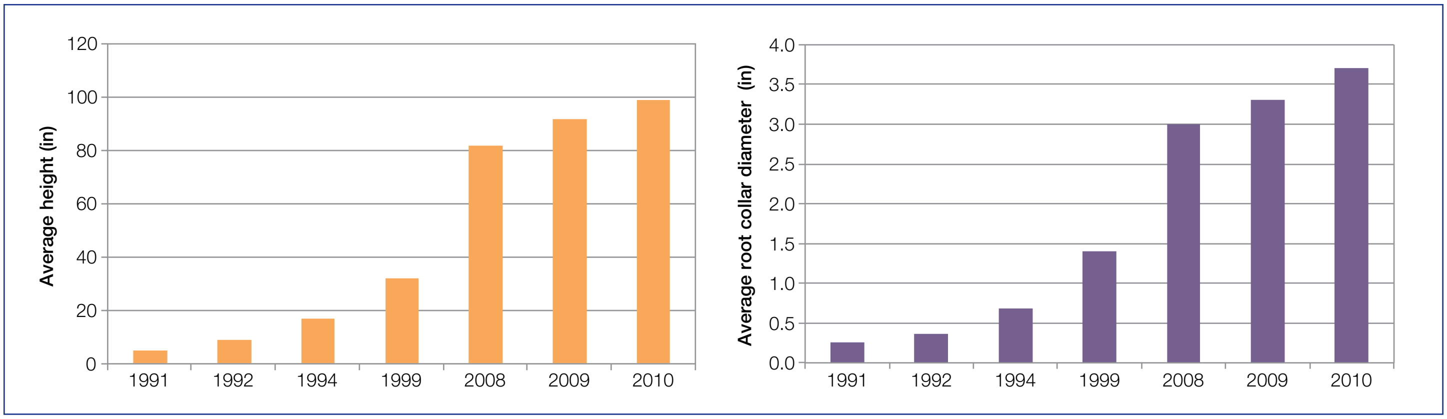

Figure 5. Average height (left) and root collar diameter (right) of surviving planted seedlings over time.

Figure 6. After 20 years, planted seedling height and diameter varied considerably. For example, the tree on the left is only 11 in (28 cm) tall with a 0.5 in (4.7 mm) root collar diameter, while the tree on the right is 17.7 ft (5.4 m) tall with a 7-in (18-cm) root collar diameter. (Photos by Amanullah K. Arbab and Leonard C. Lansing)

average after 20 years is 8.3 ft (2.5 m) in height and 4 in (10.2 cm) in diameter. This variation will have implications in the future management and harvest of the stand.

In an Arizona study of 45-year-old ponderosa pine trees, average diameter at breast height was 7.8 in (19.8 cm) with a range of values from 0.5 to 14.3 in (1.3 to 36.3 cm) (Ffolliott and others 2006). Root collar diameter measurements taken at the base of the tree and those taken at breast height cannot be compared, but the similarity in growth values between the two studies seems to be apparent.

Average root collar diameter in this study increased by 0.4 in (1 cm) and the average height increased by 7 in (17.8 cm) from 2009 to 2010. The growth rate is likely to be greater in the future. Even if the same growth rate continues, the average root collar diameter and average height in the stand will reach 5.6 in (14.2 cm) and 10.5 ft (3.2 m), respectively, in another 4 years when the trees are 24 years old.

Conclusions

Severely grazed, single-story, overmature ponderosa pine stands can be regenerated with containerized seedlings grown from locally collected seed. Fencing to exclude livestock, particularly sheep and goats, for a 10-year period is recommended. Because most grazing occurs at ground level, 10-year-old seedlings are sufficiently tall to be safe from grazing animals. On sites with low annual precipitation, such as the one described in this study, at least 500 seedlings need to be planted to get an appreciable number of surviving trees in the understory for future harvest.

Natural regeneration in normal years is a slow, sporadic process and its success depends on a number of favorable factors coming together at the same time. During the 20-year study period on this site, only 40 naturally regenerated seedlings were encountered on the 140 monitoring plots. This very small number is inadequate to restock the stand if natural regeneration is solely relied upon when prompt restocking is required. Adequate natural regeneration would have occurred ultimately at some distant future date, if time was of no consequence. By planting the stand, however, the goal of establishing an understory before the next harvest has been accomplished.

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Direct Seeding Southern Pines: Development of Techniques, Use, and Current Status

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Abstract

The "golden-age of lumbering" of the early 20th century left millions of acres of forest land in need of reforestation. Forests of the western Gulf Coast States of the South were especially decimated because of the development and use of steam-powered logging equipment. Faced with this reforestation need, scientists of the Southern Forest Experiment Station began an effort to develop direct seeding as a regeneration option. The key to successful direct seeding was found to be protecting seed from bird and rodent predation. Increasing the quantity and quality of pine seeds, controlling hardwood competition, and developing appropriate site preparation treatments were also important for successful direct seeding. The seeding technology resulted in successful restoration of millions of acres of southern pine forests. Direct seeding, however, is now infrequently used primarily because of the lack of large, open areas needing reforestation. This article includes an historical overview of direct seeding in the South as well as guidelines for current use of this reforestation technique.

The Need for Reforestation in the South

Much of the 90 million ac (36 million ha) of longleaf pine (*Pinus palustris* Mill.) throughout the coastal plain of the South were harvested by aggressive logging in the late 1800s and early 1900s. The longleaf forests of the West Gulf Coastal Plain were particularly devastated by the use of steam-powered logging equipment that was developed to harvest forests of the region (figure 1).

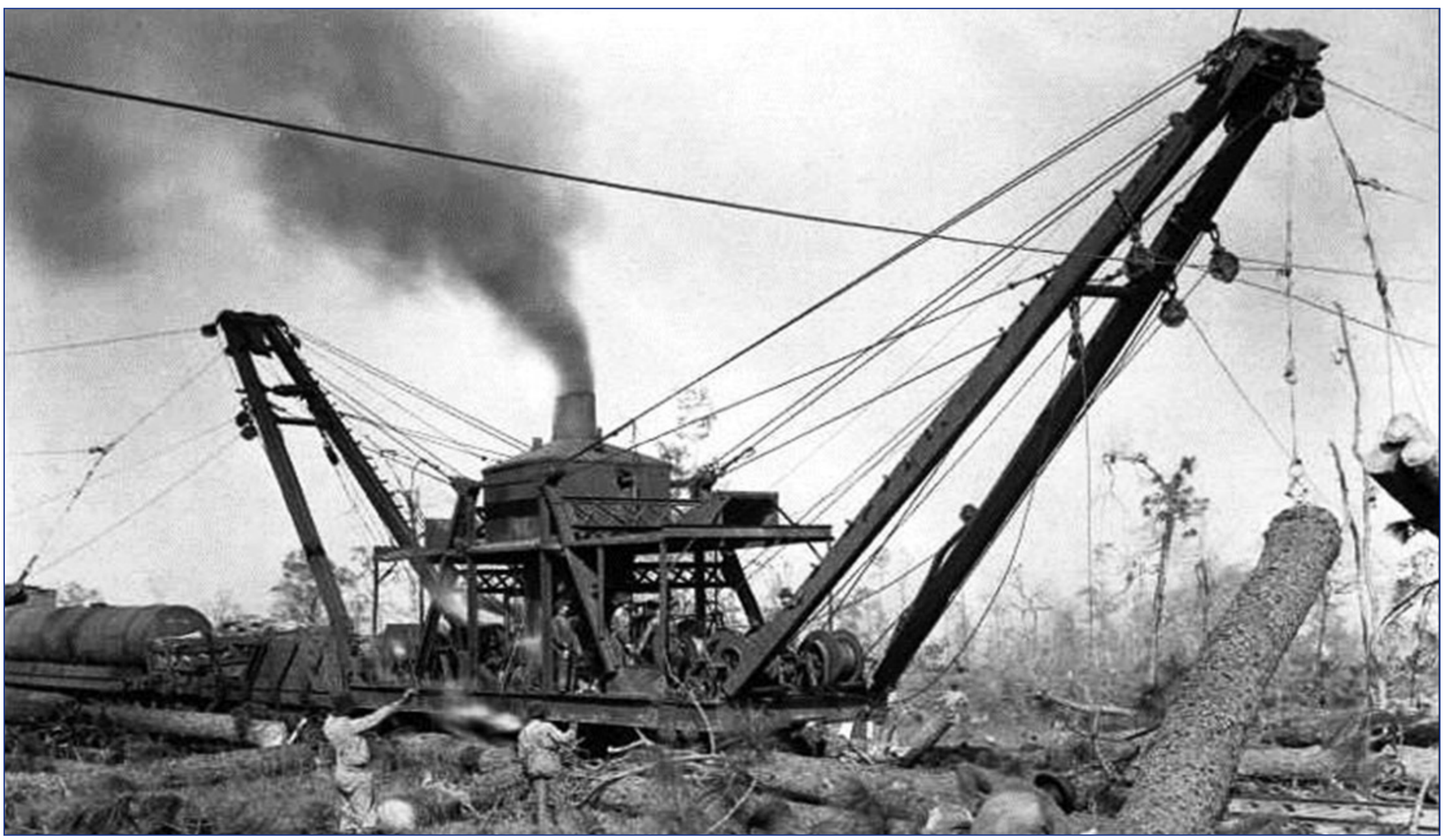

Figure 1. Steam-powered skidders manufactured by the Clyde Ironworks in Duluth, MN, greatly increased logging capability in the early 1900s. With one setting of the skidder, 40 ac (16 ha) of timber could by skidded to the railroad track for loading on train cars. (Photo from USDA Forest Service files circa 1930)

In the late 1940s and early 1950s, foresters in the South were faced with a huge reforestation problem—millions of acres of forest land clearcut in the early 1900s remained desolate and nonproductive. Much of this land was previously occupied with mature stands of longleaf pine, but the harvest was so complete that no seed sources remained to provide for natural regeneration. Planting of longleaf pine was then unreliable.

In 1954, it was estimated that about 13 million ac (5 million ha) were in need of reforestation across the South (Wakeley 1954). When the Southern Forest Experiment Station established the Alexandria Research Center in central Louisiana in 1946, the territory served by the research center covered more than 7 million ac (2.8 million ha) in western Louisiana and eastern Texas. Nearly 80 percent was commercial forest land and nearly one-half of this once supported magnificent stands of old-growth longleaf pine. More than 20 percent of the longleaf pine land was barren of pines, and another 50 percent was below its full potential because it was largely covered by grasses, scrub oaks, and other low-value hardwoods (Cassidy and Mann 1954) (figure 2).

It was estimated that if the treeless longleaf pine land in Louisiana and Texas was reforested by planting nursery-grown seedlings, the task would take 50 or more years at the rate feasible with the then-current nursery capability (Cassidy and Mann 1954). A significant need existed to develop additional technology to meet this huge reforestation need. Although expanding bareroot nursery production was an obvious goal, another option considered to speed the process was to develop direct seed capability.

Early Seeding Attempts

For generations, direct seeding had been considered a potential forest regeneration technique. Sowing of tree seeds on prepared

Figure 2. This area became part of the Palustris Experimental Forest and represented millions of acres of cutover forests across the South. (Photo from USDA Forest Service files 1950)

soils was often tried and was sometimes met with success. In 1920, the Great Southern Lumber Company of Bogalusa, LA, hand sowed slash pine (*Pinus elliottii* Engelm.) on furrows plowed by teams of mules (Barnett 2011) (figure 3). An 800-ac (314-ha) tract was successfully regenerated and is considered the first commercial direct seeding in the United States (figure 4). Great Southern Lumber Company's head ranger, F.O. (Red) Bateman, was responsible for the seeding operation. Other seeding trials, however, were not successful and Bateman later described direct seeding as generally unsuccessful because of seed losses from bird predation (Wakeley 1976).

Development of Bird and Rodent Repellents

The mission of the Alexandria Research Center was to develop improved methods of reforesting and managing forest land. Research in direct seeding began because it was seen as (1) fast and requiring minimal labor, (2) inexpensive, (3) a method to create dense stands that were particularly good for longleaf pine, and (4) an approach that could be expanded quickly to take advantage of bumper cone crops since storage of longleaf pine seeds was then problematical (Derr 1958).

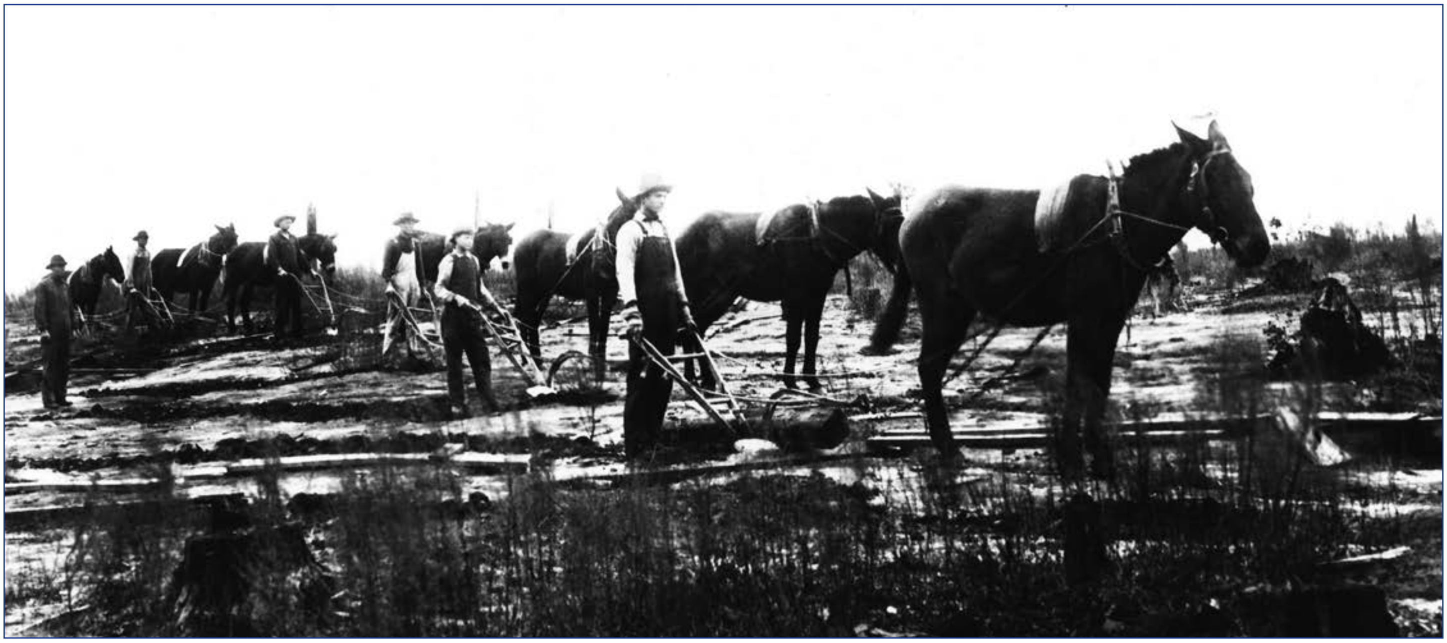

Figure 3. In 1920, the Great Southern Lumber Company reforestation efforts began with this direct seeding of slash pine on sites created by plowing furrows. (Photo from USDA Forest Service files circa 1924)

Figure 4. The 800-acre slash pine plantation 5 years after direct seeding into furrows plowed by mules. (Photo from USDA Forest Service files circa 1930)

Harold J. Derr and William F. Mann, Jr., led the direct seeding initiative. Derr was the scientist assigned to the project and Mann, the center leader, supervised and participated in the effort.

By 1954, about 3,000 ac (1,200 ha) in direct seeding experiments had been conducted using longleaf, slash, and loblolly (*Pinus taeda* L.) pines. No successful methods had been found, but the major causes of failure were identified (Cassidy and Mann 1954). Seed-eating birds were the greatest problem. The vast areas of cutover land provided ideal habitat for large flocks of eastern meadowlarks (*Sturnella magna*) (figure 5) and other birds frequenting field conditions (Burleigh 1938). Studies indicated that coating the seeds with a repellent treatment might be effective in reducing predation and a U.S. Fish and Wildlife Service scientist, Brook Meanley, was assigned to the Alexandria Research Center to intensify the search for effective chemicals.

Bird Repellents

The first chemical found to effectively reduce bird predation was Morkit®. This material was manufactured in Germany and was composed of anthraquinone, a chemical frequently used in cosmetics, and inert ingredients. When Morkit® was withdrawn from the market, anthraquinone alone became the primary candidate. Later, caged tests of Arasan Seed Disinfectant® (50 percent tetramethyl thiram disulphide) demonstrated that birds did not eat seeds treated with this chemical and also had some rodent-repellent qualities (Meanley and others 1957). Thiram 42-S®, a liquid suspension, later became the preferred formulation to use in direct seeding because it provided a durable, dust-free coating that was superior to previous formulations (Mann 1970). Thiram 42-S® is still in use today and is also an effective, registered fungicide formulation that is frequently used as a treatment to control seedborne microorganisms.

Rodent Repellents

Although early studies found birds were the primary predators of pine seeds, these tests were conducted with longleaf pine seeds sown in the fall on sites with a light grass rough (Derr 1958). Longleaf pine seeds lack dormancy and germinate soon after natural dispersal in the fall. When other, more dormant, pine species that require stratification were sown in the spring, they were subject to heavy rodent predation because losses from rodent populations increase during the fall and winter.

When Endrin-50W®, sold mainly as an insecticide, was incorporated into the repellent coating (figure 6), rodent predation decreased and seeding success was significantly increased. It was typically added to the repellent mixture at a rate of 1.0 lb (0.45 kg) (0.5 lb of active ingredient) per 100.0 lb (45 kg) of seeds (Mann 1958, Derr and Mann 1959). Endrin-50W® is a potent chlorinated hydrocarbon poison, however, and concern existed about its toxicity to the environment and animal life.

In the 1970s, public concern about the use of extremely toxic chemicals in agriculture caused Endrin-50W® to be withdrawn from the market by the manufacturer. At the same time, the use of direct seeding began to decline because large open sites where its use is best suited were generally not

Figure 5. The cutover forests provided ideal habitat for flocks of eastern meadowlarks, which ate huge quantities of seeds. (Photo from USDA Forest Service files 1958)

Figure 6. Longleaf pine seeds treated with repellent coatings consisting of Arasan 75®, latex, and aluminum flakes. (Photo from USDA Forest Service files 1960)

available. An effort was made, however, to find a chemical with rodent repellency that could replace Endrin-50W®. A number of possible replacement chemicals were evaluated, but none were environmentally safe or as effective (Campbell 1981a, Barnett 1995).

More recently, field tests have shown that oleoresin capsicum is a promising rodent repellent (Barnett 1998). Capsicum is obtained from dried cayenne peppers (*Capsicum frutescens*) and is standardized with olive oil. Its strength is measured in parts per million (ppm). The ppm are converted to Scoville Units (SV), the industry standard for measuring the heat of peppers (American Spice Trade Association 1960). One ppm is equivalent to 25 SV. Nolte and Barnett (2000) evaluated the efficacy of thiram-capsicum seed treatments (500,000 SV) on house mice (*Mus musculus*) and deer mice (*Peromyscus maniculatus*) fed longleaf pine seeds. Although positive results were obtained, it is unlikely that capsicum or any other chemical will be found to be as effective as Endrin-50W® in repelling rodents.

Figure 7. Tommy Melder mixing latex into an Arasan-42S® repellent formulation. (Photo from USDA Forest Service files 1961)

Repellent Application

An essential component of any repellent seed coating is a sticker to bind the repellent coatings to the seeds. After evaluating several chemicals, Dow Latex 512-R® was found effective when applied to pine seeds (Mann 1958). Repellent treatments were evaluated over time and modified to take advantage of improved formulations. The preferred formulation became a combination of thiram (standardized as a water suspension and marketed as Arasan 42S®), Dow Latex 512-R®, and Endrin-50W® (Derr and Mann 1971). The repellent mixture consisted of 1 gallon (3.8 liter) Arasan 42S®, 5 fl oz (150 ml) Dow Latex 512-R®, and 0.5 lb (0.23 kg) Endrin-50W®. This mixture usually treated about 50 lb (22.7 kg) of pine seeds, depending on species (figure 7). In addition, about 8 tablespoons (8 ml) of aluminum powder or flakes were typically added to the mixture to ensure the flow of seeds through sowing equipment (Derr and Mann 1971).

Figure 8. An industrial forester for T.L. James Company is evaluating a cutover site for its potential for direct seeding. (Photo from USDA Forest Service files 1963)

Application of Direct Seeding

Direct seeding was developed for use on forest lands that generally fall into one of two categories: open lands or those partially or wholly occupied by brush and low-quality hardwoods (Derr and Mann 1971). Seeding also was found to be useful in restocking stands destroyed by wildfires and wind storms. Most of the commercial pine land in the South was considered suitable for direct seedling (figure 8).

Although regenerating large areas of cutover longleaf pine forests was the driving force for developing direct seeding technology, it was also used to regenerate slash pine (Mann and Derr 1964), loblolly pine (Mann and Derr 1961), and other southern pine species (Derr and Mann 1971).

Sites and Site Preparation

Site preparation for direct seeding is important to expose mineral soil that seeds need for germination (figure 9) and to control competing vegetation that will interfere with the survival and growth of new stands. Fire is the simplest and least expensive site preparation method, and it is often sufficient on open sites. On sites with hardwood brush and trees, mechanical and chemical methods of control are typically required. Whatever means are chosen, fairly complete removal of competing hardwoods is needed, and the likelihood of sprout growth must be considered.

Figure 9. Longleaf pine seed germinating on mineral soil on a prepared site. (Photo from USDA Forest Service files circa 1959)

Timing and Rate of Distribution

Two distinct sowing seasons exist—spring and fall. Fall sowing is generally recommended for longleaf pine because these seeds germinate naturally in the fall. Seeds of other major southern pines that exhibit some level of seed dormancy—loblolly, slash, and shortleaf pine—are best sown in the spring after seed stratification.

Sowing rates vary considerably by species, quality of the seeds, method of sowing, and level of stand stocking desired by the landowner. General recommendations for broadcast seeding are to sow about 3.0 pounds (lb) (1.4 kg) of longleaf pine seeds per ac, 1.0 lb (0.45 kg) for slash and loblolly pines, and 0.5 lb (0.23 kg) for shortleaf pine (table 1). These seeding rates result in 12,000 to 20,000 viable seeds per ac and may result in as many as 2,000 to 5,000 seedlings per ac (per 0.4 ha). For sowing in rows or spots, rates should be less (table 1).

Ground Application

Sowing by hand is the oldest form of direct seeding; but, as seeding technology improved and areas to be seeded increased, mechanized ground equipment was developed. Hand-operated cyclone seeders are the simplest of such equipment. These seeders were efficient for small areas and production per day could be up to 15 ac (6 ha) (Derr and Mann 1971) (figure 10).

Sowing seeds in spots prepared by raking, hoeing, or kicking areas free of vegetation and litter were found to be effective methods for small acreages. At the recommended rate of 1,000 spots per ac (2,470 spots per ha), 2 to 4 ac (0.8 to 1.6 ha) could be seeded per day (Campbell 1982a).

Tractor-mounted seeders were frequently used and usually resulted in seeds sown in rows. Some tractor operators simply

Table 1. Average number of seeds per pound and suggested sowing rates per acre.

Species	Seeds per lb[1]	Weight of dry seeds per acre for seeding: Broadcast Number	Broadcast lb	Rows[2] Number	Rows[2] lb	Spots[3] Number	Spots[3] lb
Longleaf pine	4,700	15,000	3.24	2,900	0.63	4,350	0.94
Slash pine	14,500	14,000	1.11	2,900	0.23	4,350	0.35
Loblolly pine	18,400	12,000	0.75	2,150	0.14	3,650	0.23
Shortleaf pine	48,000	20,000	0.48	4,350	0.10	5,800	0.14

[1] Dry, untreated seed, with viability of 95 to 100 percent: averages from Wakeley (1954).

[2] Rows 10 ft (3 m) apart for all species. Spacing within rows: 1.5 ft (0.46 m) for longleaf and slash, 2.0 ft (0.6 m) for loblolly, and 1.0 ft (0.3 m) for shortleaf.

[3] Spots spaced 6 by 10 ft (1.8 by 3 m), 6 seeds per spot for longleaf and slash, 5 per spot for loblolly, and 8 per spot for shortleaf, with 1,000 spots per ac. (Adapted from Campbell 1982b)

Figure 10. Harold J. Derr, research forester for the Southern Forest Experiment Station, Pineville, LA, sowing longleaf pine seeds with a cyclone seeder in 1954. (Photo from USDA Forest Service files)

Figure 11. Thomas C. Croker demonstrating a row seeder that elevates a low ridge in a plowed furrow and drops seeds that will be pressed into the soil. (Photo from USDA Forest Service files circa 1962)

dropped seeds on previously prepared sites, but many plowed a furrow or disked a narrow strip and metered out seeds (Derr and Mann 1971) (figure 11).

Aerial Application

About 75 percent of the total acreage seeded in the South has been from the air, either with small fixed-wing aircraft or helicopters (figure 12). Seedling effectiveness differs little between planes or helicopters. Both aerial application types require constant checking of equipment and precision flying for best results. Accurate seeding requires good ground control and proper calibration of seed release equipment (Derr and Mann 1971).

Figure 12. Aerial seeding being used with a fixed-wing plane, with seed distribution controlled by flag men on the ground. (Photo from USDA Forest Service files 1959)

Appraisals

Seed losses begin on the day of seeding and continue throughout the germination period. A successful seeding is one where losses are minimized so that adequate first-year stocking is achieved using the least amount of seeds. To determine seeding success, two or three evaluations are needed during the establishment period. These evaluations determine predation activity, initial stocking, and stocking at the end of the first year.

Estimating Predator Activity

Finding the cause of failures of seeding was a difficult task. Establishing observation stations, where repeated observations could be made, became essential for evaluating predator activity. An observation station consists of an identification stake and two nearby small cleared spots containing 25 treated seeds each. An additional screened spot with at least 10 seeds can be added to provide an estimate of field germination (Derr and Mann 1971) (figure 13).

The number of stations needed varies with the acreage of the seeding and cover conditions. For small areas, a minimum of 15 stations is needed to achieve meaningful data. On large areas, one station per 10 ac (per 4 ha) may be adequate, depending on site and ground cover conditions. Frequency of examination of stations may range from daily to weekly during the germination process.

When damage is observed, additional checking is needed to determine the nature of the losses and to evaluate seed treatments. Derr and Mann (1959) provide descriptive information related to the damage to seeds that are caused by different predators (figure 14) for identifying causes of seed losses.

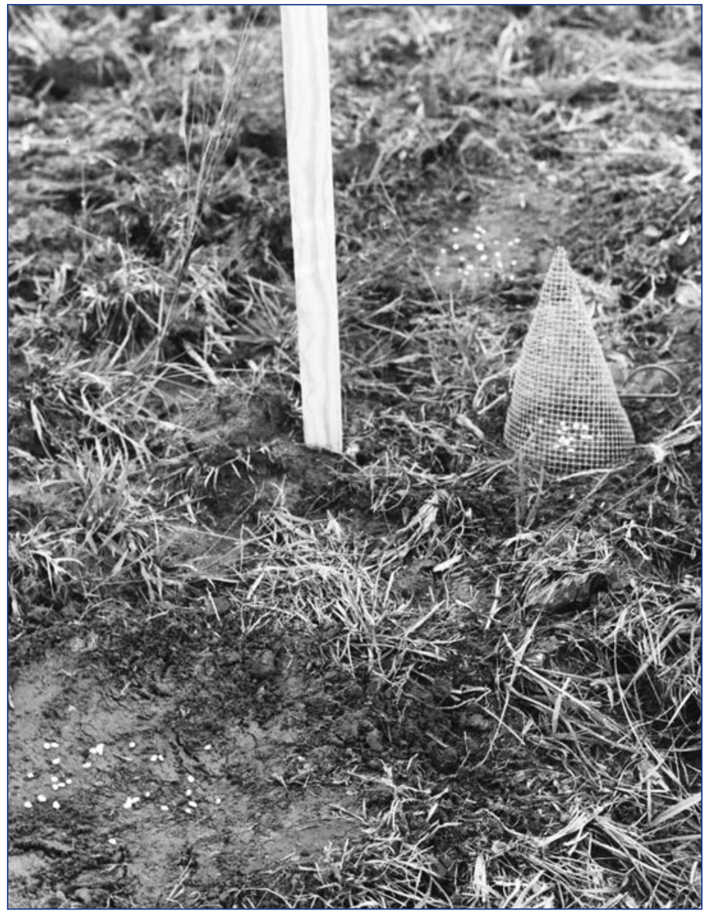

Figure 13. Observation station with center stake, two spots with 25 treated seeds each, and a screened spot with 10 seeds to evaluate germination potential. (Photo from USDA Forest Service files 1964)

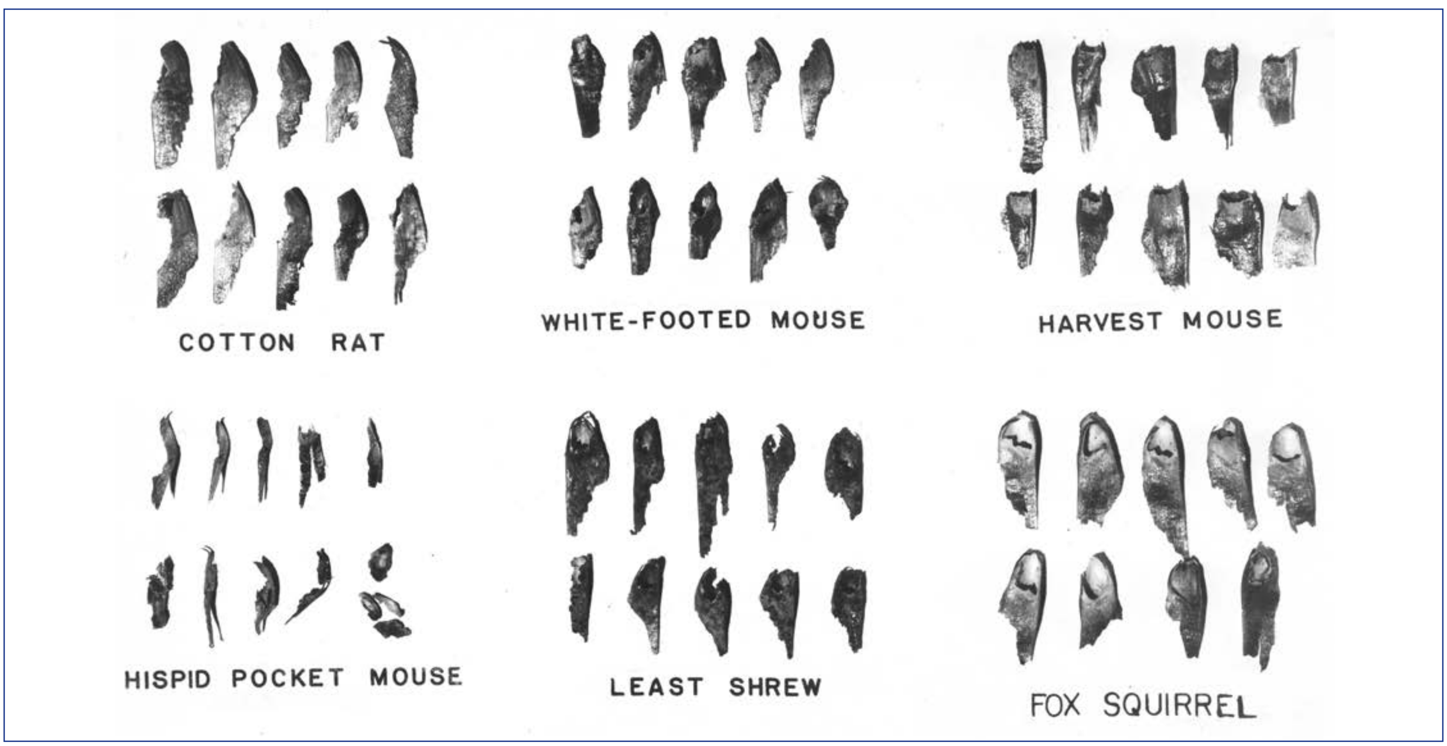

Figure 14. Characteristic damage to untreated longleaf seeds by seed predators in central Louisiana. These hull fragments were obtained from caged predators. (Photo by Brooke Meanley, U.S. Fish and Wildlife Service 1958)

Seedling Inventories

Survival of established seedlings during the first year is critical after direct seeding. To determine causes of early losses, two inventories are generally advised—one at the beginning of the summer when germination has completed, and the other at the end of the first growing season when mortality from summer drought is passed. The early inventory indicates the efficiency of the repellents. The second provides an estimate of overall seeding success.

Success of broadcast seeding can be determined by estimating the number and distribution of seedlings per acre. Estimates of both variables can be determined by installing sampling plots of a milacre (1/1,000 ac) in size. Circular milacre plots with a radius of 44.7 in (1 m) are ideal because they are quickly established and measured—a stiff wire or stick of the appropriate length is swept around a central point to establish plot boundaries and observe seedlings. Twenty-five plots is the minimum number for any seeded area. On large areas, one plot per ac (per 0.4 ha) has been used successfully (Ezell 2012).

Long-Term Protection and Management

After the first season, mortality from drought usually is not a major problem and substantial height growth begins for most southern pines. Protection from wildfire for the first few years is necessary for most southern pines. The exception is longleaf pine, which exhibits a fire-tolerant grass stage that may remain for several years (figure 15). Use of prescribed burning in the second or third year after seeding may be necessary to reduce vegetative competition and stimulate height growth of longleaf pine.

Direct seeding can result in overstocking of trees. Precommercial thinning may be needed when stocking at the end of the first year is 2,000 or more seedlings per ac (per 0.4 ha). Guidelines for timing and methods of thinning have been developed for loblolly and slash pine (Lohrey 1972, 1973). Stands basically should be precommercially thinned to about 400 to 800 seedlings per ac to improve growth and increase stand value.

Figure 15. Longleaf pine seedlings after a prescribed burn to reduce competing competition and brown-spot infected foliage. (Photo from USDA Forest Service files circa 1964)

Advantages and Disadvantages of Direct Seeding

Direct seeding can be an effective practice for regenerating southern pines. On many sites, seeding is more economical than planting nursery-grown seedlings or waiting for natural regeneration. The choice of seeding depends on the landowners' goals and economic situation, as well as the condition of the site and the capability of the land manager. Use of the direct seeding method has declined from its widespread use in the 1960s and 1970s, however. A number of reasons exist for this decline. These reasons and the merits of direct seeding are discussed in the following sections.

Advantages

The most notable advantage of direct seeding is lower initial cost compared with planting nursery stock. The cost of seeding is usually less than one-half that of planting for initial seedling establishment. Direct seeding is also beneficial for some species, notably longleaf pine, that are difficult to regenerate by planting bareroot nursery stock. Furthermore, direct seeding is a good alternative for regenerating low-quality sites.

Disadvantages

One of the most notable problems with seeding is poor control of tree spacing and stocking (number per acre). If environmental conditions are ideal after seeding, too many trees may survive and result in an overstocked situation that will require precommercial thinning. Pine stands with more than 2,000 stems per ac will result in reduced growth and financial return (Williams and others 2008). Understocking can also occur when establishment is not adequate to fully stock the area; this situation may be even more costly to the landowner.

Another disadvantage is that seeding usually does not take advantage of genetically improved seed sources because of higher costs and less availability. Large quantities of seeds are needed for broadcast seeding where tree percent (ratio of seeds sown to seedlings obtained) is significantly lower than for planting seedlings.

Seeding is best suited for use on large, open tracts of forest land. Such open areas are now seldom available for reforestation. Also, the loss of effective rodent repellent products from the market reduced the efficiency of seeding in areas were rodents are major seed predators. Although capsicum in combination with thiram does reduce rodent damage to seeds (Barnett 1998, Nolte and Barnett 2000), it is not as effective as the earlier thiram-endrin combination.

An additional problem limiting successful application of seeding is lack of availability of specialists with a high degree of technical skill, knowledge, and experience with seeding (Williston and others 1998).

Current Application of Direct Seeding Technology

Direct seeding was never meant to replace planting nursery-grown seedlings as a regeneration tool, but it was used over a 25-year period to reforest nearly 2 million ac (0.81 million ha) of forest land in the South (Campbell 1982b) (figure 16). After effective repellents were developed, supporting research

Figure 16. Men distributing longleaf pine seeds. Seeding with cyclone seeders is a viable regeneration option for land managers who have small tracts to reforest. (Photo from USDA Forest Service files 1959)

programs were established to provide necessary seed production capacity, to control competing hardwoods, and to clarify site preparation needs. These supporting programs were critical for implementing large-scale seeding operations (Mann and
Burkhalter 1961; Mann 1968, 1969). The greatest use for direct seeding has been in regenerating vast acreages of cutover forests. Many landowners, however, also saw it as an inexpensive tool for reforesting small tracts of land (Mann and Burns 1965, Campbell 1981b). Guidelines for such use are readily available (Duryea 1992, Williston and others 1998, Gwaze and others 2005, Ezell 2012).

Today, use of direct seeding is limited. Traditional forest regeneration by natural seeding or planting of genetically improved nursery stock is the prevalent means of reforesting highly productive sites. Nonetheless, direct seeding can still be an applicable technology. Some elements to be considered are summarized in the following sections.

Where Should Direct Seeding Be Used?

With the exception of excessively drought-prone areas, nearly any site that can be planted with seedlings can be direct seeded. The areas where seeding has the greatest current application are (1) large areas resulting from wildfire or other natural disasters, (2) remote or inaccessible areas, (3) low-productive sites where growth of trees would not make the cost of planting operations economically feasible, and (4) any area where a minimal investment is essential (Ezell 2012). The last category is important because many small private landowners cannot afford the cost of intensive site preparation and planting. It is better to direct seed these areas than to allow undesired species to become established.

What Species Are Best Suited for Direct Seeding?

Problems with the regeneration of longleaf pine were the primary reasons for the development of direct seeding, and seeding remains as an option for its regeneration. The development of container seedling production and planting, however, has made it a reliable method for reforestation of longleaf pine (Barnett and McGilvray 1997). Container seedlings are costly, but cost-share programs currently lower the expense to landowners.

Species selection will be affected by goals of ownership, but putting a species on sites where it grows best and with little danger of loss results in the most successful direct seeding (figure 17). Sand pine (*Pinus clausa* [Chapm. ex Engelm.] Vasey ex Sarg.) and shortleaf pine (*Pinus echinata* Mill.) are two southern pines that occur on infertile soils where seeding is a good alternative to planting (Outcalt 1985, 1990; Gwaze and others 2005).

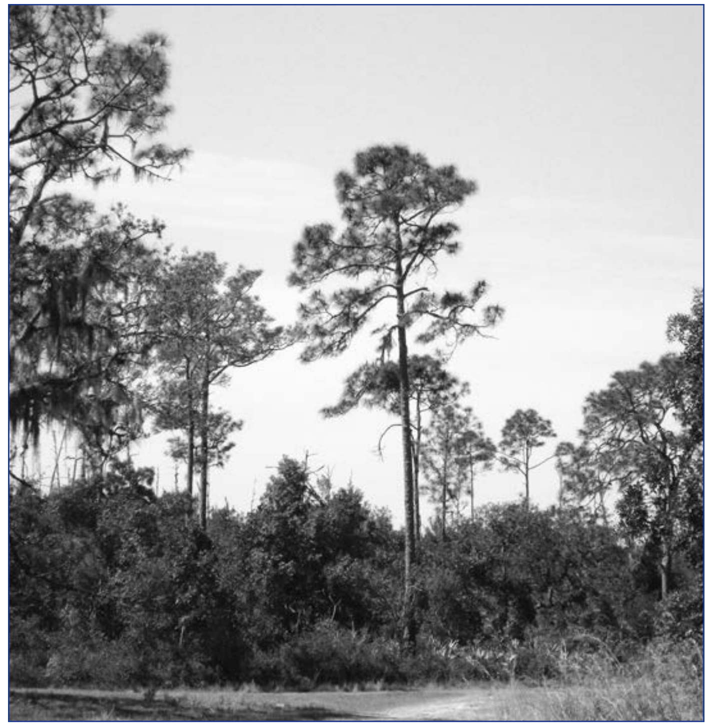

Figure 17. Sand pine growing on infertile sandhill sites in northwest Florida. This sand pine scrub ecosystem is common on these deep, sandy sites. (Photo from USDA Forest Service files circa 1965)

Seed availability must be considered for any species. Also, seeds with viability of at least 85 percent and a minimum of 95 percent sound seeds will enhance seeding success.

What Are Weather Constraints to Direct Seeding?

Arid soils and periods of low rainfall may reduce the success of direct seeding. During the late 1950s and early 1960s when direct seeding techniques were developed, the South was in a rainfall cycle that favored seeding. Fall and winter Palmer Drought Severity Index (PDSI) values between 1956 and 1962 were positive, averaging 0.76, and those of the same period between 2006 and 2012 were negative, averaging -3.27, indicating significantly drier weather conditions during recent years (Barnett 2014). These data indicate that land managers planning to use direct seeding as a management tool should consider the severity of soil moisture regimes for the areas being considered for seeding. Localized PDSI data are readily available from the NOAA National Climate Data Center Web site at http://www.ncdc.noaa.gov/oa/climate/research/prelim/drought/palmer.html.

What Does Site Preparation Need To Accomplish?

Site preparation for direct seeding should expose mineral soil for prompt seed germination and accomplish some degree of vegetative competition control. The site preparation must result in enough competition control to get a stand established and begin tree height growth. Control can be achieved by use of prescribed fire, mechanical treatments, or, in some cases, by use of herbicides.

What Seed Treatments Are Needed?

Two types of seed treatments may be required for successful direct seeding. The first depends on seed dormancy that may require stratification to assure prompt germination after sowing. Commercial forest tree seed dealers have the knowledge and resources to provide appropriate seed stratification treatments.

The second seed treatment is to protect seeds from bird and rodent predation after sowing and throughout the germination process. Thiram 42-S® is the commonly used bird repellent and also provides some initial rodent repellency. If the area to be seeded is relatively small, however, rodent predation can be a serious problem, because animals can be drawn from surrounding areas. Capsicum in combination with Thiram 42-S® provides the best available seed protection; recommended rates for this repellent coating per 1 lb (0.45 kg) of seed are 76 ml of thiram (Gustafson 42-S®), 3 ml of latex, and 1 ml of capsicum (500,000 SV).

When Should Seeds Be Sown?

Seeds that lack dormancy, e.g., longleaf and sand pine, can be sown in the fall when soil moisture is fully recharged. Seeds of other major southern pines species should be stratified before sowing in the spring. Spring sowing should be done early, about mid-February, to ensure germination is complete before droughty soil conditions develop.

How Should Seeds Be Distributed?

Large areas (more than 50 ac [20 ha]) needing reforestation can be broadcast seeded by airplanes or helicopters. Tractor-drawn row-seeding equipment is another option. Small tracts of land can be inexpensively regenerated by use of hand- and spot-sowing techniques. With use of hand-cranked cyclone seeders, one person can sow about 15 ac (6 ha) per day. Spot seeding of about 1,000 spots per ac is another option for small areas.

How Is the Success of Direct Seeding Determined?

Installation of sample plots is needed to determine seeding success. For broadcast sowing, circular plots can be established as described previously. On these plots, the number of germinated seeds are counted and recorded. An inventory at the end of the growing season will provide data to determine success of the seeding operation. About 25 plots are the minimum needed for any small seeded area and one plot per acre may be sufficient for larger areas (Ezell 2012). Sampling row- and spot-seeded areas may require a different approach, but the milacre-plot method may be used with confidence. Derr and Mann (1971) give specifics for these techniques.

Where Are Sources of Technical Expertise?

A limitation in the application of direct seeding is lack of specialists with expertise in seeding. Before beginning a large-scale operation, advice from those who have used the technique is very helpful.

Conclusions

Early studies by scientists of the Southern Forest Experiment Station in Alexandria, LA, determined that direct seeding was a viable technique to help reforest millions of acres of cutover forest land in the region. The use of direct seeding was a major achievement that resulted in large areas of devastated forest land being put back into production.

Development of repellents to protect seeds from bird and rodent predation became the key to successful direct seeding (figure 18). Effective repellents for protecting seeds from bird predation are anthraquinone and thiram. Both chemicals are not toxic and are readily available. Protection from rodents is essential on some sites but the most effective rodent repellent, Endrin-50W® a toxic hydrocarbon, was withdrawn from the market in the 1970s. A chemical as effective as Endrin-50W®, but safe to use, has not been found. A combination of Thiram 42-S® and capsicum, however, does provide a lesser level of protection from rodents.

Decline in the use of direct seeding began in the 1970s when much of the large areas of cutover forests were regenerated with pines, when the rodent repellent Endrin-50W® was withdrawn from the market, and when problems of overstocking of stands requiring precommercial thinning became apparent. Direct seeding still has applicability to large areas needing

Figure 18. Direct seeded longleaf pine seedlings that have begun height growth. Direct seeding was used to effectively reforest hundreds of thousands of acres with longleaf pine. (Photo from USDA Forest Service files circa 1963)

reforestation after wildfire and other natural disasters and to species growing on infertile soils where the cost of planting nursery stock is hard to justify economically.

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Evaluation of Drought Tolerance in Five Native Caribbean Tree Species With Landscape Potential

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Abstract

Seedlings of five tree species native to the U.S. Virgin Islands and Puerto Rico with potential for landscape plantings were grown in a greenhouse and subjected to three different watering intensities. We wanted to determine how fast nursery stock would reach an appropriate size for outplanting and how plant biomass would be allocated. Tree heights were measured weekly for 22 weeks, after which trees were harvested to determine root, stem, and leaf weights. All species survived under the different watering regimes but had different responses in both height growth and biomass allocation. Only one species, *Andira inermis*, when subjected to abundant watering reached outplanting height by the end of 22 weeks. *Plumeria alba* growth did not respond positively to increasing water and the soil's lack of field capacity wasted excess water. In terms of biomass allocation *A. inermis* was plastic in the allocation of biomass by dedicating more biomass to roots while under water stress and dedicating more biomass to stem wood when watered at field capacity. Other species, in particular, *Bucida bucera* did not change biomass allocation in response to watering levels. The results indicate that U.S. Virgin Islands nursery managers can save water during growing of these species by controlling watering levels and still obtain marketable local trees.

Introduction

The U.S. Virgin Islands (USVI) consists of four small islands in the Caribbean. When Europeans arrived in the Caribbean at the end of the 15th century, these islands were mostly covered in tropical dry forest and inhabited by natives. In the 17th and 18th centuries, African slaves cleared the islands of forest so sugar cane could be cultivated for the benefit of European planters. The cultivation of sugar cane has ceased, and the forests have grown back, but the islands are quickly urbanizing (Thomas and Devine 2005).

New urban and residential developments require bushes and trees to beautify the newly constructed areas and provide environmental services such as shade and protection from wind. Landscape planting around buildings, in parks, and along roads differs from reforestation or restoration plantings in scale (square yards and square meters versus acres and hectares) and in the size of the trees planted. The American National Standards Institute (ANSI) recommends that the minimum size for a nursery-grown tree planted for landscaping purposes is a 0.5-in (12.5-mm) diameter measured at 6 in (15 cm) above the ground, and 4.0 to 5.0 ft (1.2 to 1.5 m) (ANLA/ANSI 2004). By comparison, bare root seedlings planted for reforestation purposes are typically 1- to 2-ft (30- to 60-cm) tall.

Plant nurseries use abundant water, particularly those specializing in showy tropical plants such as species in the *Heliconaceae, Musaceae,* and *Zingiberaceae* families. These plants, after being planted in their final location, continue to need abundant water—which is a problem. Nurseries and landscape plantings cannot depend on rainfall alone in the USVI. During the dry season, access to well, municipal, or pond water is necessary to keep these plants alive.

On the islands, supplies of fresh water are limited. Rainfall is seasonal. No perennial streams or lakes exist to provide fresh water. People collect rainwater from rooftop-fed cisterns, pump water from wells, or buy desalinated seawater from the Virgin Islands Water and Power Authority. Yet, drought in the USVI is a more serious concern than ever before in recent history. Subterranean reservoirs have become depleted, although according to records, the islands receive about the same amount of rainfall as in past periods of time. Subterranean water sources have also become contaminated with salt water intrusions, waste water, and petroleum (USDA NRCS 2000).

To reduce water use by plant nurseries and property owners, we proposed the use of native tree species adapted to landscaping uses. As mentioned previously, tropical dry forest was, and still is, the predominant vegetation type in the USVI. Tropical dry forests are adapted to seasonal rainfall regimes and low levels of precipitation. Worldwide, tropical dry forests and woodlands are characterized by annual precipitation between 40 and 80 in (1,000 and 2,000 mm) and very dry tropical forests have annual precipitation between 20 and 40 in (500 and 1,000 mm) (Holdridge 1978). Tropical thorn scrub forests 10 to 20 in (250 to 500 mm) rain yearly. Based on annual precipitation and temperatures, the USVI has both dry tropical forest and very dry tropical forest.

Most tropical forests experience seasonal droughts that last for weeks or months, even in forests classified as moist or humid (Mulkey and Wright 1996). Forest plants can also suffer water limitation daily, during the heat of the midday or even from competition with other plants in the shade of the understory (Kainer and others 1998). Fresh water is a limited resource and plants have various physiological responses and strategies in response to water availability. Some of the adaptations of tropical dry forest plants to drought are leathery leaves, leaves that are deciduous in times of drought, photosynthesis through the trunk instead of the leaves during times of drought, dedication of more growth to roots instead of leaves, and storage of water within the roots and tree trunk itself (Slayter 1967, Farquhar and Sharkey 1982, Sharkey and Badger 1982, Gardner and others 1985, Shulze 1986, Anderson and others 1995, Brodribb 1996, Sanford and Cuevas 1996, Manter and Kerrigan, 2004).

To remain profitable and in business, plant nurseries need to produce a sufficient supply of plants at a price people are willing to pay. Two ways to reduce costs are to closely monitor water use and to grow native plants that are adapted to the dry environment of the USVI. The objective of our study was to determine biomass production and allocation to leaves, stems, and roots for five different species subjected to three watering regimes. This information can be an asset to nursery growers and landscapers to better understand a plant species' water-saving strategy.

Methodology

Five native tree species were included in this study: *Andira inermis* (W. Wright) Kunth ex DC, *Bucera bucida* L., *Jacquinia arborea* Vahl, *Pimenta racemosa* (Mill.) J.W. Moore, and *Plumeria alba* L. Each species was grown from seed. After two adult leaves emerged, the plants were transplanted into 61 in^3 (1,000 cm^3) pots and grown until they reached a size of 6 in (15 cm) at which point 18 individuals of each species were transplanted again into 3-gal (11,400-cm^3) black plastic pots (Custom™ Containers) and allowed to recover from transplant for 5 weeks before the experiment started. The experiment ran from July 2012 to May 2013 (28 weeks for *A. inermis*, 24 weeks for *P. racemosa*, 20 weeks for *J. arborea*, 24 weeks for *B. bucera*, and 16 weeks for *P. alba*). Variations in the length different species were subjected to treatments resulted from delays in obtaining seeds of the various species and differences in seed germination. Because St. Croix is a tropical island, freezing temperatures and low levels of winter light were not a problem. Mean daily temperature is 79 ˚F (26 ˚C), and St. Croix has roughly 12 hours of sunlight per day, year round (NOAA 2013).

Each pot was filled with a potting mix of two parts *Sphagnum* peat, one part coarse sand, and one part top soil. Top soil was obtained from agricultural fields at the UVI-STX campus. A soil survey map indicates that the soil is a Sion Clay derived from alkaline marine deposits. It is considered prime agricultural soil if irrigation is available; elsewhere, it is used as rangeland (USDA NRCS 2013, 2000). The soil is moderately alkaline and sometimes causes problems for crops because of iron deficiencies. Soil tests contracted out by UVI to Waters Agricultural Laboratories indicate that the pH is 8.

One month after transplanting, plants were assigned a weekly watering regime: 100 percent field capacity (FC), 66 percent field capacity, and 33 percent field capacity (designated hereafter as 100 FC, 66 FC, and 33 FC, respectively). Six plants of each species were in each watering regime. The pots were color-coded blue, green, and yellow to avoid confusion while watering and to symbolize a gradient from abundant watering through drought. In a previous experiment using 3-gal pots (data unpublished), the watering treatments were field capacity, 50 percent field capacity, and 33 percent field capacity, but we found no increase in plant growth when watering was increased from 33 to 50 percent field capacity. By increasing watering to 50 and 66 percent of field capacity, we were able to test water-conserving treatments while still promoting plant growth.

To determine the amount of water that each plant would receive, we needed to determine the field capacity of the planting substrate. Field capacity refers to the amount of water held in the soil after excess water has drained away. Gravity causes the excess water to drain from the macropores; water for plant use is held within the micropores via capillary action (Brady and Weil 2002). We determined field capacity two different ways; the first is theoretical and the second empirical with the expectation that both methods would produce similar results. A theoretically ideal growing medium consists of 50 percent mineral or organic particles and 50 percent pore space (Brady and Weil 2002). To simplify calculations, we estimated pore space to be evenly divided between micropores and macropores although the proportion or ratio of macropores and micropores can vary among soils. From an example taken from a soils text book (Brady and Weill 2002: 151), a representative sandy loam had a 2:1 ratio of micropores to macropores; a representative silt loam with good structure had a 1:1 ratio of micropores to macropores; and a representative silt loam with poor structure had a 4:1 ratio of micropores to macropores. In our study, the planting substrate is a mixture of *Sphagnum* peat moss and coarse river sand with a component of field soil. For our theoretical calculation of field capacity, the volume of substrate within a pot was divided by 2 to estimate the volume of pore space to particles, then the volume of the pore space was divided again by 2 to estimate the volume of macropore and micropore space. The 3-gal pots we used have a volume of 0.402 ft^3 (11,400 cm^3). So 0.201 ft^3 (5,700 cm^3) would be considered pore space. Therefore, at field capacity, the theoretical amount of water held in the micropores would be 0.101 ft^3 (2,850 cm^3) or 0.79 gal (3 L).

Next, field capacity of our pots filled with potting mix was determined in an experimental or empirical fashion. Potted plants were allowed to dry down until wilting, thus indicating dry soils. The dry pots were then weighed. Then, the potting mix was watered until water ran out the bottom of the pots. We waited an hour, until all the gravitational water had drained out of the macropores. The moist pots were then weighed. The amount of water being held in the micropores of the potting mix was calculated by subtracting the weights of the dry pots from the moist pots. On average, the difference was 6.6 lb (3 kg or 3,000 cm^3), which is equivalent to 0.79 gal (3 L) of water, the same amount estimated during our theoretical determination.

Based on our field capacity calculations, plants in the 100 FC treatment received 1.0 gal (3.8 L) of water once per week to ensure each pot would receive adequate water to achieve field capacity. Plants assigned the 66 FC treatment received 0.53 gal (2 L) of water weekly, and those assigned to the 33 FC treatment received 0.26 gal (1 L) water weekly. Macronutrients and micronutrients were supplied to the plants via a water soluble fertilizer (12-48-8 Sol-U-Gro™) once a week, when the plants were watered.

Each week, height and stem diameter were measured and recorded (figure 1). As per the guidelines for landscape planting, stem diameters were measured at 6 in (15 cm) above the soil surface (figure 2). At the end of the experiment, nine plants of each species were harvested, dried in an oven for 3 days at 122 ˚F (50 ˚C) (Ostertag and others 2008), and then separated into its components (leaves, stems, and roots) and weighed.

Each species was in a completely randomized experimental design. The data from each species were statistically analyzed separately using JMP software (John's MacIntosh Program), a menu-driven version of SAS (Statistical Analysis Software). We performed an ANOVA on the data to determine if significant differences existed among the treatments. If a statistical difference existed between treatments for a particular species, a Dunnet's test was performed. With a Dunnet's test, results are compared with a control treatment. In this study, the 100 FC treatment was considered the control treatment for purposes of the Dunnet's test.

Figure 1. Height (top) and diameter (bottom) were measured weekly on all plants in the study. (Photos by Michael Morgan with Kalunda Cuffey)

Figure 2. Stem diameter was measured 6 cm above the soil surface. (Photo by Michael Morgan)

Results and Discussion

Andira inermis

Andira inermis is an attractive, medium-sized tree with dark green leaves and small, showy, purplish pink pea-like flowers (figure 3). The round, hard fruit contains one seed (figure 4). These leguminous trees are usually 20- to 50-ft tall (6- to 15-m) with a 6- to 12-in (15- to 30-cm) diameter at breast height (dbh). In a forested setting, it can grow up to 100-ft (30-m) tall and 48 in (120 cm) in diameter. Within the forest, the tree has a narrow crown with a straight, cylindrical trunk and no low branches. Open-grown trees have a rounded, dense crown with many spreading branches (figure 5).

The English common names for *A. inermis* are dog almond, bastard mahogany, and cabbage angelin. Each name refers to a certain aspect of the tree. Dog almond refers to the tree's bat dispersed seeds that are poisonous to people. Cabbage angelin refers to the unpleasant rotting odor the bark gives off when cut. Bastard mahogany refers to its fine, furniture-quality wood. The Spanish common names are moca or motón. The species is found throughout the neotropics from south Florida to Peru and Bolivia. It is a common tree in Puerto Rico and the Virgin Islands and uncommon in Florida (Kirk 2009).

A. inermis trees grew best in the 100 FC treatment (figure 6, table 1). Trees in the 66 FC treatment grew at a slower rate, while those in the 33 FC treatment grew only 8 in (20 cm) and then stopped growing (figure 7A). Total biomass produced

Figure 3. *Andira inermis* has small, showy flowers. (Photo by Michael Morgan)

Figure 4. *Andira inermis* fruit. (Photo by Michael Morgan)

Figure 5. When open grown, *Andira inermis* forms a wide, branching canopy. (Photo by Michael Morgan)

Table 1. Tree height and diameter by species and weekly irrigation treatments at the beginning and end of each experiment.

Treatment	Initial height (cm)	Height growth (cm)	Final height (cm)	Initial diameter (mm)	Diameter growth (mm)	Final diameter (mm)
Andira inermis						
100 FC	44	82*	126	7	13*	20
66 FC	44	63	107	7	10	17
33 FC	44	19	63	7	5	12
Bucida bucera						
100 FC	36	52*	88	6.3	5.9*	12.2
66 FC	33	18	51	8.0	3.0	11.0
33 FC	36	14	50	6.0	3.0	9.0
Jacquinia arborea						
100 FC	20	19	39	4.3	4.4	8.7
66 FC	21	20	41	4.0	4.5	8.5
33 FC	20	10	30	4.0	3.2	7.2
Pimienta racemosa						
100 FC	19	55	74	4.0	4.3	8.3
66 FC	21	56	77	4.1	4.6	8.7
33 FC	20	46	66	3.6	3.6	7.2
Plumeria alba						
100 FC	84	8	92	11	4	15
66 FC	80	11	91	12	2	14
33 FC	89	7	96	12	1	13

Note: Within a species, asterisks denote instances when the 100 FC treatment was significantly different from the other two treatments ($\alpha \leq 0.05$).

Figure 6. Three *Andira inermis* trees at the end of the experiment. Weekly irrigation regime treatments from left to right are field capacity, two-thirds field capacity, and one-third field capacity. (Photo by Michael Morgan)

by *A. inermis* differed significantly among treatments ($p = 0.0002$). Significantly more biomass was allocated to roots in the drier treatments (figure 7B) suggesting an adaptation to water stress by increasing the plants water uptake capacity. The proportion of leaf biomass was similar among the 3 treatments. Allocation to stem tissue was higher for plants grown in the 100 FC treatment. During this experiment, the trees allocated all aboveground woody growth to a single stem and did not produce lateral branches. This species is often found along stream sides, but tolerates a wide range of sites; hence the differing allocations of biomass in response to site conditions (Little and Wadsworth 1964).

Bucida buceras

Bucida buceras has the English common name of black olive, yet does not bear olive-like fruits. Other common names are ucar in Spanish and gre-gre in the USVI (Kirk 2009). *B. buceras* trees produce small, greenish white flowers borne in spikes (figure 8) and can grow up to 100 ft (30 m) tall and 5.0 ft (1.5 m) dbh. Although it is considered a climax species of tropical dry forests in the Caribbean and northern South America, it is widely planted as a street tree throughout the Caribbean basin and south Florida (Francis 1998).

B. buceras did not respond well to water stress although it is often found growing close to the ocean shore on the drier east end of St. Croix, suggesting that this species has some drought tolerance. By the end of each week, all *B. buceras* plants, particularly the plants in the 66 FC and 33 FC treatments were wilting and under obvious water stress. Even the trees in the 100 FC treatment showed some signs of water stress, although they continued height growth. By the end of 16 weeks, no tree had reached the ANSI recommended size for landscape planting (table 1, figures 9A and 10). In fact, plants in the 33 FC and 66 FC had nearly no growth and were barely kept alive during the study. More frequent watering to

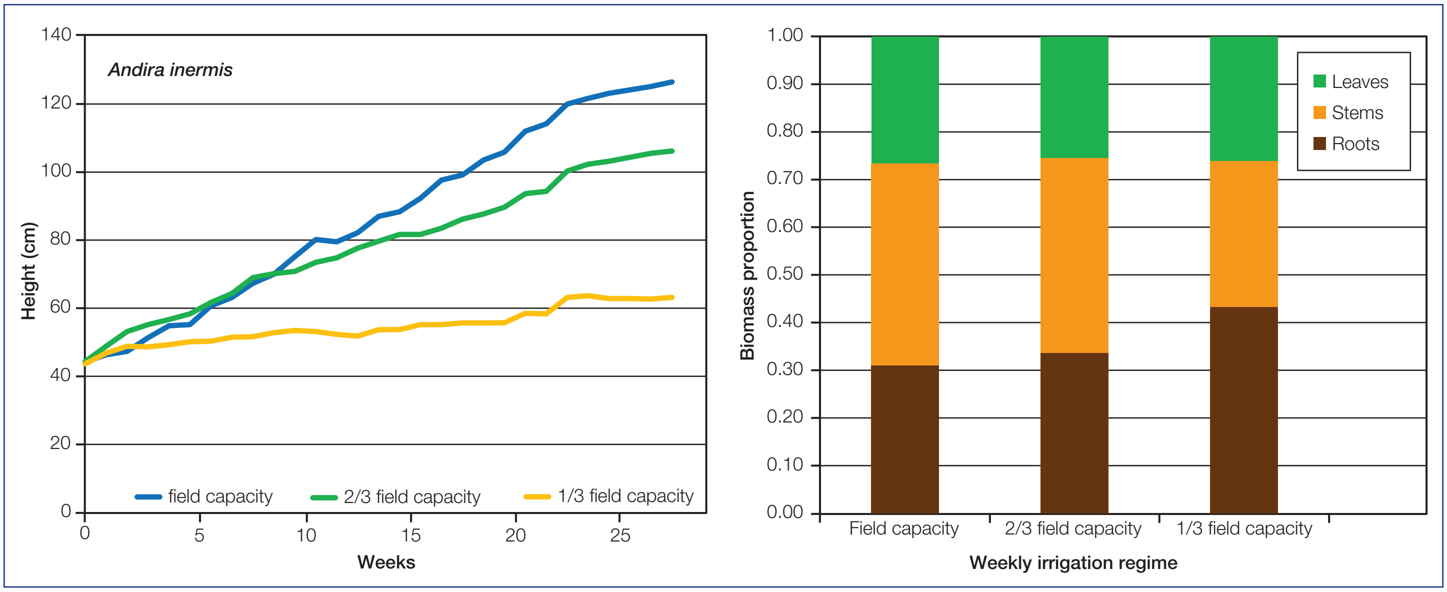

Figure 7. Height growth (left) and biomass proportioning (right) of *Andira inermis* trees subjected to three irrigation regimes.

Figure 8. *Bucida buceras* flowers. (Photo by Michael Morgan)

keep soil moisture levels more constant and at a higher level is likely to avoid water stress and encourage growth of this species.

Biomass allocation in *B. buceras* did not differ among the three watering treatments. Regardless of treatment, more than one-half of the plant biomass was allocated to stems and branches while the other one-half was more or less equally divided between roots and leaves (figure 9B). Foliar biomass allocation was underestimated for *B. bucera* plants in the 100 FC treatment. We sprayed the greenhouse with Malathion™ to control white flies (*Tria leurodes vaporarium* Westwood), and some of the trees in the 100 FC treatment lost their leaves because they were closest to the spray. They had not

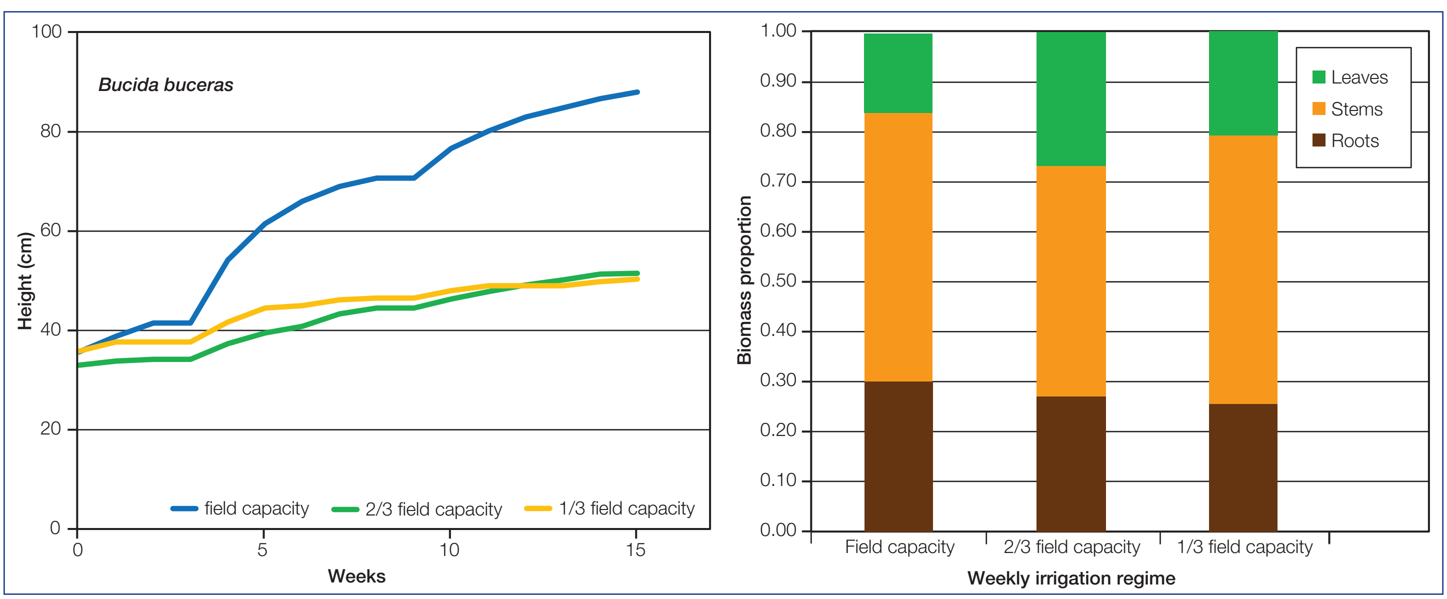

Figure 9. Height growth (left) and biomass proportioning (right) of *Bucida buceras* trees subjected to three irrigation regimes.

Figure 10. *Bucida buceras* trees arranged in a gradient of water stress. Weekly irrigation regime treatments from left to right are one-third field capacity, two-thirds field capacity, and field capacity. (Photo by Michael Morgan)

fully recovered 4 weeks later at the time of the experiment's end. We estimate that foliage allocation would have been approximately 25 percent of biomass for plants in the 100 FC treatment if the insecticide damage had not occurred.

B. buceras is a very branchy tree with many lateral branches (figure 11). The tree takes the form of a pagoda or a series of parasols that get smaller as they ascend the tree. Branches in young trees are kept close to the ground. This characteristic may serve to reduce evaporation of soil water around the tree by shading the soil in its root zone. Two other trees exist that share this pagoda-like growth form: *Terminalia catappa* L. and *Tabebuia bilbergii* (But & K. Schum) Standl ssp *ampla* A Gentry (Valverde Badillo 1998). *T. catappa* is originally from Asia, but is now a pan tropical tree species that goes by the common names of sea almond, Indian almond, and West Indian almond (Flores 2002). It often grows close to the shoreline where it tolerates sandy soils and salt from the wind and in the soil. *T. bilbergii* grows in the very dry tropical forests or tropical thorn scrub of the Ecuadorian and Peruvian coast.

Figure 11. Mature *Bucida buceras* tree. (Photo by Michael Morgan)

Jacquinia arborea

Jacquinia arborea is a shrub or small tree found on coastal outcrops and other places close to the ocean (figure 12). It has red berries and was used in the past to stupefy fish. The common name in the USVI is torchwood because of its bright red berries. In Spanish, it is called barbasco, as is any tree or plant used to stupefy and capture fish (Little and Wadsworth 1974).

J. arborea trees in the 33 FC treatment grew at a slower rate than those in the other two treatments (table 1, figure 13A). Little difference existed in height, diameter, and biomass growth between trees grown in the 100 FC and 66 FC treatments; therefore, we recommend watering with 0.53 gal (2 L) per week instead of 1.0 gal (3.8 L) to conserve water.

Figure 12. *Jacquinia arborea* tree with fruit. (Photo by Michael Morgan)

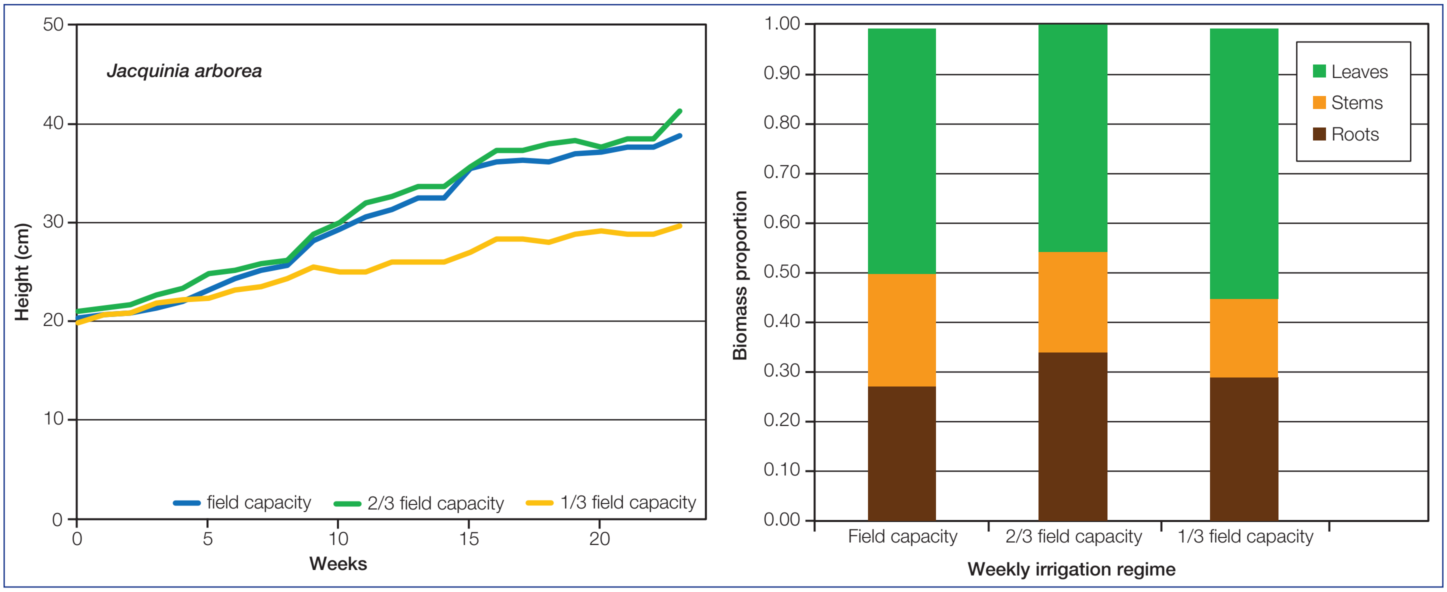

Figure 13. Height growth (left) and biomass proportioning (right) of *Jacquinia arborea* trees subjected to three irrigation regimes.

No difference existed among treatments for total biomass but differences in biomass allocation did exist (figure 13B). For all three treatments, most of the biomass was allocated to tough, leathery leaves instead of roots; in particular, the trees subjected to drought in the 33 FC treatment allocated an average of 55 percent of their biomass to leaves. Leathery leaves are a water conservation strategy.

Pimenta racemosa

The English common name for *Pimenta racemosa* is bay-rum tree, and the Spanish name is malagueta. It was extensively grown on the island of St. John in the late 19th and early 20th century for its aromatic leaf oil used in perfumes and cosmetics (Kirk 2009). It is a small- to medium-sized tree that averages 40 ft (12 m) tall and 8 in (20 cm) or more in dbh (figure 14). It has a dark green, columnar crown and peeling bark (Little and Wadsworth 1964). The berries are an important soft mast source for wildlife (Jones 1995) (figure 15). Trees of bay-rum grow throughout the Caribbean basin and have been introduced to south Florida as an ornamental (Kirk 2009, Little and Wadsworth 1964).

Figure 14. Mature *Pimenta racemosa* tree. (Photo by Michael Morgan)

Figure 15. Fruit of *Pimenta racemosa*. (Photo by Michael Morgan)

No statistical difference existed among treatments for height, stem diameter, and biomass although trees grown under the 33 FC tended to have the least growth (table 1, figure 16A). We noticed early in the experiment that the 100 FC treatment appeared excessive; the plants looked sickly and grew slower. By the end of the experiment, however, this condition was no longer evident. *P. racemosa* is moderately drought tolerant (Jones 1995) so the negative response observed in plants watered to field capacity was surprising. We did not observe this negative response for any other tree species in this study, not even for trees that normally grow on arid sites such as *Plumeria alba* and *Jacquinia arborea.*

We also observed another unusual phenomenon with *P. racemosa*—the main stem would often fall over, and the lateral branches would then grow into new terminal leaders. This phenomenon happened regardless of watering regime and resulted in a bushy plant. Little and Wadsworth (1964) make reference to a sometimes shrubby form of the tree. The reason for the main stem falling over is unknown, but this might explain why total biomass tended to be greater in the 100 FC treatment, yet tree heights were marginally taller in the 66 FC treatment. Two of the six trees in the 100 FC treatment became bushy, whereas only one tree in each of the 33 FC and the 66 FC treatments became bushy.

Pimenta racemosa trees in all three watering regimes had similar proportions of biomass allocated to leaves and roots, (figure 16B) but the trees in the 100 FC treatment had a significantly greater proportion of biomass allocated to stem, probably because two of them were so branchy. Our recommendation for this species is to water with 0.53 gal (2 L) once a week, rather than 1.0 gal (3.8 L), at least for the first 10 weeks. After the trees reach 18 to 20 in (45 to 50 cm) tall, they are big enough to use more water if one wants to, or needs to, speed up tree growth to meet a sales contract. Elsewise, watering levels can continue at the 0.53 gal (2 L) rate until growth slows or signs of water stress appear. It is important to remember that bigger trees need more water.

Plumeria alba

The English common name for *Plumeria alba* is white or wild frangipani. This species is an unusual looking small tree; its stout, sparse limbs terminate in a cluster of leaves (figure 17) and, during some parts of the year, bear very fragrant white flowers (Kirk 2009) (figure 18). *P. alba* grows up to 35 ft (11 m) tall. *P. alba* is the wild growing member of a genus best known for the ornamental species frangipani (*P. rubra)* and bridal bouquet (*P. pudica)*; both of which are now pan tropical in distribution. Their wild cousin, *P. alba,* grows on rocky outcrops and coastal thickets in Puerto Rico and the Virgin Islands. The species is tolerant of both salt and drought. Although *P. alba* is not a cultivar, it still has ornamental potential. In fact, it has been introduced to south Florida for that purpose (Little and Wadsworth 1964, Jones 1995, Kirk 2009). Jones (1995) recommends the use of *P. alba* as an ornamental in small confined gardens for its size and its tolerance of both salt and drought. In fact, this tree is mainly reproduced using cuttings, but we were very lucky to get seeds from Buck Island National Monument off the coast of St. Croix. It produces seed very infrequently, only every few years (Daley, personal communication 2013, Lundgren, personal communication 2013, Morgan, personal observation 2013).

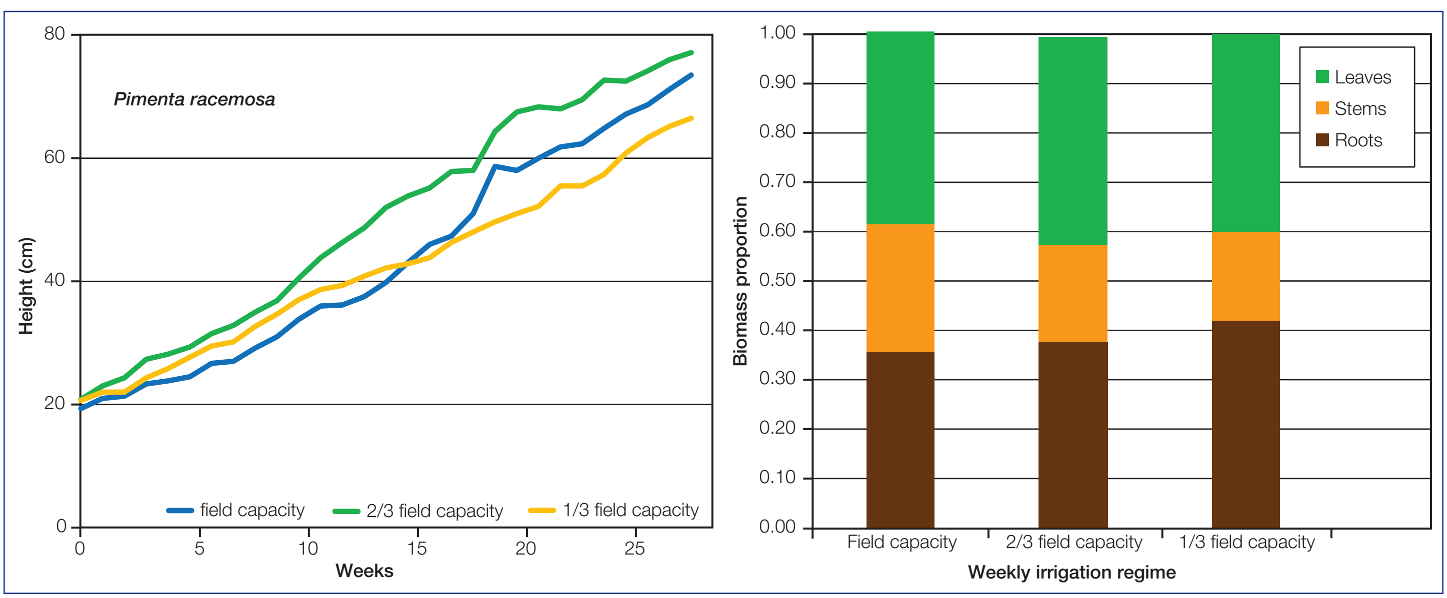

Figure 16. Height growth (left) and biomass proportioning (right) of *Pimenta racemosa* trees subjected to three irrigation regimes.

Figure 17. One of the *Plumeria alba* trees in the study showing its distinctive growth form. (Photo by Michael Morgan)

Figure 18. *Plumeria alba* flowers. (Photo by Michael Morgan)

In our study, *P. alba* was the most drought tolerant species. Average height growth was 0.3 in (0.7 cm) per week for the trees in the 66 FC treatment, and 0.2 in (0.5 cm) per week for those in the other two treatments, although no statistical difference existed between treatments (table 1, figure 19). Diameter growth was not significantly different among treatments, although trees subjected to the 100 FC treatment had diameter growth from 0.4 to 0.6 in (11 to 15 mm), whereas the trees subjected to the 66 FC and 33 FC treatments had diameter growth of only 0.08 and 0.04 in (2 and 1 mm), respectively ($p = 0.07$). We recommend watering once per week with 0.53 gal (2 L) of water, but 0.26 gal (1 L) of water per week is acceptable.

P. alba was not subjected to biomass harvest because of the rarity of the species. Observations indicate that more biomass is allocated to stem compared with leaves, however. We estimated approximately 90 percent of the aboveground portion of the tree is stem, with only a few leaves at the top of the stem.

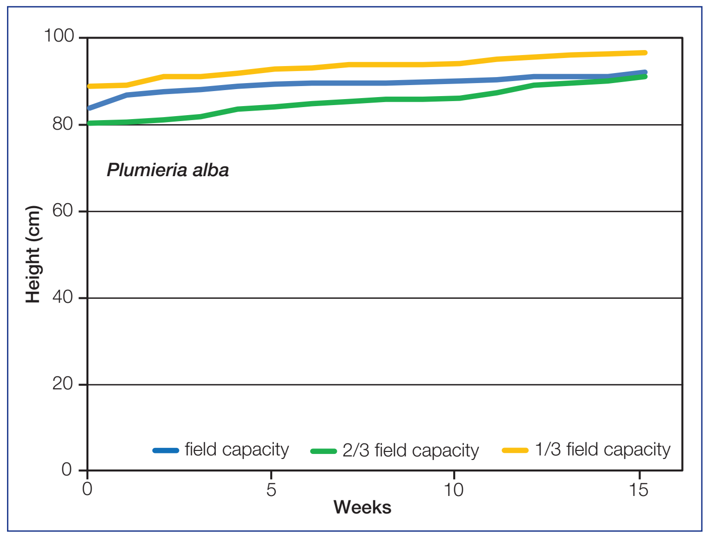

Figure 19. Height growth of *Plumeria alba* trees subjected to three irrigation regimes. Because this species is rare, no trees were harvested for measurement of biomass allocation.

Conclusions

Nursery managers ideally want to produce trees ready for landscape planting in the least amount of time possible with the least amount of water. We discovered that *A. inermis* and *B. bucera* grew best when watered to 100 percent field capacity weekly, *J. arborea* and *P. racemosa* grew best when watered to 66 percent field capacity weekly, and *P. alba* had similar growth rates regardless of irrigation regime. These relative differences are also reflected in total biomass (figure 20). Growth and biomass allocation among

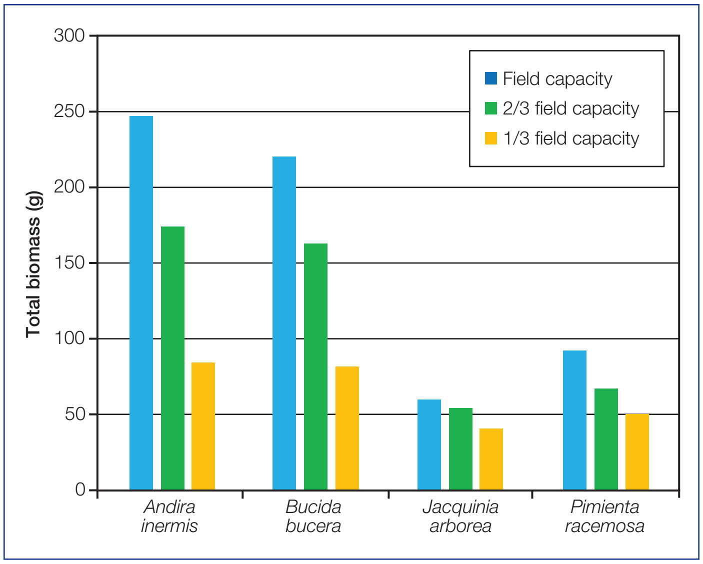

Figure 20. Total biomass of four species subjected to three irrigation regimes. Because *Plumeria alba* trees are rare, they were not measured for biomass.

treatments suggests that differences among species (although not compared statistically) can be attributed to their relative drought tolerance and natural habitats. It would be worthwhile to continue evaluation of native tree species for landscaping uses by conducting this study with other tree species as well as with the same species grown in larger pots.

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Northwest Oregon Restoration Partnership: A Model for Successful Watershed Restoration

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Abstract

In Tillamook, OR, a partnership for watershed restoration began in 2002 with several partners. By 2011, the project had grown to become the Northwest Oregon Restoration Partnership and now includes nearly 35 partners. The primary objective of this cooperative effort is to promote healthy forest and riparian ecosystem conditions by collecting and growing native plant seeds and cuttings to develop genetically adapted, large planting stock that is able to withstand vegetative competition and thrive after planting. Providing this type of plant stock is useful for meeting management plan goals and implementing restoration activities on lands administered by the U.S. Department of the Interior, Bureau of Land Management (BLM) and on lands of interest to the various watershed organizations. The effort was designed to encourage the application of innovative solutions to forest and riparian health conditions on an ongoing basis across the landscape. These actions support the Oregon Plan for Salmon and Watersheds and meet multiple BLM strategic goals and planning objectives, including but not limited to community support, partnerships, education, youth, fish and wildlife habitat, water quality, and biological system integrity.

History

In the mid-1990s, Tillamook Bay on the Oregon Coast was included as a National Estuary Project. Input from teams of researchers and numerous local community public outreach efforts resulted in the creation of a Comprehensive Conservation and Management Plan for the Tillamook Bay area and associated watersheds (Trask, Wilson, Tillamook, Kilchis, and Miami watersheds) (Tillamook County Performance Partnership 1999). The plan identified more than 400 mi (644 km) of riparian habitat degraded because of lack of vegetation. The degradation raised concerns for fish and wildlife habitat and water quality. At the same time efforts to analyze stream conditions for many of the other northwest Oregon coast range watersheds identified similar issues, such as fish passage, stream temperatures, bank stability, invasive species, and lack of appropriate native vegetation.

The restoration and protection of natural watershed processes are the foundation for achieving watershed health. Since natural watershed processes have been eliminated, altered, or reduced in many areas, habitat restoration activities are the primary method for reintroducing critical ecosystem functions to watersheds important to threatened and endangered fish and wildlife that have been negatively impacted by past management practices or disturbance events. Restoration activities are intended to address the watershed functions necessary to support natural processes that are indicative of healthy watersheds. This effort includes, but is not limited to, improving water quality, habitat complexity, floodplain interaction, vegetation structure, and species diversity. The Oregon Department of Environmental Quality's total maximum daily load studies, the North Coast Basin Water Quality Management Plans, the Watershed Council Action Plans, the Tillamook Bay Comprehensive Management Plan, and the 35 BLM watershed analyses have all concluded that native vegetation is needed in riparian zones to reduce pollutants, stabilize stream banks, and lower stream temperatures.

As implementation for restoration efforts began in the late 1990s, it soon became recognized that locally adapted native plant material was not readily available on the open market. Desired plant species could be purchased, but not with the appropriate local genetics. Most reproductive materials used by nurseries to propagate native plants were collected from the Willamette Valley east of the Oregon coast range and the associated foothills. Before watershed coordinators became educated on the importance of genetic variation and local adaptation, they purchased and planted off-site plant stock. Because of their intolerance to coastal environments, however, plants genetically adapted to the Willamette Valley did not always do well, showing low vigor and high mortality. In addition, most of the native plant material available was small bareroot stock types that were not very competitive and hard to maintain because of their relative size to the competing vegetation already dominating the site. Common competing issues were browse, overtopping, moisture competition, and matting.

Most organizations involved with restoration efforts on the Oregon coast did not have adequate funding to purchase plants. The main source of plant material came from donations of surplus upland reforestation conifer stock that were acquired through a variety of sources, including; the U.S. Department of the Interior (USDI), Bureau of Land Management (BLM); U.S. Department of Agriculture (USDA), Forest Service; Oregon Department of Forestry and several private timber companies. A typical bareroot upland reforestation conifer, such as western hemlock, Douglas-fir, western redcedar, and Sitka spruce grown for the Oregon coast has a height range of 14 to 20 in (35 to 50 cm), a 0.2- to 0.3-in (5- to 7-mm) stem diameter, and a fibrous root mass 10 to 11 in (25 to 28 cm) in length. These stock type dimensions are not ideal for planting in riparian habitat as most sites are dominated by aggressive, nonnative species or overtopped by an existing stand of hardwoods or shrubs. In these habitats, underground competition is extremely important; for example, planting a 10-in (25-cm) rooted bareroot tree seedling into reed canarygrass (*Phalaris arundinacea* L.) with root systems 14 in (35 cm) deep is not practical for survival. In these conditions, site preparation and maintenance is extremely costly to assure survival, an expense for which most watershed restoration efforts did not have adequate funding.

Donated bareroot conifer species were available only late in the planting window; sometimes well into the spring root development stage for conifers. Planning efforts were difficult because no indication existed of what stock would be available or when. These donated surplus conifers usually had problems because of moisture stress after long-term cooler storage that led to higher mortality rates. Considering most planting efforts occur on private lands, high mortality rates did not appeal to these private landowners, thereby making it difficult to recruit neighboring landowners for participation in the watershed restoration program. Landowner participation is the key to treating watersheds as a whole; thus, plant survival and vigor is crucial for successful restoration efforts

Tillamook Native Plant Cooperative

Recognizing the need to use locally adapted native plant material and create a larger more competitive stock type, a small group of restoration coordinators in the Tillamook area created a plan. In 2001, they took the entire donated seedling surplus they could get and, instead of outplanting them, they transplanted the trees back into the soil at the Oregon Youth Authority (OYA) Camp Tillamook Work Study Center, for 1 additional year, thereby creating a 3-year-old bareroot stock type (figure 1). In theory, this approach would reduce

Figure 1. Initial bareroot nursery established at the Oregon Youth Authority Camp Tillamook Work Study Center. (Photo by Kurt Heckeroth 2002)

mortality issues, create a larger, more competitive plant, and provide an inventory for planning purposes. A collaborative effort began and was called the Tillamook Native Plant Cooperative. No funding initially was available to support this effort. An agreement was established between the Tillamook Soil and Water Conservation District and the OYA Camp Tillamook Work Study Center, a State Agency that allowed the partners to use State land for their project. A local farm digester cooperative donated compost to amend the soil, a local farmer donated time and equipment to till the land, the youth from Camp Tillamook donated the labor to transplant the donated seedlings, and the BLM-donated cooler space for bareroot tree storage.

Establishing the transplant nursery created an inventory of available plants and enabled the partners to control their lifting window. Limitations still existed, however. The effort to manage the nursery without chemicals led to weed control issues because the OYA labor force was not always available for manual weed removal. The OYA inmates manually did all the nursery work, and wet weather on the coast provided only small windows of opportunity to lift seedlings for outplanting. It was difficult to remove the wet soil from the roots, and, because of the lack of weed control, roots were damaged when the workers separated the target plant from the weeds. The lifted plants had to be bagged or boxed and stored in a cooler, but the 3-year-old plants were quite large and difficult to package properly. Also, because the ideal planting window for dormant bareroot plants coincides with high streamflow events, seedling storage was needed late into the spring. This storage duration meant that the cooperative was still dealing with long-term storage issues and possibly missing spring root development.

Given the difficulties in handling and storage of bareroot plant material, the partnership decided to pursue container plant production. In 2003, all 2-year-old bareroot tree seedlings were transplanted into 1-gal (3.8-L) Tall One Treepots™ (Stuewe and Sons, Inc., 4 in [10.2 cm] wide and 14 in [35.6 cm] deep) and grown for 1 additional year. A small test area was developed and was so successful that holding racks for containers were built (figure 2), and the entire nursery area was converted to containers in 2004. Transplanting into containers resulted in larger, more competitive stock, less weeding needed, longer planting windows, and less root disturbance (figure 3) while still benefitting from the OYA labor force (figure 4).

The next issue to be addressed was species diversity. Planting solely conifers did not meet all the streamside restoration objectives (such as shade to reduce stream temperature, bank stabilization, nutrient input, etc.). Some of these objectives could be met sooner by incorporating deciduous tree and shrub species that were not available through donations. In 2002, BLM's Horning Seed Orchard (Colton, OR) had three commercial-sized greenhouses that were being used at only one-third capacity for upland conifer plug production. The BLM received a grant from the National Fish and Wildlife Foundation that was used to improve the middle greenhouse span to accommodate an area for the restoration partnership to start containerized seedling production (figure 5). To formalize this relationship, a memorandum of understanding (MOU) was constructed among BLM, 7 Watershed Councils, Tillamook County Soil and Water Conservation District, OYA, and Tillamook Estuaries Partnership, all of which were within the geographic boundaries of the Tillamook Resource Area of the BLM's Salem District. Watershed councils from the

Figure 2. Holding racks were built (left) to convert the Camp Tillamook Nursery from bareroot to container seedling production (right). Each rack holds 90 plants and will last up to 15 years. (Photos by Kurt Heckeroth 2003)

Figure 3. Western redcedar (left) and sedge (right) growing in containers at Camp Tillamook Nursery (Photos by Kurt Heckeroth 2012)

Figure 4. Oregon Youth Authority Camp Tillamook Work Study Center workers applying fertilizer to newly potted western redcedar seedlings. (Photo by Kurt Heckeroth 2012)

Figure 5. A greenhouse at the Bureau of Land Management's Horning Seed Orchard was placed into production for the Restoration Partnership. (Photo by Kurt Heckeroth 2003)

Willamette Valley were also invited to partner, which created the need to separate seed collections from coastal and valley watersheds. Because Federal dollars were now being used to fund restoration on private lands, the Wyden Amendment was used as the authority, which limited partnered projects to only watersheds that could show benefit to public lands. The Horning Seed Orchard started approximately 40,000 seedlings and grew 12,000 plants in 1.0-gal (3.8-L) Tall One Treepots™ for outplanting on a yearly basis. Trees to be outplanted were shipped to 4 drop points along the Oregon coast (figure 6).

In 2010, the BLM began a process to reorganize their tree improvement program, which would eventually reduce and eliminate the partner's ability to use the greenhouses at the Horning Seed Orchard. To adapt to this change, the partnership secured funds to build a commercial-sized greenhouse in Tillamook (figure 7) located at the OYA Camp Tillamook Work Study Center. The partnership also worked with school districts and partners throughout the northwest corner of Oregon to revitalize greenhouses in disuse from underused or unfunded

Figure 6. Trees being delivered to the U.S. Fish and Wildlife Service wildlife bird refuge just south of Pacific City, OR, one of four drop points along the Oregon coast. (Photo by Kurt Heckeroth 2005)

Figure 7. A new greenhouse was constructed at the Oregon Youth Authority Camp Tillamook Work Study Center in 2012 for seedling production after the Horning Seed Orchard greenhouse was no longer available. (Photo by Kurt Heckeroth 2012)

agriculture programs and created 13 additional satellite nurseries (table 1). These geographically dispersed nurseries significantly reduced the cost for plant distribution.

Restoration Through Education

To efficiently collect reproductive material and develop community involvement, the partnership established a workshop program in 2004 that focused on 20 different native riparian plant species including conifers, hardwoods, and shrub species. The workshops are provided to coordinators, teachers, youth corps, and volunteers (figure 8). Workshops have been offered through Oregon State University Extension offices, the BLM office in Tillamook, Lewis and Clark National Park in Astoria, or one of the partner's facilities. An additional workshop was developed for grade school and high school classes in which the students learn about plant propagation in a classroom setting (figure 9) and during hands-on sessions (figure 10). In some schools, students grow plants in a native plant nursery at the school (figure 11) and plant them 2 years later on restoration sites with the local watershed councils. All of the education sessions emphasize nonprofit, community-based restoration efforts for riparian and wetland habitats. Information provided through the workshops includes plant identification, seed collection, seed extraction (if needed),

Table 1. List of satellite nurseries in Oregon built to help educate local communities and create a sustainable supply of genetically adapted plant material; any surplus plant material is made available to all partners if the genetics are appropriate.

Site in Oregon	Infrastructure	Production capacity: 1.0-gal (3.8-L) Tall One Treepots™	Production capacity: 16-in^3 (262-cm^3) Ray Leach Cone-tainers™	Primary beneficiaries (county)
Camp Tillamook (Tillamook)	1 greenhouse		50,000	All partners
	Outdoor growing area	25,000		Lincoln, Tillamook, Clatsop
Ecotopia (Cloverdale)	Outdoor growing area	4,000		Lincoln, Tillamook
Lewis and Clark National Park (Astoria)	Emergent shade house		20,000 wetland species	Clatsop
	Outdoor growing area	2,000		
Rainier High School (Rainier)	1 greenhouse		5,000	Columbia
	Outdoor growing area	2,000		Clatsop
St. Helens High School (St. Helens)	1 greenhouse		To be determined	Columbia
	Outdoor growing area		To be determined	
Columbia River Youth Corps Campus (Warren)	Outdoor growing area	4,000		Columbia
Scappoose High School (Scappoose)	Outdoor growing area	2,000		Columbia
Vernonia High School (Vernonia)	1 greenhouse		30,000	Columbia, Tillamook, Washington
	Outdoor growing area	2,000		
Trillium Forest Nursery (Vernonia)	Outdoor growing area	2,000		Columbia, Tillamook, Washington
Newberg High School (Newberg)	3 greenhouses		5,000	Washington, Yamhill
	Outdoor growing area	2,000		
Miller Woods (McMinnville)	1 greenhouse		1,000 or more	Yamhill
Eddyville Charter School (Eddyville)	1 greenhouse		5,000	Lincoln
	Outdoor growing area	1,000		
Westwind (Lincoln City)	Outdoor growing area	2,000		Lincoln
Taft High School (Taft)	Outdoor growing area	2,000		Lincoln

Figure 8. Workshops provide partners training on seed collection, seed extraction, seed storage, and propagation techniques. (Photo by Alex Sifford, Nestucca/Neskowin/Woods Watershed Council 2010)

Figure 9. Educational programs include classroom learning and demonstrations about plant propagation. (Photo by Alex Sifford, Nestucca/Neskowin/Woods Watershed Council 2010)

Figure 10. Hands-on plant propagation is part of the educational workshop program. (Photo by Alex Sifford, Nestucca/Neskowin/Woods Watershed Council 2010)

Figure 11. At some schools, students propagate and grow plants at a native plant nursery at the school. (Photo by Alex Sifford, Nestucca/Neskowin/Woods Watershed Council 2010)

seed storage, sowing techniques, and vegetative propagation methods under controlled greenhouse environments and outdoors at the project site. The importance of genetic diversity is emphasized throughout each workshop. After a full day in a classroom setting, a field day is offered to gain hands-on experience and follow-up to the information presented in the classroom. These workshops are provided upon request by the partners and usually held in the fall when many of the native tree and shrub species are readily available to collect.

The partnership has also established relationships with several youth corps and provides them with the opportunity for natural resource conservation training. The youth help collect seed, propagate and transplant seedlings, perform site preparation and planting techniques, and provide maintenance at the project site. Their participation has been crucial to the success of this cooperative effort. Educating youth is important as they are the next land stewards and, through education and hands-on experience, will be able to make wiser choices by understanding how their activities on the landscape affect fish and wildlife habitat and impact water quality.

In addition to workshops, each partner has incorporated volunteer activities that provide opportunities for hands-on education (figure 12). These activities promote local community interest and landowner participation.

Figure 12. Partner volunteers potting tree seedlings for restoration plantings. (Photo by Kurt Heckeroth 2005)

Collection And Propagation

The partnership model initially was to provide education and to have each partner be in control of his or her community-based collection of reproductive plant material. The material was batched with other partners' collections according to seed zone and elevation or by watershed, and then propagated and returned to the appropriate location for planned restoration projects. It was soon recognized, however, that without tight control of the collection process, plant viability could be compromised because of poor collection timing and seed handling before sowing. Since 2012, all the seed that is collected for the coop is overseen by the partnership coordinator and direct sown. The seed collection protocol for a particular species batch calls for a minimum of 15 parent plants from 15 separate locations spaced at least 0.5 mi (0.8 km) apart, with each parent contributing no more than 15 percent to the batch. This protocol is also recommended for vegetative collections. Elevation bands of 500 ft (152 m) are also observed although most of the project sites are below 500-ft (152-m) elevation.

The partners produce approximately 40,000 shrub and hardwood plants annually. All seed are direct sown immediately after collection into 16-in^3 (262-cm^3) Ray Leach Cone-tainers™ and left outdoors through the winter to go through a natural stratification (figure 13). The trays and tubes are covered tightly with shade cloth to prevent predation from birds and rodents. The next spring, they are moved into the greenhouse to encourage germination. Plants are grown in the greenhouse for 4 to 6 months (figure 14) and then transplanted into 1.0-gal (3.8-L) Tall One Treepots™ in July or August, just in time to take advantage of the fall root development period and set up the plant for vigorous growth the next spring. Initially, the partnership used smaller containers to conserve greenhouse space but found transplanting was required earlier than desired, resulting in capacity issues with the outdoor nursery. For educational purposes or when the seed collection window is missed or not available based on environmental conditions, vegetative propagation is used. For some species, it is quicker to create a larger, more robust plant from cuttings than from seed. Both hard and soft tissue cuttings are used (figure 15). Cuttings are struck into Ray Leach Cone-tainers™ and transplanted to Tall One Treepots™ after adequate root growth occurs. Most shrubs and hardwoods are grown at the nursery for 2 years before outplanting.

Figure 13. Shade house being constructed at the Oregon Youth Authority Camp Tillamook Work Study Center to use for direct sowing and outdoor natural stratification over the winter. The shade cloth protects seed from bird and rodent predation yet allows for ambient temperatures and rain. (Photo by Kurt Heckeroth 2012)

Figure 14. Black twinberry seedlings being grown for restoration plantings. (Photo by Kurt Heckeroth 2013)

Figure 15. Several native plant species, including stink currant, are grown from cuttings. (Photo by Kurt Heckeroth 2013)

In addition to the shrub and hardwood plants, more than 30,000 conifer seedlings are grown as plug+1 stock at private nurseries in the Willamette Valley and then transplanted into containers at one of the established partnership nursery sites on the coast (table 1). The bareroot seedlings are lifted in mid-January and held in the BLM cooler at Tillamook until they can be transplanted in mid-to late February. The main conifer species used are Sitka spruce (*Picea sitchensis* [Bong.] Carrière), western hemlock (*Tsuga heterophylla* [Raf.] Sarg.), grand fir (*Abies grandis* [Douglas ex D. Don] Lindl.), western redcedar (*Thuja plicata* Donn ex D. Don) and Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco). All conifers are transplanted into 1.0-gal (3.8-L) Tall One Treepots™. These container dimensions force the root mass to develop to a depth that makes it more competitive underground when outplanted and provides the plant with more stability. Outside growing areas have been constructed throughout the northwest corner of Oregon to grow 45,000 of these containerized conifer and hardwood seedlings per year.

Northwest Oregon Restoration Partnership

A new partnership, the Northwest Oregon Restoration Partnership (NORP), has recently been created through a new MOU that builds upon the success of the Tillamook Native Plant Cooperative. The NORP includes the original partners plus approximately 20 additional agencies, organizations, and schools that want to share resources to restore not only riparian and wetland habitats but also prairie, Oregon white oak, high-elevation meadows, and other important habitats in and around Oregon's north coast range.

Because of the growth in the partnership, the Tillamook Bay Watershed Council (TBWC) agreed to apply and become the recipient of an Oregon Watershed Enhancement Board grant to fund a NORP coordinator and also manage Federal funds through a 5-year Cooperative Assistance Agreement with the BLM. All BLM funds that support the NORP are used to purchase supplies required to operate the partnership nurseries (such as soil, pots, fertilizers, and additional infrastructure costs such as propane, water, and electricity). The TBWC has hired the NORP coordinator as an employee with the objective to act as the central point of contact, to research funding opportunities, coordinate educational workshops, identify and coordinate seed collection windows for each plant species, and manage the plant production and dispersal for the entire partnership on an annual basis. Each fall, the partners provide the NORP coordinator with a plant request based on project needs. Plant material that is not readily available through the cooperatives, current plant inventory will be purchased from private nurseries if the appropriate genetics can be found.

This partnership has been successful for several reasons:

1. The BLM has provided essential funding and technical support for the plant propagation that has contributed to low mortality rates.
2. The partners are able to use the cost of plant material to secure grant funding for planned projects.
3. The partners are key to project implementation. They outplant the nursery plants onto the landscape, mostly on private lands, and restore approximately 20 to 25 mi (32 to 40 km) of degraded riparian areas each year.
4. The partners make the necessary landowner contacts, educate landowners why streamside restoration is important for fish, wildlife and water quality, and write grants to support the project work (site prep, planting, fencing, caging, and maintenance).
5. The process of providing plants is based on, and adjusted for, meeting partners' needs; this will continue into the future.

Using BLM funding sources that are targeted for native plant restoration through this partnership has shown recognizable benefit to whole watersheds that benefit from restoration efforts completed on public lands. In addition to using BLM funds, NORP partners are pursuing grant opportunities with the U.S. Fish and Wildlife Service, National Fish and Wildlife Foundation, Oregon Watershed Enhancement Board, Oregon's Department of Environmental Quality, and other sources to integrate funds for plant propagation so that the BLM is not the sole funding source for the propagation part of the project.

Everyone understands the importance of having a diverse funding stream that reduces the risk of failure if the BLM does not have the budget to continue funding the partnership. The contributions of BLM, however, allow the partners to use Federal contributions as match for grants, a concept that has built and maintained this partnership for more than 10 years. Partners use the initial investment by BLM to raise large amounts of additional funds for the project, bringing in more than $3 for every $1 spent by BLM. This project has made significant improvements to watershed health, and the partnership looks forward to continuing to work together to improve degraded habitats and water quality throughout the northwest corner of Oregon.

Accomplishments

From 2002 to 2011, significant landowner participation, education events, and miles of planting along streams occupied by federally listed endangered fish has occurred (table 2). Because of this level of local involvement established through the partnership, entire communities have raised their awareness concerning the benefits of healthy riparian conditions affecting fish and wildlife habitat and water quality. These efforts encourage and generate respect for good stewardship on both private and public lands. The emphasis for BLM's participation in this partnership is to support restoration projects that address problems and implement recommendations identified in 32 watershed analyses covering the north coast range completed as part of Salem District's land use planning. All these watershed analyses recognize that continuity of watershed health is needed to sustain and stabilize the resources that use or are part of BLM lands and the communities that BLM serves.

It does no good to fix just a portion of a problem that may exist only on BLM-administered lands when other parts of a watershed are unraveling or are not properly functioning. NORP is instrumental in restoring the whole watershed through all the partners working on all land ownership types. This partnership has been recognized as a successful working model to restore ecosystem function and has garnered awards in recognition of its achievements from the American Fisheries Society, the Public Lands Foundation, and from former BLM Director Robert Abbey for excellence through stewardship in BLM. NORP continues to draw interest and grow because of its success in addressing on-the-ground needs, providing community-based education, and encouraging public participation. The actions undertaken by NORP support the Oregon Plan for Salmon and Watersheds, the Oregon Conservation Strategy, Oregon Coast and the Coho Conservation Plan, and

Table 2. Summary of Tillamook Resource Area riparian restoration accomplishments.

Activity	FY 2011	Total FYs 2002–2011
Streams planted (mi)	27	256.27
Wetlands planted (ac)	22	114.03
Riparian fences constructed (mi)	4.26	51.47
Project maintenance (mi)	42.14	353.27
Number of landowners involved	411	1,937
Number of future landowners contacted	354	1,903
Number of plants propagated (other than at Horning or Camp Tillamook)	6,750	58,680
Number of education sessions or tours	43	291
Number of people attending education sessions or tours	879	7,813
Monitoring (mi)	76.6	467.93
BLM/NFWF funds expended	$115,000	$799,671
Partner donation value (includes OWEB funding)	$187,262*	$1,840,937*

BLM = Bureau of Land Management. FY = fiscal year. NFWF = National Fish and Wildlife Foundation. OWEB = Oregon Watershed Enhancement Board
*These numbers reflect only the amount reported by partners as a match for the project. When we surveyed the partners regarding total contributions, we found that they bring approximately $350,000 per year to the project. Throughout the 9 years of implementation, the Tillamook Resource Area Riparian Restoration Effort watershed organizations have contributed more than $3 million to the project.

meets multiple BLM strategic goals and planning objectives, including, but not limited to, threatened and endangered species recovery, community support, partnerships, youth, fish and wildlife habitat, water quality, and biological system integrity. In addition to providing shade and water filtering to improve salmon habitat and water quality, much of the riparian planting also helps to control invasive species such as reed canarygrass, Scotch broom (*Cytisus scoparius* [L.] Link), English ivy (*Hedera helix* L.), Himalayan blackberry (*Rubus armeniacus* Focke), and knotweed (*Polygonum* L.) that occupy many project sites.

Summary

NORP's work will make it possible to restore thousands of acres of native plant communities in riparian, wetland, and rare upland habitats at priority sites throughout watersheds in northwest Oregon. NORP supports partners' resource management plans, watershed analyses, and restoration activities by providing locally adapted native plant materials. NORP's efforts play a central role in the restoration of threatened and endangered salmonid streams and rivers and improvement of water quality throughout northwest Oregon.

NORP has transformed the geographic region in the northwest corner of Oregon from an area where a wide variety of efforts were competing to achieve the same goals into a more cohesive, cooperative effort for riparian restoration. The program has created a transition from plant material being sought out by individual entities to a collaborative effort that has created a sustainable supply of locally adapted native plant materials. In addition to sharing plant materials, technical advice is shared regarding seed collection, vegetative propagation, site preparation, planting techniques, animal damage protection, and maintenance. In some cases, proposals for grants are collaboratively written to support these cooperative efforts. Previously abandoned agriculture program greenhouses at schools are being rejuvenated to support restoration. Partners have greater opportunities to receive and give education to their local communities. This program is a working model of successful cooperative watershed management where boundaries can be crossed and restoration can be identified on an entire watershed scale.

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- For online resources, provide the URL and the month accessed.

Examples

Journal article:	Graham, J.S.; Joyner, P.A. 2011. Tree planting in Alaska. Tree Planters' Notes. 54(2): 4–11.
Entire book:	Pallardy, S.G. 2008. Physiology of woody plants. 3rd ed. Burlington, MA: Academic Press. 454 p.
Chapter in book:	Goorahoo, D.; Sharma, F.C.; Adhikari, D.D.; Benes, S.E. 2011. Soil-water-plant relations. In Stetson, L.E.; Mecham, B.Q., eds. Irrigation. 6th ed. Falls Church, VA: Irrigation Association: 23–73. Chapter 3.
Article in proceedings:	Dumroese, R.K.; Jacobs, D.F.; Davis, A.S.; Pinto, J.R.; Landis, T.D. 2007. An introduction to subirrigation in forest and conservation nurseries and some preliminary results of demonstrations. In Riley, L.E.; Dumroese, R.K.; Landis, T.D., tech. coords. National proceedings, forest and conservation nursery associations—2006. Proc. RMRS-P-50. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 20–26.
Thesis or dissertation:	Akgul, A. 2004. Performance of slash pine (*Pinus elliotti engelm*) containerized rooted cuttings and bare-root seedlings established on five planting dates in the flatlands of western Louisiana. College Station, TX: Texas A&M University. 91 p. Ph.D. dissertation.
Online resource:	Bardon, R.E.; Megalos, M.A.; New, B.; Brogan, S., eds. 2010. North Carolina's forest resources assessment: a statewide analysis of the past, current and projected future conditions of North Carolina's forest resources. Raleigh, NC: North Carolina Division of Forest Resources. 489 p. http://www.ncforestassessment.com. (January 2011).

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