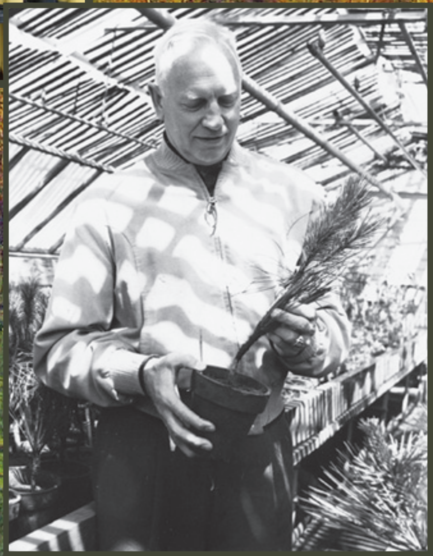
Tree Planters' Notes



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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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Editor: Diane L. Haase

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Fall 2011

Dear TPN Reader

I am pleased to bring you a second issue of *Tree Planters' Notes* (TPN) for 2011. The Spring 2011 issue was met with enthusiastic response—thanks for all your positive comments regarding the cover redesign, the use of color throughout, and the great articles.

In this Fall issue, Alaska, North Carolina, and Wisconsin are each featured in the TPN Series: Tree Planting State by State. It's interesting how diverse each State is in its environment, forest composition, and reforestation programs. In addition to the State articles, there are five other articles filled with technical and scientific information of use to nursery, reforestation, and restoration practitioners. You can read about painting hardwood seedlings in the nursery so they are easily visible for surveying after outplanting, a machine-planting system designed to accurately and efficiently establish progeny plantations, research that shows evidence of nitrogen fixation in willows, programs to establish disease-resistant Port-Orford-cedar, and results from a research trial to evaluate growth and survival of fall-planted Douglas-fir seedlings. A hearty thank you to the authors who agreed to take the time to prepare these articles.

Please consider submitting a paper to TPN. As the new editor, I'm determined to publish this journal twice annually (spring and fall issues). To accomplish that, I need more articles. Guidelines for authors appear at the end of this issue and online at http://www.RNGR.net/publications/tpn/author_guidelines.

I would also like suggestions for future articles and authors—What would you like to know more about? Do you know of someone who is doing something innovative or interesting with regard to reforestation, plant propagation, restoration, nursery management, or conservation? Please send your suggestions to me at DLHaase@fs.fed.us.

A reminder—we are updating the TPN mailing list. You MUST renew your subscription before the end of 2011 to continue receiving copies. Currently, TPN subscriptions are free. I encourage you to consider switching to an electronic subscription to minimize paper, printing, and postage costs. New subscriptions are also welcome. Instructions for subscriptions and renewals are on page 3 below the Contents.

Cheers,

Diane L. Haase

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Thank you.

Tree Planting in Alaska

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Abstract

Tree planting for reforestation in Alaska has been modest compared with other timber-producing States and has never exceeded 1 million trees a year. Most timber harvest occurs in southeast Alaska, where natural regeneration is usually prolific and logistical costs are very high. Tree planting has been more suited to the boreal forest, where white spruce (*Picea glauca* (Moench) Voss) regeneration is sought and natural regeneration can be problematic. In the 1990s, a large spruce bark beetle (*Dendroctonus rufipennis* Kirby) epidemic on the Kenai Peninsula stimulated tree planting. Planting for poplars (*Populus* spp.) may develop near rural communities as biomass energy develops. Tree planting by homeowners and communities has been growing, which has resulted in the development of several community tree inventory programs and management plans. In 2010, approximately 1,600 trees were planted on municipal property or in public rights-of-way in Anchorage, and a much higher number is estimated to have been planted on private and other public land.

Introduction

History

Eskimos, Aleuts, and Indians are Alaska's first peoples, and anthropologists believe that Native Americans have lived in parts of Alaska for at least 10,000 years (Department of Natural Resources 2000). In the mid-1700s, Russian fur traders established posts and purportedly claimed Alaska. In 1805, Russian settlers transplanted Sitka spruce to the western Aleutian Islands, far beyond the range of forests, a grove of which survives today (Rakestraw 2002). This effort may be the first toward afforestation in the Americas. In 1867, Russia sold its interest in Alaska to the U.S. Government for $7.2 million, or about $0.02 an acre. Initially, Alaska was under U.S. military administration as the Department of Alaska. In 1912, the Alaska Territory was designated.

Outlined in the Statehood Act of 1959, the Federal Government granted the new State entitlement to 105 million acres (42.5 million hectares), or 28 percent of Alaska's total area. Much of the land near major communities was granted to the State and then transferred to local governments or private individuals. Although actual homesteading is no longer offered, State land sales are ongoing, mostly in remote locations without road access.

After establishing statehood, recognition arose that Russian and United States, claims were subject to unresolved aboriginal land claims by Alaska's first peoples. In 1971, the Alaska Native Claims Settlement Act (ANCSA) was intended to settle aboriginal land claims in exchange for 44 million acres (18 million hectares) of Federal land. ANCSA established more than 220 privately owned Alaska Native corporations, which differed from the reservation system common elsewhere. In 1980, President James Carter signed the Alaska National Interest Lands Conservation Act, which designated 106 million acres (43 million hectares) of Federal lands for conservation system units, thereby greatly enlarging the amount of Federal acreage dedicated to conservation.

Economy

The petroleum industry is Alaska's most important natural resource sector, contributing roughly one-third of the State's total economy (Goldsmith 2008). Alaska's other major resource industries are seafood, mining, and timber. Government employment, including the military, is also significant to Alaska's economy. Large-scale timber harvesting in southeast Alaska began in the 1950s, but the timber industry has declined since the 1990s. Alaska is among the world's top seafood producers, and only eight countries produce more wild seafood than the State of Alaska. The value of Alaska's minerals has climbed in recent years as metal prices have risen, and feasibility studies are under way for several new, large mining prospects.

Forest Regions

Alaska has 126 million acres (51 million hectares) of forest land, which is 35 percent of the State's total area and 17 percent of all forest area of the United States (Smith and others 2009). Alaska encompasses a diverse set of geological, climatic, and vegetative conditions. The State's 365 million acres (148 million hectares), which is one-fifth of the entire United States, have been divided into six ecological units: Southeast, South-central,

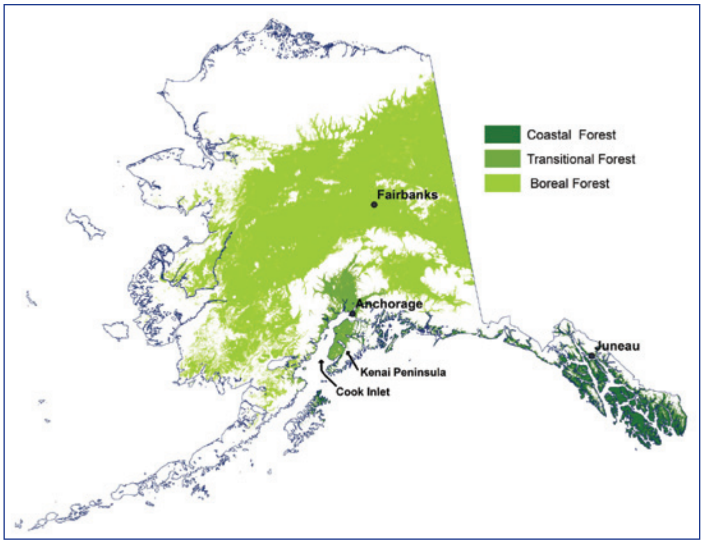

Figure 1. Alaska forest regions (Map source: Hans Buchholdt, Alaska Division of Forestry).

Southwest, Interior, Northwest, and Arctic (Viereck and others 1992). Alaska has three major forest regions (figure 1). More than two-thirds of Alaska's communities and more than three-fourths of the State's population live on or adjacent to forest lands. Of the 220 Alaska Native corporations, 90 percent own some forest land.

Coastal Forest

The coastal forest has a distinctly maritime climate with cool summers, moderate winters, and abundant rain year round. The coastal forest is part of one of the most productive forest ecosystems in the world. Western hemlock (*Tusga heterophylla* (Raf.) Sarg.)/Sitka spruce (*Picea sitchensis* (Bong.) Carr.) is the predominant forest type, and both western redcedar (*Thuja plicata* Donn) and Alaska yellow-cedar (*Chamaecyparis nootkatensis* (D. Don) Spach) are present. Large trees that exceed 6 ft (1.8 m) in diameter and reach nearly 200 ft (61 m) in height can be found in the southern part of this forest ecosystem. Tree size decreases with increasing latitude and longitude. Only pure Sitka spruce stands occur in the Kodiak archipelago, where western hemlock is not present. A wide diversity of wildlife species are found in this forest, including deer, bear, moose, mountain goat, and five species of salmon. Approximately 31 Alaska Native village corporations and three Alaska Native regional corporations are located in the coastal region. Historically, the coastal forest has supported significant timber harvest (Rakestraw 2002). Native Americans and Russian settlers used timber for buildings and vessels. In 1889, the Governor reported that 11 sawmills were operating in Alaska. Timber harvest was high during the operation of two large pulp mills, but these mills are now closed and the amount of timber harvest has greatly declined in recent years.

Boreal Forest

The interior forest is part of the circumpolar boreal forest type and comprises 115 million acres (47 million hectares) in Alaska (figure 1). Summers can be warm and dry, and long winters are among the coldest in North America. Vast areas of black spruce (*Picea mariana* (Mill.) B.S.P.) form the taiga, or "land of little sticks," and are characteristic of the boreal forest. Black spruce often grows on sites where permafrost is present. In contrast, significant stands of mature white spruce (*Picea glauca* (Moench) Voss) and mixed stands of spruce and paper birch (*Betula papyrifera* Marsh.) are found along river flood plains. In some flood plain stands, white spruce measure more than 2 ft (61 cm) in diameter and reach 100 ft (30 m) in height. Paper birch, aspen (*Populus tremuloides* Michx,), and balsam poplar (*Populus balsamifera* L.) stands are usually located on previously disturbed sites (generally fire sites). Moose, bear, caribou, beaver, and wolf are common wildlife species found in this forest type. Significant numbers of spawning salmon are found in many of the streams during the summer. The Federal Government is the principal landowner in this region, although large tracts of lands have been transferred to ANCSA corporations, to the State, and to various boroughs. Individually owned tracts are primarily along the limited road system, although native land allotments are scattered throughout the region.

Transitional Forest

In the Cook Inlet Basin of south-central Alaska, the climate forms a transitional zone between coastal and boreal (figure 1). Summers are cool but dry enough for wildfires to occur, and winters are moderate compared with the interior portions of Alaska. Outside the Cook Inlet basin, high mountain ranges separate boreal and coastal forests. On the western Kenai Peninsula and around Anchorage, the forest type is outwardly similar to the boreal forest and is mostly paper birch, quaking aspen, and white and black spruce. The highest population density and largest number of individual private forest owners are in the transitional forest zone.

Challenges to Trees

Climate Change

The University of Alaska Fairbanks research provides likely scenarios of future climate conditions in Alaska (Scenarios Network for Alaska Planning 2008). The projected Alaska statewide trends indicate that temperatures and precipitation are expected to increase across all regions. Temperature increases are predicted for every month, and increases are expected to continue throughout the century (Scenarios Network for Alaska Planning 2010). Although the growing season precipitation is likely to increase statewide, precipitation alone does not predict ecosystem moisture limitations. Increased plant growth and increased evaporation because of higher temperatures may more than offset the additional precipitation, resulting in drier soils. Climate change is expected to affect many aspects of Alaska. Forest effects are expected to include wildfire, insect epidemics, invasive species, forest regeneration and growth, and wildlife habitat. For example, the 2004 wildfire season, the largest documented since the early 1950s, was a direct result of record temperatures and little precipitation. Also, the first recorded large spruce budworm outbreak (*Choristoneura fumiferana* Clemens) occurred in the early 1990s and may have resulted from elevated summer temperatures that produced drought stress in the host white spruce trees.

Wildfire

The amount of annual acreage burned in the boreal forest ranges from an average low of about 100,000 acres to a high of more than 6 million acres (40,000 to 2.4 million hectares). Lightning causes most wildfires, but the large majority of fires that start near communities are human caused. Essentially no trees, however, are planted following wildfire in Alaska because natural regeneration is usually enhanced by fire, particularly for broadleaf browse species.

Bark Beetle

During the 1990s, a historic spruce beetle (*Dendroctonus rufipennis* Kirby) epidemic occurred in south-central Alaska, and more than 4 million acres (1.6 million hectares) of both pure white spruce and mixed spruce-hardwood forest were affected. The spruce beetle epidemic on the Kenai Peninsula that began in the late 1980s and continued into the 1990s was most likely triggered by the significant climatic shift to longer and drier spring-summer periods (Berg and others 2006, Werner and others 2006). During the epidemic, the western Kenai Peninsula sustained more than 80 percent beetle-caused mortality on approximately 1 million acres (0.4 million hectares) of mature white spruce forest. Many landowners, both public and private, conducted salvage harvesting and tree planting in response to the epidemic.

Land Ownership

Federal Land

The Federal Government is the largest landowner in Alaska and is responsible for 222 million acres (90 million hectares), or 60 percent of the State. More than a dozen Federal agencies manage lands in Alaska. Most Federal lands are reserved for conservation of natural areas, such as national parks and wildlife refuges. The Bureau of Land Management, the largest Federal land owner in Alaska, manages 82 million acres (33 million hectares). The U.S. Fish and Wildlife Service manages 79 million acres (32 million hectares) in 16 national wildlife refuges. The National Park Service manages 52 million acres (21 million hectares) in 13 national parks or preserves, including the 5 largest parks in the United States. The Forest Service manages 22 million acres (8.9 million hectares), including the two largest national forests in the United States, the Chugach and Tongass National Forests, as well as two national monuments.

Alaska Native Lands

ANCSA mandated the formation of Alaska Native corporations to accept the title for approximately 44 million acres (18 million hectares) of selected Federal lands. Most land selections are complete, but the process of transfer of title from the Federal Government to the corporations is still in progress. Great variation exists in the size of corporate holdings and management objectives. Lands granted under ANCSA are private and, thus, are not Federal trust lands, such as reservations managed by the Bureau of Indian Affairs. ANCSA corporations own an estimated 95 percent of the private forest acreage in Alaska. Less than 1 percent (about 700,000 acres or 283,000 hectares) is in individual Native allotments.

State Land and State Forests

As of 2010, the State has received patent to approximately 99 million acres (40 million hectares), 96 percent, of its total land entitlement. The State was permitted to select lands from any Federal land not already reserved for other uses. The State chose land to meet three specific needs: settlement, resource stewardship and development, and recreation. About 2 percent of Alaska's State-owned land is in three designated State forests. In 1982, the legislature established the Haines State Forest. The next year, it created the Tanana Valley State Forest. In 2010, the Southeast State Forest was established. In addition to designated State forests, much of the State's public domain land is available for multiple uses, including forest management.

The 270,410-acre (109,477-hectare) Haines State Forest is located in the northern tip of the southeast Alaska panhandle. The panhandle generally has a maritime climate, but high surrounding mountains create warmer and drier summer conditions than the rest of southeast Alaska. Hence, the forest provides suitable conditions for a diversity of vegetation. The rugged topography ranges from sea level up to a more-than-7,000-ft (2,100 m) elevation. The forest is composed mostly of two forest types, western hemlock/Sitka spruce, and black cottonwood (*Populus trichocarpa* Torr. & Gray)/willow (*Salix* spp.). Lodgepole pine (*Pinus contorta* Dougl.) and paper birch are minor species throughout the forest.

The 1.8 million acre (0.73 million hectares) Tanana Valley State Forest lies almost entirely within the Tanana River Basin and is located in the east-central part of Alaska (figure 2). The basin area elevation varies from 275 ft (84 m) along the Tanana River to a more-than-5,000-ft (1,500 m) elevation, and stretches 265 mi (127 km) from near the Canadian border to west of Fairbanks. Almost 90 percent of the Tanana Valley State Forest is forested, mostly with paper birch, quaking aspen, balsam poplar, black spruce, white spruce, and tamarack (*Larix laricina* (Du Roi) K. Koch). Timber harvest from the Tanana Valley State Forest averages around 6 million board ft annually.

The 25,291 acre (10,239 hectares) Southeast State Forest is comprised of 20 separate parcels, mostly on Prince of Wales Island with some parcels on adjacent islands and the mainland. Although this land was approved for forestry activities before its designation as a State forest, the new designation will give local processors access to a long-term supply of timber. In addition, management investments, such as precommercial thinning, will be feasible.

Figure 2. Tanana Valley near Fairbanks (Photo source: Jeff Graham, Alaska Division of Forestry).

Municipal Lands

Alaska's local government structure has only two types of municipal government: cities and organized boroughs (Bockhorst 2001). Organized boroughs are intermediate-sized governments, analogous to counties. Alaska has 16 organized boroughs that average about 17,400 mi^2 (4.6 million ha^2) and encompass about 43 percent of the geographic area of Alaska. Three boroughs own significant acreage of forested land: Matanuska-Susitna Borough, Kenai Peninsula Borough, and Fairbanks North Star Borough.

Alaska is home to 686,000 people, of which more than 60 percent live in towns with populations greater than 5,000. More than one-half of the population lives in the Municipality of Anchorage or the Matanuska-Susitna Borough. Hence, the importance of Alaska urban and community forests is increasingly recognized. The number of arborists in Alaska has grown from 1 in 1991 to 32 in 2011. Community forestry programs in six communities employ arborists, foresters, or natural resource managers. The Municipality of Anchorage hired the State's first urban forester in 2008 to manage trees and forests on 10,000 acres (4,000 hectares) of parkland, 250 mi (402 km) of trails and greenways, and more than 80 mi (129 km) of rights-of-way.

Individually Owned Private Land

Excluding Alaska Native land, individually owned private land comprises less than 1 percent of the total land in Alaska. Birch (1997) reported that Alaska has an estimated 16,600 private landowners with one or more acres of forest land. Most individual private forest lands are in the more settled areas of the State, particularly the Kenai Peninsula, the Matanuska and Susitna valleys, and the Fairbanks and Delta Junction areas. Forest management objectives of individual forest landowners are diverse. In the boreal forest region, most landowners have concerns about wildfire, damaging insects and diseases, and wildlife habitat.

Trust Lands

The University of Alaska and Alaska Mental Health Trust are significant landowners and enjoy quasi-private landowner status. These land trusts predate statehood. Currently, the Mental Health Land Trust holds 999,860 acres (40,429 hectares) and the University Land Trust holds approximately 150,000 acres (60,729 hectares). Both trusts have harvested timber in southeast Alaska and largely rely on natural regeneration for reforestation.

Tree Planting in Alaska

Tree Planting in the Recent Past

During the past 20 years, tree planting in Alaska has varied considerably (figures 3 and 4), which reflects the amounts of both legislative appropriations and Alaska Native Corporation funding for reforestation. Following major wildfires, essentially no tree planting has occurred because of the remoteness of the sites and logistical high costs associated with planting there. Spruce beetle mortality has resulted in restoration efforts, but only following harvest. Under the Alaska Forest Resource and Practices Act, reforestation is required within 7 years following commercial timber harvest. Methods of reforestation are not specified, and natural regeneration can be used.

The State operated a forest nursery from 1974 to 1996. Seedlings were produced for reforestation of harvested lands, public events such as Arbor Day and fairs, and research projects. White spruce was the major species grown using Ray Leach Cone-tainers™. To meet public interest, a variety of nonnative species were also grown, such as Siberian larch (*Larix sibirica* Ledeb.), lodgepole pine, and Scots pine (*Pinus sylvestris* L.). Average annual production was around 400,000 seedlings.

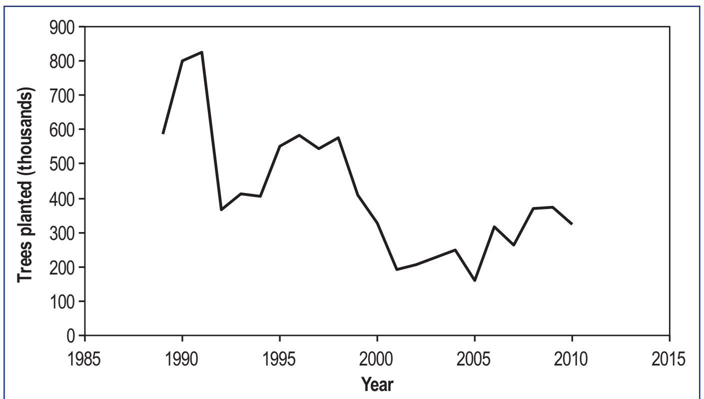

Figure 3. Trees planted for reforestation in Alaska since 1990 (Graph source: Jeff Graham, Alaska Division of Forestry).

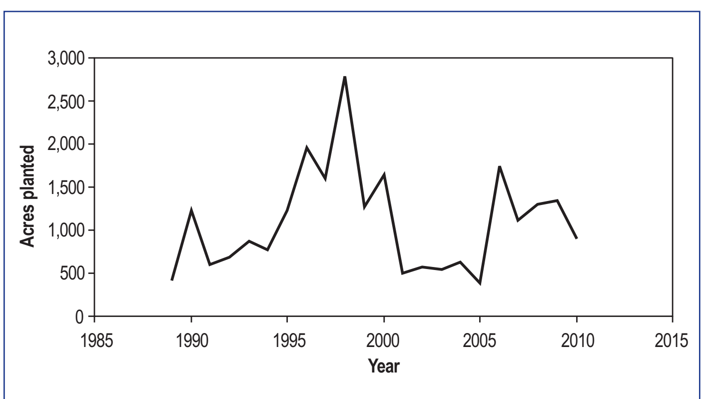

Figure 4. Acres planted for reforestation in Alaska since 1990 (Graph source: Jeff Graham, Alaska Division of Forestry).

The nursery closed because of high operating costs and availability of high-quality, less expensive, container-grown seedlings from out-of-State nurseries.

Tree Planting by Alaska Regions

Throughout most of southeast Alaska, natural regeneration of forests following timber harvest is usually abundant. Southeast second-growth forests often have densities far greater than optimum for individual tree and value growth. Thinning and pruning are silvicultural techniques that are commonly used for both timber value and wildlife habitat. Genetic gain through tree improvement has been considered for many years in Alaska. However, abundant natural regeneration in southeast Alaska and high logistical costs have hindered tree improvement development.

The Haines State Forest is located in a transitional climate in northern southeast Alaska (figure 5). In this climate some natural regeneration occurs readily. All large commercial sales have been replanted since the 1970s, however, to ensure prompt regeneration. Sitka spruce is exclusively planted and the stocktype is usually plug + 1 from an out-of-State private nursery. About 10,000 seedlings are planted annually on the Haines State Forest. Thinning and basal pruning are sometimes used on second-growth stands.

Afognak Island and the northern part of Kodiak Island have the western most commercial forest in Alaska. Afognak Island was formerly under Chugach National Forest, but a large amount was transferred to Alaska Native Corporations after ANCSA. These islands have had timber production for many decades under both Forest Service and Alaska Native corporation management. Natural regeneration has worked in some areas, but attempts in other areas have been problematic. Grass competition and browsing by hares (*Lepus* sp.) have affected

Figure 5. Timber harvest site on the Haines State Forest (Photo source: Greg Palmieri, Alaska Division of Forestry).

regeneration in some areas. Sitka spruce is exclusively planted in this region, and a southeast Alaska seed source has resulted in superior growth capabilities compared with local seed sources.

The Kenai Peninsula was heavily affected by a spruce beetle epidemic in the 1990s, and both public and private landowners have conducted salvage harvests and tree plantings. If any regeneration delay occurs, sites can become dominated by bluejoint reed grass (*Calamagrostis Canadensis* [Michx.] Beauv.) for many years. Mechanical site preparation has been commonly used. Trees planted are mostly container-grown white spruce, particularly on public and Alaska Native corporation lands. Many individual private landowners are interested in fast-growing, nonnative species such as lodgepole pine from northern Canada and Siberian larch.

Boreal forest sites are harvested for both timber and firewood. Both summer and winter logging occur, with ice roads and bridges providing the best access during winter. Mechanical scarification or fire can be effective for site preparation and natural regeneration, but winter logging alone has little site preparation effect. Without site preparation, bluejoint reed grass can be a major seedling competitor on some boreal sites. Tree planting has been effective on boreal sites (figure 6). Planting nursery grown seedlings is often too costly, however, for remote locations off the road system. White spruce seed has been collected and stored to provide out-of-State nurseries with Alaskan seed sources. Although spruce seed can retain viability for 20 years, new seed collections are made when good cone crops occur, roughly every 5 to 8 years. On the Tanana Valley State Forest, tree planting is used on a portion of harvested sites and planting averages around 400 acres (162 hectares) and 200,000 seedlings annually (figure 7). White spruce is exclusively planted on the Tanana Valley State Forest, mostly grown in Stryoblock® 313B containers.

In rural areas of interior Alaska, energy has become a major expense and is jeopardizing continued existence of many small communities. Wood energy is hoped to provide a viable alternative to fossil fuel. Studies are under way with willows (*Salix spp.*) and poplars (*Populus spp*.) to find low-cost methods of forest regeneration following biomass harvest.

Urban and Community Tree Planting

In more urban areas, Alaskans are recognizing the need for professional management of valuable forest resources, especially because they witness how pests, invasive species, wildfire, climate change, and expanding development limit the benefits that community trees and forests could be providing. Inventories and management plans are helping them select appropriate species and planting and maintenance techniques. Cities are also beginning to adopt ordinances that require developers to meet standards for the number and quality of plants installed as part of any construction project.

The palette of plant species used has expanded greatly in the past 20 years. Although only 33 native species of trees grow in Alaska, approximately 130 species are being grown successfully in the State. A description of trees and shrubs planted in Alaska has recently been developed (Alaska Cooperative Extension Service, Alaska Division of Forestry; American Society of Landscape Architects Alaska Chapter 2010).

In-State nurseries are not currently meeting the growing demand for landscape trees. This demand creates a potential market for local growers, however (figure 8). Most retail and wholesale nurseries import trees from out-of-State nurseries. Stock types include bare root, container-grown, and balled and burlapped trees, but rarely seedlings. Traditionally, large numbers of trees were dug from the wild to meet the need for

Figure 6. White spruce regeneration from planted seedlings on Toghotthele Corporation land with Jake Sprankle of Tanana Chiefs Conference (Photo source: Jeff Graham, Alaska Division of Forestry).

Figure 7. Tree planters on the Tanana Valley State Forest (Photo source: Patricia Joyner, Alaska Division of Forestry).

native plants; however, easily accessible sources are becoming more difficult to find, which is leading to an increase in locally grown plants.

In 2010, approximately 1,600 trees were planted on municipal property or in public rights-of-way in Anchorage. A much higher number was likely planted on residential, commercial, school district, university, and State and Federal Government properties. Military bases plant a large number of trees each year as part of residential development and restoration projects. In 2010, Eielson Air Force Base planted 500 trees, and Joint Base Elmendorf-Richardson planted 200 trees. Other communities around the State plant between 15 and 150 trees annually on city-maintained property.

Figure 8. Commercial nursery for landscape trees near Anchorage (Photo source: Patricia Joyner, Alaska Division of Forestry).

Figure 9. Community tree planting in Hoonah, AK (Photo source: Tina Denzl-Pederson, City of Hoonah).

Programs for Tree Planting

Most tree planting in Alaska occurs on State forests after administratively approved management plans and legislative appropriations have been established. Tree planting on private lands, including Alaska Native corporation lands, has been aided by Federal cost share from the Forest Land Enhancement Program and the Environmental Quality Incentives Program. The Forest Stewardship Program has contributed management plans for eligibility to cost share programs. Tree planting on borough lands has been aided by Federal funding from the American Recovery and Reinvestment Act of 2009. The Cook Inlet Chapter of Society of American Foresters (CISAF) has conducted an annual Arbor Day tree sale in Anchorage for many years. The CISAF tree sale has annually provided urban and suburban residents with around 10,000 seedlings, including a variety of native and nonnative species. Small-scale growers and city parks departments also take advantage of this opportunity to buy quantities of seedlings at a low cost. The Fairbanks Soil and Water Conservation District also holds an annual sale of native and nonnative tree and shrub species.

The Alaska Community Forestry Program helps communities build forestry and tree care programs that include tree planting. Since 1991, the number of Tree Cities USA in Alaska has grown from zero to eight. Anchorage, Wasilla, Homer, Sitka, Juneau, the Ketchikan Gateway Borough, and the Fairbanks North Star Borough have inventoried, or are in the process of inventorying, their public trees. Anchorage, Wasilla, and the Ketchikan Gateway Borough completed comprehensive management plans in the past 2 years, and Soldotna will complete an inventory and management plan in 2011. The plans describe conditions, threats, and opportunities, and make recommendations for creating and sustaining vibrant, healthy, and safe community forests. The plans also identify appropriate species that could be planted to diversify the urban forests. Several communities have organizations that promote tree planting and maintenance as a means of enriching communities (figure 9); the most active groups are TREErific Anchorage, the Fairbanks Arbor Day Committee, Juneau Urban Forestry Partnership, and the Sitka Tree and Landscape Committee.

Conclusion

Tree planting for reforestation in Alaska has been modest in numbers compared with other States. However, planting for both reforestation and community enhancement will continue. Although southeast Alaska forests will rely on natural regeneration, timber sales farther north should continue to have seedlings planted as part of regeneration operations. White spruce planting following the spruce beetle epidemic continues on the Kenai Peninsula. A surge in interest in biomass heating may foster poplar and willow establishment near rural communities. Communities increasingly understand the value of urban forests and trees. This understanding should lead to more tree planting and comprehensive forest management by local governments in Alaska communities.

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Forestry and Tree Planting in North Carolina

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Abstract

North Carolina's forests cover more than 18.6 million acres (7.5 million hectares), equaling more than 59 percent of the State's land area. Nearly 97 percent of this forest land is capable of timber production. Forestry contributes more than $6 billion annually to the State's economy. The State's forests are genetically and commercially diverse and support more than 60 major tree species. Many other species are also important to the State's native forest ecosystems. Major forest types are oak and hickory; loblolly and shortleaf pine; oak, gum, and cypress; oak and pine; and longleaf pine. State forestry programs support these species, other important species, and ecosystem restoration efforts. More than 50 million tree seedlings are planted annually, 16 million of which are produced by State nurseries. While most of these seedlings are softwoods, local hardwood seed is also collected and expansion of container seedling operations continues. Inroads have been made in growing more specialty species for wetland and streambank restoration needs. Understory herbaceous plants are also being grown for longleaf pine ecosystem restoration projects. Support for the State nursery is still strong, and landowners are encouraged to plant and reforest lands as part of their long-term forest management.

Introduction

Forestry in North Carolina has a long history, beginning with the naval stores industry of colonial times. From 1720 to 1860, North Carolina's pine forests were plentiful, and the resin extracted from longleaf pine was used for tar, pitch, and turpentine. This use was unsustainable, however, and partially led to the industry's demise. The State is considered the birthplace of professional forestry in America. In 1892, Gifford Pinchot, who later became the first Chief of the Federal agency that would become the Forest Service, served as the first Forest Manager for George W. Vanderbilt's Biltmore Estate where he developed and implemented a forest management plan (Goodwin 1969). Subsequently, in 1895, German forester Dr. Carl A. Schenck went to North Carolina to succeed Gifford Pinchot as manager, and 3 years later, in 1898, Schenck founded the Biltmore Forest School. About 300 students attended the school during Schenck's tenure, including Fredrick Weyerhaeuser. The students managed a nursery at Brevard that produced a wide variety of tree species. During this time, the first North Carolina (and possibly the United States) commercial forest tree plantings occurred.

In 1891, W.W. Ashe became the first State employee to carry out timber assessments for the North Carolina Geologic Survey. Ashe became the first forestry expert in 1908 when a separate State Forestry Division was created as part of the N.C. Geological and Economic Survey. In 1909, J.S. Holmes was appointed as the first State employed graduate forester. The early establishment of the State forestry agency occurred in 1921 when forest protection from pests and wildfires was the driving public concern in North Carolina.

The founding of the Civilian Conservation Corps (CCC) ushered in a period of extensive tree planting in the State. CCC crews within North Carolina planted about 15 million seedlings from 1933 to 1938. The Soil Bank days of the 1950s increased the amount of tree planting and, by the 1960s, private forestry companies began plantation management on a large scale in the State. Georgia-Pacific, Weyerhaeuser, and Federal Paperboard, among other companies, planted millions of seedlings on their land holdings. The North Carolina State nurseries produced the bulk of these seedlings by supplying more than 100 million annually. Within a short time period, Weyerhaeuser and Federal Paperboard began operating their own nurseries and the planting of genetically improved seedlings became common in the State. In 1977, the State Forest Development cost-share program was authorized by the North Carolina General Assembly and, in 2004, the one-millionth acre was planted in the State using this program.

Forestry has developed and been recognized for its outreach into management of other natural resources in addition to the scientific management of forest ecosystems. Forestry, logging, wood products manufacturing, and forest recreation contribute more than $6 billion annually to the North Carolina economy (Brown 2007, NCDFR 2009a).

North Carolina's Environment

North Carolina is one of the most physiographically diverse States in the Eastern United States. Three distinct physiographic provinces exist: the Coastal Plain, the Piedmont, and the Mountains (figure 1). Elevations range from sea level to 6,684 ft

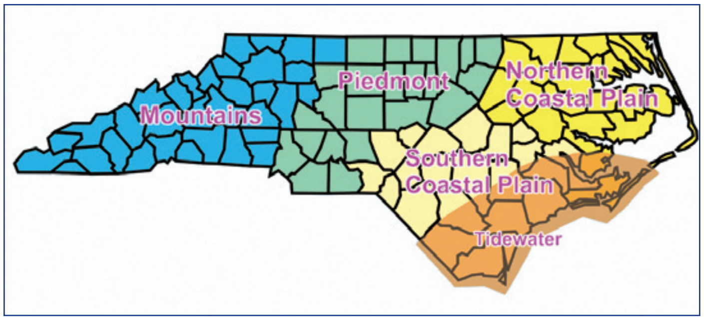

Figure 1. The three physiographic regions of North Carolina based on survey unit (county) boundaries. The tidewater area in the coastal plain is a poorly drained area adjacent to the coast (Source: Unpublished North Carolina Division of Forest Resources, 2011).

(2,037 m), the highest point east of the Rocky Mountains. The State also has more peaks higher than 6,000 ft (1,830 m) than any State east of the Mississippi River (SCONC 2011) and possesses the most extensive system of barrier islands in the United States. These islands extend east into the Atlantic Ocean and are subject to frequent exposure to Atlantic Ocean storms, including hurricanes and nor'easters. Not far inland are pocosins and Carolina bays, more concentrated in North Carolina than in any other State (NCDSS 2011). Deep swamp areas are also common in the eastern one-third of the State.

The climate in North Carolina is also diverse and varies from the Atlantic coast in the east to the Appalachian Mountain range in the west. The mountains often act as a shield by blocking cold temperatures and storms from the Midwest from entering the Piedmont region of North Carolina (SCONC 2011). Temperatures rarely go above 100 °F (38 °C) or fall below 10 °F (-12 °C), but differences in altitude and proximity to the ocean create significant local variations. Rainfall ranges from 35 to 40 in (89 to 102 cm) annually in the Piedmont region, to larger amounts along the coast (70 to 80 in [178 to 203 cm]), to greater than 100 in (254 cm) in the Great Smoky Mountains in the southwest of the State (C-DC 2010). The Mountains are as likely to experience the effects of tropical storms originating from the Gulf of Mexico as the Coastal Plain is likely to experience the effects of tropical storms originating from the Atlantic.

Natural Areas

North Carolina occupies 31.2 million acres (12.6 million hectares) (figure 2). Of this area, 59 percent is forested (Bardon and others 2010). The remaining land consists of urban and industrial development, farmland, and inland water. Of the forested areas, 2 percent are classified as reserved forest land. These forest lands extend across the 17 major river basins in North Carolina (figure 3) (NCDWR 2011).

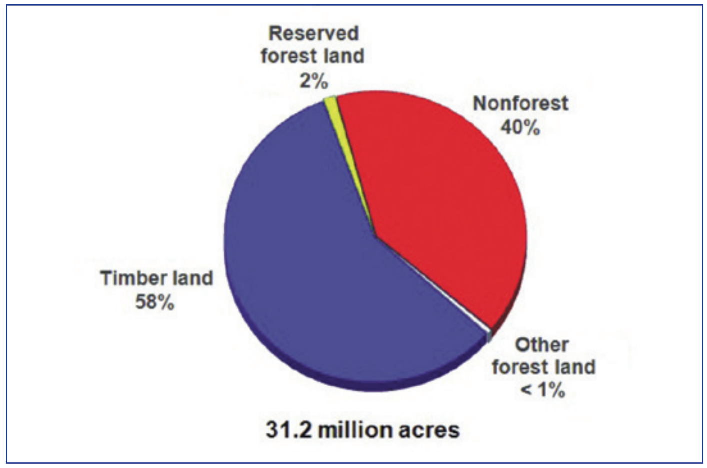

Figure 2. Classification of land area in North Carolina (Source: Bardon and others, 2010).

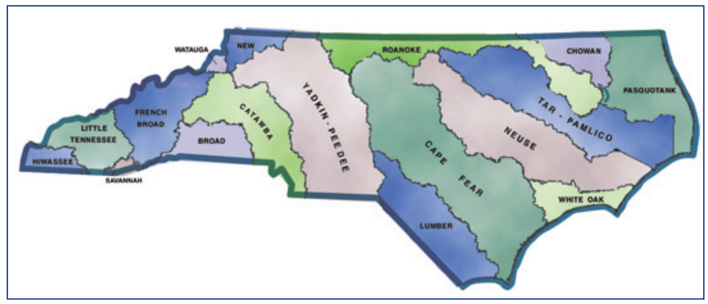

Figure 3. North Carolina river basins (Source: North Carolina Department of Environment and Natural Resources, 2011 available on Web: http://www.ee.enr.state.nc.us/public/ecoaddress/riverbasins/riverbasinmapinteractive.htm).

The North Carolina Division of Forest Resources (NCDFR) recognizes 13 major forest types; 5 are softwood types and 8 are hardwood types (table 1). The oak/hickory (upland hardwood type) and the loblolly/shortleaf pine (upland softwood type) are the most abundant forest types in the State. Planted stands account for about one-half of the loblolly/shortleaf area (figure 4). Planted oak/pine stands usually result from significant hardwood competition and pine stocking levels that precluded classification as a pine type. Many of these stands originated as pine plantations. Over time and due to natural succession, hardwood species have invaded and thrived, and the distribution of species has changed to a mixed stand.

The 13 forest types are more practically consolidated into six management units based on species, stocking, and stand origin. The six management units are upland hardwood, natural pine, plantation pine, lowland hardwood, oak-pine, and nonstocked (table 2).

Coastal Plain

The land and inland water areas of the Coastal Plain comprise nearly one-half of the State's land area and are divided into northern and southern subregions (figure 1). It can be further subdivided into two sections based on drainage: the tidewater area, which is along the coast and in large part low, flat, and swampy; and the interior portion, which is gently sloping and, for the most part, naturally well drained. Throughout the Coastal Plain, soils consist of soft sediment, with little or no underlying hard rock near the surface. The elevation ranges from about 200 ft (60 m) at the fall line, or western boundary, to less than 50 ft (15 m) higher than the tidewater area (SCONC 2011).

The Coastal Plain is 59 percent forested and contains almost 49 percent of the State's timber land (tables 1 and 2). Because the Coastal Plain contains the State's lowest elevations and has the smallest gradients in elevation, this area contains most of North Carolina's swamps and pocosins. Riverine systems are typically slow, more meandering, and of blackwater type if originating from within the region. Because of these features, most North Carolina bottomland hardwood and cypress forests (a combined 84 percent) are found in the Coastal Plain. Loblolly pine (*Pinus taeda* L.) is the most prevalent softwood type in the region, and nearly all of the State's longleaf pine (*Pinus palustris* Mill.) and pond pine (*Pinus serotina* Michx.) are found there. Unique to this region of the State, Atlantic white cedar (sometimes referred to as AWC or juniper) (*Chamaecyparis thyoides* L. [B.S. & P.]) once covered

Table 1. North Carolina timber land area by forest plant community type and survey unit (2007 survey data).

Forest plant community type	North Carolina physiographic province			
	Coastal Plain	Piedmont	Mountains	Total
	Acres (hectares)			
Hardwoods				
Aspen/birch	0 (0)	0 (0)	1,508 (610)	1,508 (610)
Elm/ash/cottonwood	253,448 (102,567)	250,686 (101,450)	12,164 (4,923)	516,298 (208,938)
Exotic hardwoods	3,775 (1,528)	0 (0)	2,948 (1,993)	6,723 (2,721)
Maple/beech/birch	0 (0)	0 (0)	56,895 (23,025)	56,895 (23,025)
Oak/gum/cypress	1,763,321 (713,590)	123,951 (50,161)	0 (0)	1,887,272 (763,752)
Oak/hickory	1,388,073 (561,733)	2,790,366 (1,129,221)	3,110,179 (1,258,645)	7,288,618 (2,949,600)
Oak/pine	1,141,857 (462,093)	792,957 (320,898)	380,836 (154,119)	2,315,650 (937,110)
Other hardwoods	5,810 (2,351)	0 (0)	109,279 (44,224)	115,089 (46,575)
Hardwoods total	4,556,284 (1,843,863)	3,957,960 (1,601,729)	3,673,809 (1,486,738)	12,188,053 (4,932,330)
Softwoods				
Loblolly/shortleaf	3,807,672 (1,540,910)	1,305,697 (528,397)	115,707 (46,825)	5,229,076 (2,116,132)
Longleaf	289,850 (117,298)	257 (104)	0 (0)	290,107 (117,402)
Other eastern softwoods	1,453 (588)	26,769 (10,833)	1,518 (614)	29,740 (12,035)
Spruce/fir	0 (0)	0 (0)	12,063 (4,882)	12,063 (4,882)
White/red/jack pine	0 (0)	1,025 (414)	134,085 (54,262)	135,110 (54,677)
Softwoods total	4,098,975 (1,658,796)	1,333,748 (539,749)	263,373 (106,583)	5,696,096 (2,305,128)
Nonstocked	111,287 (45,036)	35,978 (14,560)	11,644 (4,712)	158,909 (64,308)
Total	8,776,546 (3,551,742)	5,327,686 (2,156,038)	3,948,826 (1,598,033)	18,043,058 (7,301,766)
Total percent	49%	30%	21%	100%

Source: U.S. Department of Agriculture, Forest Service, Forest Inventory and Analysis, 2010.

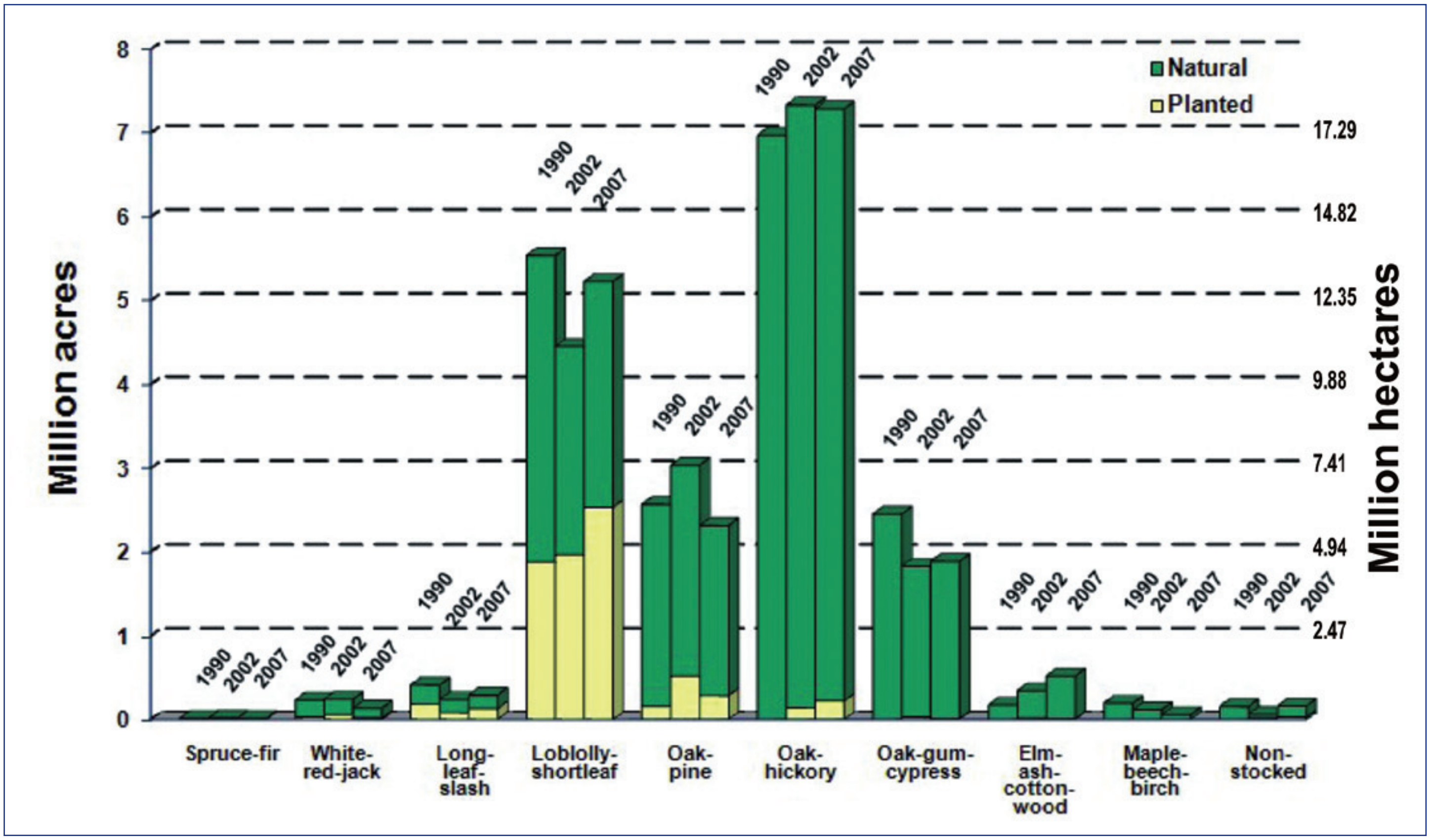

Figure 4. Trends in timber land area by seedling type and forest community type (Source: Bardon and others, 2010).

Table 2. Timber land area by North Carolina physiographic province and forest management type.

Forest management type	North Carolina physiographic province			
	Coastal Plain	Piedmont	Mountains	Total
	Acres (hectares)			
Upland hardwoods	1,397,658 (565,612)	2,790,366 (1,129,221)	3,280,809 (1,327,696)	7,468,833 (3,022,530)
Natural pine	1,956,414 (791,733)	830,384 (336,044)	229,487 (92,870)	3,016,285 (1,220,647)
Planted pine	2,142,560 (867,063)	503,365 (203,705)	33,886 (13,713)	2,679,811 (1,084,481)
Lowland hardwoods	2,016,769 (816,157)	374,637 (151,610)	12,164 (4,923)	2,403,570 (972,690)
Oak-pine	1,141,857 (462,093)	792,957 (320,898)	380,836 (154,119)	2,315,650 (937,110)
Nonstocked	111,287 (45,036)	35,978 (14,560)	11,644 (4,712)	158,909 (64,308)
Total	8,766,545 (3,547,695)	5,327,687 (2,156,038)	3,948,826 (1,598,074)	18,043,058 (7,301,766)

Source: U.S. Department of Agriculture, Forest Service, Forest Inventory and Analysis, 2010.

large expanses but is now confined to small areas. Many of the ecosystems found here are fire dependent and will change when fire is excluded.

Piedmont

The Piedmont province is 51 percent forests and represents 30 percent of the State's timber land. The Piedmont province contains the State's largest metropolitan areas, the highest population concentrations, and the most nonforested areas of all the regions in North Carolina. The Piedmont province terrain is much more varied than the Coastal Plain terrain and includes a wide range of tree species. Hardwoods predominate, but mixed stands are common, with loblolly pine the most abundant softwood type and Virginia pine (*Pinus virginiana* Mill.) second (tables 1 and 2). The most common hardwood stands are the white oak-red oak-hickory forest type followed closely by the yellow poplar-oak and the sweetgum-yellow poplar. Riverine systems encounter more gradient here; because of the higher clay mineral content of the soils and movement of these minerals into the drainages, they are referred to as the red river bottom type.

Mountains

The Mountains are 76 percent forested and contain 21 percent of the State's timber land. The region contains most of the State's reserved timber land, primarily in the Great Smoky Mountains National Park. The Mountains have the highest proportion of publicly owned timber land in the State, mainly because the Pisgah and Nantahala National Forests are located here. The Mountains have fewer large cities and urban development than the State's other regions and contain the State's highest elevations and most rugged terrain. Because of the topography, the Mountains are where the headwaters of many streams occur. Waters here are often whitewater in nature, and most are classed as freestone streams—those formed from rainfall and snowmelt. The Mountains are dominated by upland hardwoods, which account for 80 percent of the region's timber land. Chestnut oak, black oak, and scarlet oak stands dominate the region, followed by white oak, red oak, and hickory stands and then by yellow poplar, white oak, and northern red oak stands, in terms of abundance (tables 1 and 2).

The Mountains' highest elevations also contain tree genera typically occurring at more northern latitudes, such as spruce (*Picea*), fir *(Abies*), and birch *(Betula*). Eastern white pine (*Pinus strobus* L.) is the most common softwood type found here.

Forest Land Ownership

Approximately 14.1 million acres (5.7 million hectares), or about 78 percent of the State's timber land, is owned by nonindustrial private forest (NIPF) landowners (figure 5). The proportion of NIPF ownership is 91 percent in the Piedmont, 74 percent across the Coastal Plain, and 70 percent in the Mountains. Ownership by timber investment management organizations has been increasing in the past decade. Forest industry timber land ownership accounts for 8 percent of all timber land (14 percent of Coastal Plain, 3 percent of the Piedmont, and 1 percent of the Mountains).

Timber land ownership by public agencies accounts for 14 percent of all timber land in the State. Public ownership of timber land has increased by about 10 percent since 2002. Public ownership is highest in the mountains, largely due to National Forest System holdings there.

Challenges Facing the State's Forests

Urbanization

As the North Carolina population grows, so does the rural-urban interface. This expanding interface increases demand on forests for water, recreation, and aesthetics, as well as for traditional wood products. Incoming residents in these areas are typically unfamiliar with North Carolina's native forest ecosystems, management practices, and wildfire danger. Green corridors are becoming narrower and disjointed and some forests are becoming smaller. Many of the ownerships in this interface are only a few acres (hectares) in size.

Insects and Diseases

The southern pine beetle (*Dendroctonus frontalis* Zimmermann) is the most destructive forest insect in North Carolina, attacking trees of all age classes. Populations are cyclical; a beetle population-monitoring program is in place. Ips engraver beetle (*Ips* spp.) is the second most destructive insect pest in the State.

Young loblolly pine seedlings are susceptible to pine tip moth (*Rhyacionia* spp.) and to fusiform rust (*Cronartium quercuum* f. sp. *fusiforme* [Hedgc. & N. Hunt] Burdsall & G. Snow), especially when the alternate host is present. Genetic improvement of loblolly pine has made great strides in finding resistant families. These families are now recommended for high rust hazard sites.

Shortleaf pine (*Pinus echinata* Mill.) is susceptible to fusiform rust, pitch canker (*Fusarium subglutinans* (Wollenweb. & Reinking) P.E. Nelson, Toussoun & Marasas f. sp. pini), and littleleaf disease (*Phytophthora cinnamomi* Rands).

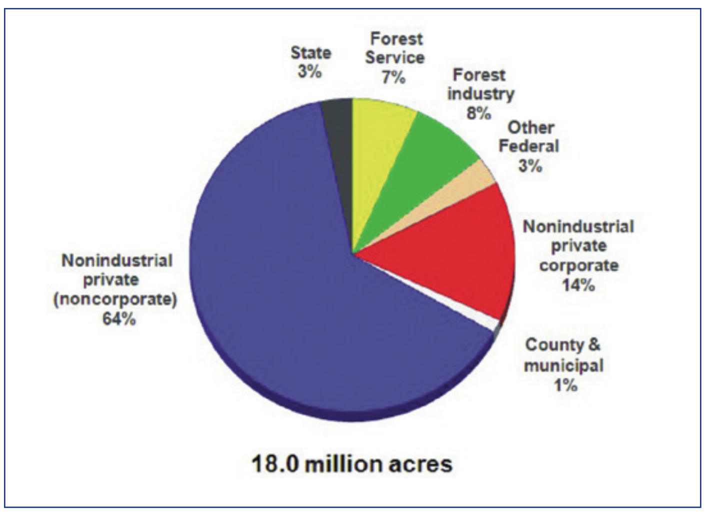

Figure 5. Area of timber land ownership in North Carolina (Source: Bardon and others, 2010).

Phytophthora is becoming endemic and also kills Fraser fir (*Abies fraseri* [Pursh.] Poir.). Eastern white pine is resistant and is recommended as an alternative species to Fraser fir on those sites, which are infected with Phytophthora. Eastern white pine, however, is susceptible to white pine blister rust, (*Cronartium ribicola* J.C.Fisch.) and white pine weevil (*Pissodes strobi* Peck). Combined, these pests reduce the value of white pine in the State.

Longleaf pine shows a high resistance to fusiform rust, tip moth, and fire (Barnard and Mayfield 2009) but is susceptible to pitch canker. Brown-spot needle blight (*Scirrhia acicola* [Dearn.] Siggers.) is also a problem.

More details regarding North Carolina's current forest health are available in the 2010 Forestry Assessment (Bardon and others 2010).

Drought

Currently, most of the North Carolina Piedmont is in a severe drought (NCDMAC 2011). Surrounding areas are designated as being in moderate drought. In recent years, drought has played a significant role in the occurrence and severity of forest fires.

Wildfire

North Carolina has a distinct forest fire season. This season has been extended due to the recent drought conditions affecting the State. In addition, fires have become more serious due to the increase in the number of residents living in the rural-urban interface. This situation is problematic due to the extent of fire-dependent ecosystems that are present.

North Carolina's State Forestry Agency

After preparation of this article, the North Carolina Division of Forest Resources that was under the North Carolina Department of Environment and Natural Resources is now the North Carolina Forest Service as of July 1, 2011, and is now part of the North Carolina Department of Agriculture and Consumer Services.

Founding legislation for NCDFR directs the forest agency to provide the State with forest protection (from wildfires and pests). NCDFR operates out of a Central Office located in the State capital in Raleigh. Forestry operations are organized under three regional offices, one located in each of the physiographic regions of the State (Region 1–Coastal Plain, Region 2–Piedmont, and Region 3–Mountains). Within each region are several districts, each covering several adjacent counties. Regional and district staff provide support to the county level programs.

The agency owns and operates very little public land but does manage two operational State forests, seven educational State forests, three training facilities, and three forestry centers. The agency also operates two State nurseries to make forest tree seedlings available to landowners and other citizens across the State. A forest tree improvement program supports the nursery operations to provide the most genetically appropriate seedlings for planting in North Carolina. NCDFR also maintains an aviation program to provide reconnaissance for forest protection efforts and suppression resources for wildland firefighting. Other programs include law enforcement, forest management, forest health, water quality, urban forestry, and other public outreach programs. NCDFR is currently involved in developing a strategic plan to better serve North Carolina citizens. This effort will also evaluate the success and role of tree planting in the State.

The largest State forest NCDFR manages is Bladen Lakes State Forest (BLSF) covering about 32,700 acres (13,233 hectares). BLSF is a working forest that is regularly harvested for timber and reforested, mostly with longleaf pine and AWC. Longleaf pine stand management goals also include pine straw, timber, poles, and charcoal. BLSF typically plants more than 200,000 seedlings annually.

Tree Production and Planting in North Carolina

Across the State, trees are typically planted for traditional forest products such as poles, timber, pulpwood, pine straw, watershed, wildlife, aesthetics, as well as for ecosystem restoration, biomass production, landscape plants, and Christmas trees. Older, natural hardwood stands are usually harvested to supply lumber to the furniture industry and pulpwood.

The most planted species in North Carolina is loblolly pine, which is the economic forestry giant in the State. Essentially all of these seedlings are genetically improved. The next most planted species is longleaf pine. More than 50 million forest tree seedlings are typically planted in North Carolina each year (table 3). These quantities are expected to remain at this level during the next few years.

For stand establishment, weed control is one of the most important cultural practices undertaken before planting (site preparation) and during early stand establishment. If weed control is not vigorously undertaken, an entire young stand can be lost.

Stand spacing depends on site and species. Pine stand spacing ranges from 400 to 600 trees per acre (tpa), while hardwoods are typically planted at 350 to 500 tpa. AWC seedlings are

Table 3. Area of pine and hardwood trees planted in North Carolina for 2004 through 2008. Number of trees planted estimated from areas of trees planted.

	2008		2007		2006		2005		2004	
	Pine	**Hardwood**	**Pine**	**Hardwood**	**Pine**	**Hardwood**	**Pine**	**Hardwood**	**Pine**	**Hardwood**
	Acres (Hectares)									
Non-cost-share	26,883 (10,879)	7,116 (2,879)	28,788 (11,650)	7,337 (2,969)	42,084 (17,030)	10,984 (4,445)	40,859 (16,535)	10,825 (4,380)	32,661 (13,217)	11,468 (4,641)
Cost-share	47,598 (19,262)	438 (177)	50,389 (20,392)	452 (183)	48,351 (19,567)	1,057 (428)	46,397 (18,776)	2,201 (890)	66,746 (27,011)	1,463 (592)
Total NIPFO	74,481 (30,141)	7,552 (3,056)	79,177 (3,204)	7,789 (3,152)	90,435 (36,598)	12,041 (4,872)	87,256 (35,311)	13,026 (5,271)	99,407 (40,228)	12,931 (5,233)
Forest industry	24,000 (9,712)	0 (0)	20,000 (8,094)	0 (0)	21,000 (8,498)	0 (0)	20,000 (8,094)	0 (0)	19,000 (7,689)	0 (0)
Government	411 (166)	0 (0)	642 (260)	0 (0)	599 (242)	0 (0)	879 (356)	0 (0)	426 (172)	0 (0)
Total acres (hectares)	98,892 (40,020)	7,552 (3,056)	99,819 (40,395)	7,789 (3,152)	93,134 (37,690)	12,041 (4,872)	108,135 (43,760)	13,026 (5,271)	118,833 (48,090)	12,931 (5,233)
Total number of trees (estimated)	51,425,000	3,250,000	51,910,000	3,350,000	48,500,000	5,200,000	56,250,000	5,600,000	61,800,000	5,500,000
	54,675,000		55,260,000		53,700,000		61,850,000		67,300,000	

NIPFO = nonindustrial private forest ownership.

Note: Numbers are likely to be underreported.

Source: Georgia Forestry Commission's Annual Reforestation Survey (2009).

typically planted at closer spacings (1,500 to 1,700 tpa). Third cycle loblolly pine require wider spacing to allow the trees to grow more freely.

North Carolina State Nurseries

NCDFR operates two public-sector nurseries. Linville River Nursery (Newland, NC) produces more than 300,000 improved Fraser fir greenhouse container seedlings and 1 million improved bareroot eastern white pine seedlings annually. Claridge Nursery (Goldsboro, NC) is located in the mid-Coastal Plain near the center of the State. This nursery grows several species of southern yellow pine and other conifers, hardwoods, and a few specialty species for forestry, reclamation, and restoration plantings. This includes 12 longleaf ecosystem herbaceous species grown for the Longleaf Pine Ecosystem Restoration Program. In all, NCDFR nurseries collect seed and grow more than 16 million seedlings of more than 40 to 50 species annually, most of which are planted as 1-year-old plants.

Both of the State nurseries grow bareroot and container seedlings (figure 6). New U.S. Environmental Protection Agency regulations for pest management chemicals are expected to severely restrict bareroot seedling production in the near future. This will likely result in a shift to container operations and possible increased seedling costs.

Seed sown in these State nurseries are usually collected and processed internally by NCDFR. Seeds are collected from wild stands, seed production areas, and genetically improved seed orchards and clone banks. Seedlings produced from these seed at these nurseries can be certified as local source material for various restoration projects. Seed production areas of the longleaf understory herbaceous species, like wire grass (*Aristida stricta* Michx.), have also been established to supply additional seed. Seedlings of other species may be grown on request as needed. Rare and hard-to-find species can also be produced if sufficient quantities are required. Claridge Nursery typically contract grows seedlings for the North Carolina Department of Transportation, local military bases, and the USDA Forest Service.

Linville River Nursery produces second generation Fraser fir as field-plantable, greenhouse-bench seedlings in 2 years (figure 7). This is a big change from 5-year-old, 3-2 transplants that the Christmas tree industry has used in the past. These field-plantable seedlings make it possible for NCDFR to move commercial quantities of genetically improved seedling to growers' fields 3 years sooner. Eastern white pine is grown and sold as a 2-year-old seedling.

Figure 6. Claridge Nursery container operation showing longleaf and Atlantic white cedar seedlings (Photo source: Brad Stevens, North Carolina Division of Forest Resources, 2008).

Figure 7. North Carolina Division of Forest Resources 2-year-old field plantable greenhouse-bench Fraser fir seedling; shearing knife is shown for scale (Photo source: Ken Roeder, North Carolina Division of Forest Resources, 2009).

Seedling sales via the Internet are increasing. Sales of seedlings have been helped by offering smaller tree quantities that cater to North Carolina residents owning only a few acres (hectares) in the rural-urban interface.

In addition to the two State nurseries, a few major, and many small nurseries are located in the State that produce about 50 million forest seedlings annually for private and industrial tree planting in North Carolina and other nearby States.

Forest Tree Improvement Program

The forest tree improvement program operates in conjunction with the nursery operation to ensure that seedlings being produced are of the best genetic quality for deployment in North Carolina. The tree improvement program's goals are to maximize forest production on the decreasing number of acres in commercial forests in the State. This set of goals means that, in addition to growth rate and wood quality, disease resistance (i.e., fusiform rust) is also being assessed in selection of improved trees. This selection process will increase stand yields of higher quality products across the State. Species being actively improved under this program are loblolly pine, longleaf pine, shortleaf pine, eastern white pine, Virginia pine, AWC, Fraser fir, and sycamore. The tree improvement program is currently producing open pollinated (half-sib from mother

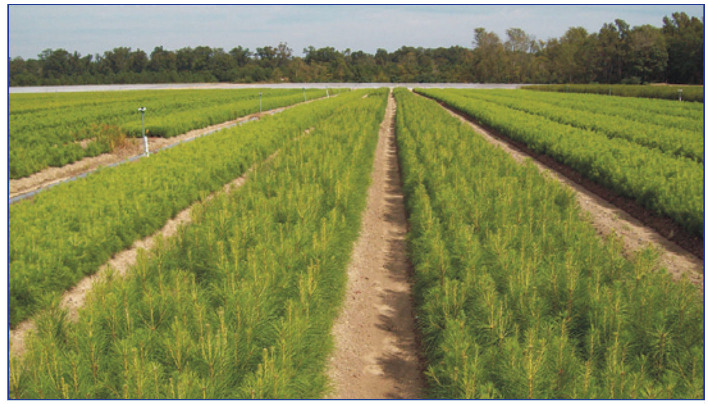

Figure 8. Third Cycle Mass Controlled Pollination seedlings are being grown at Claridge Nursery and are available for planting (Photo source: Ken Roeder, North Carolina Division of Forest Resources, 2009).

trees) and full-sib crossed seed from NCDFR seed orchards. The full-sib loblolly pine seed is from Mass Controlled Pollination, which produces commercial quantities of the best parental crosses (figure 8).

Programs Involving Tree Planting

Conservation

Two primary Federal conservation programs are administered in the State by NCDFR. The Forest Stewardship Program provides technical assistance to NIPF landowners to encourage and enable active long-term forest management including reforestation. The primary focus of the program is the development of comprehensive, multiresource management plans that provide landowners with the information they need to manage their forests for a variety of products and services. The Forest Legacy Program is a working forest conservation easement that protects habitat and provides forest products, opportunities for recreation, protection of water quality, and other public benefits.

Cost-Share Programs

Several cost-share tree-planting programs are available through NCDFR and other agencies (table 3). The Forest Development Program (FDP) is one of several cost-share programs providing funding and technical support to promote reforestation and forest improvement activities (NCDFR 2010). More than 1.5 million acres (0.6 million hectares) have been planted under this program. Under current funding levels, this program involves more than 1,500 landowners annually with an average ownership of 37 acres (15.0 hectares) (NCDFR 2009a). These cost-share programs have a large effect on the number of acres (hectares) planted (table 4).

Table 4. Forestry cost-share programs in North Carolina and longleaf pine acres planted under several of these programs.

Short title	Cost-share program title	Program agency	Longleaf pine areas planted under these programs (1997–2007) Acres (hectares)
CRP	Conservation Reserve Program	FSA	11,694 (4,732)
FDP	Forest Development Program	NCDFR	25,012 (10,122)
NCA	North Carolina Agricultural Cost-Share Program	NCDSWC	1,779 (720)
CREP	Conservation Reserve Enhancement Program	FSA	1,220 (494)
WRP	Wetland Reserves Program	NRCS	0 (0)
FIP	Forestry Incentive Program	NRCS	244 (99)
EQUIP	Environmental Quality Incentives Program	NRCS	NA
SIP	Stewardship Incentives Program	FS	NA
FLEP	Forest Land Enhancement Program	NCDFR—no longer available	869 (352)
FRRP	Forest Recovery and Rehabilitation Program	NCDFR—no longer available	4,481 (1,813)
FRP	Forest Recovery Program	NCDFR—no longer available	NA
—	No cost-share program	—	13,983 (5,659)

FS = USDA Forest Service. FSA = USDA Farm Service Agency. NA = data not available. NCDSWC = North Carolina Division of Sewer and Water Quality. NCDFR = North Carolina Division of Forest Resources. NRCS = USDA Natural Resources Conservation Service.

Source: NCDFR 2010.

Restoration Projects

Longleaf Pine Restoration

Recognizing the declining longleaf forest acreage, the NCDFR implemented the Longleaf Pine Restoration Initiative. The initiative focuses on artificial forest regeneration as the primary means to restore longleaf pine to sites where it was historically found and adapted to, especially in the southern Piedmont and Coastal Plain (figure 9). An average of 5,000 acres (2,023 hectares) of longleaf pine seedlings are now planted annually (NCDFR 2009b). Longleaf pine ecosystem restoration has also gained importance in recent years with increased production of seedlings and seeds of understory species.

Figure 9. New longleaf pine plantation during summer of second growing season (Photo source: Ken Roeder, North Carolina Division of Forest Resources, 2008).

Shortleaf Pine Restoration

For a variety of reasons, artificial regeneration of shortleaf pine has lagged behind other species. An average of 110 acres (44.5 hectares) of shortleaf was planted each year between 2005 and 2009 on NIPF land (NCDFR 2009a). A number of cost-share assistance programs support shortleaf pine establishment on private lands. North Carolina's FDP is the primary State-administered financial assistance program supporting shortleaf establishment, although the federally funded Environmental Quality Incentives Program, a program of the U.S. Department of Agriculture, Natural Resources Conservation Service, also funds the planting of shortleaf pine. NCDFR helps to develop management plans and provide technical expertise for these programs.

Atlantic White Cedar Restoration

Atlantic white cedar (AWC) was once a common forest type in North Carolina coastal wetlands, but has decreased to less than 10 percent of its original range. Most of the estimated 10,583 acres (4,283 hectares) remaining in North Carolina are on public lands. Exploitive logging, natural regeneration failure, absence of artificial regeneration, drainage effects, fire exclusion, and lack of competition control are cited as reasons behind the decline of AWC forests. North Carolina has identified AWC as a species of concern. NCDFR promotes conservation, restoration, and planting of AWC by providing forest management advice, conducting applied forest management research, and providing workshops and inhouse training.

Future Outlook for Tree Planting in North Carolina

As in most Southern States, urbanization is reducing the land area available for producing traditional forestry products in North Carolina. The acreage of the rural-urban interface is also growing resulting in more people living within native fire ecosystems. Risks to these residents from wildfire have increased. Demand for forest resources is also changing. While the demand for traditional products like pulp, timber, and poles is increasing, more residents also believe more forests are needed to provide clean water, wildlife, aesthetic value, and recreational environments.

More efficient use of North Carolina's forest land base is required. Use of more productive and disease-resistant, genetically improved trees is necessary. The best forest lands must be planted with the best trees and intensively managed with the most appropriate cultural practices. The number of acres planted annually has declined during the past few years. Productivity on every acre has increased, however. Potential productivity of forest land in the State is lost when a site is planted without using appropriate long-term stand management practices.

Some Southern States have closed their nurseries, but support in North Carolina is still strong. In fact, demand for seedlings from the two State nurseries appears to be increasing.

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A Century of Tree Planting: Wisconsin's Forest Nursery System

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Abstract

This report summarizes the history of the Wisconsin nursery system, including the tenuous beginning in the Wisconsin Conservation Department after the initial cutover of the State's forests, the boom years during the middle of the 20th century, the current challenges, and future projections.

Wisconsin and Its Landscape

Wisconsin Overview

Wisconsin lies in the upper Midwest between Lake Superior, Upper Michigan, Lake Michigan, and the Mississippi and Saint Croix Rivers. Glaciations largely determined the topography and soils of the State with the exception of more than 13,000 mi^2 (33,670 km^2) of a driftless area in southwestern Wisconsin. The various glaciations created rolling terrain, nearly 9,000 lakes, and several large marsh and swamp areas. Elevations range from about 600 ft (180 m) along the Lake Superior and Lake Michigan shores and in the Mississippi flood plain in southwestern Wisconsin, to nearly 1,950 ft (600 m) in the north-central highlands.

The Wisconsin climate is typically continental with some modification by Lakes Michigan and Superior. Mean annual precipitation ranges from 28 to 34 in (70 to 85 cm) annually. The land immediately south of Lake Superior is characterized by rolling to flat topography with heavier clay soils. The northern tier of the State is dominated by rolling topography and silt loam soils. Large areas of sandy outwash are located in the central and far northwest and northeast parts of the State that include some large, scattered wetlands. The west and southwest portions of the State have a mix of silt loam and sandy soils that support oak savanna, open oak woodlands, and prairie. The eastern and southeastern portions of the State have loam, silt loam, and clay soils. Of the State's 34.8 million acres (14.1 million hectares), about 45 percent are currently covered by forests, with most in the northern third of the State. Most of the flat, fertile terrain in the southern portion of the State is agricultural land.

Early Wisconsin Forest Cover

Prior to European settlement, mixed hardwood and conifer forests covered most of northern Wisconsin (figure 1). Hard maple (*Acer sacchrum* Marsh.), yellow birch (*Betula alleghaniensis* Britt.), basswood (*Tilia americana* L.), American elm (*Ulmus americana* L.), rock elm (*Ulmus thomasii* Sarg.), and northern red oak (*Quercus rubra* L.) represented the bulk of the species. American beech (*Fagus grandifolia* Ehrh.) occurred along Lake Michigan and Green Bay. Hemlock (*Tsuga canadensis* Carr.) was the principal conifer associated with these hardwoods, but scattered areas of white pine (*Pinus strobus* L.), balsam fir (*Abies balsamea* [L.] P. Mill), and white spruce (*Picea glauca* [Moehn] Voss) could be found as well. Within this mixed hardwood and conifer forest were lowland or swamp areas characterized by white cedar (*Thuja occidentalis* L.), black spruce (*Picea mariana* [P. Mill] B.S.P.), tamarack (*Larix laricina* [Du Roi] K. Koch), balsam fir, black ash (*Fraxinus nigra* Marsh.), and elm. Sandy soils in parts of central and northern Wisconsin supported vast tracts of white pine, red pine (*Pinus resinosa* Soland.), jack pine (*Pinus banksiana* Lamb.), and scrub oak. Oak, hickory (*Carya* sp. Nutt.), hard maple, basswood, black walnut (*Juglans nigra* L.), and white ash (*Fraxinus americana* L.) dominated the southern forest, which also contained extensive prairie openings covered with thick grasses, interspersed with hardwood islands.

The Lumbering Era

With vast acreages of white pine, a species highly sought by ambitious timber barons, the logging industry started, in earnest, at the end of the Civil War. By 1869, Wisconsin's annual lumber production had reached more than 1 billion board feet (2.3 million m^3) and would continue at that level, or higher, until the early 1900s. With such accelerated rates of cutting, the forest was unable to sustain the early logging industry's insatiable appetite for timber. Soon sawmills, lumber companies, and jobs disappeared. Forest lands were abandoned and left to recuperate on their own. Thousands of acres of tax delinquent lands reverted to public ownership by the State or county. The lumber and land companies, in conjunction with well meaning members of the University of Wisconsin

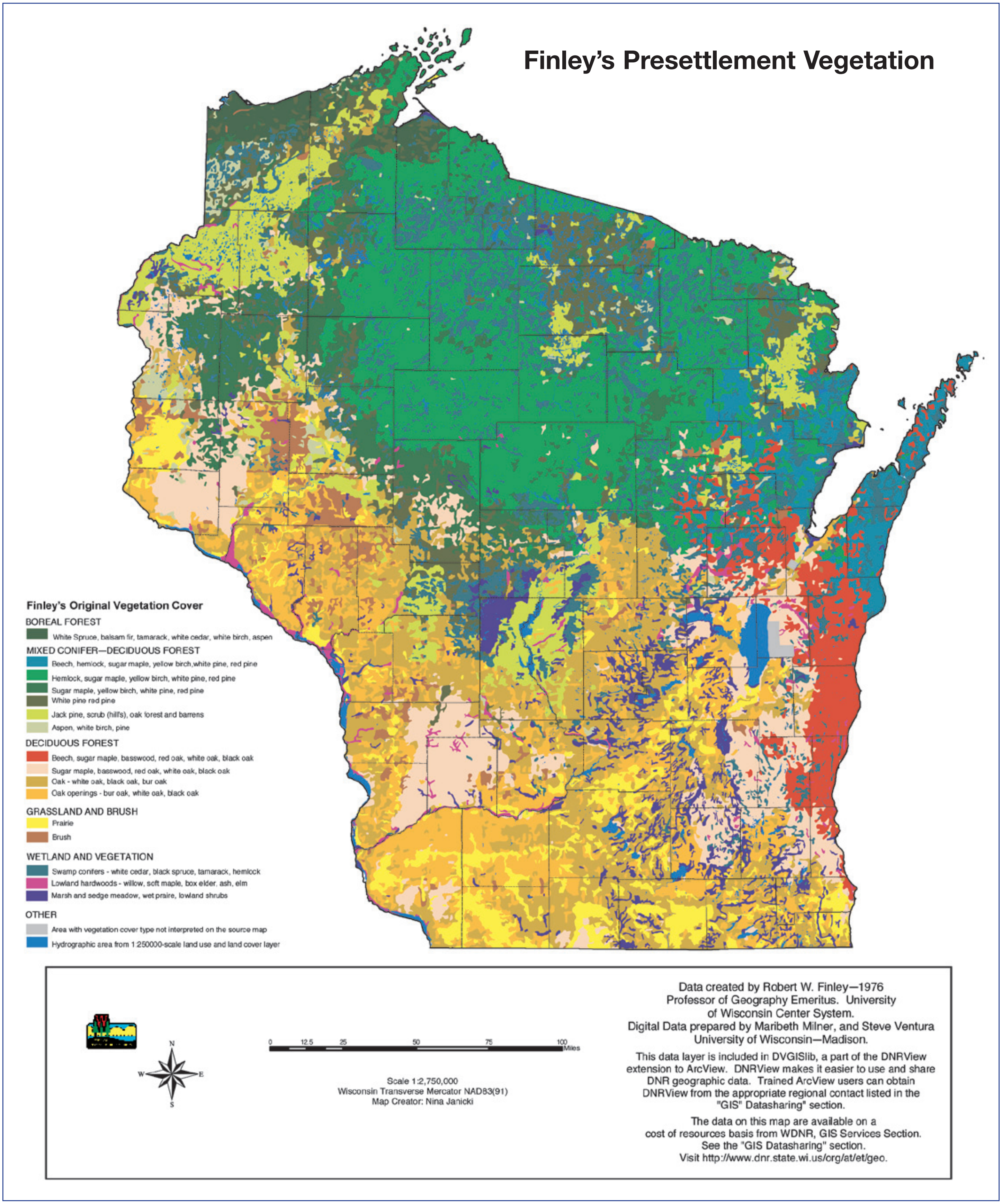

Figure 1. Presettlement vegetation distribution in Wisconsin.

College of Agriculture, encouraged settlement and farming of the recently cutover lands. Unproductive soils, vast stump fields, frequent wildfires, lack of infrastructure, and economic opportunities led to a mass exodus of settlers, however. These vacant lands were the precursors to the national, State, county, and municipal forest reserves that are currently managed throughout the northern half of Wisconsin (Rohe and others 2004).

Current Wisconsin Forest Lands

The composition of Wisconsin forests has changed significantly since early settlement. Conifers, specifically hemlock and white pine, are just remnants of their once vast expanses. The oak savannas and pine barrens are also less prevalent on the landscape. Some forests, specifically the aspen and birch, however, are more important in many areas. Currently, 16 million acres (6.5 million hectares) are covered in forest land and encompass a number of different forest types (figure 2). The hardwood forests are the most abundant forest type, but the oak-hickory and maple-basswood forest type have the largest trees. Significant areas of softwoods, red pine, white pine, and jack pine also occupy large swaths of land in northern and central portions of the State. Private, nonindustrial landowners own nearly 70 percent of this property (figure 3). Large, contiguous acreage of public land is located in the central, northern, and northwestern parts of the State. The east and southern portions of the State are dominated by land with agricultural uses.

History of Wisconsin's Reforestation

Early Efforts

The following paragraphs are excerpted from a personal narrative written by William Brener in 1944, reflecting on the history and legacy of reforestation in Wisconsin (Brener 1944). Brener (figure 4) began his career as a forester for the Wisconsin Conservation Department (precursor of the Wisconsin Department of Natural Resources) in 1931 and served as Nursery Supervisor at Central State Nursery (changed in 1940 to Griffith State Nursery) and later as Chief of the State Nursery Program. Brener maintained detailed records of events at the nursery every year, including climate, insect and disease problems, research, working conditions, sales, and correspondence with other members of the nursery community within the State. During his 41 years of distinguished service, he was credited with establishing and developing more than seven State nurseries, which provided 900 million tree seedlings for reforestation of forest land in Wisconsin (figures 5, 6, and 7). He was inducted into the Wisconsin Forestry Hall of Fame on November 3, 1995.

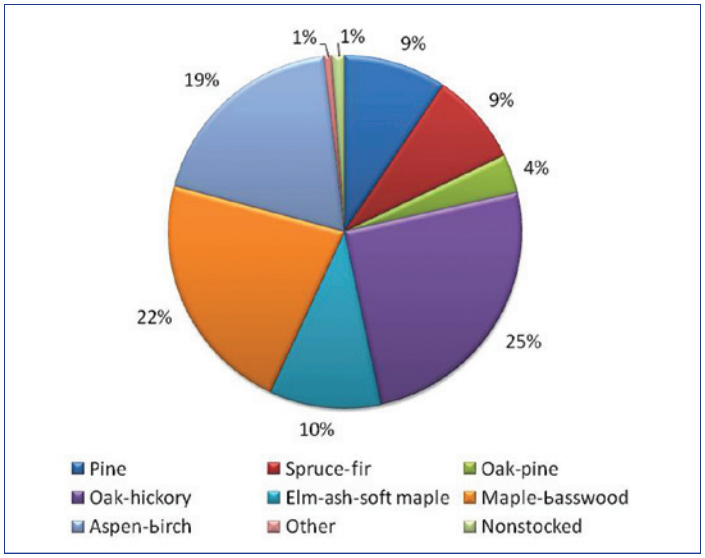

Figure 2. Wisconsin forest cover types.

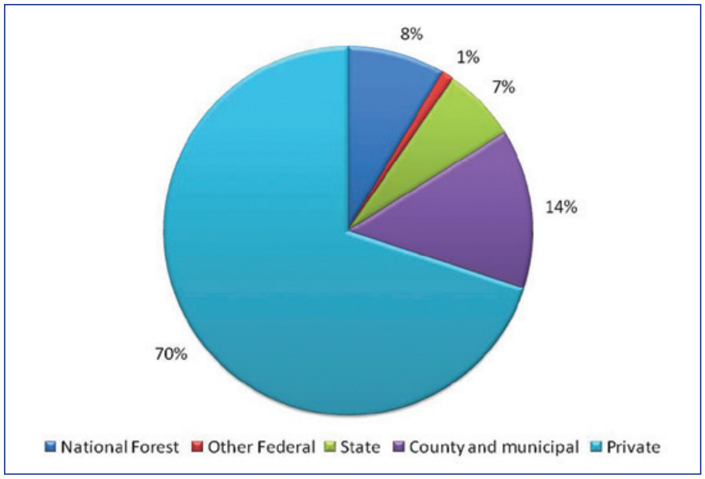

Figure 3. Forest land ownership in Wisconsin as of 2009.

Figure 4. William Brener (shown here in 1960 holding a pine graft seedling) was an early advocate for producing high-quality seedlings to reforest lands in Wisconsin (Photo source: Wisconsin Department of Natural Resources files).

Figure 5. An early view of the nursery beds and facilities at Griffith State Nursery, located in Wisconsin Rapids, WI (Photo source: Ray Amiel, Wisconsin Department of Natural Resources files).

Figure 6. Historical photo of lifting nursery stock in Wisconsin destined for reforestation of publicly owned lands (Photo source: Ray Amiel, Wisconsin Department of Natural Resources files).

Figure 7. Loading bundles of seedlings for distribution (Photo source: Ray Amiel, Wisconsin Department of Natural Resources files).

A Brief History of Tree Planting in Wisconsin

As we look back over the record, the first appreciable amount of tree planting in Wisconsin began in 1911 under the tutelage of the Conservation Department. At that time 192,000 seedlings were planted on State-owned land with stock secured from Michigan State College. The young conifers were planted near Trout Lake in Vilas County and presented a fresh start for long-range sustainability and management of the State's forest resource. An additional 18,000 trees were purchased and planted the following year. Meanwhile, a State-operated nursery was constructed at Trout Lake. In 1913, the nursery's first production of 68,500 trees was added to the State plantations.

Initial Expansion and 1915 Setback

The period from 1911 to 1915 was an active one in forestry work, filled with much hope. Due to favorable legislation and the acquisition of State forest lands, the Trout Lake nursery was expanded and by 1914 had an output of 1/2 million trees. During the pioneer days of forestry and reforestation strides, many recognized this as a significant achievement.

Although the populous supported restoration activities with their votes, opposition began to develop and culminated in 1915. The question of forestry was presented to the State Supreme Court in a friendly suit to determine the exact status of forestry work and the legal structure supporting it.

After an intensive review, the court rendered an opinion declaring forestry work illegal and in conflict with the State constitution on a number of fronts. This decision practically nullified the entire reforestation program that had been growing in intensity. In 1915 only 77,400 trees were distributed from Trout Lake.

Interest in Reforestation Revived

The 1915 decision was a significant milestone in the history and development of reforestation in Wisconsin. It was a great shock to those who were interested in the movement of forestry in the State, and it looked as if the business of forest restoration was out for good. It took nearly 10 years to recover from the setback.

However, the public interest in reforestation was so pronounced that after the close of World War I in 1924, an identical amendment to the State constitution was again submitted to the voters and approved by an overwhelming majority. The Supreme Court reviewed the amendment and found it sufficient. The record shows that over 1 million trees were distributed and planted in 1926 with an ensuing expansion of effort and facilities until entrance into World War II.

1932 Expansion and Establishment of a New Nursery at Wisconsin Rapids

Late in 1931, a special Governor's subcommittee, committed to land use and forestry, was appointed to study the need for accelerated reforestation. The subcommittee's report, presented in early 1932 to the Conservation Commission, readily approved the recommendations that the State should commence at once a forest planting program on suitable lands. The over-riding goals were to sustain industry, to afford employment, and to keep land best suited for forestry in a productive capacity.

The tremendous expansion of the planting activities necessitated the purchase of planting stock from private nurseries, principally those located in Wisconsin. The enlarged reforestation initiative made it more imperative than ever to construct a new nursery in the central part of the State. Coupled with this was the need to supply seedlings approximately two weeks earlier for planting in the southern and central parts of the State than was possible from the more northern Trout Lake nursery.

A survey to determine suitable sites was conducted, resulting in the selection of an area near Wisconsin Rapids for the new State nursery (the future Griffith State Nursery). Site development started in the fall of 1932 with the first stock becoming available in 1934. That year over 16.5 million trees were distributed and planted.

Nurseries Enlarged and Improved

The tree growing facilities of the department again were materially improved and increased during 1936 and 1937. This work was done in cooperation with the Civilian Conservation Corps and CCC camps. As the work of these camps in truck trail construction was completed, more of their attention was directed to reforestation of publicly owned lands. To furnish the trees needed for this expanding planting program, further facilities were required. Additional land was purchased, and general amplification of all facilities, including buildings, water systems, and other equipment was necessitated. The Wisconsin Rapids facility was trebled, and additional improvements were completed at Trout Lake. A new nursery was established near Gordon in the northwest portion of the State. In the work of the enlarged nursery facilities, the CCC camps and the WPA crews furnished by far the bulk of the labor and shared expenses with the Conservation Department.

County Forest and Private Landowner Planting

While the principal reforestation work was done on lands owned by the State, primarily State forests, much work also was done on county lands. The location of the CCC camps and the enormous acreage of plantable land on county forests were contributing factors. Over 2 million trees were planted on county forests in 1933. In 1940 more than 25 million trees were planted, representing the highest annual distribution to county forest lands in the history of Wisconsin's State nursery program. Today, planting on the county forests has dwindled to less than 4 million trees annually.

The policy under which planting stock was furnished at reasonable prices to private landowners for reforestation purposes in the State continued, but suffered little because of the war. While State and county forest planting decreased drastically during Word War II, the demand for trees from farmers and other private landowners held up surprisingly well.

Shelterbelt Project

The hot, dry weather of 1933, and particularly in 1934, the lowering of the water table in various communities, together with the dust storms, focused attention on the need for trees and shelterbelts for windbreak purposes. A well-organized and enthusiastic demand arose in the central counties for an extensive tree planting program. Through the county agricultural agents and other interested parties, surveys were conducted to determine the tree requirements for shelterbelts. As a result, the Conservation Department was called upon to furnish over 14 million trees, mostly transplants, during the 10-year period of 1934 to 1944. The Conservation Department entered into cooperative agreements with the County Board Agricultural Committees of the counties concerned, and each farmer signed an agreement to plant the trees as instructed and to give proper care to the plantation. The trees were planted in three row shelterbelts, and a total of 5,942 miles of plantings were completed by 1944.

Research Studies and Industrial Forests

The Conservation Commission, in cooperation with the University of Wisconsin, began investigating depletion of soil fertility at all State nurseries. This led to a soil rejuvenation program, especially important due to a general decline in vitality and size of nursery stock.

Studies were also initiated to control damaging soil and tree diseases, and a separate experimental nursery was established in conjunction with the College of Agriculture and the U.S. Department of Agriculture, where investigations were carried out to possibly propagate disease-resistant varieties.

During these years, several industrial corporations, mainly paper companies, also conducted extensive forest plantings as an integral part of their forestry programs. While several of the corporations operated their own nurseries, the Conservation Department continued to provide them with a goodly portion of forest planting stock at nominal prices.

Effects of World War II

Even before the United States' entry into the war, the loss of the CCC camps caused a decided drop in tree planting activities on public lands in Wisconsin. From an all-time high of over 38 million trees planted in the year 1940, there was a drop to 18 million in the year 1942, the first full year of active participation in the war. In succeeding years, the drop in tree planting continued as the shortage of labor became more apparent, until 1944 when only 10 million trees were distributed and planted. However, it was gratifying to note that the majority of these trees went to farmers and other private landowners who took the time to plant the trees themselves or with help from the immediate members of their families.

Brener continued the story to include some inner workings of the nursery and information on the trials, tribulations, and successes of the reforestation efforts of 1944. His personal reports, writings, and correspondence are still held in the archives of the Griffith State Nursery. Brener was a part of the nursery system, long after his retirement. He had a deep admiration for the nursery and was very proud of the work he and others did. He made an annual trip to Griffith State Nursery during Memorial Day weekend, until his health declined in the mid-1990s, to view and walk the property.

Wisconsin Nursery System Today and in the Future

Many years have passed since Brener wrote his narrative, and the Wisconsin State nurseries have gone through many changes. The Wisconsin Conservation Department and other resource-related State organizations were combined to create the Wisconsin Department of Natural Resources in 1967. At the height of seedling demand in the 1950s, the State operated six seedling nurseries, with a number of smaller transplant nurseries. As technology and seedling growing techniques improved, facility needs declined. Today, State nurseries in Hayward, Wisconsin Rapids, and Boscobel are able to satisfy demand from both public land managers and private landowners. The nurseries have always produced bareroot seedlings, but the species of trees and shrubs produced has changed dramatically over the years. The first seedlings produced were mostly conifers (red pine, Scotch pine, white pine, white spruce, and balsam fir). Only a small quantity of oak and ash were raised. Most trees were sold as 1-, 2-, or 3-year-old seedlings, but many transplants were also produced. Transplants were phased out in the late 1980s, however. In addition, the nurseries stopped growing nonnative species. The list of available species has expanded to include nearly all native trees and shrubs, including species with only a minor presence in Wisconsin.

Current Reforestation Efforts in Wisconsin

Wisconsin nurseries have experienced a decline in sales during the past 5 years. The 2010 nursery sales were just more than 7.7 million seedlings, a decrease of 900,000 from 2009, and about 4.1 million less than was sold in 2008 (WDNR 2010). The effects of reduced Federal cost-share programs for private landowners interested in tree planting, shifting land ownership priorities, forest fragmentation, competition with agricultural land values, and the downturn in the economy have affected tree planting efforts. By Wisconsin State statute, the nursery program must cover its costs with the price of stock. Accomplishing this has been a challenge, given declining sales, increasing input costs, and infrastructure costs. Fortunately, innovative thinking and new techniques enable the same quality seedling to be sold at an economical price.

Landowner Goals

Most seedling orders are from private landowners. Overall, however, the greatest numbers of seedlings are purchased and planted by State and county land managers for their publicly owned forest land. The seedlings planted on State- and county-owned property are typically destined for the forest products industry. The private landowners have a range of reasons for planting trees. The most cited reasons are for wildlife habitat improvements, privacy screens and shelterbelts, aesthetics, and timber products. Wisconsin State statutes require a minimum order size of 1,000 trees, 500 shrubs, or 1 packet (300) of stems. This relatively large quantity of seedlings requires engaged landowners.

Reforestation Assistance

To provide more value to customers, the nursery staff expanded landowner assistance and outreach. In 2007, the nursery increased its effort to improve planting success. It is believed that a better relationship with landowners will increase their satisfaction, which translates into better served customers. Nursery staff, specifically the assistant nursery managers, contact landowners throughout the State each spring after seedling delivery and planting.The staff inquires about site preparation, planting technique, seedling status, and current and future plantation maintenance practices. Then, with landowner permission, these plantations are visited throughout the summer. The data collected include seedling health and growth, site characteristics, maintenance efforts, and insect and disease problems, etc. This information is entered into a database. The monitoring will follow a plantation through its first, third, and seventh years of growth. Nursery staff has been able to assist with herbicide use, site preparation techniques, and plantation maintenance practices. The ultimate goal is to provide foresters and landowners with the best information about successful reforestation strategies in their areas. Many landowners are impressed with the increased attention and interest in the success of their tree planting.

The Future of the Wisconsin State Nursery Program

The current economic climate has been a challenge for the Wisconsin State Nursery Program. The current emphasis on increasing biomass, carbon sequestration, and sustainability, however, may translate into a greater need for nursery stock. Wisconsin's nursery program is proud to celebrate its centennial in 2011 and to honor the reforestation legacy. Since the beginning of the nursery program, more than 1.5 billion seedlings have been distributed throughout the State. After 100 years of growing trees, the mission remains the same, "to insure a consistent supply of high quality seedlings, of desirable forest species, at an economical price, to encourage reforestation in Wisconsin."

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Note: Climate and topography information contained in this article is from the Wisconsin State Climate Office available online at http://www.aos.wisc.edu/%7Esco/clim-history/state/stateclimate.html.

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Use of Painted Hardwood Seedlings in Reforestation

Deb Pitt

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Field foresters specializing in reforestation have long known the dilemma of determining the success or failure of a hardwood planting project when conducting the first regeneration survey in the fall following planting. Frequently, the seedlings are difficult to locate among the competing vegetation and are harder yet to distinguish from volunteer seedlings on the site (figure 1). If significant competition exists, locating planted seedlings can also be frustrating for contractors doing timber stand improvement work.

The idea of painting seedlings first took root several years ago when a forester with the Minnesota Department of Natural Resources (MNDNR) suggested painting red oak seedlings at the nursery before delivering them to a site to be underplanted. The seedlings were laid out on cardboard with the roots covered with wet burlap. The stems were then painted blue, using Aero-spot tree paint in an aerosol can, and allowed to dry. This successful attempt at a relatively small project (figure 2) enabled foresters to identify planted seedlings for about a year after planting. The blue paint stood out in sharp contrast to the surrounding vegetation, enabling the forester to see the actual distribution and conduct regeneration surveys that accurately accounted for planted seedlings.

After the first project, interest in this practice grew among MNDNR foresters who plant hardwoods, and demand for painted seedlings increased dramatically. The challenge for nursery staff proved to be the creation of a system that could apply paint to a large quantity of seedlings in a cost-effective and logistically practical manner. During a 3-year period, personnel at General Andrews State Forest Nursery (Willow River, MN) tried several strategies. Using a panama backpack sprayer to paint oak seedlings in the nursery seedbed was labor intensive and did not easily penetrate the leaf canopy to reach the stem. Another attempt was using aerosol cans of tree paint to treat the hardwoods as they were lifted in the fall. This method was expensive, logistically cumbersome, and very dependent on weather. In another effort, a small number of seedlings were dipped into an oil-based tree-marking paint, but the thick coating hampered bud break in the spring. Using tree-marking paint in a sprayer mounted behind a tractor also proved problematic because the paint needed thinning and an oil-based thinner would have been required; it was assumed that the thinner would be toxic to the seedlings. Finally,

Figure 1. A typical hardwood planting site in southeast Minnesota (Photo source: Doug Rau, Minnesota Department of Natural Resources, 2006).

Figure 2. A painted red oak seedling (Photo source: Rick Klevorn, Minnesota Department of Natural Resources, 2009).

several test applications of outdoor latex paint were made to determine how well the paint flowed through the equipment, to assess negative effects on the seedlings, and to determine if the paint would last a full growing season on the trees. After rejecting several methods, this final attempt produced positive results for each situation.

In 2010, the nursery purchased Latex Zone Marking Paint (manufactured by Ace Hardware Corporation), traditionally used for painting handicap signage. The bright blue paint can be thinned with water. A 55-gal (208-L) sprayer tank, equipped with a Hypro PTO Roller Pump (Model 7560C) mounted on a tractor, was used for application (figure 3). Nursery staff modified the boom with drop arms, which were adjusted with the tractor's three-point hitch to the height of the seedlings. Three floodjet nozzles (figure 4) were positioned to direct spray on the lower portion of the stems. When nozzle strainers were in place, the pressure was set to 35 to 40 psi, but it was common for the nozzles to become plugged. Thereafter, strainers were removed from the nozzles and pressure was calibrated to 10 to 15 psi. After several trials, a formula of 2 gal (7.57 L) of paint mixed with 3 gal (11.36 L) of water was established. This amount of thinned paint is sufficient to treat two 600-ft (183-m) nursery beds at two passes per bed, or the equivalent of 20,000 to 30,000 seedlings. Two passes ensures that paint is on all sides of the seedlings. Applications are made in September on sunny days when foliage and stems are dry to ensure adhesion of the paint (figure 5). These applications have been successfully made to red oak (*Quercus rubra* L.), white oak (*Quercus alba* L.), swamp white oak (*Quercus bicolor* Willd.), bur oak (*Quercus macrocarpa* Michx.), black walnut (*Juglans nigra* L.), and silver maple (*Acer saccharinum* L.). Nursery staff have painted as many as 500,000 or more hardwood seedlings per year.

Figure 3. The sprayer setup at General Andrews Nursery (Photo source: Theresa Dobosenski, Minnesota Department of Natural Resources, 2011).

Figure 4. Nozzle placement on sprayer (Photo source: Theresa Dobosenski, Minnesota Department of Natural Resources, 2011).

A benefit of using latex paint is the quick drying time. On a warm, sunny day the paint will dry to the touch within 1 hour of application and it seems to set within a day. Painted seedlings at General Andrews Nursery are usually left in the nursery bed for at least a week before lifting, but may remain there until the following spring (figure 5). The paint adheres well and does not easily rub off when the seedling is handled. The blue color stands out well against green summer foliage as well as bright fall colors. The cost of the paint was $99.95 per 5-gal (18.9-L) pail, which is enough to treat about 65,000 seedlings. To cover the cost of paint and labor, a fee of $20.00 per thousand seedlings is charged.

The time saved in the field and the increased data accuracy for regeneration surveys continue to make painted seedlings popular with many Minnesota DNR foresters. As long as demand continues for this service, a system for painting hardwood seedlings in a practical, efficient, and cost-effective manner will continue to evolve in the State nurseries.

Figure 5. Painted red oak 6 months after application (Photo source: Deb Pitt, Minnesota Department of Natural Resources, 2011).

A Highly Efficient Machine Planting System for Forestry Research Plantations—The Wright-MSU Method

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Abstract

For forestry research purposes, grid planting with uniform tree spacing is superior to planting with nonuniform spacing because it controls density across the plantation and facilitates accurate repeat measurements. The ability to cross-check tree positions in a grid-type plantation avoids problems associated with dead or missing trees and increases the efficiency and accuracy of data collection. Such features are particularly beneficial for long-term research plantations. The time and effort required to achieve an accurate grid plantation can be substantial, however, especially in large plantations. This article describes a new, efficient system for machine planting trees on a grid that is useful for a variety of forestry progeny tests—the "Wright-Michigan State University" (W-MSU) method developed by the late Dr. Jonathan Wright and others at Michigan State University. This study compared the W-MSU method with more labor-intensive and common methods of planting trees on a precise grid (direct seeding and planting into augered holes) and found the accuracy of spacing trees was statistically similar among the three methods.

Introduction

Stand density (number of stems per unit area) affects the growth rate and stem form of trees (Jagodzinski and Oleksyn 2009; Jiang and others 2007). Given the importance of stand density for growth and timber form, research designed to evaluate these characteristics should hold spacing consistent across a plantation. Stand density in a plantation is a product of two linear dimensions: row and within-row spacing, and thus, follows a logarithmic, rather than a linear curve. As a result, deviations up or down do not have equal effects on density and tighter spacing increases density more so than wider spacing decreases density (figure 1).

Consistent spacing among rows is essential if mechanized cultural practices such as mowing or band applications of herbicides are planned. Agricultural and orchard systems often specify very precise and tight tolerances for row spacing (± 0.1 in/0.25 cm) so that mechanized operations can be performed without damage to the crop and to enable multiple row operations. Multiple row spraying or cultivation is uncommon in forestry, making such tight tolerances unnecessary. For forestry plantations, typical row spacings range from 6 to 14 ft (1.8 to 4.3 m), and the tolerance can be up to ± 6 to 9 in (15 to 23 cm). Single-row cultural operations consist of strip spraying herbicides and mowing vegetation in the middle of rows with a small tractor.

Within-row spacing is the distance of plants down a row. The regularity of within-row spacing for both agriculture

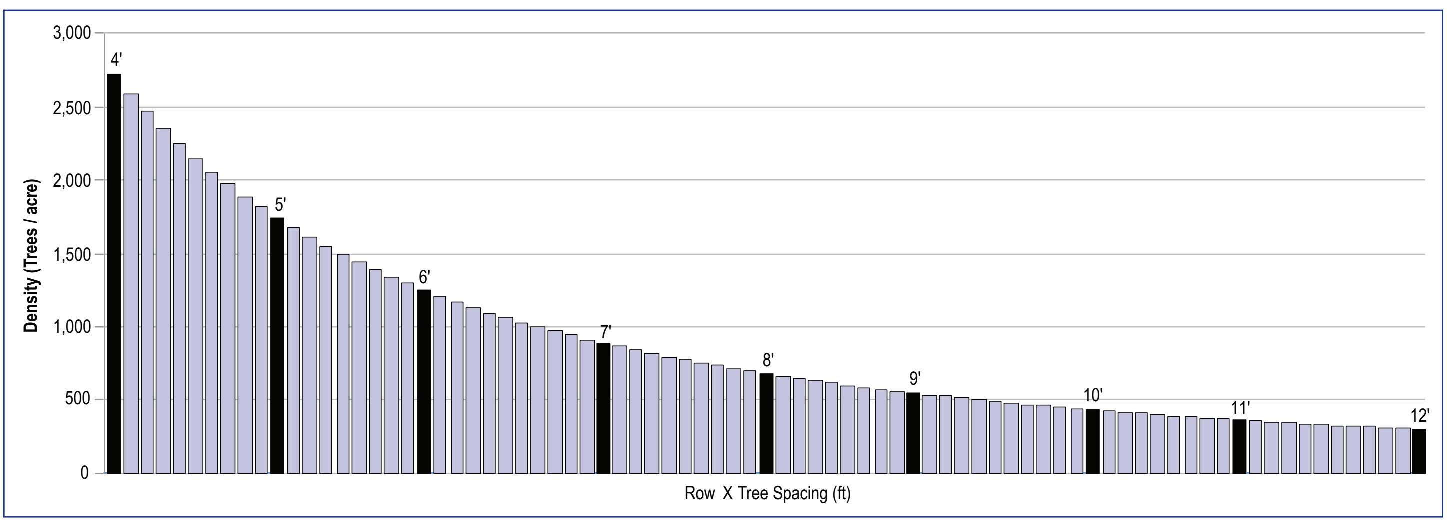

Figure 1. Calculated plantation stand density of a perfect square grid based on deviations of 0.1 ft (3 cm) on overall tree spacing.

and forestry plantings determines overall stand density. The tolerance of within-row spacing in forestry systems is often less critical, however, because cultural operations are rarely conducted between plants. For forestry plantations, consistent within-row spacing is useful to keep competition from neighboring trees constant, and to simplify data collection. Precise grids permit accurate crosschecking of each tree's position with others in neighboring rows and, thereby, reduce errors that may occur when trees die or volunteer seedlings have grown up in rows. Consistent within-row spacing also enables workers to cross mow vegetation if desired.

Site conditions, weather, planting method, and plantation goals determine how tree positions are marked. Uneven terrain and the absence of straight reference lines from which to orient require modest surveying techniques to mark a plantation. Various planting methods exist, each with its own virtue for different stock types, field conditions, and scales. For afforestation research in particular, a robust planting method capable of executing various experimental designs across many site types is needed. The W-MSU machine planting method is described and deviations in intended row and within-row spacing are compared with two common methods used to achieve a precisely spaced grid plantation: direct seeding and planting into augered holes.

Methods

Plantations and Plant Material

Nine progeny test plantations established by the Forest Service Northern Research Station, Hardwood Tree Improvement and Regeneration Center, Purdue University, were used for this study (n = three plantations per planting method). Plantations were located in Indiana and Michigan. Each planting is comprised of half-sib progeny from numerous families. For each of the nine plantations, the experimental design of the progeny test is either a randomized complete block design with 6 to 18 blocks or a randomized incomplete block design with 20 to 30 blocks. Each experimental block is composed of 36 to 64 trees arranged as square as possible, for example 6 rows by 6 trees, 6 rows by 8 trees, etc. Each planting has a 95-percent or better stocking rate, achieved by replanting in the second or third year if needed. Black cherry (*Prunus serotina*), black walnut (*Juglans nigra*), butternut (*J. cinerea*), and northern red oak (*Quercus rubra*) seeds were collected from clone banks or seed orchards at Purdue University or the Indiana Division of Forestry Nursery (INDoF), Vallonia, IN. For trees planted in augered holes and machine-planted trees (W-MSU method), seeds were fall sown at the INDoF. Seedlings (1-0) were lifted while they were dormant with 10 to 12 in (25 to 30 cm) of root and 2 to 5 ft (0.6 to 1.5 m) tall stems. For direct seeding, seed was stratified at Purdue and sprouted before planting in the spring.

Direct Seeding

Two black walnut progeny tests at 8 by 8 ft (2.4 by 2.4 m) and one butternut progeny test at 12 by 6 ft (3.6 by 1.8 m) were direct seeded. Plantation grids were delineated by defining a front and back baseline and marking rows with 18-in (45-cm) wire flag stakes. Within-row tree positions were marked with plastic drinking straws. To protect seed from squirrel predation, 6- by 4-in-diameter (15- by 10-cm-diameter) plastic tubes were buried around each seed. The seed was then planted 2-in (5-cm) deep inside the tube and covered with a 12-in (30.5-cm) square of poultry wire that was secured with two "U" shaped metal rods. Seedlings were allowed to grow through the wire for the first season after which the wire was removed. Weeds were controlled by a combination of hand cultivation and herbicide applications to achieve a 3-ft (0.9-m), weed-free strip down each row. Vegetation in the middle of rows was mowed several times during the season and at the end of the season. A 7.5-ft (2.3-m) plastic mesh fence surrounded the plantings to prevent browse from white tail deer (*Odocoileus virginianus*).

Augered Holes

Two black walnut and one black cherry progeny tests, each at 8 by 8 ft (2.4 by 2.4 m) spacing, were planted using augers. Plantation grids were marked as described above for direct seeding. Planting holes were drilled 16-in (40.6-cm) deep with a 12-in-wide (30.5-cm-wide) auger mounted on the front of a skid steer. Straws, or 6.0 by 0.5 in (15 by 1 cm) wooden stakes if the soil was hard, were used to mark the center point of each tree down each row, and both were painted orange to facilitate the skid steer operator's view. The operator targeted the straws or stakes to drill each hole. Planters typically centered trees in each hole, but occasionally tree positions were adjusted by visually sighting down each row and perpendicular to the row for holes drilled off center. Weeds were controlled by herbicide applications to achieve a 3-ft (0.9-m), weed-free strip down each row. Vegetation in the middle of rows was mowed once or twice during the growing season and at the end of the season. Plantations were fenced to prevent deer browse.

Machine Planting—The W-MSU Method

The W-MSU method requires three people to execute: a tractor operator, a planter, and a tree handler. A fourth person is helpful to check the within-row spacing of trees and replant trees planted too high, too low, or too far from the intended spacing. A Whitfield Model '88-2N' machine planter was used and was pulled by a John Deere 6410 front wheel assist, 100 horsepower tractor. The machine planter has a 26-in (66-cm) coulter wheel followed by a 2-in (5-cm) trencher foot that opens a slit in the ground as the tractor drives forward and two packing wheels behind the unit closes the slit to set the trees.

All three machine-planted (W-MSU method) plantations were planted at 8 by 8 ft (2.4 by 2.4 m) spacing and each was a different species: black cherry, black walnut, and northern red oak. On the baseline of the edge of each planting, each 8-ft-row position was marked with an 18-in wire flag stake (figure 2). Odd rows were marked with pink-colored flags and even rows were marked with white-colored flag stakes. This pattern of alternating colors was maintained across each plantation to aid in navigation. At 160-ft to 200-ft intervals (multiples of 8 ft), a parallel line of flag stakes was repeated. At a minimum, three such lines were marked out so that the tractor operator could use three or more flag stakes to sight on (figure 2).

A secondary method of keeping the tractor straight was to mount a 16-ft (4.8-m) bar on the front of the tractor and hang chains on both sides 8 ft (2.4 m) from center to run along the last planted row of trees. Thus, when the tractor operator and others were sighting the tractor path using the flag stakes, they could also crosscheck the position of the tractor by checking where the chains fell on the previously planted row. The tractor travels at the lowest gear possible at a throttle speed between 1,400 and 1,600 revolutions per minute.

At the time of marking baselines with flag stakes, a third colored flag stake (yellow) was inserted exactly in between tree rows, matching the pattern diagrammed in figure 2. A 200- or 300-ft (60- to 90-m) rope with marks at 8-ft (2.4-m) intervals was strung tight between the yellow flags so that orange painted wooden stakes could be quickly inserted on the center of each mark, with the broad side of each stake parallel to the marking rope. This step was repeated for each line of yellow flags. To save time, three rows of orange stakes were marked and then five rows are skipped before another three rows are marked with orange painted stakes. When completed, the rows of orange stakes provide a straight line-of-sight corresponding to the proper within-row spacing. Because the orange stakes are placed in the middle of the tree rows, they are

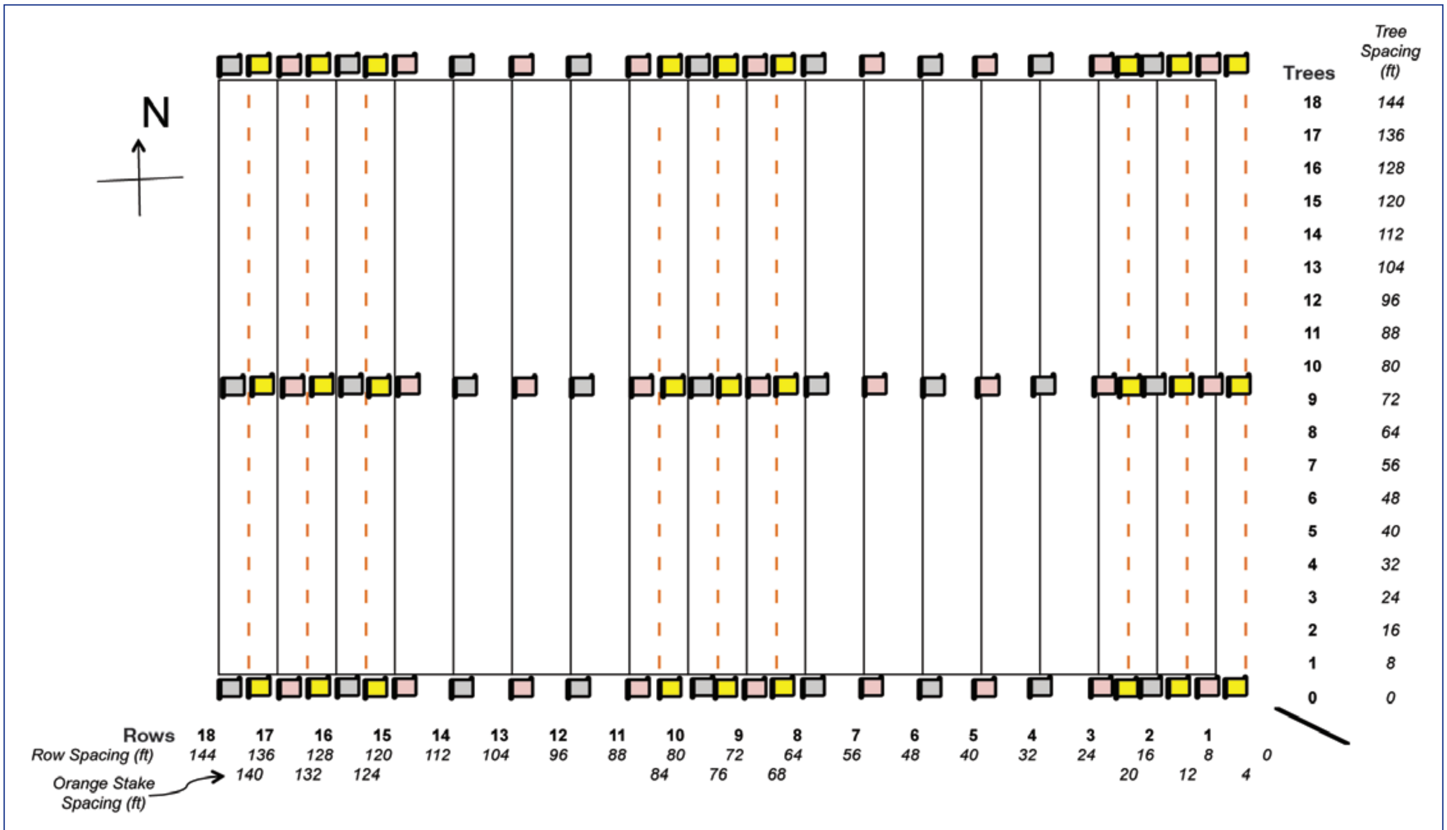

Figure 2. Diagram of the Wright-Michigan State University (W-MSU) method for an 8- by 8-ft plantation containing 324 trees. Three lines of flag stakes on the ends and in the middle of the plantation are baselines the tractor operator will sight on; interior baselines are set at multiples of 8 ft to facilitate marking the orange painted stakes. The orange stakes are positioned in the middle of three rows as indicated; in this example, four rows are skipped and another set of three rows of orange stakes are installed. A string or tape measure is run between the yellow flags on the baseline to mark every 8 ft where the orange stakes are placed.

not run over by the tractor. As the tree planter physically sets trees, they set each one at the point where the orange-painted stakes visually appear as a straight line (figure 3) and all of the lines of orange painted stakes provide a consistent visual reference across the entire plantation. This key aspect of the W-MSU method enables good control of within-row spacing.

The tree handler hands groups of trees to the planter in their proper order according to the experimental design as the tractor travels down the row. Depending on the specific design and personal preferences, the tree handler can ride on the tree planter itself, or walk along on the ground. In all cases, blocks of trees were presorted ahead of planting to contain a prescribed number of families and set number of trees per block. Each replicate block was randomized and bundled so that it was ready to load onto the planter at the time of planting (figure 4).

Figure 3. Orange wooden stakes in alignment for the planter to sight on to set trees at the correct point down the rows (top) and a field after being planted (bottom) (Photo source for both: Forest Service, Northern Research Station).

In every plantation, each block was as square as possible. For instance, in cases where blocks contained 48 trees, they were planted as 6 rows with 8 trees in each row. If 56 trees could fit down each row, 7 blocks could then be planted across 6 rows. Boxes on the planter are numbered 1 through 7. To begin planting, the tree handler grabs 8 trees from box 1 and hands those to the planter and then begins pulling 8 trees from box 2. As the planter plants the 8th tree of block 1, the handler hands the planter the next 8 trees for block 2 and so on. The pattern continues down the row until the 8 trees of block 7 are planted. After the row is complete, the tractor turns around and the handler now reverses the order; i.e., grabbing 8 trees from block 7, then block 6, then block 5, etc. To avoid planting trees from the wrong block, the handler places a single unique flag stake in the box with the correct block to plant and after the 8 trees of that block are pulled, counted, and ready to hand off to the planter—and only then—the flag is moved to the next box to repeat the process. In addition, unique colored flag stakes are placed ahead of planting across the plantation to define block lines; e.g., after every 8 tree and down every 6 rows, so that all members of the crew are able to check block lines and avoid miscounting. After planting, each plantation was fenced to exclude deer, and vegetation was managed as described for augered-hole plantations.

Measuring Deviations

Nine plantations, three planted by each method, were sampled in the winters of 2010 and 2011 for deviations from the intended row and within-row spacing. Trees ranged from 2 to 7 years of age at the time of measurement. An area approximately 4,350 ft^2 (400 m^2) was randomly selected within each plantation and the row and within-row spacing of 44 to 64 trees

Figure 4. Whitfield two-seat planter and black cherry trees sorted out by replicate and genotype ready to load into the boxes on the planter representing the different experimental blocks (Photo source: Forest Service, Northern Research Station).

were measured. A taut string was run down a row approximately 1 ft (0.3 m) from the center of the stems to reference the spacing of adjacent rows and a second string was run perpendicular to reference the within-row spacing of trees down the row. Measuring the ground-line caliper of stems and subtracting one-half of the result determined the center point of each tree. Missing or replanted trees were omitted. These positional data were compared with a geometric model of the intended spacing pattern; the absolute value of deviations for each tree for row spacing, within-row spacing, and overall spacing (i.e., nondirectional) was averaged by plantation. To compare planting methods, deviations were analyzed by one-way analysis of variance using Excel® (Microsoft Corp., 2007) with each plantation as a replicate.

Results and Discussion

No statistical difference in deviation from the intended spacing occurred among any planting method or between rows versus within-rows spacing (figure 5). Instead, variance in spacing for all planting methods was greater between sites, suggesting inconsistent implementation rather than variance in the accuracy of the methods themselves (table 1). The three planting methods analyzed were chosen for their practicality and accuracy to achieve a precise grid. The expectation was that direct seeding (with sprouted seed) would lead to the most precise grid, planting into augured holes would follow, and machine planting by the W-MSU method would be least accurate. Both direct seeding and machine planting were expected to lead to straighter rows compared with augered holes, and visually they do, because the center of the stem can vary in all directions when planting seedlings into a 12-in-diameter (30.5-cm-diameter) hole. The average deviations from intended spacing were similar among planting methods, however, and thus all three planting methods achieve the same plantation density.

The same work crew was not used for each plantation included in this study, nor was a precise record of labor hours kept; thus, only estimates are used to compare the relative efficiencies of each method. Although the time to plant a tree is one measure of efficiency, the amount of energy to plant is a further consideration. Less tangible, but important too, is the planning and site preparation each method requires and any additional post-planting management needs. Progeny tests, by definition, consist of seedlots of known parentage that need to be replicated throughout a plantation. As such, they are inherently time consuming to plant due to the need to keep track of the genetic identity of each tree.

To minimize physical labor, easily establish a precise grid, clearly keep track of genotypes, and minimize variation in initial stock-plant size and condition, direct seeding was assumed to be a good method for progeny testing. In general, three people could plant about 500 sprouted seeds (walnuts or butternuts) per day. The overall reliability and robustness of direct seeding, however, was unpredictable and poor. Walnut

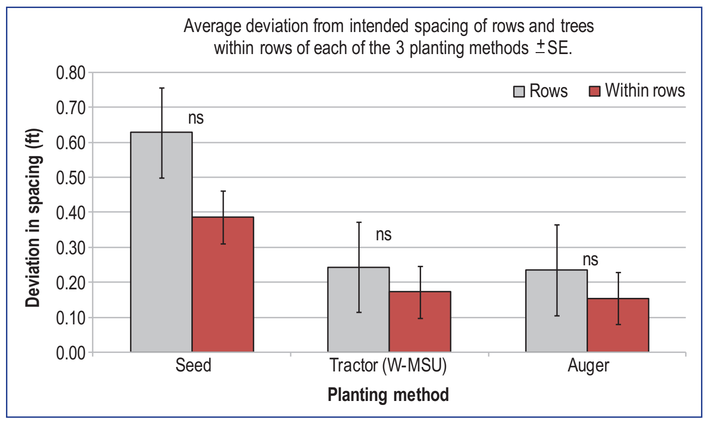

Figure 5. Comparison of the deviations from intended spacing of both row and within-row spacing for each planting method. Values are mean absolute values + standard errors of the mean. No significant differences among planting methods or for row versus within-row spacing were detected by Analysis of Variance (ANOVA).

Table 1. Summary of nine plantations sampled to compare three different planting methods with the deviation in spacing of rows and trees within rows from the intended spacing.

Planting method	Species	Year planted	Plantation location	Number of trees/ plantation	Intended spacing (ft)	Number of trees measured	Rep	Average deviation from intended spacing (ft)	
								Row	Within row
Tractor (W-MSU)	N. red oak	2007	W. Lafayette, IN	1,700	8' x 8'	58	1	0.34	0.33
Tractor (W-MSU)	Black walnut	2008	Grand Rapids, MI	1,450	8' x 8'	64	2	0.17	0.02
Tractor (W-MSU)	Black cherry	2009	Grand Rapids, MI	550	8' x 8'	64	3	0.22	0.16
Seed	Black walnut	2004	Buttlerville, IN	1,200	8' x 8'	60	1	0.45	0.31
Seed	Butternut	2003	W. Lafayette, IN	370	12' x 6'	44	2	1.38	0.76
Seed	Black walnut	2004	Lafayette, IN	450	8' x 8'	60	3	0.05	0.08
Auger	Black walnut	2005	Lafayette-H, IN	1,600	8' x 8'	64	1	0.08	0.14
Auger	Black cherry	2005	Buttlerville, IN	1,200	8' x 8'	60	2	0.19	0.28
Auger	Black walnut	2004	Lafayette-28, IN	1,200	8' x 8'	63	3	0.43	0.05
Total				9,720		537		0.37	0.24

and butternut need to be presprouted because germination rates vary. Sprouting, storing, and transporting sprouted seeds are much more cumbersome than handling dormant 1-0 seedlings to plant. Additional management tasks included planting seed inside “squirrel guards” to limit predation (which could amount to 100 percent if not checked), hand weeding around young seedlings, and additional replanting due to variable success rates (40 to 95 percent), all of which adds additional labor to the method.

Planting into augered holes is a method comparable to planting sprouted seed but, because a dormant 1-0 seedling has already germinated and survived for 1 year in the nursery, seedlings planted into augered holes prove to be more robust and predictable than sprouted seed. The larger problem with planting into augured holes is the physical challenge. Heavy clay soils, compaction, and very wet conditions make it difficult for planters to cover the roots. Workers become tired and trees can be planted poorly. For the three plantations in this study, approximately 12 people were needed to plant between 1,200 and 1,600 trees per day, not counting the skid-steer oper.ator who began drilling holes ahead of the planting crew—sometimes before dawn.

Planting seedlings with a tractor-mounted machine planter is certainly the quickest and physically easiest method for planting 1-0 bareroot dormant trees. The W-MSU method overcomes two principal problems with using tractor-driven tree planters for research plantations: establishing complex experimental designs and achieving consistent within-row spacing to achieve a precise grid. Because of the relative speed with which trees are planted, experimental replicates must be well organized. The Hardwood Tree Improvement and Regeneration Center has used the W-MSU method to establish numerous other progeny tests and silvicultural research plantations with spacings from 8 by 4 ft to 12 by 6 ft consisting of experimental designs with single-tree plots, four- or five-tree row plots, and alternating multiple species. The W-MSU method has proven to be a robust planting method across a wide variety of field sites with different vegetation types, terrain, slopes, and soil types and under various weather conditions. Using the W-MSU method, four workers were able to mark and plant 1,400 to 1,700 trees in 1 day with relative physical ease, making the method the most efficient by far for establishing high-quality plantations accurately and safely.

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Evidence for Nitrogen-Fixation in the Salicaceae Family

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Abstract

It has been shown that poplars and willows are able to produce high amounts of biomass even at low soil nutrient levels and that the application of nitrogen (N) fertilizers typically results in little or no increase in growth. Poplars growing in rocks and gravel in their native riparian habitat were well supplied with N despite low soil N availability. In different poplar and willow individuals, diverse endophytic bacteria were identified, including a diazotrophic species in which molecular nitrogen-fixation (N_2-fixation) could be verified. Most fast-growing *Populus* and *Salix* species will fix N_2. These findings provide a greater understanding on the Salicaceae family with respect to sustainability of biomass production at low-input energy levels.

Key words: *Populus*, *Salix*, nitrogen-fixation, endophytic bacteria, diazotrophic bacteria

Introduction

Poplar (*Populus* spp.) and willow (*Salix* spp.) species are early successional trees with rapid growth, deep roots, and the ability to grow fast, even in nutrient-poor environments. Because of their fast growth, poplar cultivars are grown widely in plantations, mostly in temperate zones (figure 1). About 25 million acres (10 million hectares) of poplar plantations exist worldwide. Many trials have examined the factors influencing biomass production of poplar cultivars. These trials show that N fertilization usually has little or no effect (Heilman and Xie 1993, Jug and others 1999, Liesebach and others 1999, Coleman and others 2004, DesRochers and others 2006, Booth 2008, Mao and others 2010). Free-air carbon dioxide (CO_2) enrichment experiments (FACE) showed that higher CO_2 levels also require higher soil-N. Poplar was able to increase biomass production under elevated CO_2, however, without additional N (Pregitzer and others 2000, Luo and others 2006). Also, no yield response curves and few detailed fertilizer recommendations exist for poplar or willow.

Poplars growing on rocks and gravel in their native riparian habitat (figure 2) were found to have sufficient amounts of N in their tissues despite low soil N availability (Coleman and others 1994, Lawrence and others 1997). The explanation for the indifference of poplar towards soil N availability has been studied recently. The purpose of this paper is to summarize these findings and discuss the associated opportunities and implications.

Diazotrophic Bacteria

It is well known that a large endophytic community resides in the stem tissue of poplar and willow species, the function of which is still mostly unknown. Ulrich and others (2008b) found a total of 53 genera including *Proteobacteria*, *Actinobacteria*, *Firmicutes,* and *Bacteroidetes*. In poplar and willow grown in contaminated soil, Taghavi and others (2009) identified 78 endophytic strains, of which 71 percent belonged to Gammaproteobacteria, with others from *Serratia* spp.,

Figure 1. Stand of black poplar (*Populus nigra* L.) (Photo source: *Populus nigra* Network, EUFORGEN, Bioversitiy International, Rome).

Figure 2. Seedlings of black poplar from natural regeneration growing in its native habitat on gravel poor in nutrients (Photo source: *Populus nigra* Network, EUFORGEN, Bioversitiy International, Rome).

Rahnella spp., *Pseudomonas* spp., and *Enterobacter* spp. Among these endophytes, several diazotrophic (nitrogen-fixing) bacteria were identified. They remained undiscovered because of their inconspicuous occurrence in the living tissues of the stem and branches and not in root nodules like the legume family (Fabaceae).

Legumes form a symbiosis with *Rhizobia*, a genus of soil bacteria capable of biological N_2-fixation of atmospheric N_2, where the plant exchanges its carbohydrates from photosynthesis for the combined N from its root nodule inhabitants. In this process, N_2 becomes accessible to the plant by conversion into ammonia (NH_3). This conversion requires a high amount of energy in the form of adenosine triphosphate (ATP). Through a particular interaction, a specific bacterium associates with a specific legume, resulting in the familiar root nodules, in which N_2-fixation occurs. In addition to the legumes, woody plant species of nine families (Betulaceae, Cannabaceae, Casuarinaceae, Coriariaceae, Datiscaceae, Elaeagnaceae, Myricaceae, Rhamnaceae, and Rosaceae) are known to associate with other N_2-fixing microbes living in specialized root nodules. Well known are *Frankia* bacteria found in *Alnus* spp. of the Betulaceae family.

Verification of N_2-fixation in *Salicaceae*

In poplars, endophytic bacteria were found inside stem tissues. These endophytes do not cause disease but rather are beneficial to the host by providing hormones, peptide antibiotics, enzymes, and other beneficial substances, thus classified as plant-growth promoting bacteria (Doty and others 2005, 2009; Ulrich and others 2008b; Scherling and others 2009). Plant-growth promoting bacteria were found in poplar and willow species (table 1). Among this array of growth-promoting substances, ammonia is also present in several other plant species without root nodules such as sugar cane, rice, coffee, and sweet potato (Reinhold-Hurek and Hurek 1998, Xin and others 2009). Thus, the common conclusion that plant species without root nodules are not associated with N_2-fixing bacteria has been proven incorrect.

To verify the ability to fix N_2, a first screening is efficient by employing the polymerase chain reaction to look for the presence of *nifH*, a gene encoding for one of the subunits of nitrogenase, the enzyme facilitating N-fixation (Doty and others 2009). Conclusive is also the acetylene reduction assay in which positive N_2-fixation activity of bacterial cultures is demonstrated by increased ethylene concentration over time (Doty and others 2009). Xin and others (2009) analyzed incorporation of the rare isotope $^{15}N_2$ instead of the common $^{14}N_2$ and showed that a strain of the endophytic bacteria *Burkholderia vietnamensis* isolated from a wild-grown *Populus trichocarpa* tree was able to fix $^{15}N_2$ by a 20-fold higher concentration of this isotope when compared with normal air. This endophyte was then inoculated onto Kentucky bluegrass (*Poa pratensis* L.) cultured on an N-free medium. After 50 days, the inoculated plants had increased 42 percent in weight and 37 percent in N when compared with the uninoculated control plants—showing that inoculation of N-fixing endophytes may enhance plant growth under N-limiting conditions. This particular *B. vietnamensis* strain is also able to provide IAA, a growth promoting hormone to the hosting plant, which may also have played a role in the biomass gain.

Another example of growth enhancement was shown by Ulrich and others (2008a) using an endophytic strain P22 of *Paenibacillus humicus* isolated from poplar. It caused a pronounced increase in root number and root length in poplar compared with uninoculated controls. The same effect was found when rooting macro cuttings of this poplar clone (Ulrich and others 2010). An analysis of the metabolites produced by the inoculated poplar showed that the poplar reacted pronouncedly to the presence of this endophyte by producing much higher amounts of asparagines and plant accessible urea (CH_4N_2O), but reduced amounts of organic acids of the tricarboxylic acid cycle. This effect on the metabolite profiles reflects remarkable changes in N assimilation in the plant (Scherling and others 2009).

Table 1. Bacteria isolated from poplar and willow host tree species showing nitrogenase activity.

Tree species	Bacterial strain	Method of verification	Reference
P. trichocarpa × P. deltoides	*Rhizobium tropici*	Culture on N-free medium	Doty and others 2005
[Populus alba × (Populus davidiana + Populus simonii) × Populus tomentosa]	*Paenibacillus humicus strain P22*	Metabolite analysis (urea)	Scherling and others 2009
P. trichocarpa, Salix sitchensis	*Burkholderia, Rahnella, Enterobacter, Acinetobacter,*	Culture on N-free medium; PCR with nifH primer; acetylene reduction assay	Doty and others 2009
P. trichocarpa	*Burkholderia vietnamensis*	Culture on N-free medium; PCR with nifH primer; acetylene reduction assay; $^{15}N_2$ incorporation assay; inoculation on other organism	Xin and others 2009

PCR = polymerase chain reaction.

Thus far, it is unknown if diazotrophic bacteria are present in all Salicaceae species. It can be expected that fast growing poplar and willow species adapted to riparian habitats with sandy soils poor in N availability are able to fix N. With respect to potential uses of plant-growth promoting bacteria, the best approach will be to quantify growth enhancement because of the symbiotic interactions between specific poplar and willow genotypes with specific bacterial strains.

Opportunities for Practical Use

The technical fixation process of plant-accessible ammonia from molecular N_2 requires an energy-input of 946 kJ $mole^{-1}$ and is thus highly energy consumptive. For this reason, plants favored for renewable energy crops are those able to produce high amounts of biomass with low requirements for synthetic fertilizer. Furthermore, negative influences of excessive N on the environment (e.g., groundwater leaching and emission of detrimental N_2O) can be avoided when growing N_2-fixing plants.

The energy source for the biological N_2-fixation is ATP of which an equivalent of 16 moles is hydrolyzed in the process. Biological N_2-fixation is more energy efficient than the inorganic process because it is enzyme supported and because the N is produced in the required amount and location. N_2-fixing plant species have therefore received much attention for both soil improvement and for reducing fertilizer usage. For those reasons, methods to initiate N_2-fixation in crop species by inoculation of diazotrophic endophytes have been investigated (Cocking 2005).

Because N_2-fixation is an energy-intensive process, N_2-fixing plants make ready use of freely available N in the soil (Cooke and others 2005). They can therefore be used to sequester surplus N in N-rich sites. For example, poplars and willows are being used to sequester N from sewage sludge (Dimitriou and Aronsson 2004). Other species, however, may be able to sequester higher amounts of N.

In agroforestry systems, poplar is being grown admixed with numerous crop plants (Yadava 2010). These systems have become common in many places and yield high-quality crops and high monetary returns for both the poplars and the crop plants (Bangarwa and von Wuehlisch 2009). In another study, poplars were grown in agroforestry systems with N_2-fixing plants; e.g., *Hippophae rhamnoides* (Mao and others 2010). Although the soil N increased, no biomass increase in the poplars occurred. This unexpected result is easily explainable when considering the N_2-fixing ability of poplar.

Implications for Tree Improvement

Analyses of endophytic bacteria in poplar and willow individuals showed that the bacterial communities differed considerably between trees (Ulrich and others 2008a, 2008b; Scherling and others 2009) indicating that the tree and bacteria interact in such a way that a certain bacteria community evolves within a particular tree genotype. The tree can thus acquire supplementary adaptive characteristics, which are not encoded by its genes. This adaptation may offset predicted gene expressions; e.g., in marker-assisted selections. The success of artificial inoculations with growth-promoting bacteria depends on the harmony of the bacterial strain and the genotype of the hosting tree.

It would be of practical importance to know the extent to which species or genotypes within the Salicaceae family vary in their ability to fix N_2. The special spectrum of bacteria found in different host genotypes suggests considerable variability. There may even be species that are unable to fix N_2. This inability could apply to species having evolved on sites where N was at or above sufficiency. Further research is warranted to better understand differences among genotypes and the potential for tree improvement on sites where N is limiting.

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The Future Looks Bright for Port-Orford-Cedar

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Abstract

Port-Orford-cedar (*Chamaecyparis lawsoniana* [A. Murr.] Parl.), also known as Lawson cypress, is native to a small area in Oregon and California, and is highly valued in many areas of the world for its wood and as an ornamental. Unfortunately, it is affected by a lethal root disease caused by *Phytophthora lateralis*. Because of the efforts of many individuals and agencies, heritable resistance to the disease has been confirmed and a breeding program to produce disease-resistant plant material is underway. This article describes these efforts and provides recommendations for obtaining and planting disease-resistant seedlings and preventing spread of the root disease.

Introduction

Port-Orford-cedar (*Chamaecyparis lawsoniana* [A. Murr.] Parl.), also known as Lawson cypress, is a large and attractive conifer that is native to a small area of southwestern Oregon and northwestern California (figure 1). The species is found in the coastal ranges and Klamath Mountains, from the Oregon Dunes in Coos County, Oregon, and south to the Mad River in Humboldt County, California. A disjunct population occurs in the Trinity and Scott Mountains near the headwaters of the Trinity and Sacramento Rivers in California (figure 2).

Although geographically limited, within its small range Port-Orford-cedar is found in a wide variety of plant communities and environments, from sea level up to 6,400 ft (1,950 m), and in many soil types, including ultramafics (serpentine). Port-Orford-cedar is more drought tolerant than western hemlock (*Tsuga heterophylla* [Raf.] Sarg.) or Sitka spruce (*Picea sitchensis* [Bong.] Carr.), but less drought tolerant than most of its other conifer associates. The limiting factor in the natural distribution of Port-Orford-cedar is most likely its requirement for consistent moisture during the summer (Zobel and others 1985). Port-Orford-cedar seed germinates late in the spring, and its seedlings are small and shallow-rooted. Natural seedling success is dependent on moisture near the surface and high water potential in summer. Thus, natural stands of Port-Orford-cedar are limited to locations with consistent groundwater, including high water table and seep areas, along rivers and streams, lakeshores, slumps, cool microsites, and upper slopes in areas with summer fog.

Port-Orford-cedar is moderately high in shade tolerance, but also grows well in the open. This species is the most shade tolerant of all its conifer associates with the exception of western hemlock. Port-Orford-cedar is also tolerant of repeated fire. This species is less fire resistant than Douglas-fir (Mirb.) Franco, but more resistant than true firs or hemlock. Pole-sized trees generally are able to survive light to moderate ground fires (Jimerson and others 2001, Zobel and others 1985).

Port-Orford-cedar plays a significant role in riparian zones within its range. This species provides streamside shade,

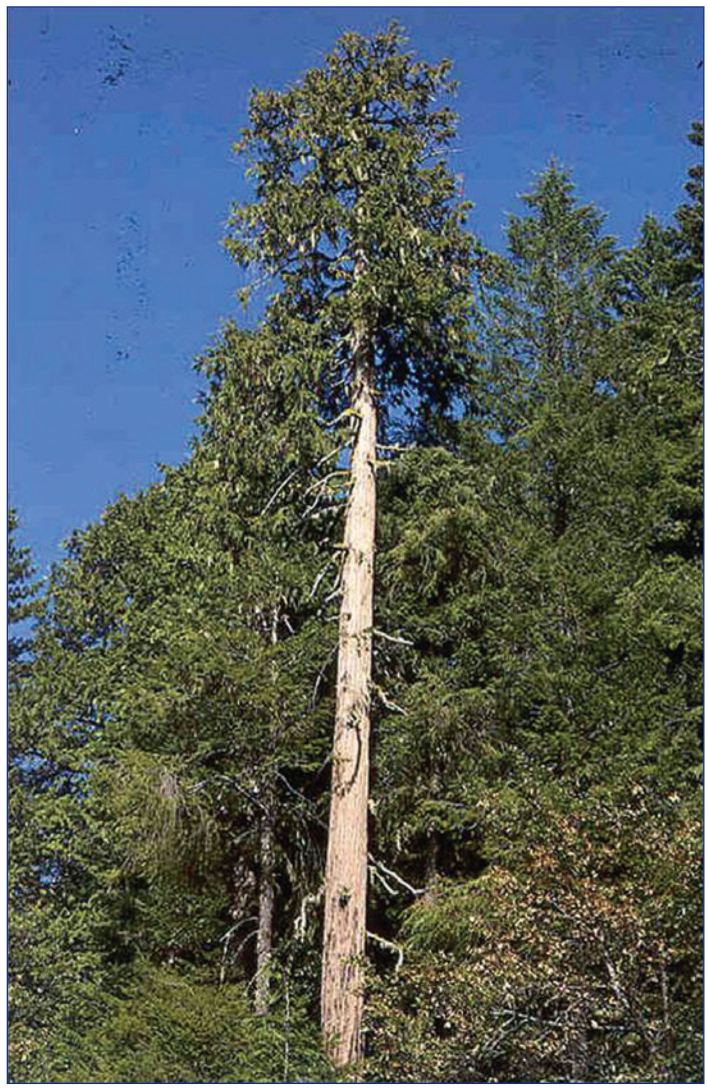

Figure 1. A large healthy Port-Orford-cedar (Photo source: Forest Service Pacific Northwest Region archives).

Figure 2. The native range of Port-Orford-cedar (Map source: Zobel 1990).

bank stability, and decay-resistant large woody material for in-stream structure. Along streams on ultramafic sites where Port-Orford-cedar is often the only large conifer, these functions are particularly critical. On ultramafic sites, rare and unique plants are often found in association with Port-Orford-cedar (USDA and USDI 2004).

Port-Orford-cedar has been highly prized as an ornamental since it was first collected and propagated by early botanical explorers in the Pacific Northwest. At least 250 named varieties have been propagated for a diversity of size, color, branching habit, and foliage. Port-Orford-cedar performs well in many areas outside its natural range. This species has been planted in residential gardens, hedges, and parks around the world. Port-Orford-cedar is also valued for its decay-resistant, fine-grained, white wood. Native Americans use the wood in traditional plank houses, for storage boxes and regalia items; and the shoots, bark, and twigs for medicinal purposes, as well as for baskets, clothing, and mats. Euro-Americans began large-scale harvesting of Port-Orford-cedar to provide lumber for the building booms of the Gold Rush. Harvest for lumber and many other uses continued through two world wars. Old-growth Port-Orford-cedar is highly valued in Japan and was the basis of a thriving export market until old-growth Port-Orford-cedar became much less available. Today, Port-Orford-cedar is harvested primarily for domestic uses. This species is milled for lumber, paneling, decking, fencing, and arrow shafts. The essential oil is used in organic insect repellents and a large market exists for the boughs, which are used in wreaths and floral arrangements.

Port-Orford-cedar is affected by a lethal root disease, which was first reported in a nursery in Seattle, WA, in 1923. At the time, the disease had already been observed killing planted specimens in area gardens (Zobel and others 1985). The root disease was widespread and had already devastated the horticultural trade in Port-Orford-cedar in the Northwest before the causal agent was identified and named *Phytophthora lateralis* by Tucker and Milbrath (1942). By 1952, the pathogen had spread south into the natural range of Port-Orford-cedar, where it moved rapidly along roads and streams with devastating results. The most severe effects have been on privately owned land along the coastal plain and farther inland on both public and private land in wet areas, riparian zones, and ultramafic sites.

Port-Orford-Cedar Root Disease

Port-Orford-cedar and Pacific yew (*Taxus brevifolia* Nutt.) are the only species known to be affected by *P. lateralis*. Nearly all Port-Orford-cedar are very susceptible, and most of the infected trees are quickly killed. Yew is much less susceptible and becomes infected only when growing in close proximity to diseased Port-Orford-cedar (Murray and Hansen 1997).

Like other members of the genus *Phytophthora*, *P. lateralis* is a water mold, more closely related to brown algae than to fungi, which it superficially resembles. *Phytophthora* species, including *P. lateralis*, produce swimming zoospores that infect the fine roots of their hosts. Growth of *P. lateralis* in the roots of infected trees cuts off the flow of water and nutrients, resulting in rapid mortality. Aboveground symptoms are typical of water stress, and include reduced growth, wilting, and fading of the entire crown from green to yellow to bronze. Until the cambium dries out, a cinnamon-orange stain (figure 3) with a distinct margin is visible under the bark in the phloem of the roots and root collar of diseased trees (Hansen 1997).

P. lateralis is a cool-climate *Phytophthora* species. This species is active during mild, wet weather and is inactive when conditions are hot and dry. Spread of the pathogen over long distances is accomplished by resting spores transported in infested plant material and soil, primarily by humans. This is the most common means of introduction into new areas.

Within an infested area, *P. lateralis* spreads mainly by waterborne spores in ditches, streams, and overland flow. Movement of the pathogen along root-to-root contacts between infected and uninfected trees is also an important mechanism of spread between adjacent trees, although it appears to be less important than spread by movement of spores in water or soil (Zobel and others 1985).

The risk that trees on a site may become infected is largely based on factors that aid or inhibit the movement of infested water and soil. High-risk sites for infection include low-lying wet areas downslope from already infested areas, sites below open roads and trails, areas within the high water mark of stream channels and riparian areas, as well as ditches, gullies, swamps, seeps, ponds, lakes, and concave slopes where water collects.

Low-risk sites for infection are upland sites, sites on convex slopes, areas above the high water mark of stream channels, and areas away from roads and trails where topography provides protection from the introduction of the pathogen into soil or water.

After trees become infected, *P. lateralis* survives in their roots and root fragments until the roots decompose, which may take at least 7 years under cool moist conditions (Hansen and Hamm 1996). Under less favorable conditions, survival of the pathogen is greatly reduced. If all the host trees, including natural regeneration, can be eradicated from an infested site, the pathogen will be eliminated from the site after the roots have decomposed.

Breeding Port-Orford-Cedar for Resistance to Root Disease

Hansen and others (1989) confirmed the existence of heritable resistance to Port-Orford-cedar root disease. As a result, the Forest Service and the U.S. Department of the Interior, Bureau of Land Management began an operational breeding program in cooperation with Oregon State University in 1996. The goal of the program is to develop durable resistance to *P. lateralis* while maintaining broad genetic diversity within the species (USDA 2004). The first phase of the program was selection of phenotypically resistant trees from diseased populations throughout the range of Port-Orford-cedar. Small branches from approximately 12,000 trees were screened for disease resistance using a stem dip test that artificially inoculated stem tissue with the pathogen. The results of this test identified approximately 1,600 potentially resistant parent trees. Seedlings and rooted cuttings propagated from these trees were subjected to additional testing by artificial root inoculation in the greenhouse (figure 4) and by outplanting in naturally infested field sites. In short-term greenhouse trials, seedlings from disease-resistant parents had between 50 and 100 percent survival compared with less than 10 percent survival of seedlings from susceptible parents (Sniezko and others 2006). In a long-term field test, seedlings and rooted cuttings of disease-resistant families had 20 to 80 percent survival after 16 years compared with 0 to 8 percent survival of susceptible families (Oh and others 2006). Several disease-resistant individuals have survived for 22 years on an infested site at Oregon State University.

Figure 3. Stem of a young Port-Orford-cedar with diagnostic stain caused by Phytophthora lateralis (Photo source: Forest Service Pacific Northwest Region archives).

Figure 4. Testing rooted cuttings for resistance to Port-Orford-cedar root disease by artificial root inoculation in the greenhouse (Photo source: Richard Sniezko, Forest Service).

Short-term greenhouse trials have shown that at least two types of disease resistance exist: major gene and slow dying resistance. In addition, McWilliams (2000) found that isolates of *P. lateralis* from Western North America have only limited genetic variability. The possibility of several resistance mechanisms, coupled with uniformity in the pathogen, increases the chance that resistance to the root disease will persist over time (USDA and USDI 2004). Both short- and long-term field trials are continuing (Sniezko and others 2009). The durability of disease resistance in long-term field trials will determine the ultimate success of the program.

The first containerized breeding orchards of disease-resistant Port-Orford-cedar were established in 2001 (figure 5). The long-term objective is to have 30 disease-resistant selections per breeding zone. The resistance level of parent trees in the orchards is continually increasing as new parents are added following the results of ongoing trials, as orchards are rogued to meet new selection criteria, and as second generation breeding increases disease resistance (USDA 2006). Orchard development and the entire breeding program are greatly benefitted by the fact that Port-Orford-cedar can be induced to flower, and produce cones and seed at a very young age.

Figure 5. A containerized orchard for breeding root disease-resistant Port-Orford-cedar (Photo source: Richard Sniezko, Forest Service).

The orchards are propagated and organized according to breeding blocks, which were determined by studies of the genetic variability in Port-Orford-cedar. Within the blocks, breeding zones were delineated that further subdivide the blocks into elevational bands (figure 6). The purpose of breeding blocks and breeding zones is to guide breeding activities, and specify where seeds and other reproductive material are gathered and then deployed (table 1). This approach ensures that nursery stock is adapted to the outplanting site, and conserves the natural genetic structure of Port-Orford-cedar (USDA and USDI 2004).

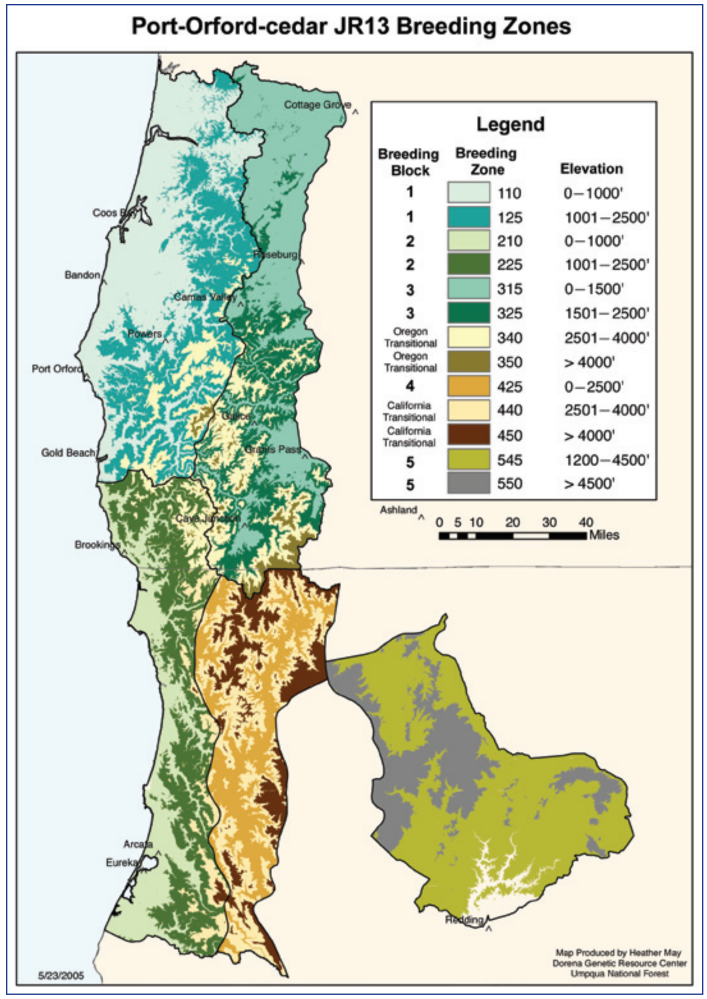

Figure 6. Breeding zones for Port-Orford-cedar. Note: "JR13" refers to Jim Hamlin and Rod Stevens, Geneticists, respectively, Forest Service and U.S. Department of the Interior, Bureau of Land Management (retired), who determined the boundaries of the 13 breeding zones (Map source: Heather May, Forest Service).

Table 1. Seed zones for Port-Orford-cedar

Breeding block	Breeding zone[a]	Elevation ft (m)
1	110	0–1,000 (0–304)
1	125	1,001–2,500 (305–762)
2	210	0–1,000 (0–304)
2	225	1,001–2,500 (305–762)
3	315	0–1,500 (0–457)
3	325	1,501–2,500 (458–762)
OR transitional[b]	340	2,501–4,000 (459–1,219)
OR transitional	350	> 4,000 (> 1,219)
4	425	0–2,500 (0–762)
CA transitional	440	2,501–4,000 (763–1,219)
CA transitional	450	> 4,000 (> 1,219)
5	545	1,200–4,500 (366–1,372)
5	550	> 4,500 (> 1,372)

[a] The first digit represents the breeding block, and the second and third digits represent the upper limit of the elevational band.

[b] Seed and seedlings from transitional zones may be planted anywhere in the State within the respective elevation band.

Why Plant Disease-Resistant Port-Orford-Cedar?

On many currently infested and previously infested sites, few large Port-Orford-cedar remain. Planting disease-resistant Port-Orford-cedar will increase the probability that the trees will survive to a large size and regain their ecological role as a source of shade and decay-resistant wood, particularly important in riparian areas. On ultramafic soils, the reintroduction of Port-Orford-cedar will restore a primary source of shade and soil stability. Planting disease-resistant Port-Orford-cedar will also provide a source of resistant genes for future natural regeneration. Disease-resistant Port-Orford-cedar will be a particularly valuable addition on sites where increased species diversity would benefit forest management. For example, disease-resistant Port-Orford-cedar may be an appropriate alternative in areas along the southern Oregon coast where Swiss needle cast (caused by the fungus *Phaeocryptopus gaeumannii* [Rohde]Petrak) is causing significant reductions in the yield of Douglas-fir (Duddles 1999), or on sites where Douglas-fir is affected by laminated root rot. Even where the performance of Douglas-fir is not an issue, Port-Orford-cedar may be a bonus in stands, adding to total yield, because it does not significantly compete with Douglas-fir (Zobel and others 1985). Since it performs well in the understory, Port-Orford-cedar can add structural diversity and would be a valuable addition where uneven-age management is preferred.

The pond value of Port-Orford-cedar logs, compares favorably with Douglas-fir logs and prices for Port-Orford-cedar logs have remained more stable than Douglas-fir log prices during the past 10 years (Huff 2011). Port-Orford-cedar may also be a desirable component of managed stands because of its value for boughs and specialty wood products. Carefully controlled bough harvest can provide intermediate income, while individual trees can be selectively harvested for specialty products. Planting disease-resistant Port-Orford-cedar will also ensure its availability for traditional tribal uses.

Port-Orford-cedar was once widely planted and highly valued as an ornamental in the Pacific Northwest and around the world. This species is seldom damaged by foliage diseases, stem decay, or insects. The bark of mature trees is thick and resistant to damage. The species resists moderate air pollution and recovers well when the terminal leader is lost (Zobel 1990). The availability of these new disease-resistant varieties should encourage renewed planting of Port-Orford-cedar in parks, gardens, and other urban settings.

Where To Plant Port-Orford-Cedar

Current recommendations for planting disease-resistant Port-Orford-cedar are to plant on sites that are low risk for root disease, in riparian areas, in adjacent uplands up to 100 yd (91 m) upslope from previously known locations of Port-Orford-cedar, on concave slopes, and in areas with an open or partially open canopy. Sites where all Port-Orford-cedar (including natural regeneration) have been eradicated by treatment or by the root disease for at least 7 years are also good candidates for planting.

In addition to planting on sites where Port-Orford-cedar loss has occurred because of fire or root disease, disease-resistant Port-Orford-cedar can also be planted on new sites within its natural range. Containerized seedlings or bareroot seedlings with a large root mass may perform well on drier sites that would be marginal for natural regeneration of Port-Orford-cedar (Lucas 2011). On upland sites, seedlings should be planted in moist microsites, such as on the north side of stumps or snags, and in areas where brush or other regeneration will not hinder seedling growth. In general, sites with red alder (*Alnus rubra* Bong.) are considered suitable for planting Port-Orford-cedar (USDA and USDI 2004).

The current focus of Port-Orford-cedar planting on Federal land is on sites where its ecological function is most critical, such as along streams on ultramafic soils, or where the species has been lost to wildfire. The largest operational planting of disease-resistant Port-Orford-cedar on Federal land was in 2010. Approximately 48,000 seedlings were planted on 1,470 acres (595 hectare) on the Six Rivers and Klamath National Forests that burned in a 2008 wildfire. Seedlings were planted in areas where Port-Orford-cedar grew before the fire, as well as in adjacent areas where it had not been present (Angwin and others 2010). Disease-resistant stock has been planted in smaller amounts on Federal land in Oregon since 2004.

In landscape settings, disease-resistant Port-Orford-cedar is best suited for areas with well-drained (but not droughty) soil, on high ground, away from areas where water runs off or puddles, and away from roads, parking lots, trailheads, and other heavily trafficked areas.

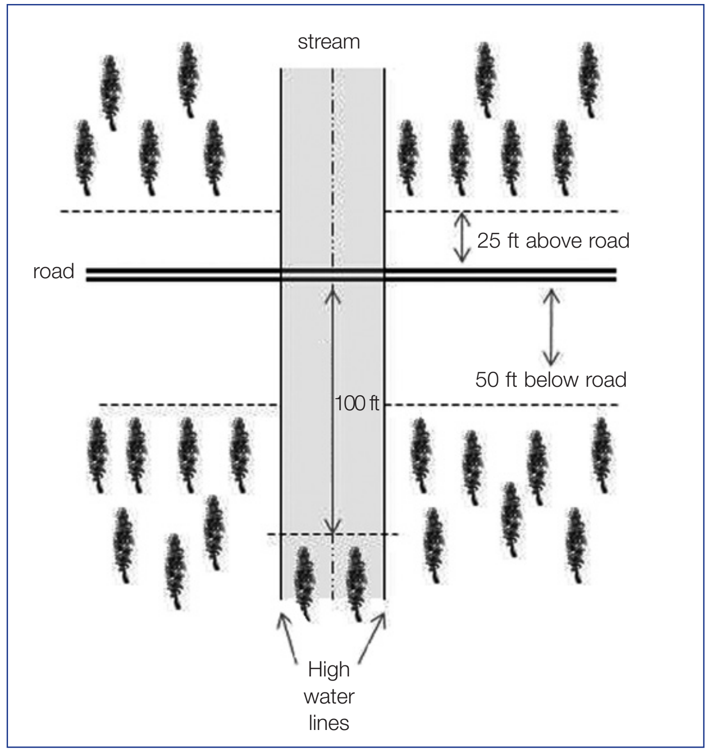

Figure 7. Guidelines for planting resistant Port-Orford-cedar along roads and streams (Graphic source: Katy Mallams, Forest Service).

Where Not To Plant Port-Orford-Cedar

Seedlings that are resistant to Port-Orford-cedar root disease are not completely immune to the disease. Therefore, disease-resistant Port-Orford-cedar should not be planted where vehicle, foot, or animal traffic is likely to introduce soil infested by *P. lateralis*. Port-Orford-cedar should not be planted within 50 ft (15 m) of the downhill side of roads that are open to vehicles, or within 25 ft (8 m) of the uphill side of open roads, or within the high water line of stream channels within 100 ft (30 m) of roads (figure 7).

Port-Orford-cedar should not be planted in areas where the root disease has caused recent mortality, as indicated by the presence of brown needles or fine branches on the dead trees, or where eradication treatments are under way. Planting in these areas would provide new host material for the pathogen, allowing it to persist on the site. In addition, the resulting selective pressure would provide an opportunity for the pathogen to mutate to a new, possibly more virulent strain. Port-Orford-cedar should also not be planted in unstocked areas between infested and uninfested sites to avoid creating a bridge for movement of the pathogen into uninfested areas.

In landscape settings, Port-Orford-cedar should not be planted near recently dead Port-Orford-cedar, anywhere water runs or puddles, in low spots, or along roads, driveways, or trails, or other areas frequented by people.

Preventing Introduction of *P. lateralis* During and After Planting

A number of measures can be taken to exclude *P. lateralis* from uninfested sites, and prevent its reintroduction to previously infested sites during and after planting and other activities. These measures include choosing entry and exit routes to avoid infested areas; planting uninfested sites before those with a history of root disease; washing and inspecting vehicles, planting tools, and planter's (and inspector's) footwear before entering planting areas; and rewashing and reinspecting vehicles and equipment leaving the area before they return.

Wash vehicles, equipment, and footwear with uninfested water or with water treated with Clorox® bleach according to the label instructions (mix at a ratio of one part Clorox® to 1,000 parts water at least 5 minutes before use). A stiff brush or vigorous stream of water is usually sufficient to remove potentially infested soil. Take care that wash water does not drain into watercourses or areas with uninfected Port-Orford-cedar. Whenever possible, limit visits to planted areas, bough collecting, and other harvest activities to the dry season when conditions that favor pathogen spread are limited.

Availability of Disease-Resistant Plant Material

Seed and seedlings from disease-resistant parents are available to Federal agencies from the Forest Service J. Herbert Stone Nursery in Central Point, OR (phone: 541–858–6100). Non-Federal agencies and private landowners in Oregon interested in purchasing seed can contact the Oregon Department of Forestry (ODF), Private Forests Program (http://www.oregon.gov/ODF/privateforests/index.shtml). Several commercial forest tree nurseries in the region have experience growing Port-Orford-cedar. These nurseries can purchase the seed from ODF and will grow specific amounts on contract. For individual plantings around homes, gardens, parks, and other landscaped settings, named varieties of Port-Orford-cedar that are propagated on disease-resistant rootstock are available from retail nurseries.

Summary

Port-Orford-cedar has been recognized as a beautiful and highly valuable tree species since humans first encountered it in the forests of southwest Oregon and northern California. In the early 20th century, introduction of a nonnative pathogen, *Phytophthora lateralis*, devastated the Port-Orford-cedar horticultural and timber industries, and led to significant changes in forest structure and function, particularly in riparian and ultramafic ecosystems. For many years, it appeared that no resistance to the root disease existed, and that the future of Port-Orford-cedar was uncertain at best. Fortunately, some people refused to give up hope and, in 1989, it was shown that heritable resistance exists in a small number of families. Since then, an active search has identified disease-resistant parent trees from many areas in the natural range of Port-Orford-cedar. An ongoing breeding program provides seed from disease-resistant parents to public agencies and private landowners, and continues efforts to increase the level of resistance. These efforts have renewed interest in Port-Orford-cedar by the horticulture industry and named varieties of Port-Orford-cedar on disease-resistant rootstock are now available.

The availability of disease-resistant stock, awareness of how *P. lateralis* moves, and commitment to using the best management practices to prevent disease spread are more important than ever. Given these means, there is renewed hope that Port-Orford-cedar will survive and flourish again in many of the places where it once thrived.

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Effects of Plant Date and Nursery Dormancy Induction on Field Performance of Douglas-Fir Seedlings in Western Oregon

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Abstract

The effects of nursery dormancy-induction treatments and planting date on growth and survival of Douglas-fir (*Pseudotsuga menziesii* var. *menziesii* [Mirb.] Franco) seedlings were tested on six sites in western Oregon, selected across a geographic moisture gradient. Seedlings were outplanted on eight dates between mid-August 2005 and mid-January 2006 and four dates between August 2006 and January 2007. Two dormancy-induction treatments were tested: shortened daylength and moisture stress. Seedlings exposed to a shortened daylength had earlier bud primordia production and less lammas growth than the moisture-stressed seedlings. Few differences existed in seedling height, root-collar diameter, height:root-collar diameter, and survival between the two dormancy-induction treatments 3 years after outplanting. Plant date had a strong effect on seedling growth and survival. Seedlings planted in early fall, when roots were still elongating, were up to 39 percent taller than winter-planted seedlings 3 years after outplanting. Survival was lowest for trees planted in August, particularly at the two driest sites. If timed correctly to avoid late summer drought, fall planting is a viable alternative to winter planting in western Oregon.

Introduction

Fall planting has been perceived to be a risky, but viable alternative to the normal winter and early spring planting season in western Oregon. Because fall weather is sometimes hot and droughty, planting in this region most commonly occurs between mid-December and March, after the cold rains have arrived and seedlings are most stress resistant. At the beginning of this planting period, air and soil temperatures are cold and daylength is at a minimum. As the planting season progresses, soils begin to warm and daylength increases; trees planted too late in the spring are unable to complete primary growth before soil moisture deficits and high evaporative demands occur (Hunt 2004).

Interest is increasing to extend the operational planting window for Douglas-fir (*Pseudotsuga menziesii* var. *menziesii* [Mirb.] Franco) seedlings planted on the west side of the Oregon Cascade Range to include the fall. Fall planting allows access to high elevation sites before winter snows accumulate and block roads and reduces the need for costly long-term cold storage (Adams and others 1991). The rationale behind fall planting is that seedlings are phenologically poised for rapid establishment when soil temperatures are still in the optimum range (10 to 20 °C [50 to 68 °F]) for root elongation (Lopushinsky and Max 1990) but shoot growth has ceased. Seedlings are, therefore, likely to establish root-to-soil contact immediately after planting. In addition, daylength is still long enough to allow continued photosynthesis, thereby increasing stored carbohydrates available for root growth in spring (van den Driessche 1987). This early establishment allows for two cycles of field root growth before initiation of shoot growth the following spring, resulting in increased growth, survival, and competitive ability relative to noncrop vegetation.

Some organizations have attempted operational fall planting with mixed success. The timing of fall planting has always presented a significant risk to seedling survival. Early fall planting in dry soils with no assurance of forthcoming rain can be an expensive gamble. Planting early in the fall also means risking whether the seedlings possess the proper morphological and physiological conditioning to survive. Seedling dormancy status (quiescence, in which dormancy is imposed by environment, or rest, when a shoot will not elongate even under favorable environments) is particularly important, not only because it is directly related to the stress resistance of the seedlings, but also because it affects growth and survival after outplanting (Lavender 1985). Planting success benefits from matching the plant growth cycle with the growing season (Turner and Mitchell 2003). Key concerns include knowing when it is safe to plant in the fall, determining the optimal physiological condition of seedlings, and understanding how to best match seedlings with the site conditions to ensure seedling survival into the following spring.

Beginning around July, most nurseries in western Oregon and Washington use moisture stress and changes in fertilization to induce terminal bud dormancy in Douglas-fir seedlings. Reducing water and shifting nutrients are techniques used to mimic natural Mediterranean seasonal changes that cause seedlings to set a terminal bud and enter into quiescence (Lavender 1990). After this stage of dormancy has been achieved, a new fertilization regime is resumed at a reduced rate to encourage stem diameter and root growth and to increase whole plant nutrition to move the seedlings into rest (Lavender and Cleary 1974). Water and nutrition must be carefully monitored in the nursery from midsummer into fall to prevent lammas growth (fall bud break) from occurring (Hahn 1984).

Canadian nurseries at higher latitude sites have successfully used photoperiod manipulation using artificially induced short-day treatments to achieve the quiescent dormant state in container seedlings (Hawkins and Draper 1991). Nursery managers refer to this manipulation as "blackout" because greenhouse interiors or seedling benches are covered with black cloth or curtains for up to 16 hours to simulate short days. During long nights (or induced periods of darkness), phytochrome is inactivated and bud formation is promoted (Colombo and others 2001).

The evidence concerning the pros and cons of fall planting is largely anecdotal; therefore, this study was initiated to quantify Douglas-fir container seedling performance as influenced by planting date, nursery dormancy-induction treatment, and environmental conditions. The null hypotheses were that the dormancy-induction method is unrelated to subsequent growth and survival and that no relationship exists between the planting date and subsequent growth and survival rates.

Materials and Methods

Planting Sites and Planting Stock

Douglas-fir seedlings were grown at the PRT (Pacific Regeneration Technologies, Inc.) nursery in Hubbard, OR. Seedlings for the moderate moisture sites (described in the following section) were grown in 615A Styroblock® containers (213 cavities per m^2, 336 ml/cavity) and those for the low- and high-moisture sites were grown in 515A Styroblock® containers (284 cavities per m^2, 250 ml/cavity). The growing medium was 100 percent Sphagnum peat moss. Before each plant date, seedlings were hand lifted and graded according to contract specifications (615A stocktype: 30 to 50 cm [12 to 20 in] height and a minimum 3.5 mm [0.14 in] root-collar diameter [RCD]; 515A stocktype: 18 to 45 cm [7 to 18 in] height and a minimum of 3.2 mm [0.13 in] RCD). Any seedlings with deformities or undesirable traits were excluded from the study.

Six western Oregon sites were selected across a geographic moisture gradient to maximize the climatic variability among sites (table 1). Operational site preparation (e.g., aerial herbicide spraying and/or slash piling) was carried out as required for each site. Three sites were planted in the 2005–06 planting season (Series 1) and three were planted in the 2006–07 planting season (Series 2). Mean annual precipitation differs among the sites, but seasonal patterns are similar to low-precipitation inputs during summer months and high-precipitation inputs through fall and winter months.

A randomized complete block design was used at each study site, with five blocks per site (with the exception of Southern Comfort, which had only four blocks because of space limitations). Each block consisted of 16 (Series 1) or 8 (Series 2) factorial treatment plots (plant dates times two dormancy-induction treatments). Each treatment plot consisted of 20 to 25 seedlings planted at a 3 m by 3 m (10 ft by 10 ft) spacing. In addition, 10 seedlings were interplanted within each plot (Series 1 only) and designated for excavation to assess the first season's fall and spring root development.

At the Series 1 dry site, Pedee Guppy 2005, three of the five blocks were situated on an extremely dry sandy slope and the other two were located in a flat area with seasonal drainage. At the Series 1 moderate site, South Red Fir, one block was on a steep slope with a condensed block design because of space constraints. The Series 1 wet site, Southern Comfort, is a productive site with well-drained soils and high organic matter content.

The Series 2 dry site, Pedee Guppy 2006, was similar to, and located near, the Series 1 Pedee Guppy 2005 site. All blocks at Pedee Guppy 2006 were laid out on a steep sandy slope. The Series 2 moderate site, Mid Polly's View, was a productive site located on well-drained loamy soils with high organic matter. The Series 2 wet site, Mohican, was situated on flat, poorly drained ground with heavy clay soil. This site had significant standing water in the winter, and stayed wet into the spring. An elk herd lived near this site; not only was browsing a problem, but the herd also used the site as a bedding area.

Dormancy-Induction Treatment

All seedlings were grown under identical water and nutrient regimes until the initiation of dormancy-induction treatments, at which point seedlings were randomly assigned to either a short-day (SD) treatment or a moisture-stress (MS) treatment.

Table 1. Site attributes for Series 1 and Series 2.

Relative site moisture	Series 1: 2005–06 planting year		
	Dry	Moderate	Wet
Site	*Pedee Guppy 2005*	*South Red Fir*	*Southern Comfort*
Latitude	44°47’20.03”N	44°37’25.27”N	44°47’58.44”N
Longitude	123°27’52.62”W	123°34’46.44”W	123°41’55.76”W
Distance from coast (km)	48	38	29
Annual precipitation (cm)	100–150	175–230	315–355
Elevation (m)	270	230	345
Aspect	SE	N	W
Site index (m)*	32	39	38
Site preparation	aerial spray	piled, spray	piled
Stock type†	515A	615A	515A
Seed source elevation (m)	122–640	152–823	122–640
Seed source latitude	44°45’N–45°25’N	44°20’N–44°45’N	44°45’N–45°25’N
Relative site moisture	**Series 2: 2006–07 planting year**		
	Dry	**Moderate**	**Wet**
Site	*Pedee Guppy 2006*	*Mid Polly’s View*	*Mohican*
Latitude	44°47’12.75”N	44°36’20.86”N	44°49’40.68”N
Longitude	123°28’7.09”W	123°32’57.24”W	123°37’39.42”W
Distance from coast (km)	48	42	34
Annual precipitation (cm)	100–150	175–230	315–355
Elevation (m)	300	300	360
Aspect	SW	N	flat
Site index (m)*	32	39	38
Site preparation	—	piled, spray	aerial spray
Stock type†	515A	615A	515A
Seed source elevation (m)	122–640	152–823	122–640
Seed source latitude	44°45’N–45°25’N	44°20’N–44°45’N	44°45’N–45°25’N

* King’s 50-year site index (King 1966).

† 515A = Styroblock® container 515A, 250 cm^3 root volume, 60 cavities/block; 615A = Styroblock® container 615A, 336 cm^3 root volume, 45 cavities/block.

Dormancy induction was initiated in late June for seedlings scheduled for August and September plant dates, and in mid-July for seedlings scheduled for outplanting at later dates. Seedlings designated for the SD treatment were leached twice with water to remove media nutrients and then subjected to 14-hour nightlength for 21 days by covering with black cloth. Seedlings were then kept in alternating periods of 7 days with ambient photoperiod and 7 days with 14-hour nightlength until early September. Seedlings designated for the MS treatment were exposed to ambient photoperiods and leached twice with water to remove media nutrients, then allowed to dry to 65 to 70 percent of field capacity (measured gravimetrically). Seedlings of both treatments were then fertilized with Scotts Peters Conifer Finisher© (4-25-35 plus micronutrients) at 50 ppm N, and were irrigated only when crop wilting was visible.

Planting Date

Seedlings were outplanted from late summer through early winter (table 2). Dates were selected to encompass expected environmental thresholds for planting success. In the 2005–2006 season (Series 1), eight plant dates were spaced at 3-week intervals between August and January. Initial results showed little difference in performance among seedlings planted after mid-October; therefore, only four plant dates were included in the 2006–2007 season (Series 2). Plastic mesh Vexar™ tubing (15 cm by 90 cm [6 in by 36 in]) was installed at the time of planting to protect seedlings from animal browse.

Table 2. Planting dates for each planting series. For all dates, the moderate site was planted on the first day and the other two (dry and wet) sites were planted on the second day.

Series 1: 2005–06 planting year		Series 2: 2006–07 planting year	
1	*August 16 and 17*	*1*	*August 22 and 23*
2	*September 7 and 8*	*2*	*September 12 and 13*
3	*September 27 and 28*	*3*	*October 3 and 4*
4	*October 18 and 19*		
5	*November 8 and 9*		
6	*November 29 and 30*		
7	*December 20 and 21*		
8	*January 10 and 11*	*8*	*January 9 and 23*

Measurements

Bud development was evaluated on a random sample of 10 seedlings from each dormancy-induction treatment on each plant date in Series 1. Shoot tips were dissected according to the procedures described by Templeton and others (1993). The excised embryonic shoot was examined under a dissecting scope and the number of short columns and rows were counted and then multiplied together to estimate the total number of needle primordia. Buds were preserved in 100 percent ethyl alcohol and later photographed using a scanning electron microscope.

HOBO microstations (Onset Computer Corporation, Bourne, MA) were installed at each site to monitor air temperature (1.1 m [3.6 ft] above the ground), relative humidity, precipitation, soil temperature at 15-cm (6-in) depth, and soil moisture at 10- and 20-cm (4- and 8-in) depths (ECH_2O probes, Decagon Devices Inc., Pullman, WA, installed horizontally); the microstations logged measurements every 6 hours for 1 year after planting. Vapor pressure deficit was calculated according to the procedures of Murray (1967). Two soil samples, from a depth of 18 cm (7 in), were collected from each block on each planting date using a soil corer with slide hammer (101.29 cm^3 [6.2 in^3] core volume, AMS signature series, American Falls, ID). Samples were kept in zip-sealed plastic bags and weighed within 24 hours. Dry weights were determined after each soil sample was dried for 48 hours at 68 °C (154 °F). Soil samples provided metrics for bulk density and gravimetric water content in the root zone at the time of planting. Volumetric soil water content (θ) was then determined using the following formula:

$$\theta = (m_{wet} - m_{dry}) / V_b$$

Where:

m_{wet} and m_{dry} are the weight of the sample before and after drying, V_b is the volume of the cylinder. ECH_2O probe data at 20-cm depth were calibrated by linear regression for each site with the data collected from soil cores (Czarnomski and others 2005); the 10-cm (4-in) depth data was then adjusted according to its relative difference with the 20-cm (8-in) depth.

At each planting date, 20 seedlings were assessed for root growth potential (RGP). In addition, during Series 1, a sample of 60 seedlings from each dormancy-induction treatment was measured for cold hardiness using the procedures of Tanaka and others (1997). Incidence of lammas growth during the fall when seedlings were planted was recorded. In Series 1, a sample of interplanted seedlings was excavated and assessed for new root growth 3 weeks after planting, in April 2006 before bud break, and in November 2006 fallowing budset. Seedling height (ht), RCD, and survival were measured in the spring after planting, before budbreak, and again at the end of the first, second, and third growing seasons. In addition, ht:RCD (mm:mm) was calculated for each seedling.

Statistical Analyses

Data were tested and examined for normality. The plot survival percentages were arcsine-transformed before analysis (Zar 1984). Survival assessments were carried out using all plots, including those with high mortality.

For field growth traits, plot means were used in all analyses. Survival after 2006 was low in some plots from both Series 1 and Series 2. Therefore, all plots with lower than 40-percent survival rate (fewer than 10 live trees from the 25 tree plots) in a particular year were eliminated before further analyses, except for the first-year (2006) measurements in Series 1. At the dry Series 2 Pedee Guppy 2006 site, survival was so low at the August and October planting dates that they were not included in the analyses, leaving only the September and January planting dates.

A mixed-model approach was used for analyses (SAS® PROC MIXED version 9.2). Because sites were confounded with seedlot and stock type, only single-site analyses were carried out. The following general linear model was fitted to the data from each site:

$$[2]\ Y_{ijk} = \mu + D_i + T_j + DT_{ij} + B_k + \varepsilon_{(ij)k}$$

where Y_{ijk} is the observed plot mean response for the ith plant date and the jth dormancy treatment in the kth block; μ is the overall mean; D_i is the fixed effect of plant date; T_j is the fixed effect of dormancy treatment, DT_{ij} is the interaction between the ith plant date and jth dormancy treatment; B_k is the random effect of block; and $\varepsilon_{(ij)k}$ is the residual error. Because block interactions with either treatment or plant date were not significant, they were not included in the final model.

Tukey-Kramer multiple comparison tests of least squared means were carried out to examine both dormancy treatment and planting date differences. Contrasts were made to compare growth of seedlings planted before root growth cessation with those planted after presumed root growth cessation. For the purposes of these contrasts, November 1 was arbitrarily designated as a reasonable date when most roots within the planting region would stop growing.

Results

Overall Site Effects

Each series had one site with superior growth. In Series 1, the best height growth occurred on the wet, productive Southern Comfort site, despite the fact that the moderate South Red Fir site was planted with a larger seedling stock type (figure 1a).

In Series 2, the best growth occurred at the moderate Mid Polly's View site which had the most productive soil and was planted with the largest stock type.

Severe ungulate browsing occurred at two sites from Series 2. After 3 years in the field, elk had browsed 48 percent of the living trees at Mohican, and deer had browsed 42 percent of the live trees at Mid Polly's View. The fast-growing trees at the latter site were able to rapidly outgrow the reach of the deer, however, but growth at Mohican was severely affected by browsing.

The ht:RCD decreased at all sites during the first 3 years after planting (figure 1b). Lower ht:RCD are desirable; ideally, this ratio will be less than 70 in young plantations (Cole and Newton 1987). By the second year after planting, ht:RCD at all sites were less than this threshold. Survival was lowest at the dry site per series (figure 1c). The wet Series 2 site, Mohican, also had low survival.

Soil temperatures during the first year after planting followed typical seasonal patterns for the western Oregon climate with soil temperature dropping below the ideal temperature range for root growth by the first week of November (figure 2). Soil moisture levels and the amount of precipitation varied considerably by site and series, especially during the earliest plant dates (figure 3). Soil moisture contents during the winter were similar at all six sites (figure 3), but summer differences were evident and reflected the dry, moderate, and wet site moisture environments. In particular, the wet Series 2 Mohican site retained high soil moisture levels during the first summer after planting, and the dry Series 2 Pedee Guppy 2006 site experienced very low volumetric soil moisture water content in late summer through mid-October. During the summer months, soil moisture content at 10-cm (4-in) depth tended to be lower than at 20-cm (8-in) depth.

Dormancy-Induction Treatment

Buds from SD-treated seedlings in Series 1 produced more needle primordia earlier in the fall than those from the MS treatment (figure 4). By December, however, trees from the MS treatment had an equivalent number of primordia as those from the SD treatment, and terminal buds of both treatments were approximately the same average diameter. Cold hardiness (Series 1 only) followed typical seasonal development, but did not differ between dormancy-induction treatments despite the early differences in bud development (data not shown). RGP of SD-treated seedlings in Series 1 was significantly lower than MS-treated seedlings on the two September plant dates (data not shown). Very little lammas growth was

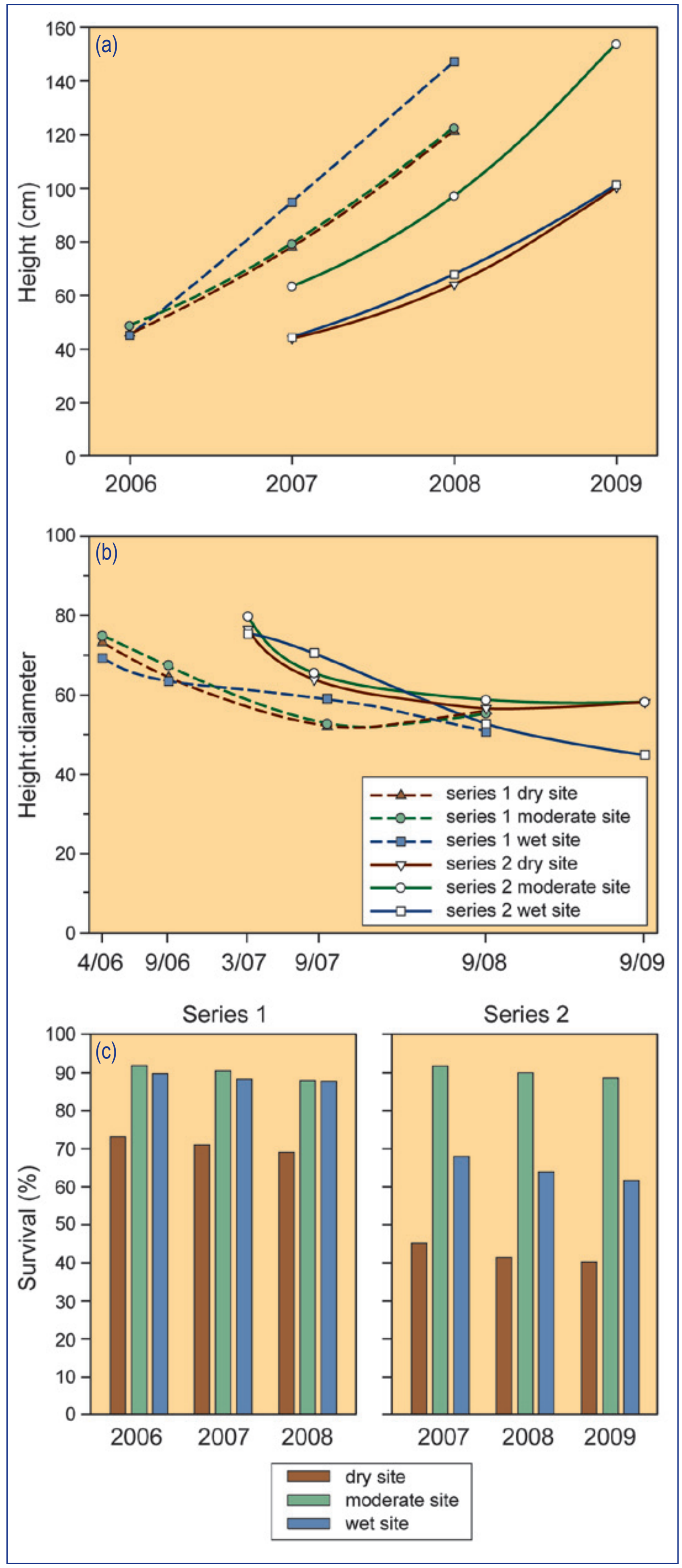

Figure 1. Overall mean height (a), height:diameter ratio (b), and survival (c) for the two series, where ▲ denotes the dry site, ● denotes the moderate site, and ■ denotes the wet site per series.

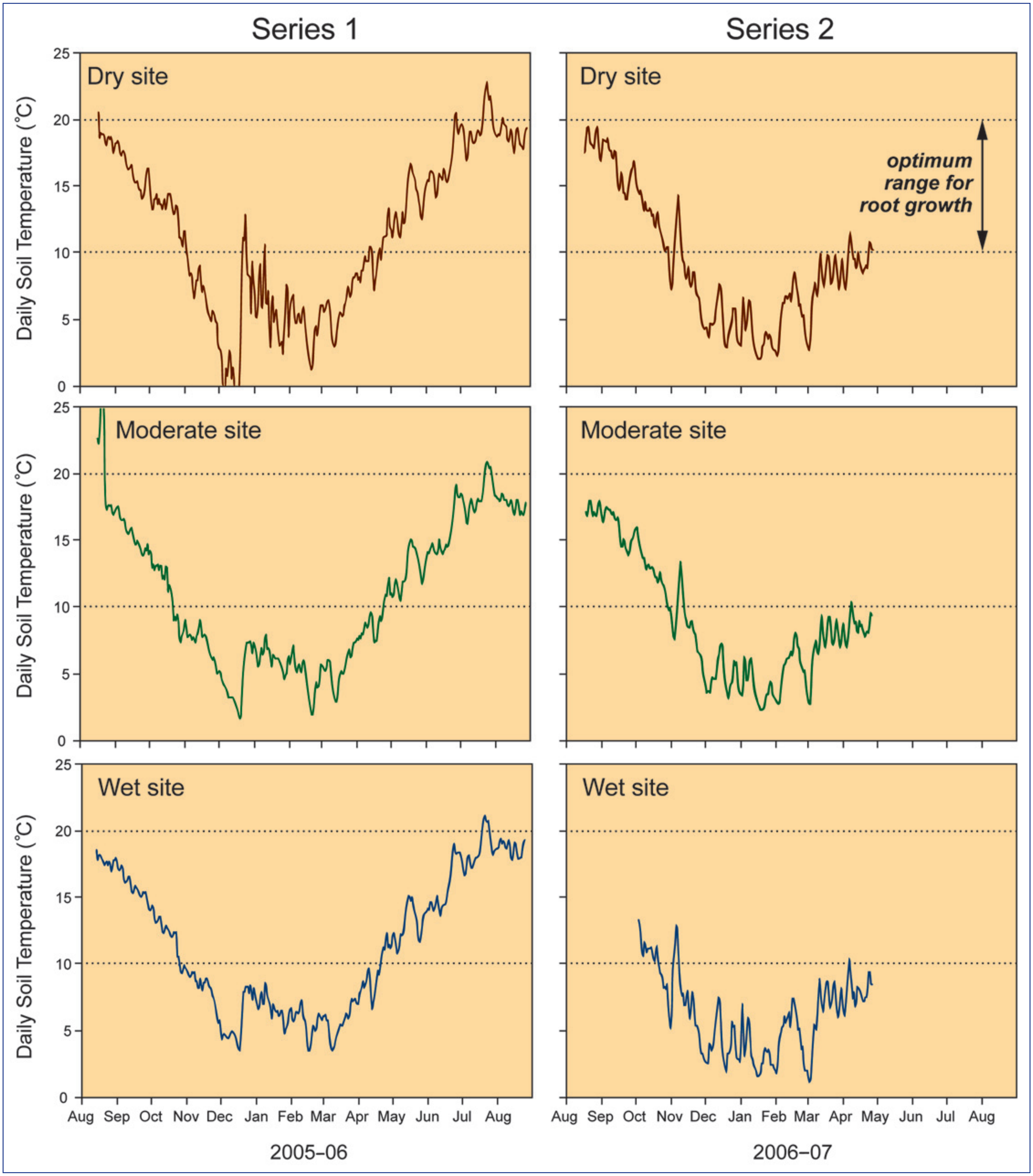

Figure 2. Average daily soil temperature at a 15-cm depth for each of the three sites planted in Series 1 and Series 2.

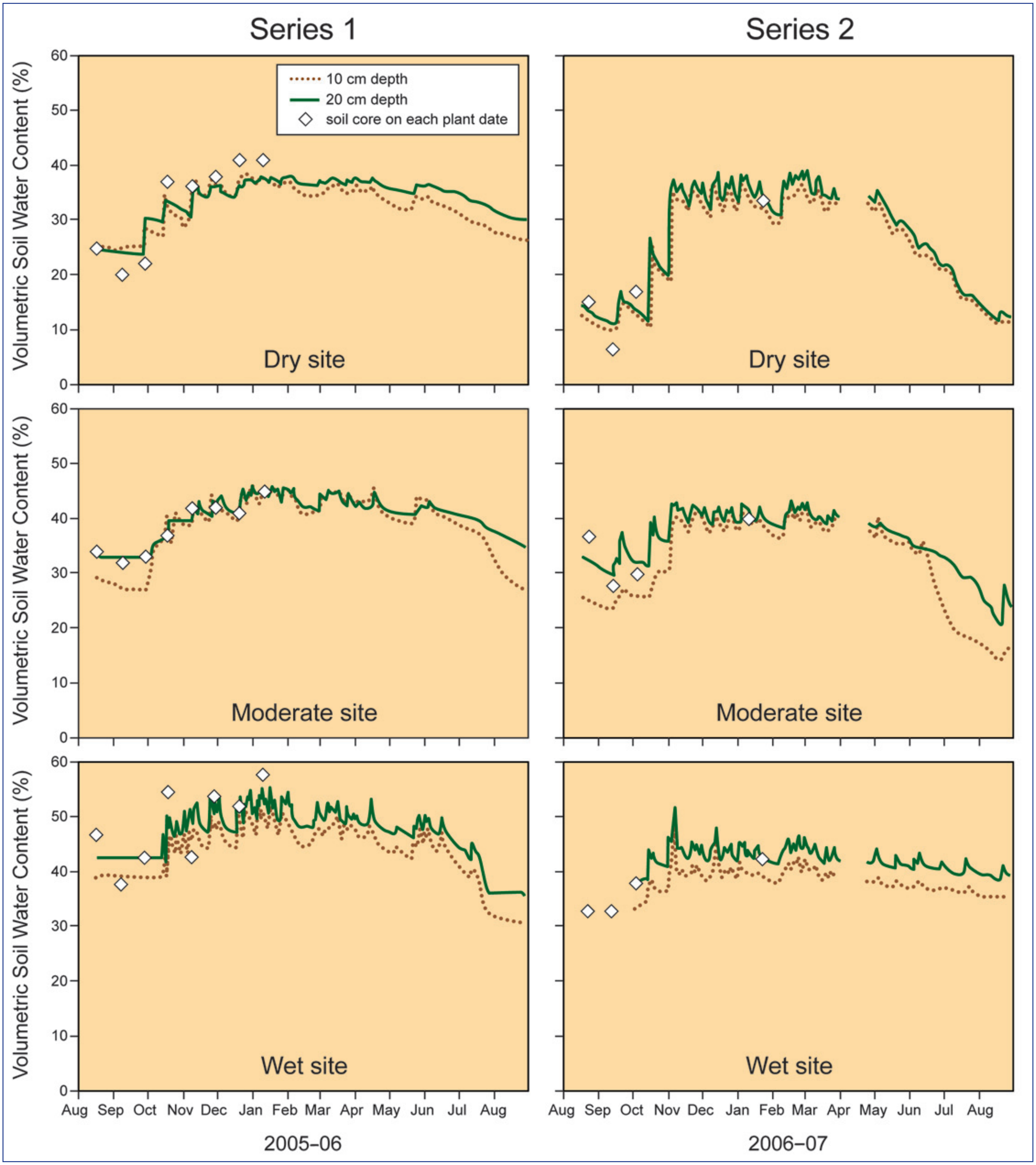

Figure 3. Average daily volumetric soil water content measured at two depths via ECH_20 probes during the first year after planting for each of the three sites planted in Series 1 and Series 2.

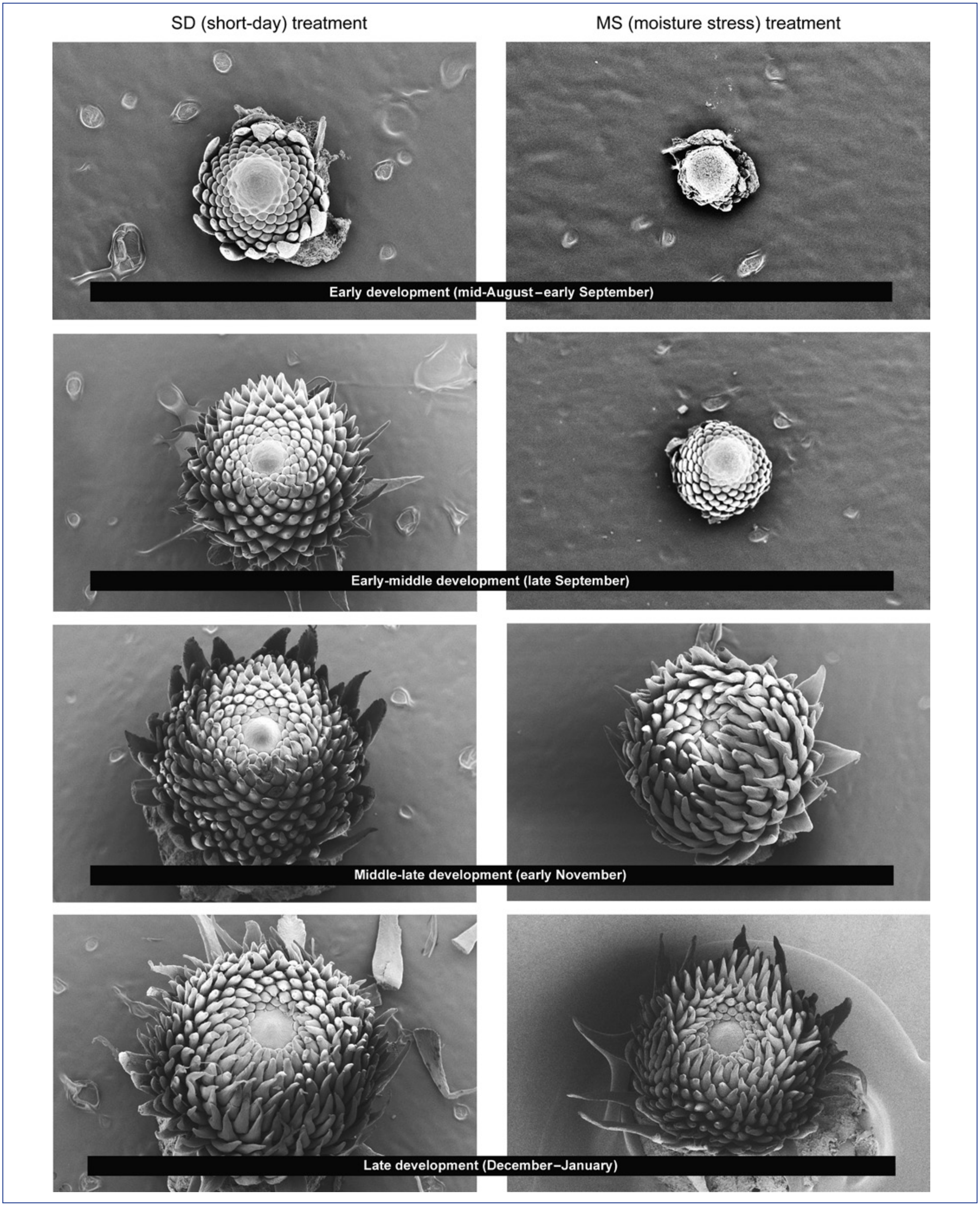

Figure 4. Scanning electron microscopy photos, taken at the time of planting, of typical terminal buds in both dormancy-induction treatments for seedlings planted in Series 1.

observed in Series 1, but in Series 2, lammas growth after planting was 7.5 times more prevalent in MS-treated trees (323 trees across three sites) than in SD-treated trees (43 trees across three sites). Most of the lammas growth occurred for trees planted in either mid-September or early October (plant dates 2 and 3).

After three field growing seasons, height, RCD, ht:RCD, and survival showed few differences between dormancy-induction treatments (Tukey-Kramer multiple comparison test; $p < 0.05$) (table 3). In Series 2, the MS treatment yielded significantly better survival than the SD treatment at the dry Pedee Guppy 2006 site, which had the lowest survival of all six sites (figure 1c). Height and RCD means for MS seedlings were significantly larger than those for the SD treatment at the dry (Pedee Guppy 2005) and wet (Southern Comfort) sites from Series 1. Mixed-model analyses (table 4) and repeated measures analyses generally concurred with the Tukey-Kramer means separations test (table 3).

Planting Date

RGP of seedlings potted in the greenhouse and root growth of seedlings excavated 3 weeks after planting (Series 1 only) tended to be greatest in the August and September plant dates (data not shown). Although little difference in initial height existed among trees from the different plant dates, by the end of three seasons, mean height differences were significant at four of the six sites (Tukey-Kramer multiple comparison test; $p < 0.05$) (figure 5). On the best sites, these growth differences after three growing seasons were striking (figure 6). On the two moderate sites, height increased by 39 (South Red Fir) and 32 percent (Mid Polly's View) between the best performing fall planting dates and the winter (January) plant date after three growing seasons. Fall planting also resulted in greater height growth than winter planting at the other Series 1 sites (23- and 15-percent increases at the wet Southern Comfort and dry Pedee Guppy 2005 sites, respectively), but these differences were less evident at the other Series 2 sites (wet Mohican: 11 percent; dry Pedee Guppy 2006: 4 percent).

At the dry Pedee Guppy 2006 site, growth differences between planting dates was likely influenced by low survival attributed to extreme late summer soil moisture deficit, which led to only two of four plant dates (September 12 and January 9) remaining in the dataset for analysis of growth traits. At the wet Mohican site, seedling height was most likely compromised by both flooding and high browsing. Interestingly, although planting date effects were not observed for height at Mohican,

Table 3. Third-year dormancy-induction treatment measurement means (± s.e.) of growth traits. For each column within a site, means followed by the same letter are not significantly different according to the Tukey-Kramer multiple comparison test of least squared means (α = 0.05).

Treatment	Series 1: 2005–06 planting year				
	n	Height 2008 (cm)	RCD† 2008 (mm)	Ht:RCD† ratio 2008	Survival 2008 (cm)
	Pedee Guppy 2005, dry site				
SD	37	115.9 (3.62) b	21.8 (0.88) b	56.2 (1.48) a	69.7 (3.00) a
MS	36	127.4 (4.03) a	23.8 (0.95) a	55.8 (1.12) a	68.3 (3.45) a
	South Red Fir, moderate site				
SD	40	121.8 (4.85) a	24.1 (1.13) a	54.0 (1.15) b	88.1 (1.82) a
MS	40	119.4 (5.11) a	22.8 (1.11) a	56.3 (0.81) a	87.6 (1.67) a
	Southern Comfort, wet site				
SD	32	136.1 (3.67) b	28.3 (0.95) b	50.7 (0.96) a	85.2 (2.27) a
MS	32	157.0 (3.91) a	32.4 (0.88) a	50.7 (0.99) a	90.0 (1.57) a
Treatment	**Series 2: 2006–07 planting year**				
	n	**Height 2009 (cm)**	**RCD† 2009 (mm)**	**Ht:RCD† ratio 2009**	**Survival 2009 (cm)**
	Pedee Guppy 2006, dry site				
SD	9	91.8 (4.59) a	15.9 (0.94) a	58.7 (0.85) a	28.0 (6.68) b
MS	11	100.1 (3.48) a	17.8 (0.69) a	57.8 (1.44) a	40.0 (6.95) a
	Mid Polly's View, moderate site				
SD	19	144.7 (6.41) a	26.3 (1.36) a	58.0 (2.13) a	83.6 (3.89)a
MS	20	152.5 (6.79) a	27.4 (1.56) a	59.6 (2.12) a	88.8 (2.04) a
	Mohican, wet site				
SD	16	97.2 (4.80) a	22.3 (1.41) a	46.1 (1.81) a	61.2 (5.45) a
MS	15	99.7 (4.29) a	23.5 (1.18) a	44.0 (0.93) a	58.3 (6.62) a

Notes: Means are based on plot averages. Statistical tests of survival are based on arcsine square root transformed data.

SD = short-day dormancy treatment. MS = moisture and nutrient stress dormancy treatment.

† RCD = root-collar diameter, stem diameter at ground level; Ht:RCD is the ratio of height to RCD.

Table 4. Mixed-model analyses p-values for third-season field data for Series 1 and Series 2 (data collected in 2008 and 2009, respectively). Values in **bold** are significant at α = 0.05.

Source of variation	Series 1: 2005–06 planting year				Series 2: 2006–07 planting year			
	Height 2008	RCD 2008	Ht:RCD 2008	Survival 2008	Height 2009	RCD 2009	Ht:RCD 2009	Survival 2009
	Pedee Guppy 2005, dry site				Pedee Guppy 2006, dry site			
Date planted	**0.0025**	**0.0002**	0.4678	**< 0.0001**	0.5147	0.5330	0.6368	**< 0.0001**
Treatment	**0.0013**	**0.0008**	0.5227	0.7698	0.0767	0.1467	0.8905	**0.0016**
Date × treatment	0.1960	0.3281	0.1693	0.1597	0.9980	0.8257	0.3823	**0.0132**
Block	0.0925	0.0839	0.1013	0.1213	0.1585	0.2565	0.2340	0
Contrast†	**0.0003**	**< 0.0001**	0.1132	**< 0.0001**				
	South Red Fir, moderate site				Mid Polly's View, moderate site			
Date planted	**< 0.0001**	**< 0.0001**	**< 0.0001**	0.5000	**< 0.0001**	**< 0.0001**	0.9452	**0.0040**
Treatment	0.5580	0.1370	**0.0354**	0.6713	0.1600	0.3669	0.6010	0.3718
Date × treatment	0.2497	0.1433	0.0524	0.8774	0.1940	0.8688	0.8408	0.4488
Block	0.1003	0.1069	0.1604	0.2121	0.1802	0.1257	0.1263	0
Contrast†	**< 0.0001**	**< 0.0001**	**< 0.0001**	0.5809	**< 0.0001**	**< 0.0001**	0.5595	0.9905
	Southern Comfort, wet site				Mohican, wet site			
Date planted	**< 0.0001**	**< 0.0001**	0.1075	0.0791	0.4029	**0.0209**	**0.0403**	**0.0342**
Treatment	**< 0.0001**	**< 0.0001**	1.0000	0.0976	0.9808	0.8101	0.8491	0.5989
Date × treatment	0.6853	0.5600	0.5165	0.1309	0.0738	0.4049	0.2303	0.2233
Block	0.2375	0.3492	0.1886	0	0.2365	0.1278	0.1347	0.2093
Contrast†	**< 0.0001**	**< 0.0001**	0.2043	0.7776	0.1244	**0.0156**	**0.0435**	0.3133

Note: Block is a random effect; all other effects are fixed. Statistical tests of survival are based on arcsine square root transformed data. Analyses were carried out using SAS PROC MIXED.

RCD = root-collar diameter, stem diameter at ground level. Ht:RCD is the ratio of height to RCD.

† Contrast = contrast of four plant dates before root growth cessation (defined as before November 1) versus four plant dates after root growth cessation (after November 1).

significant differences in RCD growth did occur at this site. The ht:RCD was not significantly different among plant dates in most cases.

The dry Pedee Guppy 2006 site was excluded from contrast analyses investigating growth and survival differences of seedlings planted before or after the assumed date of root elongation cessation, because only two planting dates remained in that dataset (table 4). At the five sites where growth of seedlings planted before November 1 were contrasted with seedlings planted after this date, growth for the earlier plant dates was significantly higher than for seedlings planted late at all sites except for wet Mohican (table 4). Average height after three field seasons at Mohican was lowest for the January planting (figure 5), however, despite no statistically significant difference.

At three of the six sites (wet Southern Comfort, moderate South Red Fir, and moderate Mid Polly's View), survival by plant date after three growing seasons ranged between 75 and 96 percent (data not shown). Survival was lowest on the earliest (August) planting date for all sites, except the moderate South Red Fir (with uniformly high survival across all plant dates) and the wet Mohican sites (August survival = 56 percent). Survival for trees planted during August at the two dry sites was particularly low (Pedee Guppy 2005: 38 percent; Pedee Guppy 2006: 0 percent), with mortality occurring immediately after planting on these dry sites.

Survival was also low for two of the Series 2 sites on the October 3 plant date (dry Pedee Guppy 2006: survival = 16 percent; wet Mohican: survival = 43 percent). Although soil temperature in early October of the planting year was similar for the two series (figure 2), volumetric soil water content was lower at the beginning of October 2006 than for the same time period in 2005, most notably for the wet and dry sites (figure 3).

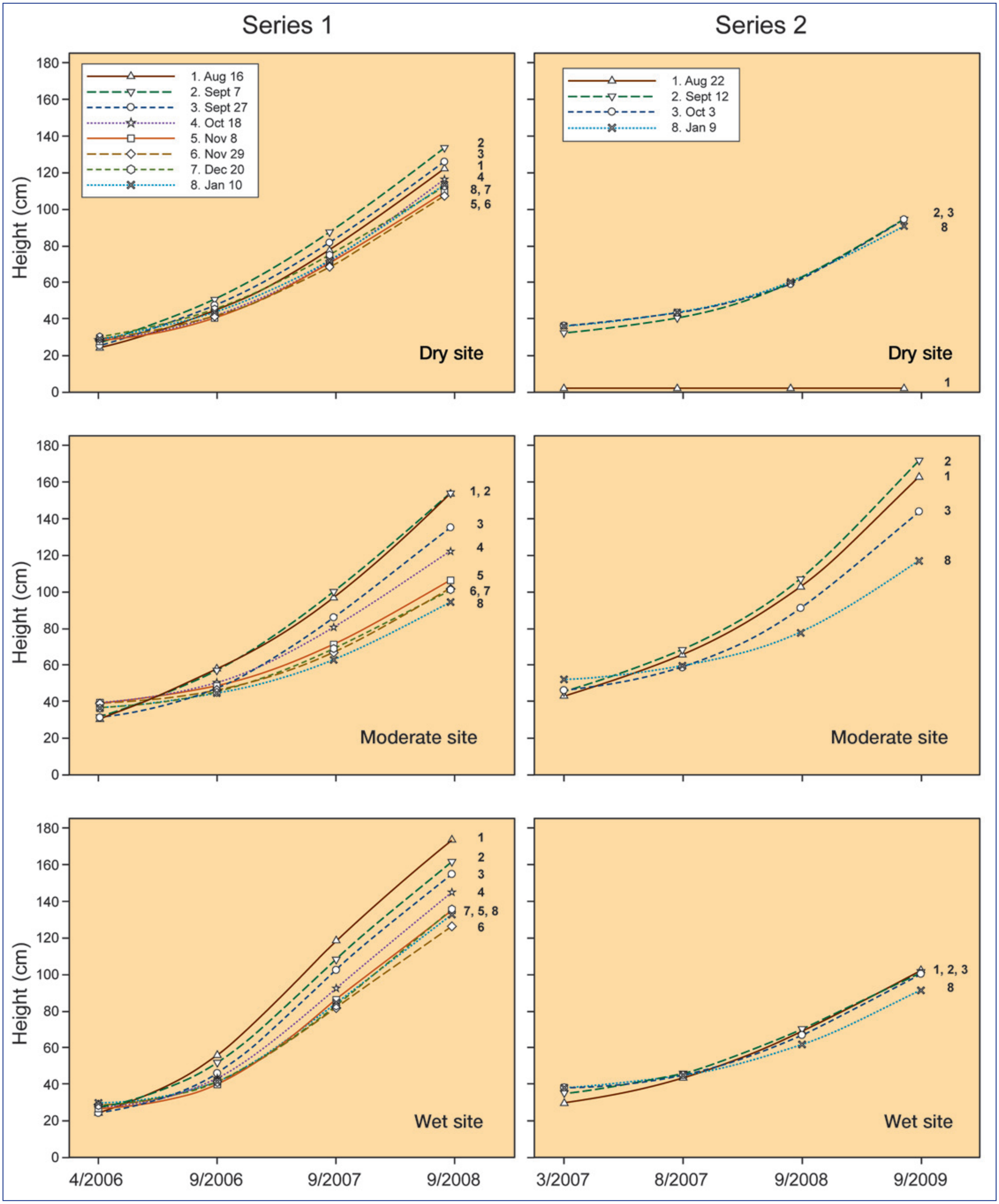

Figure 5. Mean seedling height by planting date per site for the two series.

Figure 6. Seedlings planted during the fall were notably taller than those planted in the winter on favorable sites. Shown here are seedlings planted September 7 (left) and December 21 (right) after two growing seasons (August 2007) at the Series 1 wet Southern Comfort site (Photos source: Diane L. Haase).

Discussion

Dormancy-Induction Treatment Effects Are Minimal

Seedling physiological condition at outplanting is vitally important to subsequent field performance. In particular, seedling dormancy status can affect seedling stress resistance and influence growth and survival after outplanting (van den Driessche 1991). Short-day regimes have been used in forest nurseries for more than 20 years to control seedling morphology and physiology. These treatments have resulted in earlier budset (MacDonald and Owens 2006) and reduced seedling height (Jacobs and others 2008) in previous Douglas-fir studies. Accordingly, shortened photoperiods have been used to manipulate ht:RCD, control lammas growth, and maintain seedlings within target nursery specifications (Turner and Mitchell 2003). Short-day treatments have also been shown to increase fall cold hardiness (Jacobs and others 2008), decrease late fall root growth capacity, and cause earlier spring dormancy release (Turner and Mitchell 2003). However, Jacobs and others (2008) found that short day-treated seedlings had greater new root proliferation at cold soil temperatures, but less new root growth at warm temperatures, than seedlings grown under ambient photoperiods.

In this study, earlier budset and initially greater primordia production were observed with the SD treatment, but this effect was only short term, and buds from both treatments were approximately the same size by December. Few differences between SD- or MS-treated trees were seen in growth or survival during this study with the exception of lammas growth after planting in Series 2. The SD treatment successfully prevented lammas growth, whereas the MS treatment did not prevent a second flushing in seedlings planted at the same time and also exhibited greater RGP on the September plant dates (Series 1, data not shown). This indicates that the MS trees were quiescent, whereas the SD trees were transitioning into the rest stage of dormancy. Where growth differences were significant, the SD trees were smaller than the MS trees. Survival at the harshest site, Series 2, dry Pedee Guppy 2006, was significantly higher for the MS treatment than for the SD treatment. Exposure to moisture stress may have decreased transplant shock in the MS seedlings, because they were more conditioned to moisture stress at the time of planting as compared with the SD seedlings, which had minimal moisture stress in the nursery.

The findings of this study concur with those of MacDonald and Owens (2006), who found no survival or morphological differences after 1 year between SD- and MS-treated seedlings of a coastal Douglas-fir seedlot from British Columbia. Although Jacobs and others (2008) suggested that Douglas-fir sources from latitudes more southerly than 45º N might show strong responses to photoperiod, little evidence was found in this study to support this suggestion.

Planting Date Affects Plantation Growth and Survival

This study demonstrates that tree height significantly increased after three field seasons for trees planted while root egress was still occurring in the fall (August through October plant dates). Presumably, the new root growth that occurred for trees planted before November 1 conferred a growth advantage that was still evident 3 years later. These growth differences were most dramatic on the sites where soil moisture levels were least limiting. Scagel and others (1990) found that root growth of excavated Engelmann spruce seedlings (*Picea engelmannii* Parry ex Engelm.) within a few months of planting was largest on seedlings from the earliest planting and decreased with later planting days. Barber (1989) found that western larch (*Larix occidentalis* Nutt.) seedlings planted in fall (October) were superior to those planted in spring (April) with respect to survival, height growth, and total height.

A true assessment of tree height could not be made at the wet Mohican site from Series 2 because of severe browsing. For the other sites, overall growth during the first 3 years related well to the volumetric soil water content at the time of planting; growth was poor on the two dry sites where 20 cm soil moisture content was less than 20 percent during August through October (figure 3). Akgul (2004) observed an increasing relationship between volumetric soil moisture content at the time of planting (September through April) and first-year survival of bareroot slash pine (*Pinus elliottii* Engelm.) seedlings planted in the flatlands of western Louisiana. The sites used in the current study had little competing vegetation. Although Grossnickle (2005) cited numerous studies where removal of vegetation cover caused soil temperatures to rise, no evidence existed in the current study of soil temperatures greater than the optimum range for Douglas-fir root growth (10 to 20 ºC) (Lopushinsky and Max 1990) were observed in the first autumn after planting.

Most of the observed lammas growth occurred for trees planted between mid-September and early October. Trees planted before this period would have been exposed to moisture stress and, therefore, be less prone to flushing. Trees planted after this time would be more dormant, and combined with the colder soil temperatures and shorter photoperiod, new shoot growth would have been unlikely. Although the autumn of 2006 (when planting of Series 2 began) was drier than the previous autumn (when Series 1 was planted), lammas growth was much higher for Series 2 seedlings planted in 2006. Seedlings grown in 2006 were assumed to be less dormant at the time of planting than those grown and planted the previous year.

Survival at the two dry sites (Pedee Guppy 2005 and 2006) was unacceptably low for the August plant dates. As this study shows, the potential benefits of late summer planting may be great on some sites, but the risks are high on drier sites. High temperature and low soil moisture levels at the time of planting may result in stresses leading to reduced growth or increased mortality. Upon planting, roots must have the ability to supply enough water to transpiring needles to maintain proper plant water balance (Grossnickle 2005). New root growth is especially critical on harsh planting sites, where the existing root system may not be adequate to supply enough water to the shoot system to meet transpirational demand (Simpson and Ritchie 1997). Although some degree of planting stress is unavoidable, a seedling on a droughty or nutrient-poor site will allocate much of its stored photosynthate to extending its root system, contributing to planting check (Lavender 1990). If soil moisture levels are too limiting, seedling survival will be severely affected. Conversely, high water tables affected survival at the wet Series 2 Mohican site. Mortality at this site was not a direct result of planting timing, because winter-planted seedlings also died due to seasonal flooding.

Little difference existed in growth and survival rates between seedlings planted late in the fall and those planted in winter because, beginning in late fall, soil temperatures were likely too low for root egress. The optimal planting window between the onset of adequate seedling dormancy at the nursery and the end of the fall planting season is relatively short. Colder soil temperatures cause an increase in plant resistance to water flow (Grossnickle 2005); after soil temperatures drop to less than 5 °C, root growth is impeded (Lopushinsky and Max 1990). If seedlings are planted too late in the fall when soil temperature is no longer favorable for growth, they may have a poorly developed root system, lower carbohydrate reserves, and the inability to promptly use water and nutrients for growth the next season compared with spring and early fall planted seedlings (Adams and others 1991).

Taking into account moisture and temperature influences on seedling growth and survival, the data suggest that the optimal planting time is mid-September through mid-October. Compared with winter-planted seedlings, the increase in growth for seedlings planted during this timeframe was impressive at four of the six sites (figure 5). Hunt (2004) observed similar, albeit less dramatic, results 7 years after planting Douglas-fir seedlings in the coast-interior transition zone of southwestern British Columbia. In his study, survival was lowest (about 40 percent) for seedlings planted at the end of August; however, growth for trees planted in late August and late September tended to be greater compared with spring-planted trees. For Douglas-fir seedlings planted on harsh, high-elevation sites in Washington between late September and late October, Taylor and others (2009) noted best growth and survival for the early October plant date, and lowest survival at the September plant date. Together, these studies indicate that throughout the Pacific Northwest, fall planting is a viable option when implemented after the cessation of summer drought.

Implications

For coastal Douglas-fir plantations in Oregon, no advantage was observed for using short-day (blackout) treatments to induce fall dormancy. Moisture-stress treatments cost less to implement, and are easier to apply. As suggested by MacDonald and Owens (2006), however, short-day-treated seedlings may be desirable for fall planting at higher elevation sites where earlier budset is advantageous. Also, if early fall planting is planned for sites that are at high risk of lammas growth, short day treatments may be warranted.

This study demonstrates that with the judicial timing of fall planting on productive sites in western Oregon, height 3 years after planting can be increased by as much as 39 percent compared with winter planting.

Success or failure of fall planting depends on both seedling physiology and environmental conditions, especially soil temperature and moisture levels. Fall planting can be a viable alternative to winter planting as long as three critical elements are present: soil temperature is favorable for root egress (at or above 10 ºC), root-to-soil contact occurs soon after planting, and soil moisture is available (greater than 20 percent) for seedling uptake. In regions such as western Oregon, however, where late summer is typically very hot and dry and soil moisture very low, planting is not recommended before September, especially on drier sites. If precipitation is adequate, mid-September to late September may be an optimal planting window for these sites. In extremely dry years, planting should be delayed until mid-October.

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- Use numerals when referring to money, time, and measurement and for all numbers 10 and above.
- Abbreviate all units, except those with no numerical value (e.g., "results are provided in parts per million" in contrast to "only 0.05 ppm was effective").
- Provide both metric and English units for all values.
- Nomenclature—Use common names of organisms, if available, in the title, abstract, and text. At first mention in the abstract and in the text, provide the scientific name with authority in parentheses; e.g., white pine (*Pinus strobus L.*) The taxonomic standard for USDA publications is the Integrated Taxonomic Information System online database (http://www.itis.gov).

References

- List citations in the text by date, oldest first, then alphabetically by author (for example, Roberts 1982; Jones 1984, 1989; Smith and Jones 1990; Roberts 1991; Smith 1991; Smith and others 1999).
- In the references section, list references alphabetically by author, then by date, with oldest first. When there are multiple articles by the same author, list first those articles with one author only, oldest first; then list articles with two authors, and so on, alphabetically by second author, oldest first.
- For journal articles, use the full journal name, rather than the abbreviated version.
- For meeting proceedings, follow the date and location of the meeting with the city of publication and publishing body. If the proceedings are a part of a Government publication series, put that information after the publishing body.

Examples:

Journal article:	Smith, A.B.; Jones, C.D. 1999. Seedling production at Georgia nurseries. Tree Planters' Notes. 10(1): 11–21.
Entire book:	Brown, E.F. 1988. Trees of the Eastern United States. 2nd ed. Cambridge, MA: MIT Press. 1,200 p.
Chapter in book:	Jones, C.D. 1988. Hemlock. In: Brown E.F., editor. Trees of the Eastern United States. 2nd ed. Cambridge, MA: MIT Press: 1123–1134. Chapter 13.
Article in proceedings:	Smith, A.B.; Brown, E.F.; Jones, C.D. 1999. Tree planting in Oregon. In: Roberts, G.H.; Jones, C.D., eds. 22nd Annual Meeting of the Northern Tree Planters Association; 1998 August 11; Seattle, WA. General Technical Report PNW-444. Portland, OR: USDA Forest Service, Pacific Northwest Research Station: 120–122.
Thesis or dissertation:	Roberts, G.H. 1977. Root form of planted trees. Berkeley, CA: University of California. 111 p. M.S. thesis.

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