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Editor: Diane L. Haase

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E-mail: DLHaase@fs.fed.us

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Dear TPN Reader

Letter From the Editor

Spring Greetings! I hope you enjoy this first Tree Planters' Notes (TPN) issue of 2012. Inside, you will find three more articles in TPN's State-by-State Tree Planting series—Washington, Arkansas, and Missouri. I've really enjoyed learning more about the past and present reforestation and conservation programs in each of the nine States covered thus far in the series. Ultimately, after all 50 States and the territories have been featured in TPN, I'd like to have each article updated and, then, compile all of them into a separate publication. But, first things first—there are still many States yet to go.

In addition to articles about the three States, this issue includes three technical articles. Michelle M. Cram and Stephen W. Fraedrich provide a great overview of nematode damage in nurseries along with management options to control this potentially damaging pest. Along with co-authors Robin Rose and Dave Henneman, I present results from a research trial conducted with the Bureau of Land Management and the Nursery Technology Cooperative to examine growth and survival of seedlings of varying stocktypes planted after the 2002 Biscuit Fire in southern Oregon. The trial also evaluated the distribution of seedlings and competing vegetation in planted and unplanted plots. Steven Kiiskila describes the effects of initial size and presence of primary or secondary needles on subsequent field performance of lodgepole pine container seedlings after 13 growing seasons.

For the past 18 months, I've contacted potential authors to round up enough articles to fill each issue. With two issues published in 2011 and TPN's new look, I'm delighted that some authors are now contacting me, wishing to submit their papers for publication in TPN. Please consider submitting your paper to TPN. Also, please send suggestions for future articles or authors. This journal is read worldwide. In fact, it is one of the most popular resources on the RNGR.net Web site.

Best wishes to all of you for 2012.

Diane

Diane L. Haase

Contents

SEE PAGE 14

SEE PAGE 48

Forest Seedling Planting in Washington State

John Trobaugh

Manager, L.T. Mike Webster Nursery, Washington Department of Natural Resources, Olympia, WA

Abstract

Washington State is geologically and climatically diverse, with a warm, wet climate on the west side of the Cascade Mountain Range and a dry climate with cold winters and hot summers on the east side. This diversity has allowed much of The Evergreen State to become heavily forested with a variety of conifer species. In Washington, which has a long history of timber harvesting and reforestation, the first forest seedling nursery was built in 1911. Since the early 1990s, the total annual harvest volume has trended downward, resulting in declining numbers of seedlings being grown and planted. A current survey of nurseries in the region estimates that an average of 52 million seedlings are planted in Washington State each year.

Washington has 18 million acres (7.3 million hectares) of unreserved timber land, with 48 percent in Federal Government or other government ownership. In addition, 3.3 million acres (1.3 million hectares) of reserved forest land are located in wilderness areas and national parks.

With the wide variation in forested elevation and precipitation, numerous species are used for reforestation, each with considerable genetic variation to reflect local adaptation to the range of growing conditions. Consequently, one size does not fit all, and foresters use a variety of species, seed zones, and stock types to accomplish the objective of successful reforestation.

Figure 1. The Cascade Mountain Range is a prominent feature of Washington and divides the State into eastside and westside. (Photo source: John Trobaugh, WA DNR).

Geographic Variation

In Washington, tremendous geographic variation in forested elevations range from sea level to more than 9,000 ft (2,740 m). The dominant feature is the Cascade Mountain Range (figure 1), which runs north and south through the State and includes the volcanic peaks of Mt. Baker, Mt. St. Helens, Mt. Adams, and Mt. Rainier (the State's highest point at 14,410 ft [4,392 m]). The average statewide elevation is 1,700 ft (518 m).

Washington is divided into eight distinct geographic provinces (figure 2). In general terms, however, the State is divided into the westside and the eastside of the Cascade Mountain Range.

Soil parent material is very complex in the Cascade Mountain Range due to the uplifting and folding of the mountains, mountain glaciations, and volcanic deposits of lava, ash, and pumice. The Coast Range is primarily uplifted ocean floor sandstone with intrusions of basalts. The last continental glacier from the Cordilleran Ice Sheet came down the Puget Trough as far south as Olympia, and at its maximum Seattle was covered by 2,000 ft (610 m) of glacial ice (U.S. Department of the Interior 2011).

Climatic Variation

West of the Cascade Mountain Range

Western Washington has a wet, marine climate, which is mild for its latitude due to the presence of the warm, North Pacific,

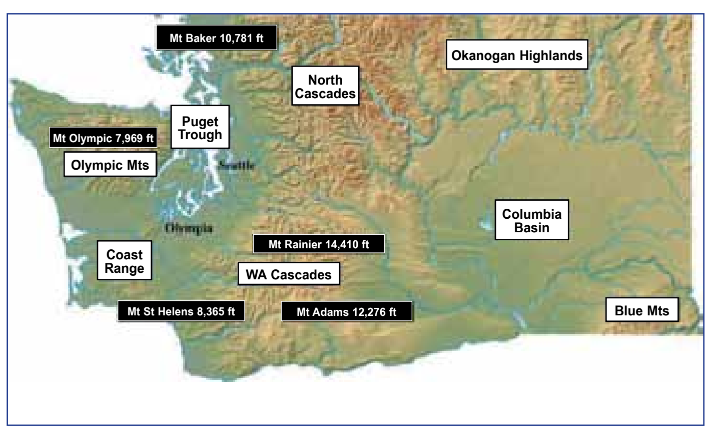

Figure 2. Washington State's eight geographic provinces and five notable mountains. The Cascade Mountain Range runs north and south through the middle of the State.

offshore ocean current. The region has frequent cloud cover, considerable fog, and long-lasting drizzle. Weeks, or even months, may pass without a clear day. Moss grows not only on the north side of trees, but on roofs, lawns, rocks, and just about everywhere. The west side of the Olympic Peninsula receives as much as 150 to 170 in (380 to 430 cm) of precipitation annually, making it the wettest area of the 48 contiguous States and home to the Olympic temperate rain forest (figure 3). The west slope of the Cascade Mountain Range receives some of the heaviest annual snowfall in the country, with some places receiving more than 200 in (500 cm) of wet, heavy snow. Summer is the sunniest season and usually very dry.

In western Washington, the planting season for forestry seedlings is December through March, depending on the snow line elevation. Ideal planting conditions are 34 °F (1 °C) and 100 percent humidity, which are normal conditions for the winter months. Weather, however, combined with steep, mountainous terrain can present some challenging planting conditions (figure 4).

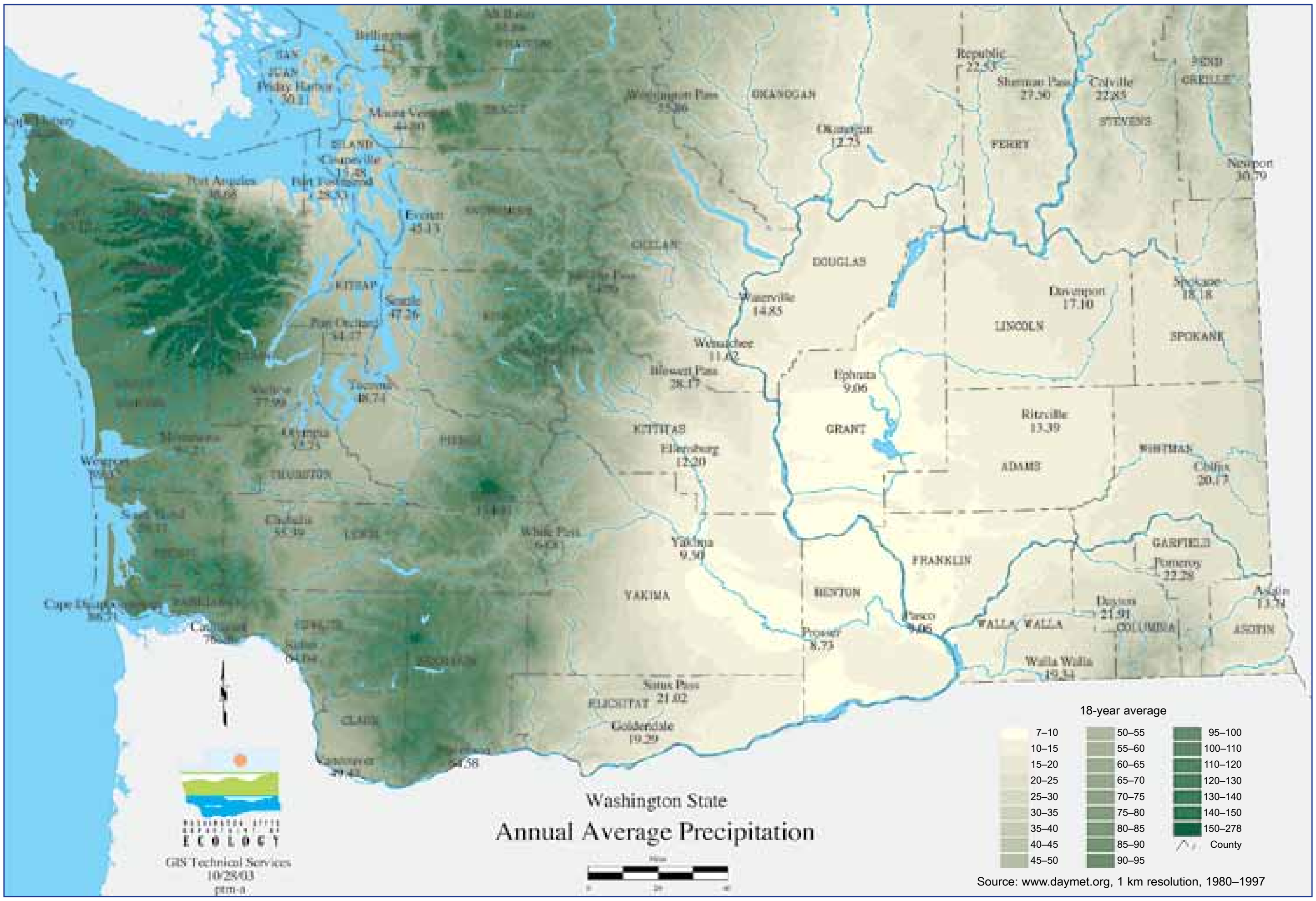

Figure 3. Washington State average annual precipitation. (Source: Washington State Department of Ecology 2011).

Figure 4. Tree planting in the steep foggy conditions of western Washington (left). A member of the planting crew carries two bags of seedlings to tree planters (right). Each bag contains about 150 seedlings and weighs about 50 lbs (23 kg). (Photo source: Chris Rasor, WA DNR 2008).

East of the Cascade Mountain Range

A dry climate prevails east of the Cascade Mountain Range with cold winters and hot summers. In the rain shadow east of the Cascade Mountain Range, the annual precipitation can be as low as 9 in (23 cm) (figure 3), with most of that falling as winter snow.

In eastern Washington, given the cold, snowy winters, the planting season starts in the spring as soon as crews can access the sites. Patches of snow scattered throughout the planting unit may be the only moisture the seedlings will have to establish new root growth and survive the first year after outplanting.

Land Area and Ownership

Washington State encompasses 45.6 million acres (18.5 million hectares) (18th largest State in the United States), with 42.6 million acres (17.2 million hectares) of land area and 3.0 million acres (1.2 million hectares) covered by water. Of the total land area, 43.4 percent is considered unreserved (not withheld from harvest by statute) timber land (capable of growing 20 ft^3 per acre per yr [1.4 m^3 per hectare per yr] mean annual increment). Much of eastern Washington is agricultural, with 2.3 million acres (809,400 hectares) of wheat, 395,900 acres (160,220 hectares) of apples, 31,000 acres (12,546 hectares) of grapes, and 29,000 acres (11,736 hectares) of cherries (figure 5).

Of the 18.3 million acres (7.4 million hectares) of unreserved timber land in Washington, 34 percent is Federal land (figure 6), composed primarily of national forests (Olympic, Gifford Pinchot, Okanogan-Wenatchee, Mount Baker-Snoqualmie, and Colville). In addition, 3.3 million acres (1.3 million hectares) are reserved forest land (withheld from harvest by statute), composed primarily of wilderness areas and national parks (Olympic, Mount Rainier, and North Cascades).

Corporations and other private landowners own 52 percent (9,580,000 acres [3,877,000 hectares]) of timber land in Washington State (figure 6). Most of the privately owned lands are west of the Cascade Mountain Range, low elevation, and very productive.

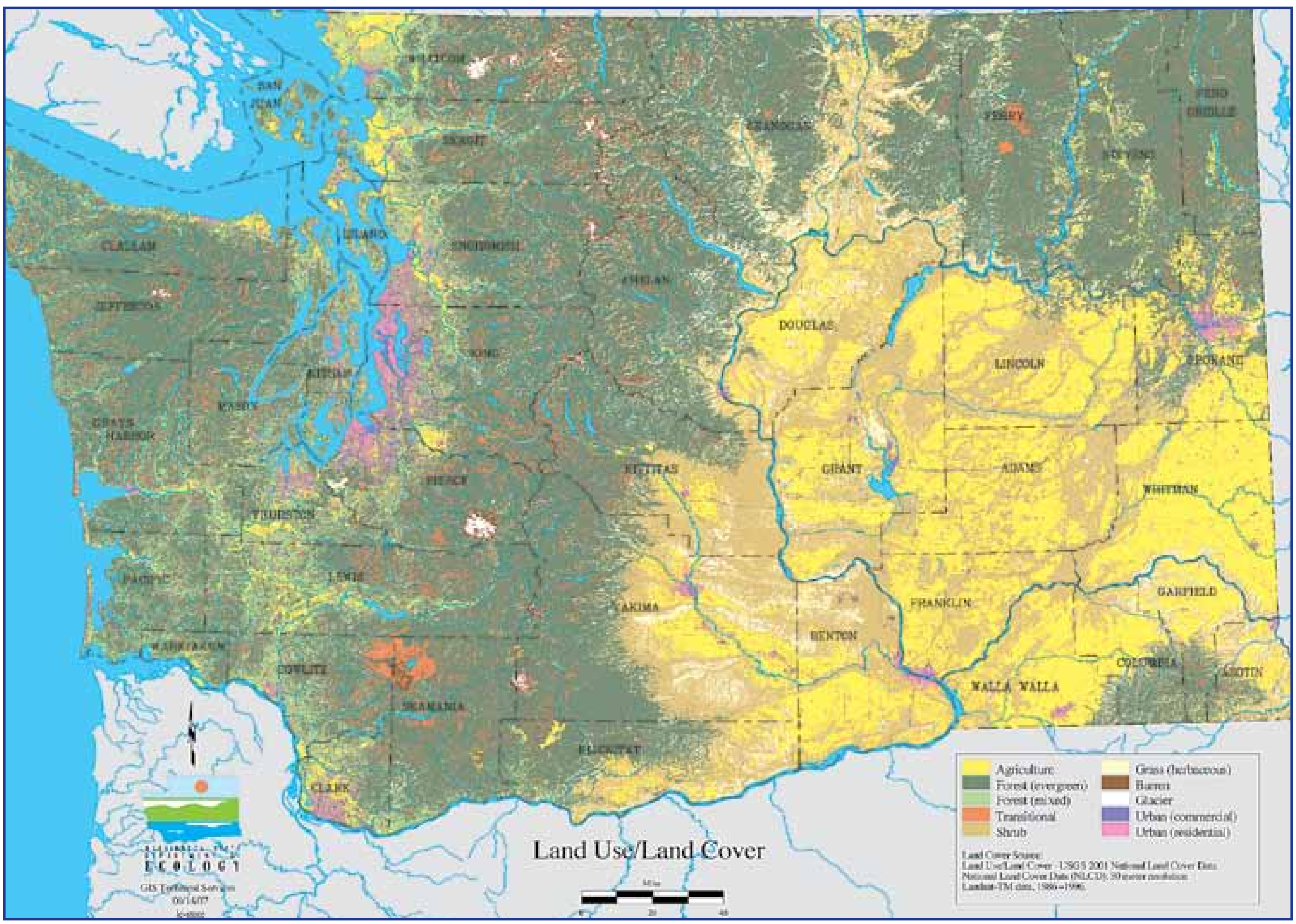

Figure 5. Washington State land use/land cover. (Source: Washington State Department of Ecology 2011).

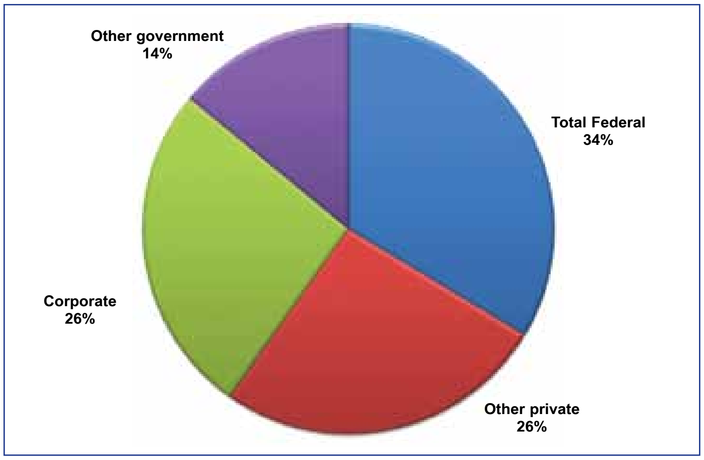

Figure 6. Distribution of unreserved timber land in Washington State, 18,303,000 acres (7,407,224 hectares). (Data source: Campbell and others 2010).

Washington Department of Natural Resources (WA DNR) is responsible for managing approximately 2.1 million acres (0.85 million hectares) of forested trust lands plus leases and permits on 1 million acres (0.4 million hectares) of agriculture lands. Management of trust lands generates about $200 million each year in nontax revenue for public beneficiaries, including kindergarten through 12th grade schools, universities, county governments, and other public institutions.

History of Reforestation in Washington

Some key milestones for reforestation in Washington State, listed by year, are highlighted in the following list.

- **1911:** First forest seedling nursery opened in Washington (U.S. Department of Agriculture [USDA], Forest Service's Wind River Nursery—closed in 1997).
- **1936:** First State nursery, Capitol Forest opened (closed in the 1950s when seedling production was relocated to Webster Forest Nursery).
- **1938:** First industrial nursery (Weyerhaeuser) opened near Snoqualmie Falls, WA. Currently, four industrial nurseries operate in the State along with approximately seven private forest seedling nurseries and dozens of conservation nurseries.
- **1946:** Washington State's first Forest Practices Act required reforestation of harvested lands.
- **1957:** First seedling shipment from WA DNR's, L.T. Mike Webster Forest Nursery, established just south of Olympia. Today, Webster nursery consists of 270 acres (110 hectares) of bareroot ground and 72,000 ft^2 (6,700 m^2) of greenhouses (figure 7).
- **1970s**: Container seedling production began with greenhouses constructed by WA DNR, forestry companies, and private nurseries.

Figure 7. Washington State's Webster Nursery near Olympia produces both container and bareroot seedlings. Top to bottom: seedlings are grown in the greenhouse for outplanting or transplanting, bareroot seedlings during summer growth, and bareroot seedlings during fall frost protection. (Photo source: John Trobaugh, WA DNR).

- **1974:** Forest Practices Act established (amended many times since).
  - Western Washington: Within 3 years of harvest, at least 190 trees per acre (469 per hectare) must be established (healthy trees remaining after first growing season). (Note: common practice is to plant approximately 390 seedlings per acre (964 per hectare), with an expected fifth year survival of 88 percent [Trobaugh 2008]).
  - Eastern Washington: Within 3 years of harvest, at least 150 trees per acre (370 per hectare) must be established.
- **1990s:** Northwest Forest Plan was adopted for 25 million acres (10 million hectares) administered by the USDA Forest Service and the Bureau of Land Management within the range of the spotted owl.
- **1999:** Washington Forests & Fish Law passed; regulates habitat along 60,000 mi (96,558 km) of streams in the State. Riparian Management Zone can be up to 200 ft (61 m) on each side of streams, lakes, and ponds that are used by fish, amphibians, wildlife, and for drinking water (WA DNR 2009).

Timber Harvest and Seedling Production

Currently, no established reporting method tracks how many seedlings are planted annually in Washington State. For this article, timber harvest volumes are used as a rough surrogate for the number of seedlings planted for reforestation along with a survey sent to 19 forest seedling nurseries in the region regarding the average number of seedlings grown for Washington State during the past 5 years. Variations in the volume harvested per acre, along with the type of harvest (clearcut versus partial harvest), result in an element of uncertainty for estimating seedling planting, but given the lack of other data sources, it is the closest approximation that can be made. From 1965 to 1989, considerable market fluctuations occurred, but annual harvest volume averaged approximately 6.5 billion board ft (15.3 million m^3) (figure 8). Since 1990, harvest volumes have declined to a record low of 2.2 billion board ft (5.2 million m^3) in 2009 (figure 8). Because of demand from China, total harvest volume increased in 2010 to 2.7 billion board ft (6.4 million m^3) (figure 8). To put this production level into national perspective, in 2004 Washington State harvested 3.8 billion board ft and ranked ninth nationwide for total value of Forest Products Shipments ($9,655,591,000), with 51 percent paper and 49 percent wood products (U.S. Census Bureau 2006).

Figure 8. Timber harvest in Washington State: 1965–2010 (Data source: WA DNR 2010).

A reasonable assumption is that the number of seedlings planted for reforestation has followed trends similar to timber harvest rates. Of the largest nurseries in the region, 11 responded to a 2011 survey, and reported that approximately 52 million seedlings were planted each year. Similar to the harvest trends, this seedling planting level was down from the 85 million seedlings reported as planted in 1997 (Moulton 1999).

Forest Health

In eastern Washington, widespread damage, primarily from insects, has caused cumulative tree mortality and a predicted risk of mortality to 2.8 million acres (1.1 million hectares). In November 2011, WA DNR initiated a tier-two forest health hazard warning (WA DNR 2011a). The amount of acreage that was damaged by disease and insects during the past decade is estimated to be 150 percent greater than the amount damaged in the 1990s, and 200 percent greater than the amount damaged in the 1980s (WA DNR 2011b). Additional information concerning the health of Washington's forests can be found on the WA DNR Forest Health Program Web site (WA DNR 2011c).

Forest Types and Seed Zones

Forests in The Evergreen State are dominated by conifers (table 1). Consequently, most of the seedlings that are planted are conifers. The WA DNR's Webster Forest Nursery grows 73 percent Douglas-fir (*Pseudotsuga menziesii* Mirb. Franco), 7 percent western redcedar (*Thuja plicata* Donn ex D. Don), 6 percent ponderosa pine (*Pinus ponderosa* Dougl. ex Laws), and 5 percent western larch (*Larix occidentalis* Nutt.). The other 9 percent consists of 11 relatively minor species.

Because of the large geographic and climatic variation, large genetic variations also exist within most species. For example, Douglas-fir has 16 seed zones, which are further divided by elevation bands every 1,000 ft (305 m) on the westside of the Cascade Mountain Range and every 700 ft (213 m) on the eastside of the Cascade Mountain Range (figure 9) (Randall and Berrang 2002).

Seedling Stock Types

During the early years of seedling production in Washington, Douglas-fir 2 + 0 seedlings (2 years in the seed bed plus 0 years in the transplant bed) were the standard stock type grown (figure 10). When larger seedlings were needed, 1 + 2 or 2 + 1 seedlings were grown, but they were the exception. In those days, large contiguous clearcuts with hot broadcast burns were the standard harvest and site preparation methods, and 2 + 0 seedlings were very successful. Today, planting sites are not broadcast burned, resulting in more slash and brush (figure 4) and a preference by reforestation foresters for larger 1 + 1 (1 year in a bareroot seed bed plus 1 year in the transplant bed) and plug + 1 (started as a plug seedling plus 1 year in a transplant bed) seedlings (figure 10).

Table 1. Forest types in Washington State.

Forest type	Acres	Percent
Douglas-fir	8,658,000	39.00
Fir/spruce/mountain hemlock	3,992,000	18.00
Western hemlock/sitka spruce	3,300,000	15.00
Ponderosa pine	2,069,000	9.00
Lodgepole pine	651,000	3.00
Western larch	318,000	1.00
Western white pine	11,000	0.05
Other softwoods	186,000	1.00
Alder/maple	1,905,000	9.00
Other hardwoods	673,000	3.00
Nonstocked	625,000	3.00
Total	**22,388,000**	**100.00**

(Source: Campbell, Waddell, and Gray 2010).

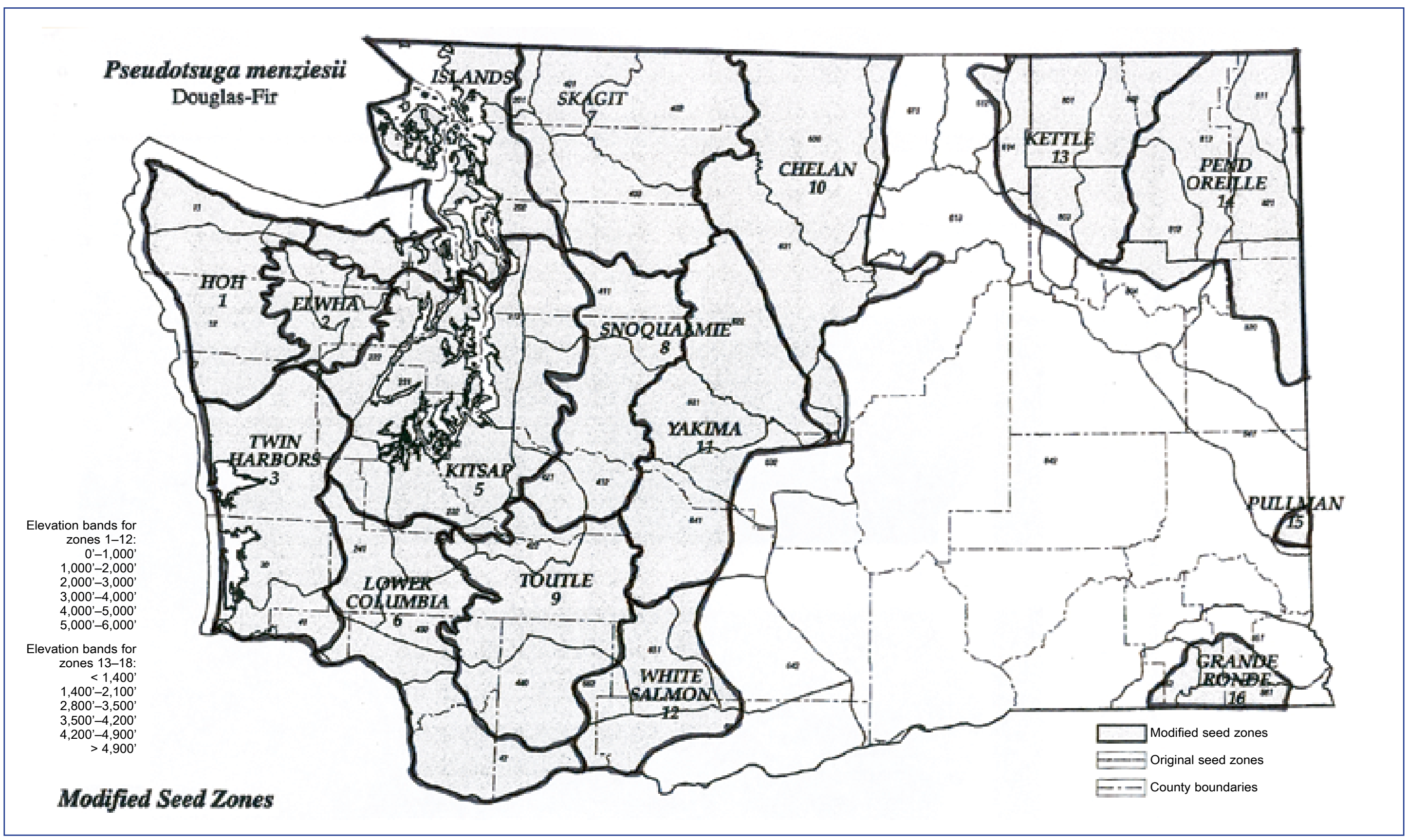

Figure 9. Seed transfer zones for Douglas-fir within Washington State. (Source: Randall and Berrang 2002).

In the 1970s, container (plug) seedlings became a popular choice in Washington, with several organizations building greenhouse facilities to cultivate the plug seedlings. Early production focused on S-2, S-4, S-6, and S-8 stock types (seedlings grown in Styroblocks™ with 2, 4, 6, or 8 in^3 cavities [33, 36, 98, or 131 cm^3]) (figure 11). Use of the Styroblock™ container system (Beaver Plastics Ltd, distributed in the United States by Stuewe and Sons, Inc.) became the standard for forest container nurseries in the Pacific Northwest. Some species such as Sitka spruce (*Picea sitchensis* [Bong.] Carrière), western redcedar, and western hemlock (*Tsuga heterophylla* [Raf.] Sarg.) can have 200,000 to 400,000 seeds per lb (90,909 to 181,818 seeds per kg) and are best started in containers.

Improved cultural treatments during the past few decades have led to the ability to produce increasingly larger seedlings. Today, a Douglas-fir 1 + 1 seedling is as large as a 1 + 2 or 2 + 1 seedling was in the past. The demand for larger seedlings has increased and 1 + 1 and plug + 1 are currently the preferred bareroot stock type seedlings that are used for reforestation in Washington State (figures 10 and 12). Demand for larger container seedlings has also increased with S-10, S-15, and S-20 seedlings being the most common stock types grown for outplanting on the westside of the Cascade Mountain Range (figures 11 and 12) (Briggs and Trobaugh 2001).

Figure 10. Douglas-fir bareroot stock types. From left to right: 2 + 0 (2 years in a seed bed plus 0 years in a transplant bed), 1 + 1 (1 year in a bareroot seed bed plus 1 year in a transplant bed), and plug + 1 (started as a container ["plug"] seedling plus 1 year in a transplant bed). (Photo source: John Trobaugh, WA DNR).

Figure 11. Douglas-fir container stock types. From left to right: S-4 (4 cubic inch root plug, 313A), S-10 (10 cubic inch root plug, 415D), and S-20 (20 cubic inch root plug, 615A). (Photo source: John Trobaugh, WA DNR).

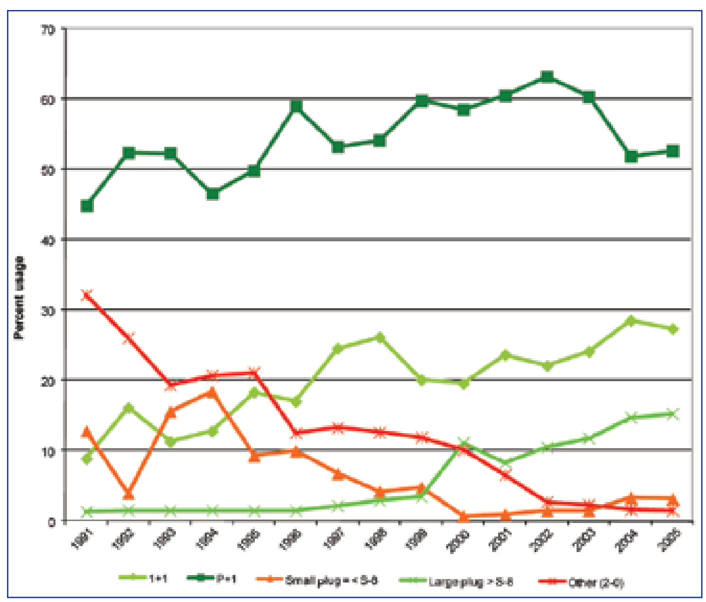

Figure 12. Douglas-fir stock type trends (1991–2005) for large forest landowners in western Washington and Oregon. (Data source: Briggs and Trobaugh 2001).

Because of the variety of site conditions, tree species, and potential browse damage from deer and elk, reforestation foresters use a variety of stock types to accomplish the objective of successful reforestation within 3 years of a harvest. Container seedlings are preferred on harsh, dry, rocky sites (especially on the eastside of the Cascade Mountain Range), while a large, woody 1 + 1 or P + 1 seedling is preferred on sites where a high level of animal damage is expected.

Washington Tree Planting Into the Future

Washington State has some of the most productive forests in the world, grows a high-value product, and has a long, rich history of forestry. Despite many, often competing interests, forestry continues to be a vital part of the State's economy. In 2009, the forest seedling industry experienced a crash in the demand for seedlings and surplus seedlings were destroyed by the millions. Since then, the high demand for wood in Asia has led to increased timber harvesting. As a result, seedling demand in Washington is up and, for the second year in a row, most nurseries are sold out of seedlings. Washington is well situated to provide wood for both the U.S. and Pacific Rim markets. For the foreseeable future, reforestation in Washington will continue to be a strong and green industry.

Address correspondence to:

John Trobaugh, Program Manager, Webster Forest Nursery, P.O. Box 47017, Olympia, WA 98504; e-mail: john.trobaugh@dnr.wa.gov; phone: 360–902–1270.

References

Briggs, D.; Trobaugh, J. 2001. Management practices on Pacific Northwest west-side industrial forest lands, 1991–2000: with projections to 2005. Stand Management Cooperative Working Paper No. 2. Seattle: University of Washington. 72 p. http://www.cfr.washington.edu/research.smc/research/working%20paper%202.pdf. (December 2011).

Campbell, S.; Waddell, K.; Gray, A. 2010. Washington's forest resources, 2002–2006: 5-year forest inventory and analysis report. General Technical Report PNW-GTR-800. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 189 p.

Moulton, R.J. 1999. Tree planting in the United States—1997. Tree Planters' Notes. 49(1): 5–15.

Randall, W.K.; Berrang, P. 2002. Washington tree seed transfer zones. Olympia: Washington Department of Natural Resources. 84 p. http://www.dnr.wa.gov/Publications/lm_wfn_seedzone_book.pdf. (December 2011).

Trobaugh, J. 2008. Reforestation planting densities in the Northwest. Northwest Woodlands. 24(4): 20–22.

U.S. Census Bureau. 2006. Geographic area statistics: 2004, annual survey of manufacturers. M04(AS)-3. 74 p. www.census.gov/prod/ec02/am0431as1.pdf. (December 2011).

U.S. Department of the Interior, U.S. Geological Survey. 2011. Glaciations, ice sheets, and glacial lakes. http://vulcan.wr.usgs.gov/Glossary/Glaciers/IceSheets/. (December 2011).

Washington State Department of Ecology. 2011. Washington State maps. http://www.ecy.wa.gov/services/gis/maps/state/state.htm. (December 2011).

Washington State Department of Natural Resources (WA DNR). 2009. Forest practices illustrated: a simplified guide to forest practices rules in Washington State. http://www.dnr.wa.gov/BusinessPermits/Topics/ForestPracticesRules/Pages/fp_fpi.aspx. (December 2011).

Washington State Department of Natural Resources (WA DNR). 2010. Washington State timber harvest reports. http://www.dnr.wa.gov/BusinessPermits/Topics/EconomicReports/Pages/obe_washington_timber_harvest_reports.aspx. (March 2012).

Washington State Department of Natural Resources (WA DNR). 2011a. Commissioner Goldmark initiates tier two forest health hazard warning. Press release, November 14, 2011. http://www.dnr.wa.gov/ResearchScience/News/Pages/2011_11_14_foresthealth.aspx. (December 2011).

Washington State Department of Natural Resources (WA DNR). 2011b. Goldmark alarmed by the health of forests: testifies before legislative committee. Ear to the Ground, December 2, 2011. http://washingtondnr.wordpress.com/2011/12/02/goldmark-alarmed-by-the-health-of-forests-testifies-before-legislative-committee/. (December 2011).

Washington State Department of Natural Resources (WA DNR). 2011c. Forest health program. http://www.dnr.wa.gov/ResearchScience/Topics/ForestHealthEcology/Pages/rp_foresthealth.aspx. (December 2011).

A Brief History of Forests and Tree Planting in Arkansas

Don C. Bragg

Research Forester, Forest Service, Southern Research Station, Monticello, AR

Forests are vital to the socioeconomic well-being of Arkansas. According to one recent report, Arkansas is the eighth leading wood-producing State (Smith and others 2009), providing billions of dollars of economic contributions related to the timber industry (University of Arkansas Division of Agriculture 2009). Additional benefits of Arkansas forests include tourism, hunting and fishing, water and air quality, and other goods and services that collectively make Arkansas forests an unsurpassed resource (figure 1). With such abundance today, it is difficult to imagine how much the Arkansas timber resource has changed during the past two centuries and, in particular, how much the forests have recovered since large-scale lumbering ended around 1930. Although most of this renewal started with forest protection and natural regeneration, much of the revitalization is also attributable to widespread replanting, including the reclamation of former agricultural lands.

Arkansas has long enjoyed ample rainfall, good soils, and a temperate climate, circumstances that are favorable for producing dense forests when their growth is not constrained by local site conditions or disturbance patterns. Geographers typically subdivide Arkansas into seven physiographic regions (figure 2). These include the low rolling hills of the timber-covered West Gulf Coastal Plain, where most of the loblolly pine (*Pinus taeda* L.) is grown; the Mississippi River Alluvial Plain, a broad, flat agricultural region now largely cleared of its original bottomland hardwoods and baldcypress (*Taxodium distichum* (L.) Rich.); Crowley's Ridge, a prominent line of hardwood-covered hills in northeastern Arkansas that sit above the surrounding river plains; the Ouachita Mountains, heavily forested with shortleaf pine (*Pinus echinata* Mill.) and mixed hardwoods; the Arkansas River Valley, a combination of agricultural and forested lands along the Arkansas River; the steeply incised Boston Mountains cloaked in oak-hickory forests; and the Ozark Plateau, also dominated by oak-hickory forests, with scattered shortleaf pine.

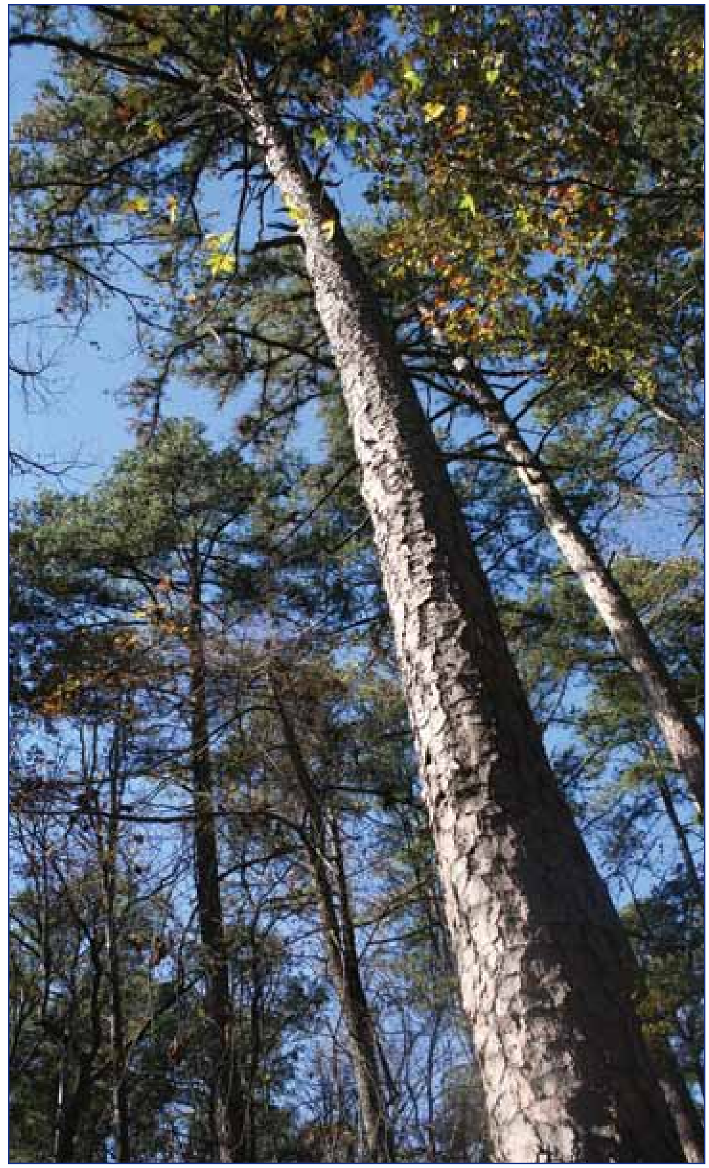

Figure 1. A mature, unmanaged second-growth stand of shortleaf pine, oak, and hickory in the Ouachita Mountains near Hot Springs, AR. (Photo source: Don C. Bragg).

Today, much of Arkansas is forested. In 2005, forests covered about 54 percent of the State's 33.3 million acres (13.3 million hectares), with most of the remaining land dedicated to agricultural, residential, or commercial uses (Rosson and Rose 2010). Of these timbered lands, more than 58 percent were owned by nonindustrial private forest landowners in 2005 and nearly 19 percent were held in various public ownerships—the remaining 23 percent was owned by industrial or commercial interests (figure 3). The most recent Forest Inventory and Analysis (FIA) survey listed 100 tree species statewide, but only a handful (table 1) contributed most of the 27.1 billion ft^3 (767.5 million m^3) of standing live timber (Rosson and Rose 2010).

Figure 2. The topography of Arkansas, overlain by the physiographic provinces. (Map adapted from Woods and others 2004).

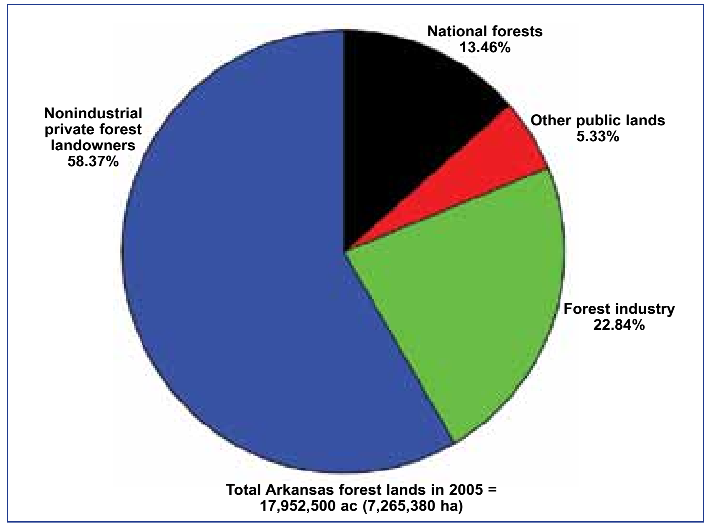

Figure 3. Forest land-ownership patterns for Arkansas in 2005. (Data source: Rosson and Rose 2010).

Table 1. Live tree volume of stems at least 5 in (12.7 cm) d.b.h. reported in the 2005 FIA survey of Arkansas forests.

Tree species	Live tree volume (millions of units) (ft^3)	(m^3)	Species total (%)	Cumulative total (%)
Loblolly pine (*Pinus taeda* L.)	6,040.1	171.1	22.29	22.29
Shortleaf pine (*Pinus echinata* Mill.)	3,467.5	98.2	12.80	35.08
White oak (*Quercus alba* L.)	2,555.4	72.4	9.43	44.51
Sweetgum (*Liquidambar styraciflua* L.)	1,922.2	54.4	7.09	51.61
Post oak (*Quercus stellata* Wang.)	1,441.5	40.8	5.32	56.93
Northern red oak (*Quercus rubra* L.)	974.3	27.6	3.60	60.52
Black oak (*Quercus velutina* Lam.)	876.2	24.8	3.23	63.75
Southern red oak (*Quercus falcata* Michx.)	850.9	24.1	3.14	66.89
Black hickory (*Carya texana* Buckl.)	639.7	18.1	2.36	69.25
Water oak (*Quercus nigra* L.)	612.9	17.4	2.26	71.52
All other 90+ species	7,719.3	218.6	28.48	100.00
Totals:	**27,100.0**	**767.5**	**100.00**	

FIA = Forest Inventory and Analysis. (Data source: Rosson and Rose 2010).

Past Forest Conditions

At the end of the last glaciation, pollen and other fossil records suggest a much cooler climate for Arkansas, with evidence of northern conifers such as jack pine (*Pinus banksiana* Lamb.), fir (*Abies* spp.), and spruce (*Picea* spp.) present in the Mississippi River Alluvial Plain, while the uplands were dominated by trees from more northerly climates (Delcourt and Delcourt 1981, Royall and others 1991). Thus, when the first Arkansans (the Paleoindians) arrived more than 13,000 years ago, they experienced completely different landscapes than seen today. As the glaciers melted during the next few thousand years, oak-hickory forests occupied most uplands and southern pines gradually spread into Arkansas. Modern forest assemblages followed a more stable and moderate climate approximately 4,000 to 5,000 years ago (Royall and others 1991). The recent climatic norm has been periodically interrupted by megadroughts, however, sometimes lasting for decades (Stahle and others 1985, Stahle and others 2007).

During the Holocene epoch, which began about 12,000 years ago, human populations fluctuated considerably, with long periods of limited population followed by rapid increases (and some declines). Native Americans affected Arkansas forests by using fire to manipulate the vegetation, consuming and disseminating the seeds of trees, and clearing forests. The practice of agriculture during the late Archaic and Woodland Periods (approximately 1,000 to 3,000 years ago) greatly increased during the Mississippian Period (between 500 and 1,000 years ago) and profoundly affected parts of the State. According to the earliest European chroniclers, Native American farmers cleared extensive tracts of forest land in eastern

Arkansas to grow corn, beans, and squash. For example, in the early 1540s, Spanish conquistador Hernando de Soto would sometimes travel for days in these tribal agricultural fields (Dye 1993). In southwestern Arkansas, the Caddoans were also farming extensively when initial contact was made with Europeans (Schambach 1993).

Unfortunately, written records of Arkansas forests before 1800 are very limited. Across much of the New World, indigenous populations plummeted after initial European contact. The extensive Mississippian agriculture witnessed by de Soto vanished by the time French missionaries and traders returned to the area 150 years later (Burnett and Murray 1993). The 1803 Louisiana Purchase included only a few French and Spanish settlers among a handful of Native Americans, including the Caddo, Quapaw, and Osage Nations. After this transition, the westward expansion of the United States brought increasing numbers of settlers to Arkansas, especially after General Land Office surveyors started subdividing the territory in 1815 (Gill 2004). Native American population removals by the early 1830s further accelerated Euro-American settlement, and by 1860 more than 430,000 people lived in Arkansas. During the antebellum period, demand for species such as baldcypress drove lumbermen up the large rivers into the virgin forests (Bragg 2011). The Civil War and Reconstruction periods appreciably slowed population expansion in Arkansas, but in the 1880s, dramatic growth returned, sparking markedly higher demand for forest products.

The exhaustion of the pineries in the Lake States and New England that occurred by the late 1800s sent more lumbermen southward. Some have estimated that the original forests of Arkansas had between 200 and 300 billion board ft of timber before extensive Euro-American settlement (Bruner 1930). Early reports on Arkansas forest conditions showed only limited exploitation of the timber resources in the immediate proximity of the major railroads (for example, Sargent 1884, Mohr 1897). By 1900, the infrastructure had greatly improved, making the extraction of timber resources much more efficient (figure 4). During this period, timber speculators purchased blocks of forest land and sold them to lumber companies which then constructed large mills and cleared the land. Operations such as the Crossett Lumber Company in southern Arkansas and Dierks Lumber and Coal Company in western Arkansas were able to acquire large holdings of virgin pine, hardwood, and cypress at a low cost (Smith 1986, Darling and Bragg 2008).

During the first few decades of the 20th century, the big cut of industrial lumbering in Arkansas occurred, with timber production peaking statewide in 1909. More than 2 billion board ft of lumber, 2.6 billion board ft of firewood, and hundreds of millions of board ft of cooperage, lath, shingles, crossties, veneer, and other wood products were cut in 1909, most of which was then shipped to out-of-State markets (Harris and Maxwell 1912). This rate of consumption far exceeded the growth of Arkansas forests. As in many parts of the United States, the Federal Government grew concerned about a possible timber famine and thus established the Arkansas (now Ouachita) and Ozark National Forests in 1907 and 1908, respectively, from parts of the public domain in the western and northern sections of Arkansas (Strausberg and Hough 1997). Timber volumes continued to fall precipitously in Arkansas, and many lumber operations closed their doors or moved on to the Western United States. By the late 1920s, much of the State's timber had been cutover, burned over, abandoned, or converted to nonforest uses. Forest cover, once estimated at 32 million acres (12.95 million hectares), declined steadily until stabilizing between 18 and 20 million acres (7.3 and 8.1 million hectares) in the mid-1900s (figure 5).

Figure 4. An example of the prime pine sawtimber found in southern Arkansas during the historic lumbering period. (Photo source: USDA Forest Service picture #353379).

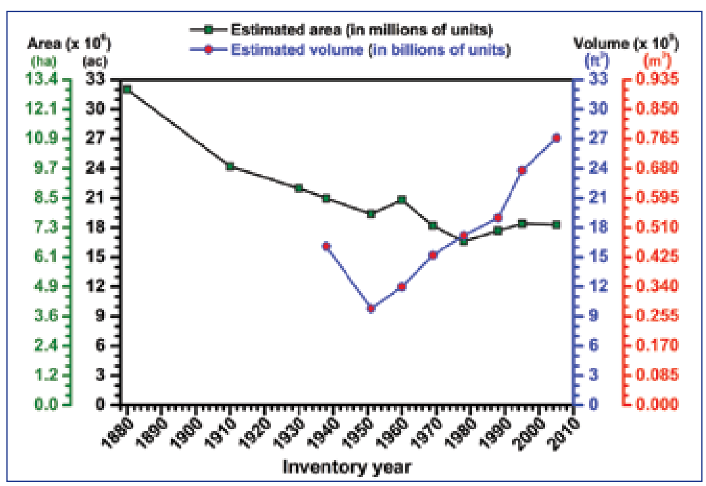

Figure 5. Forest area (1880 to 2005) and live tree volume (1938 to 2005) estimates for Arkansas. (Data sources: Record 1910; Cruikshank 1937, 1938; Winters 1938, 1939; Duerr 1948; Conner and Hartsell 2002; Rosson and Rose 2010).

After the collapse of the lumbering industry and the virtual disappearance of the virgin forest in Arkansas, attitudes towards forests and forestry began to change (Bragg 2010). Public outcry, the promotional efforts of private citizens, and pressure from the remaining industry eventually led the State legislature to establish the Arkansas State Forestry Commission in 1931 (Lang 1965). During the 1930s lands were added to Arkansas national forests when Federal legislation permitted the acquisition of abandoned or tax delinquent properties, and tree planting programs were incorporated into some of the relief work projects that were undertaken by various agencies during the Great Depression (Bass 1981, Strausberg and Hough 1997). Fire control, improved silviculture, conservation and education programs, and the reforestation of former farmlands helped reverse timber land decline in the State and led to decades of increasing forest volume (figure 5).

After silvicultural techniques for the most productive forest types were developed, the timber industry quickly rebounded in Southern States (Heyward 1958). Corporations, such as International Paper Company, Georgia-Pacific, Weyerhaeuser, and Potlatch, acquired large tracts of Arkansas timber land during the 20th century, especially in the West Gulf Coastal Plain and Ouachita Mountains. Because these large companies continually sought to increase the productivity of their lands, even-aged management approaches became favored over the uneven-aged silviculture that initially dominated timber harvesting practices in the State. Natural pine regeneration practices using seed tree- and shelterwood-based systems became prominent (figure 6), commonly with prescribed fire to control competing vegetation. International competition, continued improvement in genetics, herbicides, and stand density management, however, coupled with changes to tax and investment laws, have in combination increasingly steered timber companies towards operating even more productive loblolly pine plantations, especially after 1980.

Arkansas Forest Management Today

The mid-South region, which includes Arkansas, is currently projected to increase in forest acreage and overall timber volume, largely because of limited (or negative) population growth and the continued afforestation of former agricultural lands (Wear and Greis 2002). Arkansas depends on its forests to provide tangible and intangible benefits to its citizens and millions of visitors. According to a recent survey, more than 33,000 Arkansans were employed in forest-related industries that generated more than \$1.6 billion in labor income and an overall economic impact of at least \$2.8 billion (University of Arkansas, Division of Agriculture 2009). Timber harvests removed more than 810 million ft^3 (23 million m^3) of wood in 2006 (Smith and others 2009). Tourism is also critical to the State's economy, with more than \$5.5 billion spent by visitors in 2010, much of which was related to forest-based experiences (Arkansas Department of Parks and Tourism 2011).

Arkansas forests remain in a state of flux. The coverage of natural origin pine, oak-pine, and bottomland hardwood forests in Arkansas (figure 7) has declined steadily since the early 1960s (Conner and Hartsell 2002), although these forest types still comprise 84 percent of current forests (Rosson and Rose 2010). During this same period, upland hardwood coverage has remained relatively constant and forests dominated by eastern redcedar (*Juniperus virginiana* L.) have increased significantly. Pine plantations (primarily of loblolly pine) have increased most dramatically (figure 7), increasing from

Figure 6. A modern-day example of successful seed tree regeneration of loblolly pine in the West Gulf Coastal Plain of Arkansas. (Photo source: Don C. Bragg).

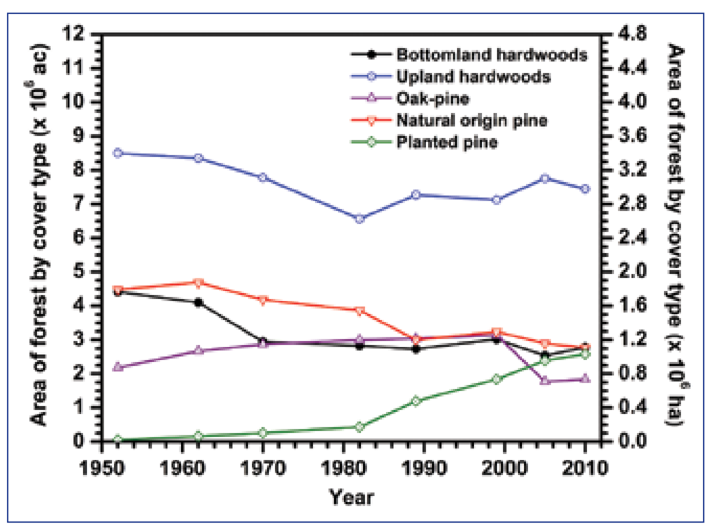

Figure 7. Change in Arkansas forest area by cover type from 1952 until 2010. (Data sources: Conner and Hartsell 2002; Rosson and Rose 2010; USDA Forest Service FIA 2011).

approximately 55,000 acres (22,300 hectares) in 1952 to just more than 2.94 million acres (1.19 million hectares) in 2005 (Conner and Hartsell 2002, Rosson and Rose 2010). Most of this increase has occurred since the early 1980s—the 2005 total represents 675 percent more land in plantations than the 1982 FIA estimate of 436,000 acres (176,400 hectares).

Not surprisingly, silvicultural practices have intensified during the past 50 years. Many landscapes once dominated by naturally regenerated, even-aged stands have become short rotation loblolly pine plantations, often with intensive site preparation (for example, ripping and bedding), improved seedling genetics, midrotation fertilization, and vegetative competition control (figure 8). Foresters plant improved pine seedlings at low densities and conduct precommercial thinnings in more heavily stocked pine plantations, often to remove naturally seeded volunteer pines. Arkansas forest owners generally do not use large quantities of fertilizer on their properties, which is common practice in other parts of the Southeastern United States. Most plantations receive one or two commercial thinnings before the stand is cleared and replanted, often on a rotation length of 25 to 35 years.

Figure 8. Ripped and bedded cutover pine plantation about to be replanted to loblolly pine. (Photo source: Don C. Bragg).

A History of Tree Planting in Arkansas

Undoubtedly, Native Americans were the first Arkansans to have planted seeds with the intent of starting new trees. It is likely that nut- and fruit-bearing species were cultivated near many Native American villages before Euro-American colonization (Davies 1994, Nuttall 1999, Abrams and Nowacki 2008). A number of Eurasian fruit trees, including the peach (*Prunus persica* [L.] Batsch), apple (*Malus pumila* Mill.), and pear (*Pyrus* spp.), were planted in Arkansas by either historic tribes or the earliest Euro-American colonists (for example, Bragg 2003). Early settlers also planted a number of ornamental trees from other regions, including southern catalpa (*Catalpa bignonioides* Walter), southern magnolia (*Magnolia grandiflora* L.), mimosa (*Albizia julibrissin* Durazz.), and tree-of-heaven (*Ailanthus altissima* (Mill.) Swingle) (Harvey 1880, 1883; Nuttall 1999). Before 1850, a few Arkansans even tried to get into the silk business by planting Chinese mulberry (*Morus alba* L.), although these efforts failed (Brown 1984). Settlers also learned of the benefits of certain native tree species—bois d'arc (*Maclura pomifera* (Raf.) C.K. Schneid.), for example, was prized as a living hedge and the source of durable, decay-resistant wood and a bright yellow dye (Gregg 1844, Robinson 1849, Harvey 1883) and, thus, was planted extensively.

In 1840, Arkansas produced $10,680 worth of products of the orchard (U.S. Department of State 1841). Nurseries that produced trees for planting began to appear in the State during the 1850s (Brown 1984). A growing horticulture industry resulted in the widespread planting of commercial fruit trees, particularly in northwestern parts of the State—in 1899, Benton and Washington counties each had more than 1.5 million apple trees (U.S. Census Office 1902). By 1919, apple production peaked statewide with a yield of more than 7 million bushels of apples (247,000 m^3) (U.S. Census Bureau 1922). Problems with insect pests, economics, and environmental conditions contributed to a steady decline in the industry, however, throughout the 20th century (Rom 2009). Commercial varieties of pecan (*Carya illinoinensis* (Wangenh.) K. Koch) and walnut (*Juglans* spp.) were also planted statewide during the 20th century, although the nut tree industry in Arkansas has never been prominent. For example, Arkansas pecan production in 1919 barely exceeded 364,000 pounds (165,000 kg), compared with nearly 17 million pounds (7.7 million kg) grown that same year in Texas (U.S. Census Bureau 1922). Christmas trees have also been planted in Arkansas, especially eastern redcedar and Virginia pine (*Pinus virginiana* Mill.), but production is very limited, with only 10,636 trees cut in 2007 (USDA 2009).

Outside of these ornamental and horticultural efforts, few people were interested in tree planting in Arkansas until near the end of the lumbering era. Around the 1920s, a few large family-owned lumber companies began to experiment with sustainable forestry practices (Hall 1925, Williams 1925, Woods 1925, Gray 1954), but they focused almost exclusively on natural regeneration. Through various programs and incentives, the Federal Government initiated a number of tree planting efforts. The passage of the Knutson-Vandenberg Act in 1930 further facilitated Federal tree planting by helping to fund postharvest reforestation work, using the proceeds of timber sales from national forest lands, including seedling production, site preparation, and tree planting (Strausberg and Hough 1997). Additional reforestation efforts followed the acquisition of abandoned farmland and cutover forests that was made possible by the passage of the Clark-McNary Act in 1924. During the Great Depression, the Civilian Conservation Corps planted shortleaf pine, eastern redcedar, and various hardwood species on thousands of denuded acres acquired for the Ouachita and Ozark National Forests by the U.S. Department of Agriculture (USDA) Agricultural Resettlement Administration Program (Gray 1993). To meet these new tree planting demands, Ozark National Forest staff opened a nursery at Fairview on the Pleasant Hill Ranger District in the spring of 1929, but the nursery failed due to an inadequate water supply (Bass 1981). The next year, a new nursery was established on lands leased from Arkansas Polytechnic College (now Arkansas Technological University) in Russellville, and this facility entered full production by 1932 when an irrigation system was installed (Bass 1981). This nursery was turned over to the university by the 1940s, shortly after which it ceased seedling production. Over the years, most Federal research on forestry in Arkansas concentrated on naturally regenerated forests, although some study of tree planting and plantation forestry has occurred, including the largely unsuccessful testing of a number of exotic species (for example, Grigsby 1969).

Although initially beset by funding and staffing issues, by the mid-1930s, the newly formed Arkansas State Forestry Commission was producing millions of bareroot tree seedlings each year at nurseries near Conway (opened in 1934, now closed) and Scott (the Baucum Nursery, opened in 1936 and still in operation) (Arkansas State Forestry Commission 1934, 1936). Because tree breeding programs had not yet begun, these nurseries used seeds collected in the field, and primarily produced hardwoods for use in land stabilization projects. Of the seedlings grown at the Conway Nursery in 1935, more than 92 percent were distributed to two Federal agencies (the Rural Resettlement Administration and the Soil Conservation Service) (Arkansas State Forestry Commission 1936). In 1936 and 1937, the Baucum Nursery produced more than 10 million seedlings, of which nearly 90 percent were black locust (*Robinia pseudoacacia* L.), 8 percent were shortleaf pine, nearly 2 percent were Chinese elm (*Ulmus parvifolia* Jacq.), and the remaining fraction were other taxa, including loblolly pine (Arkansas State Forestry Commission 1936; David Bowling, Baucum Nursery, personal communication). Over the years, seedling production levels have fluctuated from a low of 355,000 in 1944 to more than 78 million in 1959, although recent production levels have been between 6 and 15 million seedlings per year (David Bowling, Baucum Nursery, personal communication).

Modern Tree Planting in Arkansas

Today, Arkansas is one of the leading producers of nursery-grown seedlings, especially bare-root loblolly pine, hardwood, and baldcypress (Moulton and Hernandez 2000, McNabb and Enebak 2008). For example, in the 2005 to 2006 planting season, Arkansas nurseries produced 12 percent of the loblolly pine, 31 percent of the baldcypress, and nearly 24 percent of hardwood bare-root seedlings grown in the Southeastern United States (McNabb and Enebak 2008). Most of the roughly 110 million trees produced annually in Arkansas nurseries are native species. In 1998, nearly 114,000 acres (46,100 hectares) of trees were planted in the State (Moulton and Hernandez 2000). Most of this acreage has loblolly pine plantations that were established by industrial and other private timberland owners in the southern half of the State (Rosson and Rose 2010). Oaks are planted primarily in the uplands of western and northern Arkansas, and a mixture of bottomland hardwoods are planted in the major river bottoms, especially for government conservation programs. Research into hardwood planting continues, with particular emphasis on native oaks, ash, and cottonwood, as well as some exotic hardwoods (for examples, see Grigsby 1969, Guo and others 1998, Heitzman and Grell 2006, and Spetich and others 2009). Unlike pine varieties in the State, there have been minimal tree improvement efforts for Arkansas hardwoods, with the exception of some hybrid *Populus* and second-generation cherrybark oak (*Quercus pagoda* Raf.).

To satisfy demand for hardwoods, two major industry-owned nurseries have supplemented seedling production efforts of the Baucum Nursery. In 1972, Weyerhaeuser produced its initial crop of seedlings at a nursery near Magnolia, AR. This facility produces mostly bare-root loblolly pine seedlings, averaging approximately 50 million annually over the years. In 2011, Weyerhaeuser's Magnolia Nursery also produced 2.9 million bare-root hardwood seedlings of more than a dozen species (primarily native oaks and baldcypress). All of the hardwoods and 70 to 75 percent of the loblolly pine seedlings produced at Magnolia are planted outside of the company's lands (Kevin Richardson, Magnolia Nursery, personal communication). In 1979, International Paper Company established a nursery near Bluff City, AR. Annual production quickly increased from 17 million pine seedlings (virtually all loblolly, with a small amount of shortleaf) in 1980 to more than 62 million seedlings by 1997 (Bill Abernathy, Gragg SuperTree Nursery, personal communication). In 2007, International Paper Company sold this facility to ArborGen. The nursery, now known as the Fred C. Gragg SuperTree Nursery, produced 38 million pines in 2011, 98 percent of which grew from open-pollinated seeds. All seedlings are bare rooted, with the exception of a few thousand cottonwood cuttings. Production of various hardwood seedlings started in 1992, and now exceeds 4 million seedlings annually. Most pine seedlings that are produced at the Gragg SuperTree Nursery are distributed within Arkansas, while many hardwood seedlings are exported. To date, Magnolia has produced approximately 1.9 billion seedlings and Bluff City has produced more than 1.5 billion seedlings, and the Arkansas Forestry Commission has grown 1.3 billion seedlings since 1935.

Future Issues

Over the past few decades, almost all of the vertically integrated timber companies have divested themselves of their timber lands and now purchase raw materials on the open market. Most of these former company lands are currently owned by some type of a real estate investment trust or timberland investment management organization. These new landowners typically practice plantation-based forestry, especially in the piney woods of southern Arkansas (figure 9). During this period, government agencies and nongovernmental organizations also acquired a number of large parcels, primarily for conservation purposes. Public land management in Arkansas is usually considerably less intensive than private industrial land management. The Federal Government has shifted almost entirely away from clearcutting and planting and has moved toward ecosystem restoration using natural regeneration (Guldin and Lowenstein 1999). Typically, forestry consultants steer their clients towards intensively managed pine plantations, although many small landowners place wood production relatively low on their list of objectives (Rosson and Rose 2010). Private, nonindustrial forest owners are the least likely to manage their timbered lands in Arkansas, however, where many acres are still harvested with little concern for the future.

Figure 9. Precommercial thinning of loblolly pine plantations is frequently done to shorten rotation lengths in Arkansas. (Photo source: Don C. Bragg).

Seedling plantations also face a number of environmental challenges. Locally, native white-tailed deer (*Odocoileus virginianus* Zimm.), beavers (*Castor canadensis* Kuhl), rabbits (*Sylvilagus* spp.), other rodents, and even terrestrial crayfish have damaged or killed young planted trees. Many invasive species can be found in Arkansas, but rarely reach critical levels. Feral hog (*Sus scrofa* L.) populations have grown rapidly in recent years, and their rooting threatens new plantations. Kudzu (*Pueraria montana* (Lour.) Merr. var. *lobata* (Willd.) Maesen & S. Almeida), Chinese privet (*Ligustrum sinense* Lour.), and Japanese honeysuckle (*Lonicera japonica* Thunb.) are locally abundant but are generally not considered major forestry threats; however, a number of other exotic plant species do threaten the State's forests. Japanese climbing fern (*Lygodium japonicum* (Thunb.) Sw.) and Chinese tallowtree (*Triadica sebifera* (L.) Small) have recently invaded forests in extreme southern Arkansas, and cogongrass (*Imperata cylindrica* (L.) P. Beauv.) found in nearby States will likely reach Arkansas soon (Miller 2004). The effect of climate change on Arkansas plantations is still uncertain. If the climate does get warmer and wetter as predicted, however, it is possible that some landowners may eventually plant longleaf (*Pinus palustris* Mill.) or slash pine (*Pinus elliottii* Engelm.), rather than loblolly pine in the southern portion of the State, and perhaps continue to expand loblolly pine plantations farther north.

Address correspondence to:

Don C. Bragg, USDA Forest Service, Southern Research Station, P.O. Box 3516 UAM, Monticello, AR 71656; e-mail: dbragg@fs.fed.us.

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References

Abrams, M.D.; Nowacki, G.J. 2008. Native Americans as active and passive promoters of mast and fruit trees in the Eastern USA. The Holocene. 18(7): 1123–1137.

Arkansas Department of Parks and Tourism. 2011. Arkansas Department of Parks and Tourism. http://www.arkansas.com/!userfiles/apt_2011_annual_report.pdf. (18 August 2011).

Arkansas State Forestry Commission. 1934. First annual report of the State Forestry Commission for the fiscal year ending June 30, 1934. Little Rock: State of Arkansas. 48 p.

Arkansas State Forestry Commission. 1936. Third annual report of the State Forestry Commission for the fiscal year ending June 30, 1936. Little Rock: State of Arkansas. 51 p.

Bass, S.M.W. 1981. For the trees: an illustrated history of the Ozark-St. Francis National Forests 1908–1978. Atlanta, GA: U.S. Department of Agriculture, Forest Service, Southern Region. 171 p.

Bragg, D.C. 2003. Natural presettlement features of the Ashley County, Arkansas area. American Midland Naturalist. 149: 1–20.

Bragg, D.C. 2010. Percy George and the pine tree menace. Arkansas Historical Quarterly. 69: 346–367.

Bragg, D.C. 2011. Cypress lumbering in antebellum Arkansas. Arkansas Review: A Journal of Delta Studies. 42(3): 185–196.

Brown, C.A. 1984. Horticulture in early Arkansas. Arkansas Historical Quarterly. 43(2): 99–124.

Bruner, E.M. 1930. Forestry and forest fires in Arkansas. Circular 281. Fayetteville, AR: University of Arkansas, Agricultural Extension Service. 30 p.

Burnett, B.A.; Murray, K.A. 1993. Death, drought, and de Soto: the bioarcheology of depopulation. In: Young, G.A.; Hoffman, M.P., eds. The expedition of Hernando de Soto west of the Mississippi, 1541–1543: Proceedings of the de Soto Symposia 1988 and 1990. Fayetteville, AR: University of Arkansas Press: 227–236.

Conner R.C.; Hartsell, A.J. 2002. Forest area and conditions. In: Wear, D.N.; Greis, J.G., eds. Southern forest resource assessment. General Technical Report SRS-53. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 357–402.

Cruikshank, J.W. 1937. Forest resources of southwest Arkansas. Forest Survey Release 27. New Orleans: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 21 p.

Cruikshank, J.W. 1938. Forest resources of the Ouachita Mountain region of Arkansas. Forest Survey Release 36. New Orleans: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 27 p.

Darling, O.H.; Bragg, D.C. 2008. The early mills, railroads, and logging camps of the Crossett Lumber Company. Arkansas Historical Quarterly. 67(2): 107–140.

Davies, K.M. 1994. Some ecological aspects of northeastern American Indian agroforestry practices. Northern Nut Growers Association Annual Report. 85: 25–37.

Delcourt, P.A.; Delcourt, H.R. 1981. Vegetation maps for eastern North America: 40,000 yr B.P. to the present. In: Romans, R.C., ed. Geobotany II. New York: Plenum Press: 123–165.

Duerr, W.A. 1948. Forest statistics for the Arkansas Ozarks. Forest Survey Release 57. New Orleans: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 23 p.

Dye, D.H. 1993. Reconstruction of the de Soto expedition route in Arkansas: the Mississippi Alluvial Plain. In: Young, G.A.; Hoffman, M.P., eds. The expedition of Hernando de Soto west of the Mississippi, 1541–1543: Proceedings of the de Soto Symposia 1988 and 1990. Fayetteville, AR: University of Arkansas Press: 36–57.

Gill, J.P., ed. 2004. Journal of the Louisiana Purchase 2002 base line expedition. Little Rock: Louisiana-Purchase Bicentennial Committee of Arkansas. 88 p.

Gray, G.W. 1954. The forest lives on, part II. Forest Echoes. 14: 13–15.

Gray, J. 1993. Arkansas forest history. http://arkforests.org/resources-foresthistory.html. (19 July 2011).

Gregg, J. 1844. Commerce of the prairies: or the journal of a Santa Fe trader. Vol. 1. New York: Henry G. Langley. 320 p.

Grigsby, H.C. 1969. Exotic trees unsatisfactory for forestry in southern Arkansas and northern Louisiana. Research Note SO-92. New Orleans: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 5 p.

Guldin, J.M.; Lowenstein, E.F. 1999. Silvicultural practices. In: Ozark-Ouachita Highlands assessment: terrestrial vegetation and wildlife (Report 5). General Technical Report SRS-35. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 73–102.

Guo, Y.; Shelton, M.G.; Lockhart, B.R. 1998. Effects of flood duration and season on germination of black, cherrybark, northern red, and water oak acorns. New Forests. 15(1): 69–76.

Hall, W.L. 1925. The Dierks policy of permanent operation. Southern Lumberman. 121(1576): 155–157.

Harris, J.T.; Maxwell, H. 1912. Wood-using industries and national forests of Arkansas: part I.—uses and supply of wood in Arkansas. Bulletin 106. Washington, DC: U.S. Department of Agriculture, Forest Service. 40 p.

Harvey, F.L. 1880. Notes from Arkansas. Botanical Gazette. 5(8/9): 91–93.

Harvey, F.L. 1883. The arboreal flora of Arkansas. American Journal of Forestry. 1: 413–424, 451–458.

Heitzman, E.; Grell, A. 2006. Planting oaks in group selection openings on upland sites: two case studies from Arkansas. Southern Journal of Applied Forestry. 30: 117–122.

Heyward, F. 1958. History of industrial forestry in the South. Colonel William B. Greeley lecture in industrial forestry 2. Seattle: University of Washington. 50 p.

Lang, F.H. 1965. Two decades of State forestry in Arkansas. Arkansas Historical Quarterly. 24: 208–219.

McNabb, K.; Enebak, S. 2008. Forest tree seedling production in the Southern United States: the 2005–2006 planting season. Tree Planters' Notes. 53(1): 47–56.

Miller, J.H. 2004. Nonnative invasive plants of southern forests: a field guide for identification and control. General Technical Report SRS-62 (revised). Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 93 p.

Mohr, C. 1897. The timber pines of the Southern United States. Bulletin 13 (revised). Washington, DC: U.S. Department of Agriculture, Forest Service, Division of Forestry. 160 p.

Moulton, R.J.; Hernandez, G. 2000. Tree planting in the United States—1998. Tree Planters' Notes. 49(2): 23–36.

Nuttall, T. 1999. A journal of travels into the Arkansas Territory during the year 1819. Fayetteville, AR: University of Arkansas Press. 361 p.

Record, S.J. 1910. The forest resources of Arkansas. Little Rock: Central Printing Company. 38 p.

Robinson, F. 1849. Western recollections: the Illinois River and the Ozark Mountains. Graham's American Monthly Magazine of Literature, Arts, and Fashion. 34(3): 178–181.

Rom, R.C. 2009. Apple industry. Encyclopedia of Arkansas history and culture online. http://www.encyclopediaofarkansas.net/encyclopedia/entry-detail.aspx?entryID=2098. (19 July 2011).

Rosson, J.F.; Rose, A.K. 2010. Arkansas' forests, 2005. General Technical Report SRS-166. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 126 p.

Royall, P.D.; Delcourt, P.A.; Delcourt, H.R. 1991. Late quaternary paleoecology and paleoenvironments of the central Mississippi Alluvial Valley. Geological Society of America Bulletin. 103(2): 157–170.

Sargent, C.S. 1884. Forests, prairie, and treeless regions of North America exclusive of Mexico. 10th Census of the United States. Washington, DC: Government Printing Office: 543–544.

Schambach, F.E. 1993. The end of the trail: reconstruction of the route of Hernando de Soto's army through southwest Arkansas and east Texas. In: Young, G.A.; Hoffman, M.P., eds. The expedition of Hernando de Soto west of the Mississippi, 1541–1543: Proceedings of the de Soto Symposia 1988 and 1990. Fayetteville, AR: University of Arkansas Press: 78–105.

Smith, K.L. 1986. Sawmill: the story of cutting the last great virgin forest east of the Rockies. Fayetteville, AR: University of Arkansas Press. 246 p.

Smith, W.B.; Miles, P.D.; Perry, C.H.; Pugh, S.A. 2009. Forest resources of the United States, 2007. General Technical Report WO-78. Washington, DC: U.S. Department of Agriculture, Forest Service, Washington Office. 336 p.

Spetich, M.A.; Dey, D.; Johnson, P. 2009. Shelterwood-planted northern red oaks: integrated costs and options. Southern Journal of Applied Forestry. 33(4): 182–187.

Stahle, D.W.; Cleaveland, M.K.; Hehr, J.G. 1985. A 450-year drought reconstruction for Arkansas, United States. Nature. 316: 530–532.

Stahle, D.W.; Fye, F.K.; Cook, E.R.; Griffin, R.D. 2007. Tree-ring reconstructed megadroughts over North America since A.D. 1300. Climatic Change. 83: 133–149.

Strausberg, S.; Hough, W.A. 1997. The Ouachita and Ozark-St. Francis National Forests: a history of the lands and USDA Forest Service tenure. General Technical Report SO-121. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 45 p.

University of Arkansas Division of Agriculture. 2009. Economic impact of Arkansas agriculture 2009. [online extension report]. http://division.uaex.edu/news_publications/default.htm. (26 July 2010).

U.S. Census Bureau. 1922. Fourteenth Census of the United States taken in the Year 1920: volume V, agriculture: general report and analytical tables. Washington, DC: Government Printing Office. 886 p.

U.S. Census Office. 1902. Census reports volume VI: Twelfth Census of the United States, taken in the year 1900—agriculture, part II: crops and irrigation. Washington, D.C.: U.S. Census Office. 757 p.

U.S. Department of Agriculture (USDA). 2009. 2007 Census of agriculture. Report AC-07-A-51. Washington, DC: USDA National Agricultural Statistics Service. 639 p.

U.S. Department of Agriculture (USDA), Forest Service Forest Inventory and Analysis (FIA). 2011. Forest Inventory Data Online (FIDO). http://apps.fs.fed.us/fido/. (18 July 2011).

U.S. Department of State. 1841. Compendium of the enumeration of the inhabitants and statistics of the United States, at the Department of State, from the returns of the Sixth Census, by counties and principal towns. Washington, D.C: U.S. Department of State. 364 p.

Wear, D.N.; Greis, J.G., eds. 2002. Southern forest resource assessment. General Technical Report SRS-53. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 635 p.

Williams, W.K. 1925. The forestry situation in Arkansas: lumber firms initiate steps to insure timber supply. Southern Lumberman. 121(1576): 160–162.

Winters, R.K. 1938. Forest resources of the north Arkansas Delta. Forest Survey Release 32. New Orleans: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 21 p.

Winters, R.K. 1939. Forest resources of the south Arkansas Delta. Forest Survey Release 46. New Orleans: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 24 p.

Woods, J.B. 1925. Timber growing in the South: steps taken to maintain growth on Long-Bell holdings. Southern Lumberman. 121(1576): 157–159.

Woods, A.J.; Foti, T.L.; Chapman, S.S.; Omernik, J.M.; Wise, J.A. [and others]. 2004. Ecoregions of Arkansas. (Color poster with map, descriptive text, summary tables, and photographs): Reston, Virginia: U.S. Geological Survey.

Past and Present Forest Restoration in Missouri

Greg Hoss

Forest Nursery Supervisor, George O. White State Forest Nursery, Missouri Department of Conservation, Licking, MO

History of Missouri Forests

When the first European pioneers arrived in Missouri at the beginning of the 19th century, much of Missouri forests, particularly those found in the Ozarks, must have looked like a paradise. Explorers and later settlers found a rich land with few human inhabitants, herds of elk and buffalo, and vast forests of giant old growth shortleaf pine (*Pinus echinata* Mill.) and oak (*Quercus* spp.) that covered 70 percent of the State. Forests of open, park-like stands, with an understory of native grasses dominated the landscape. For many years this resource was inaccessible, but, eventually, this forest land was viewed as the raw stuff of industrial development. Rivers, then roads, then railroads were used to ship the lumber to Eastern U.S. markets.

The first settlers cut wood for houses, for fuel, and to sell, but had little effect on the timber resource. Within a few decades, however, Missouri's timber resources were increasingly harvested (Benac and Flader 2004). Timber was cut and floated downstream to mills in larger settlement areas, where it might be used for lumber or as cordwood to fuel the boilers of steam-powered riverboats. The pine forests of the Ozarks attracted lumbermen from the Eastern United States, and from about 1880 until 1920, Missouri was one of the leading lumber-producing States in the Nation. Huge sawmills in the towns of Grandin and Eminence produced building lumber, shingles, molding, and railroad ties for a growing Nation. Narrow gauge railroads were built to access every creek and river valley, facilitating the harvesting of even the most remote stands of timber. For a number of years in the early 1900s, Missouri boasted the largest sawmill in the Nation (Nagel 1970).

By 1920, the big mills, the jobs, and much of the vast forests of the State were gone, except for the swamplands of the Missouri bootheel. In the bootheel of Missouri, swamps kept the heavy logging out for awhile, but during the early 1900s huge drainage canals were built to drain the swamps and during the next 50 years about 2.5 million acres of bottomland forests were drained, logged, and converted to farmland. In the Ozarks, homesteaders moved in and began farming the thin soils. This farming lasted less than a generation as the soils produced poor crops and erosion soon forced much land to be abandoned. Annual burning and open range grazing of hogs and cattle further reduced the already depleted timber resource of the State.

As with many other parts of the United States, the term "harvest" was not used to describe the destruction of Missouri forests—it was more of a cut-and-get-out approach that forever changed the forest landscape. It was not until 1925 that any attempt was made to manage the State forests (Nagel 1970). In 1925, the State Legislature created the office of State Forester under the Missouri Department of Agriculture. The 1931 legislative session, however, neglected to budget funds for the Forestry Division and after 6 short years and only a few employees, the Division ceased to exist. An attempt had been made to do some fire control in the central Ozarks, but the departing State Forester concluded in his final report that "it was impossible to establish fire control in the Ozarks" (Keefe 1987).

A Change in Fortunes

From 1931 until 1936, Missouri had no organized forestry agency. By the mid-1930s, Missouri's fish, wildlife, and forestry resources were nearly depleted after years of uncontrolled burning, unregulated harvests of wildlife and fish, and repeated harvests and conversion of forests. Much of the Ozark region was in economic and ecological ruin. But change was in the air. A group of concerned citizens got together in Columbia, MO, in 1935 and began an initiative petition drive to create a nonpolitical, Constitution-based, conservation agency. Forestry was included along with fish and wildlife in the proposed new agency. Citizens saw forest management as an important part of fish and wildlife restoration. Without good forest management and control of wildfires, fish and wildlife restoration would not be possible (Keefe 1987). In November 1936, Missouri voters approved Amendment 4, creating the Missouri Conservation Commission (now Missouri Department of Conservation [MDC]), one agency that manages the State's fish, forests, and wildlife. Creating a land management agency, by Constitutional amendment, was and still is very unusual in the United States and it gives stability to land management by taking it out of the hands of politicians and putting into the hands of wildlife, forestry, and fishery professionals.

In 1976, Missouri voters went another step to ensure quality management of the fish, forests, and wildlife by passing a one-eighth of 1 percent sales tax to fund the agency. The Missouri Department of Conservation, including its Forestry Division, is now fully self-funded and self-governed. The agency receives no funds from the Missouri legislature.

When the Missouri Department of Conservation began business on July 1, 1937, the Forestry Division was created and began to form a plan to restore the State's forests. Forest fire control was the first and foremost challenge for the Forestry Division. Without controlling the wildfires, which, in some years of the 1930s had burned more than 50 percent of the land area in the Ozarks, forest management would be difficult, if not impossible (Nagel 1970). In the 1930s, fire control was considered impossible, but by 1950, total area burned had been reduced to less than 1 percent of the land area. In most recent years, annual wildfire losses are minimal.

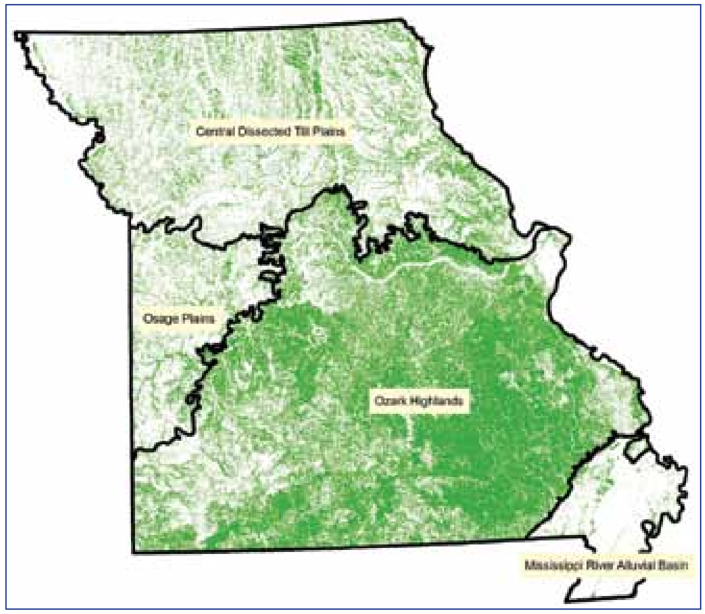

Figure 1. Missouri forest cover and ecological regions. (Map source: National Land Cover Database [NLCD] 2006).

Forest Cover and Land Types

Currently, nearly one-third of Missouri acreage is forest land (figure 1). During the past 25 years, the forest area in the State has actually increased slightly. The annual growth of Missouri forests now far exceeds the annual harvest, ensuring forests for future generations (figure 2). Today, Missouri boasts more than 15 million acres (6.07 million hectares) of forest land (Moser and others 2011). Most of this acreage is owned by private landowners (figure 3). The remainder is owned by the Federal Government (mostly in the Mark Twain National Forest), the State of Missouri, and local governments.

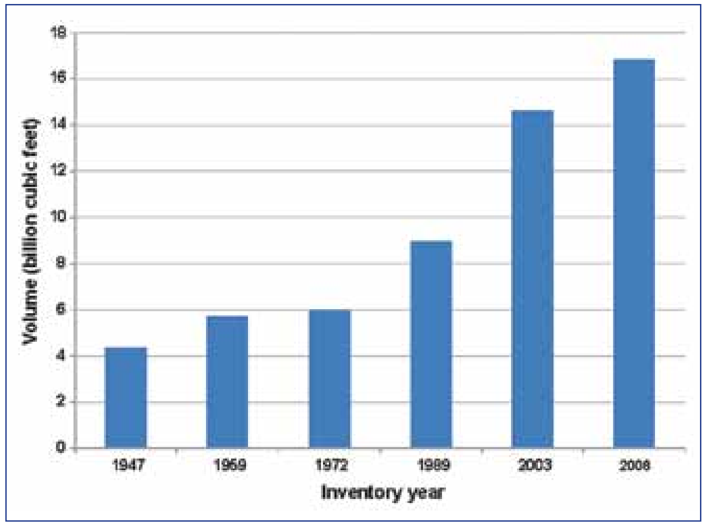

Figure 2. Growing stock volume on timber land in Missouri, 1947–2008. (Source: Raeker and others 2011).

Shortleaf pine was once the dominant species in much of the Ozarks, but today oak and hickory dominate nearly all the forest land in the State. Northern and western Missouri, never heavily forested and mostly native prairie in presettlement times, are oak forests where black walnut (*Juglans nigra* L), bur oak (*Quercus macrocarpa* Michx.), swamp white oak (*Quercus bicolor* Willd.), eastern red cedar (*Juniperus virginiana* L.), Kentucky coffeetree (*Gymnocladus dioicus* [L.] K. Koch), northern red oak (*Quercus rubra* L.), and white oak (*Quercus alba* L.) are the dominant species. Along the river bottoms of the Missouri and Mississippi Rivers, silver maple (*Acer saccharinum* L.), sycamore (*Platanus occidentalis* L.), hackberry (*Celtis occidentalis* L.), cottonwood (*Populus deltoides* Bartram ex Marsh.), pecan (*Carya illinoinensis* [Wangenh.] K. Koch), shellbark hickory (*Carya laciniosa* [Michx. f.] G. Don), willow (*Salix* L.), pin oak (*Quercus palustris* Münchh.), and green ash (*Fraxinus pennsylvanica* Marsh.) dominate. In the Bootheel area of Missouri, where very little forest land remains, tree species include bald cypress (*Taxodium distichum*

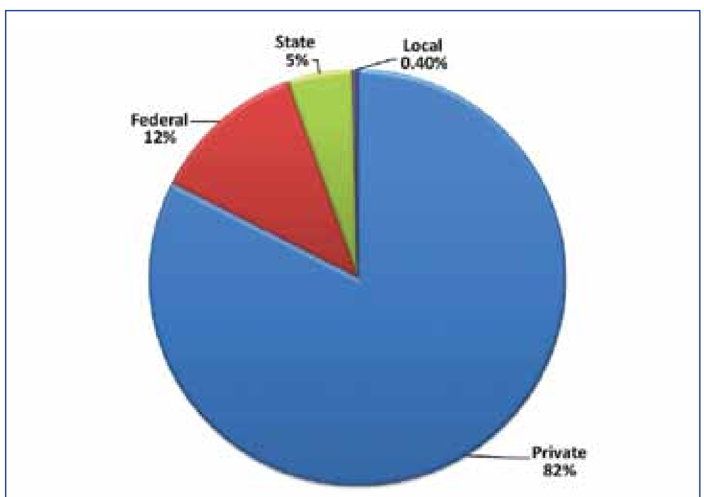

Figure 3. Missouri forest land ownership. (Source: Butler 2008).

(L.) Rich.), water tupelo (*Nyssa aquatica* L.), pin oak, overcup oak (*Quercus lyrata* Walter), Nuttall oak (*Quercus texana* Buckley), water oak (*Quercus nigra* L.), willow oak (*Quercus phellos* L.), and cherrybark oak (*Quercus pagoda* Raf.). Most of the forest land in Missouri is located in the Ozark Highlands (figure 1), a large land mass of thin soils and steep river hills that stretches from the Missouri River south into Arkansas and east and west across the southern third of the State. The main forest species in the Ozarks are red, black (*Quercus velutina* Lam.), and white oak, various hickory species, sugar maple (*Acer saccharum* Marsh.), black walnut, and shortleaf pine.

Nursery Production

From the inception of the Forestry Division in 1937, one of the agency's priorities was to grow bareroot seedlings to reforest Missouri. The Meramec Nursery, near Sullivan, opened and began seedling production in 1938, primarily producing hardwood tree and shrub seedlings. The seedlings were planted on Conservation Areas and sold to private landowners. In 1947, a second nursery was acquired. This was the U.S. Department of Agriculture (USDA), Forest Service Licking Nursery, which originally opened in 1935 as part of the Blooming Rose Civilian Conservation Corps (CCC) camp (figure 4). The original 40-acre nursery had about 15 acres of seedbeds, two bunkhouses and a mess hall for the CCC enrollees, a nursery residence, an office, and a shop. Seedling production was nearly all shortleaf pine and some hardwoods for reforesting the newly acquired Federal land that later became the Mark Twain National Forest. The Licking Nursery was shut down in 1942 during World War II, reopened briefly in 1946, and then closed. In 1947, the MDC assumed management and later full ownership of the Licking Nursery (figure 5). In 1960, it was renamed the George O. White State Forest Nursery to honor George O. White, the first MDC State forester. By 1962, the Meramec Nursery closed, and since that time all of Missouri's seedling production has been at the George O. White Nursery. Since 1947, the nursery has expanded from 15 acres of seedbeds to more than 50 acres in production and the total nursery property is now more than 750 acres.

During the early years of production, shortleaf pine was the dominant species grown at the nursery. During the 1950s, 1960s, and 1970s, many nonnative species were grown, including autumn olive (*Elaeagnus umbellata* Thunb.), vitex (*Vitex* L.), mulitflora rose (*Rosa multiflora* Thunb.), mimosa (*Albizia julibrissin* Durazz.), scotch pine (*Pinus sylvestris* L.), tatarian honeysuckle (*Lonicera tatarica* L.), and others. Native plant species that were grown included black walnut, many oak species, and some native shrubs. By the late 1990s, all of the nonnative hardwoods had been eliminated from production and only native hardwood trees and shrubs have been grown since (Hoss 2002). The conifer species that are grown include native shortleaf pine and eastern red cedar, and nonnative white (*Pinus strobus* L.), red (*Pinus resinosa* Aiton), and loblolly pine (*Pinus taeda* L.). Currently, the species inventory includes more than 70 species of hardwood trees and shrubs. Hardwood production and sales rates are about three times greater than the conifer production and sales rates (figure 6). The nursery's capacity can provide about 6 to 7 million seedlings annually, with the current mix of hardwoods and conifers.

For many years, shortleaf pine dominated nursery seedling production, with more than 10 million shortleaf pine seedlings produced in some years (figure 7). Most of these shortleaf seedlings were for USDA Forest Service and Conservation Department plantings. Many private landowners also established shortleaf pine plantations. During the early 2000s, under the Conservation Reserve Program (CRP), pine

Figure 4. Civil Conservation Corps enrollees tamping the nursery soil after seed was sown. (Photo Source: USDA Forest Service archives, 1934).

Figure 5. Nursery crew grading shortleaf pine seedlings, winter 1952. (Photo source: Don Wooldridge, Missouri Department of Conservation).

Figure 6. The George O. White State Forest Nursery currently grows more than 70 hardwood tree and shrub species. On the left, a bed of pecan is irrigated. On the right, the nursery crew lifts a crop of swamp white oak seedlings. (Photo source: Greg Hoss, Missouri Department of Conservation).

Figure 7. Four-year-old shortleaf pine plantation located on the nursery property. (Photo source: Greg Hoss, Missouri Department of Conservation).

became less important to tree planters and hardwoods became the dominant tree purchased. By 2005, hardwood seedling production peaked at more than 5 million seedlings a year. Today, shortleaf pine is still one of the most popular species grown and sold, but black walnut, bur oak, pecan, northern red oak, white oak, and pin oak dominate hardwood sales.

Currently, many landowners seem to be more interested in planting trees and shrubs for wildlife than for forestry purposes. The production levels and variety of wildlife trees and shrubs have increased during the past 10 years, while the production of conifers and hardwood trees has declined. More than 10 new shrub species have been added to the inventory in the past 10 years. Hazelnut (*Corylus americana* Walter), blackberry (*Rubus* L.), and wild plum (*Prunus* L.) are usually the shrubs most in demand. Gray dogwood (*Cornus racemosa* Lam.), roughleaf dogwood (*Cornus drummondii* C.A. Mey.), witch hazel (*Hamamelis vernalis* Sarg.), paw paw (*Asimina triloba* (L.) Dunal), aromatic sumac (*Rhus aromatica* Aiton), and a number of other shrubs species are in high demand (Hoss 2006).

The reduction in funding from Federal Cost Share programs and the poor economy have led to a slow decline in nursery seedling sales since 2008 (table 1). The popularity of the State seedling program is high and the customer base is still large, but the huge tree planting projects of the early CRP days seem to be a thing of the past. In addition to adding new species over the past decade, the nursery now offers a wider variety of special bundles to landowners in an effort to increase sales volumes and add customers. The nursery offers tree and shrub bundles for fruit production, wildlife cover, nut production, and quail habitat improvement. These bundles

Table 1. Seedlings distributed by the George O. White State Forest Nursery during the past decade.

Year	Total seedlings distributed
2001–2002	*6,970,525*
2002–2003	*5,528,125*
2003–2004	*6,305,750*
2004–2005	*4,707,125*
2005–2006	*5,022,175*
2006–2007	*5,050,875*
2007–2008	*4,190,600*
2008–2009	*3,863,550*
2009–2010	*3,564,725*
2010–2011	*3,333,200*

offer landowners a wider variety of species in lower numbers and have been very popular. In some of the hardwood species, extra large seedlings, more than 30 in (76 cm) tall, are offered for sale. All of the tall oak, walnut, bald cypress, and tulip poplar seedlings produced at the nursery are sold each year.

Future Outlook

The future looks very good for the George O. White State Forest Nursery and forest restoration efforts in Missouri. The MDC Administration continues to have strong support for growing native plants in Missouri. Supporting a State-owned nursery that grows native seedlings from in-State seed sources shows citizens that MDC has a strong commitment to restoration, reforestation, wildlife habitat improvement, and the many other benefits of planting native trees and shrubs. Landowners continue to use State nursery planting stock for a wide variety of projects. MDC has teamed up with the Missouri Department of Transportation to provide free trees to all fourth graders in the State for Arbor Day and to provide trees to Future Farmers of America, Scouts, 4H, and other youth organizations for projects. MDC foresters and wildlife and fisheries managers regularly use seedlings for planting on agency-owned lands, for programs affecting a wide variety of State citizens, and for giving away at fairs and exhibits. The nursery will continue to add native species and drop other species as demand changes. Total production may decrease as Federal Cost Share program funding continues to decline, but quality seedlings from a wide variety of species will keep the nursery program viable for years to come.

Address correspondence to:

Greg Hoss, Forest Nursery Supervisor, George O. White State Forest Nursery, Missouri Department of Conservation, 14027 Shafer Road, Licking MO 65542; e-mail: greg.hoss@mdc.mo.gov; phone: 573–674–3229, ext. 222.

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References

Benac, D.; Flader, S. 2004. History of Missouri forests in the era of exploitation and conservation. General Technical Report SRS-73. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 36–41.

Butler, B.J. 2008. Family forest owners of the United States, 2006. Gen. Tech. Rep. NRS-27. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station: 44–45.

Hoss, G. 2002. George O. White State Park Forest nursery—Licking, Missouri. In: Dumroese, R.K.; Riley, L.E.; Landis, T.D., tech. coords. National proceedings: forest and conservation nursery associations—1999, 2000, and 2001. Proceedings RMRS-P-24. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 183–186.

Hoss, G. 2006. Growing shrubs at the George O. White State Forest nursery: what has worked and what has not. In: Riley, L.E.; Dumroese, R.K.; Landis, T.D., tech. coords. National Proceedings: Forest and Conservation Nursery Associations—2005. Proc. RMRS-P-43. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 111–114.

Keefe, J.F. 1987. The first 50 years. Jefferson City, MO: Missouri Department of Conservation. 446 p.

Moser, W.K.; Barnett, C.H.; Hansen, M.H.; Kurtz, C.M.; Treiman, T.B. 2011. Missouri's forest resources, 2010. Research Note NRS-117. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 4 p.

Nagel, W.O. 1970. Conservation contrasts: three decades of non-political management of wildlife and forests in Missouri. Jefferson City, MO: Missouri Department of Conservation. 453 p.

National Land Cover Database (NLCD). 2006. Multi-resolution land characterization consortium. Sioux Falls, SD: U.S. Geological Survey, Earth Resources Observation and Science Center. http://www.mrlc.gov. (December 2011).

Raeker, G.; Moser, W.K.; Butler, B.J.; Fleming, J.; Gormanson, D.D.; Hansen, M.H.; Kurtz, C.M.; Miles, P.D.; Morris, M.; Treiman, T.B. 2011. Missouri's forests 2008. Resource Bulletin NRS-54. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 55 p.

Nematode Damage and Management in North American Forest Nurseries

Michelle M. Cram and Stephen W. Fraedrich

Plant Pathologist, Forest Service, Forest Health Protection, Athens, GA; Research Plant Pathologist, Forest Service, Southern Research Station, Athens, GA

Abstract

Plant-parasitic nematodes can affect seedling production in forest nurseries when host seedlings are developmentally vulnerable, nematode populations are high, or opportunistic pathogens are present. Soil fumigation has been important for plant-parasitic nematode control in forest nurseries. Regulatory changes and rising costs of fumigant application are expected to affect nursery pest management programs. In the future, management strategies for the control of various nematodes will increasingly depend on the biology of the nematodes and hosts. This article provides a brief review of nematode problems that affect seedlings in forest nurseries, symptoms of nematode damage, and nematode control practices.

Introduction

Nematodes have long been associated with bareroot seedling damage in North American forest nurseries and some plant-parasitic species cause significant stunting and chlorosis of seedlings (Hopper 1958, Johnson and others 1970, Sutherland and Sluggett 1975, Peterson and Riffle 1986, Fraedrich and Cram 2002). Plant-parasitic nematodes are microscopic worms that feed on plants by removing the cell contents with a hollow, needle-like mouthpart called a stylet, which functions much like a straw (figures 1 and 2). Some plant-parasitic nematodes remain in the soil and feed by repeatedly thrusting their stylets into seedling roots. These nematodes are referred to as ectoparasites. Other plant-parasitic nematodes are endoparasites and invade root systems to feed inside the root tissues. Among the numerous species of plant-parasitic nematodes, many are specialized to attack various types of plant tissues including leaves, flowers, stems, and roots; however, most damaging nematodes are soilborne and feed on roots (Shurtleff and Averre 2000). In some instances, root diseases can develop from the interaction of the physical damage caused by nematode feeding and soilborne fungal pathogens that colonize the wounded root tissues (Dwinell and Sinclair 1967, Shurtleff and Averre 2000).

Figure 1. A translucent, worm-shaped stunt nematode (*Tylenchorhynchus ewingi*.) (Photo source: Stephen W. Fraedrich).

The environmental conditions in most forest nurseries are ideal for many species of plant-parasitic nematodes. In addition to high host densities, bareroot nurseries are typically located on well-drained sandy soils that are irrigated regularly. Highly porous soils, where pore sizes exceed 30 microns, allow for the free movement of most plant-parasitic nematodes. Large

Figure 2. Head of a *Tylenchorhynchus ewingi* nematode with a clearly visible stylet. (Photo source: Michelle M. Cram).

nematodes such as *Xiphinema* spp. and *Longidorus* spp. require larger pore sizes (60 microns) and are typically found in coarse-textured, sandy soils (Jones and others 1969, Norton 1979). Although these soils dry quickly, which could immobilize and desiccate nematodes, nursery irrigation for optimum seedling growth also provides optimal conditions for nematode movement and survival (Jones and others 1969, Norton 1979).

Prior to the 1970s, cases of severe seedling losses thought to be associated with nematodes were controlled in research studies by a variety of soil fumigants (Henry 1953, Bloomberg and Orchard 1969, Peterson 1970). Eventually, methyl bromide fumigation became the standard preplant soil treatment in nurseries (Fraedrich and Dwinell 2005, Zasada and others 2010). In a 1993 national survey of forest nursery managers, soil fumigation for nematode control had some importance to 44 of 52 southern nurseries, 28 of 35 northeastern nurseries, and 10 of 21 western nurseries (Fraedrich 1993).

Although fumigation is initially highly effective for reducing nematode populations, the populations will rebound over the growing season and can damage the next seedling crop unless preplant control practices are applied again (Fraedrich and others 2003, Fraedrich and Dwinell 2005, Enebak and others 2011). An integrated pest management program that uses fumigants in conjunction with periods of fallow and rotations with nonhost cover crops is expected to provide increased control of plant-parasitic nematodes and associated diseases (Fraedrich and others 2005).

Plant-Pathogenic Nematodes of Forest Nurseries

Surveys of forest nurseries in North America before 1970 documented numerous species of plant-parasitic nematodes in the soils; however, only a few species were thought to be associated with seedling injury (Hopper 1958, Peterson 1962, Sutherland and Dunn 1970). Nematode species currently known to damage seedlings in forest nurseries are listed in table 1. This list is likely incomplete because many more nematode species are capable of feeding on roots of forest

Table 1. Plant-parasitic nematodes known to damage seedlings in the North America forest nurseries.

Feeding class	Common name	Nematode species	Tree host(s)	Citation
Endoparasite Migratory	Lance	*Hoplolaimus cronatus* Cobb	*Pinus taeda* L., *Pinus elliottii* Engelm. var. *elliottii*	Ruehle 1962, Ruehle and Sasser 1962
	Root-lesion	*Pratylenchus brachyurus* (Godfrey) Filip. & Stek.	*Pinus palustris* Mill., *Pinus taeda*	Hopper 1958, Ruehle 1973a
		P. penetrans (Cobb) Chitwood and Oteifa	*Pseudotsuga menziesii* (Mirb.) Fran	McElroy 1985
			Juniperus virginiana L., *Pinus ponderosa* P. & C. Lawson	Caveness 1957, Peterson 1970, Viglierchio 1979
Sedentary	Pine cystoid	*Meloidodera floridensis* Chitwood, Hannon, and Esser	*Pinus taeda, Pinus elliottii* var. *elliottii, Pinus clausa* (Chapm. ex Engelm.) Vasey ex Sarg.	Hopper 1958, Ruehle and Sasser 1962, Ruehle 1973a
	Root-knot	*Meloidogyne javanica* (Treub) Chitwood	*Pinus elliottii* var. *elliottii Liriodendron tulipifera* L.	Donaldson 1967, Ruehle 1971
		M. incognita (Kofoid and White) Chitwood	*Cornus florida* L.	Johnson and others 1970
Ectoparasite	Sting	*Belonolaimus* sp.	*Pinus* sp.	Esser 1977
	Needle	*Longidorus americanus* Handoo	*Pinus taeda, Pinus elliottii* var. *elliottii*	Fraedrich and Cram 2002, Fraedrich and others 2003
			Quercus spp.	Fraedrich and others 2003, Cram and Fraedrich 2005
	Stunt	*Tylenchorhynchus claytoni* Steiner	*Pinus palustris, Pinus taeda, Pinus elliottii* var. *elliottii*	Hopper 1958, Ruehle 1973a, Cram and Fraedrich 2009
		T. ewingi Hopper	*Pinus elliottii,* var. *elliottii* *Pinus taeda*	Hopper 1959, Fraedrich and others 2012
	Dagger	*Xiphinema bakeri* Williams	*Pseudotsuga menziesii Tsuga heterophylla* (Raf.) Sarg. *Picea stchensis* (Bong.) Carr. *Picea glauca* (Moench) Voss	Sutherland 1970, Bloomberg and Sutherland 1971, Sutherland and Sluggett 1975
	Stubby-root	*Paratrichodorus minor* (Colbran) Siddiqi	*Pinus elliottii* var. *elliottii, Pinus taeda, Pinus palustris*	Ruehle 1969
	Spiral	*Helicotylenchus nannus* Steiner	*Pinus taeda*	Ruehle and Sasser 1962

seedlings, but their potential to cause significant damage and affect seedling growth has not been fully investigated. Likewise, various plant-parasitic nematode species are associated with outplanted seedlings or mature trees (Ruehle and Sasser 1962, Ruehle 1966, Riffle and Kuntz 1967, Sanzo and Rohde 1967, Ruehle 1968b, Riffle 1970, Churchill and Ruehle 1971, Riffle 1972, Ruehle 1972, Ruehle 1973b, Maggenti and Viglierchio 1975, Viglierchio 1979, Eisenback and others 1985), but these parasitic species are not listed in table 1 because they have not been documented to cause problems on seedlings in forest nurseries.

The level of damage caused by plant-parasitic nematodes is often determined by the age of seedlings when the first attack occurs and the population densities of nematodes in the fields. Seedlings are most susceptible to the damage caused by plant-parasitic nematodes during the weeks after seed germination. Studies using agricultural crop plants have shown that delaying nematode attacks on young seedlings by several weeks can dramatically reduce nematode effects on plant growth and final development (Wong and Mai 1973, Seinhorst 1995, Ploeg and Phillips 2001). Nematode host studies in forestry have often used seedlings 2 to 9 months old or low population densities that are only adequate to determine if a nematode species was parasitic on a crop. Older seedlings can better tolerate the effects of some nematode feeding without losses in seedling quality, similar to how they can tolerate the effects of undercutting and lateral pruning. Controlled studies that applied nematodes to soil before sowing or at the time of seed germination have typically shown significant seedling growth losses (Ruehle 1969, Sutherland and Sluggett 1975, Fraedrich and others 2003, Cram and Fraedrich 2009, Fraedrich and others 2012). Other studies have demonstrated significant seedling growth losses by using high population densities or by assessing damage over longer periods of time (Ruehle and Sasser 1962, Ruehle 1968a, Johnson and others 1970, Ruehle 1973a). High populations of plant-parasitic nematodes in forest nurseries that occur later in the growing season will likely cause some reduction in seedling growth. The degree of stunting, however, will not be as devastating as when young seedlings are attacked early in the growing season.

Few studies have attempted to determine relationships between nematode population densities before seed sowing and subsequent damage to forest-tree seedlings. The number of nematodes associated with damaged bareroot seedlings varies by nematode species, host species, and timeframe. Many assessments of nematode populations have been made only when damaged seedlings have been observed. For example, 315 to 422 *Tylenchorhynchus claytoni* Steiner per 100 cc soil were associated with severe injury of *Pinus* seedlings (Hopper 1958), and 40 to 208 *Longidorus americanus* Handoo per 100 g soil were associated with stunted loblolly pine (*Pinus taeda* L.) seedlings (Fraedrich and Cram 2002). These field cases are of little value for predicting the potential for seedling damage at the beginning of a growing season. Controlled studies that examined the effect of a range of nematode population densities on young seedlings have shown that much lower populations can damage seedlings. Several tests with stunt nematodes demonstrated that 60 nematodes per 100 cc soil, at or within 1 month of germination, could significantly reduce root weight of seedlings (Ruehle 1973a, Fraedrich and others 2012). The much larger nematode, *L. americanus*, decreases seedling root weights if only 30 nematodes per 100 g soil are present in soil at the time of seed germination (Fraedrich and Cram 2002, Fraedrich and others 2003). More research is needed on individual nematode pests and their effect on tree seedlings to better determine the relationship between population density and economic losses.

Plant-parasitic nematodes can become established in forest nurseries in several ways. In many cases, the nematodes were probably already established in fields when the land was converted from agricultural crop production or forests. Nursery fields can also become infested with nematodes by soil movement through mechanical means (e.g., tractors, equipment), wind or flooding, and by transplanting infected plants (Shurtleff and Averre 2000). Sutherland and Dunn (1970) found greater populations of *Xiphinema bakeri* Williams in British Columbia where field soils were ameliorated with sand to increase the porosity. A similar case was documented in a Florida nursery where a *Belonolaimus* sp. was brought in with forest soil that was used to fill a low area (Esser 1977). In the case of *L. americanus* at a Georgia nursery, we speculate that the nematode was introduced to fields during a flood, which occurs periodically because of the nursery's close proximity to a major river. After a plant-parasitic nematode is introduced into a nursery, it is unlikely to be eradicated and therefore will require a long-term management plan.

Although it is possible that plant-parasitic nematodes are transported to outplanting sites, there is no documented case of nematodes from a nursery affecting outplanted seedlings. Ruehle and Sasser (1962) attempted to investigate whether nematodes from a North Carolina nursery were the cause of stunting in outplanted seedlings. They found that pine cystoid nematodes indigenous to the outplanting site were the cause of damage, while the lance nematodes from the planting stock were nearly nonexistent after 2 years.

Symptoms of Damage by Plant-Parasitic Nematode

The aboveground symptoms associated with nematode damage can be highly variable. In some cases, the seedlings will be severely stunted, chlorotic, and even wilted (figure 3). In other cases, the symptoms caused by nematodes may be much less severe and primarily noted because seedlings are growing slower than normal and are off color. Adequate moisture and fertilizer can sometimes compensate for nematode feeding and minimize aboveground symptoms (Ruehle 1973b). In some cases, symptoms of nematode damage may be confused with other factors, including nutrient deficiencies, root disease, insect damage, seasonal effects, and inadequate or excess water (Ruehle 1973b, Shurtleff and Averre 2000). These factors sometimes occur in combination with nematode damage, thereby complicating identification of the primary cause of damage. Nematode injury can predispose seedling roots to opportunistic and pathogenic fungi resulting in greater damage and root rot (Bloomberg and Sutherland 1971, Ruehle 1973b, Barham and others 1974). The ability of roots to form mycorrhizae is also impeded by nematodes (Ruehle 1973b). Ultimately, nematode-damaged seedlings with compromised root systems can have difficulty absorbing water and nutrients, which can be misdiagnosed as a nutrient-deficiency problem.

The distribution of damage in nursery fields can be somewhat helpful in the diagnosis of nematode problems. Early in an infestation, the pattern of damage often occurs as discreet patches of affected seedlings, which can expand to larger areas that encompass entire fields (figures 4 and 5). Nursery equipment will move soil and nematodes within a field and to other uninfested fields. A recent example of this contamination occurred in a Georgia nursery where *L. americanus* initially caused seedling stunting in a few small patches of 3 to 9 m (6 to 27 ft) of nursery bed that within a few years spread throughout one-half of a 10-acre (4-hectare) field (Fraedrich and others 2003).

The feeding class of a plant-parasitic nematode will often affect the type of symptoms observed on roots. Migratory endoparasitic nematodes colonize roots and frequently cause necrotic lesions that allow bacteria and fungi to colonize. Other endoparasitic nematodes become sedentary and stimulate the formation of root galls or swellings. *Meloidogyne* spp. (root-knot nematodes) are known to form galls on hardwoods, but only cause a slight root swelling in conifers (Ruehle 1973b). *Meloidodera* spp. (cystoids nematodes) also produce only a slight swelling on pines and, at maturity, their bodies can protrude from roots and appear much like small pearls on the surface of roots (Ruehle and Sasser 1962). Some ectoparasitic

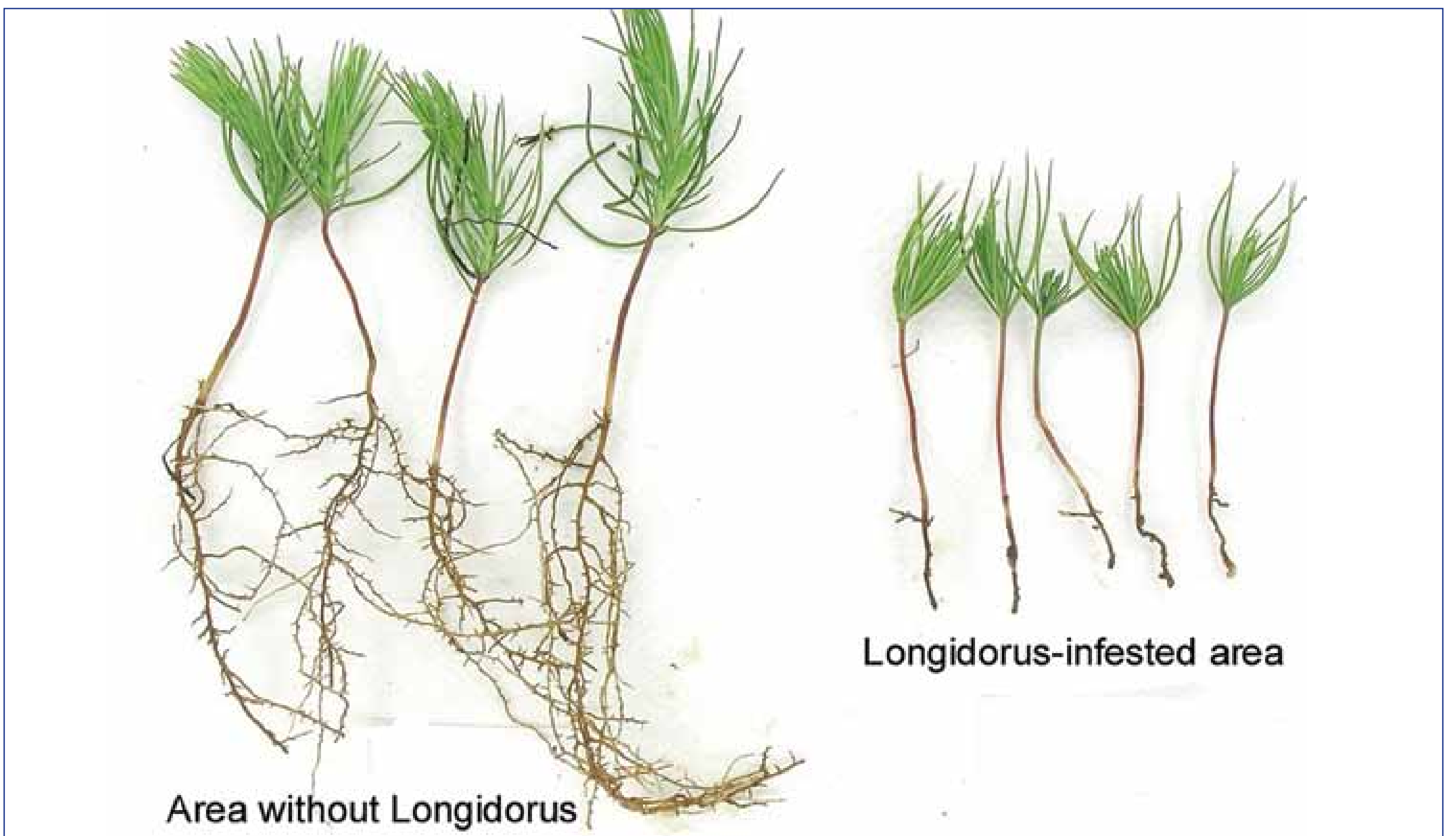

Figure 3. Loblolly pine (*Pinus taeda*) seedlings from nursery beds infested and uninfested by *Longidorus americanus.* (Photo source: Stephen W. Fraedrich).

Figure 4. Patches of stunted loblolly pine (*Pinus taeda*) seedlings damaged by *Longidorus americanus*. (Photo source: Stephen W. Fraedrich).

Figure 5. Chlorotic and stunted slash pine (*Pinus elliottii* Engelm. var. *elliottii*) seedlings damaged by *Tylenchorhynchus claytoni*. (Photo source: Michelle M. Cram).

nematodes that feed near the root tip, such as *Longidorus* and *Xiphinema* spp., can also stimulate swellings consisting of compact parenchyma cells (Ruehle 1973b). Feeding by most ectoparasitic nematodes, however, results in suppressed cell division and reduced water and nutrient uptake (Shurtleff and Averre 2000). Roots become underdeveloped and stubby when fed upon by ectoparasitic nematodes such as *Tylenchorhynchus* spp. and *Paratrichodorus* spp.

Collecting Samples

To determine if plant-parasitic nematodes are a problem or have the potential to become a problem in nursery crops, soil samples need to be sent to laboratories that offer nematode identification services. The use of a number of nematode extraction techniques may be necessary to diagnose nematode problems. Techniques used to diagnose problems caused by sedentary, endoparasitic nematodes often differ from those caused by ectoparasitic nematodes. It may also be necessary to request that the laboratory use techniques specifically for larger nematodes, such as *Longidorus* spp., as well as standard techniques used for quantification of smaller nematodes like *Tylenchorrhynchus* spp. The identification of *L. americanus* as the cause of severe stunting of loblolly pine seedlings in a Georgia nursery was delayed due to the testing laboratory's use of a sugar floatation method that is better suited for smaller nematodes (Fraedrich and Cram 2002). Extraction techniques for larger nematodes require some minor modifications of standard techniques used for smaller nematodes (Flegg 1967, Shurtleff and Averre 2000, Fraedrich and Cram 2002).

Soil samples for nematode extraction need to always be taken in the root zone, generally in the upper 15 to 20 cm (6 to 8 in). If a nursery manager is assessing a field before growing seedlings, a composite soil sample should be obtained that consists of 20 to 25 samples from across the field (Shurtleff and Averre 2000). For larger fields and for more accurate information about the risks of particular nematodes, the field needs to be divided and sampled by quadrant. If a problem is being diagnosed during a growing season, a composite sample consisting of several subsamples needs to be taken from the root zone of affected seedlings. Samples of seedlings should also be taken and sent with the soil samples. The best location to sample for plant-parasitic nematodes is normally towards the edges of patches of stunted seedlings. Avoid sampling soil and roots of severely damaged seedlings in the center of stunted seedling patches because the nematode populations have usually declined and moved outward to the patch edges where seedlings have larger root systems (Shurtleff and Averre 2000, Fraedrich and Cram 2002). The moisture level of soil needs to be neither excessively wet nor dry at the time of sampling. Sampling when moisture levels are between 75 to 100 percent of field capacity is best for nematode survival (Norton 1979). Nematodes are essentially aquatic worms that require water to survive and move in soils; therefore, samples need to always be placed in plastic bags to maintain the moisture level. Prevent samples from being exposed to temperatures less than 4 °C (40 °F) or greater than 27 °C (80 °F). Nematodes can be stored in plastic bags for a few weeks at temperatures between 4 °C and 18 °C (40 °F to 65 °F) (Shurtleff and Averre 2000).

Control of Plant-Parasitic Nematodes

Forest nurseries routinely practice an integrated approach to manage most soilborne pests, including plant-parasitic nematodes. The average nursery fumigates fields and then produces seedlings for 2 years followed by 1 or 2 years of green-manure crops. This combination of fumigation with crop rotation can help to reduce many soilborne pests. When a nematode problem does occur, most nurseries use sanitation measures to avoid infesting new fields. Ultimately, managers need to know what species of plant-parasitic nematodes are present and the host range of those nematodes to develop an effective management strategy.

Soil fumigation has been the primary means of controlling plant-parasitic nematodes in forest nurseries for the past four decades (Fraedrich and Dwinell 2005, Zasada and others 2010). Prior to the 1970s, seedling losses due to damage associated with nematodes were routinely reported by nurseries throughout North America (Hopper 1958, Johnson and others 1970, Sutherland and Sluggett 1975, Peterson and Riffle 1986). Early trials of fumigants for forest nurseries found that chloropicrin, methyl bromide, and methylisothiocyanate products such as Vapam significantly reduced nematode populations and improved seedling growth (Henry 1953, Hansbrough and Hollis 1957, Bloomberg and Orchard 1969). By the late 1980s, methyl bromide with chloropicrin was the primary fumigant for many growers in the United States who relied on preplant fumigation for their crops (Zasada and others 2010). This combination remains the preferred fumigant for forest nurseries in some parts of the United States to this day, despite the continued phase out of methyl bromide under the Montreal Protocol and Clean Air Act (Enebak and others 2011).

Research conducted in forest nurseries during the past two decades to find replacement fumigants for methyl bromide has found that most alternative fumigants provide good control of plant-parasitic nematodes (Fraedrich and Dwinell 2005, Cram and others 2007, Enebak and others 2011). Although fumigants are highly effective against nematodes, fumigation does not eradicate nematodes in fields (Lembright 1990) because toxic concentrations of the fumigants may not reach all plant-parasitic nematodes throughout the soil horizon (McKenry and Thomason 1976, Lembright 1990). Nematodes may survive fumigation if they are located beneath the fumigant's effective concentration zone or if they occur in areas of the soil where moisture levels are too high for effective fumigation. Nematodes may also occur in soil clods or hardpans where the fumigant is excluded. Endoparasitic nematodes can escape if the fumigant fails to penetrate the host's roots. A fumigant may also be ineffective when nematodes are in a more tolerant form such as a cyst or an anhydrobiotic state. Nematode population densities often begin to rebound during the first year and can reach sufficiently high levels to damage subsequent seedling crops (McKenry and Thomason 1976, Fraedrich and Dwinell 2005, Enebak and others 2011). Populations of plant-parasitic nematodes can increase very rapidly in fields because of their relatively short life cycles (3 to 6 weeks), plentiful egg production, and abundance of host roots (Shurtleff and Averre 2000). A more integrated approach to control a specific plant-parasitic nematode may be necessary due to the high cost of fumigation and the ability of nematode populations to rebound after fumigation.

Crop rotation is a common cultural management practice used to reduce soilborne pests such as nematodes. Most nurseries rotate their production crops with cover crops (e.g., green manure crops) to increase soil organic matter, reduce compaction, and reduce pests. When damaging levels of a plant-parasitic nematode develops in a field, the nursery manager may have unknowingly used a host cover crop. For example, populations of *L. americanus* at a Georgia nursery continuously increased over a period of several years and damaged increasing numbers of loblolly pine seedlings. The field where the problem occurred had been used to test the feasibility of alternating production of loblolly pine seedlings with white oak (*Quercus alba* L.) seedlings (a host) instead of rotating to small grains (nonhosts), which were the normal cover crops used after seedling production (Cram and Fraedrich 2005). Similarly, *Tylenchorrhynchus ewingi* Hopper damaged pine seedling production at a Texas nursery where cowpeas (*Vigna unguiculata* L.), sorghum-sudan grass (*Sorghum bicolor* [L.] Moench), and rye (*Secale cerale* L.) were used as cover crops, all of which have been shown to be excellent hosts of *T. ewingi* (Fraedrich and others 2012). *Tylenchorhynchus* spp. such as *T. ewingi* and *T. claytoni* Steiner, that are found in some nurseries in the South, generally have wide host ranges that include sorghum-sudan grass, rye, corn (*Zea mays* L.), ryegrass (*Lolium multiflorum* Lam.), oats (*Avena sativa* L.), buckwheat (*Fagopryum esculentum* Moench), and various legumes (Cram and Fraedrich 2009, Fraedrich and others 2012). The common use of these species and other small-grain hosts for cover crops has probably made these plant-parasitic nematodes more difficult to control in some nurseries. Currently, the best, nonhost grain identified for control of *T. ewingi* and *T. claytoni* are certain varieties of pearl millet (*Pennisetum americanum* [L.] Leeke) (Johnson and Burton 1973, Cram and Fraedrich 2009, Fraedrich and others 2012). Pearl millet hybrids have been tested and bred for resistance to nematodes for many decades in the agriculture industry and various pearl millet cultivars have been reported to be resistant to

Paratrichodorus minor (Colbran) Siddiqi, *Meloidogyne* spp. *Belonolaimus longicaudatus* Rau, and *Pratylenchus brachyurus* (Godfrey) Filip. & Stek. (Johnson and Burton 1973, Timper and others 2002, Timper and Hanna 2005).

The practice of fallowing fields is an effective cultural practice to control plant-parasitic nematodes through starvation (Duncan and Noling 1998, Zasada and others 2010). Several field studies in forest nurseries have shown that fallowed fields kept weed free had significantly reduced nematode population densities. In the South, *L. americanus* and *T. claytoni* were controlled in fallowed fields within 1 year (Fraedrich and others 2005, Cram and Fraedrich 2009). In the North, Sutherland and Sluggett (1975) reported that corky root disease caused by *X. bakeri* could be controlled with fallow for 1 year and frequent disking during the summer months. Many nurseries can only afford a 1-year rotation with an alternate crop or fallow because of limited land base. The length of time it takes for a nematode population to decline to nondamaging levels in a fallow field or a field with a nonhost crop may determine which rotation option is best suited for the nursery.

Other nematode control methods, such as soil solarization, biofumigation, and steam treatments, have not proven reliable or practical for operational use (Zasada and others 2010). The use of solar heat has been tested in some nurseries and provided nematode control in one nursery, and controlled some fungi and weeds in several cases (Hildebrand 1989). Soil solarization works best in a hot climate where the soil can remain tarped for 4 to 6 weeks during the summer and where the soil temperatures over time reach a lethal level (Wang and McSorley 2008). One potential drawback of using solarization in forest nurseries is the failure of this practice to control heat tolerant fungi such as *Macrophomina phaseolina* (Tassi) Goid. (Mihail and Alcorn 1984, McCain and others 1986). The unpredictable nature of solarization to provide broad spectrum pest control and the need to apply the treatment over an extended period during summer months means that solarization is unlikely to replace fumigation and crop rotations for nematode control in most nurseries. In some individual cases, however, solarization could be useful when used in combination with other control practices.

Future Outlook for Nematode Control

Since the 1960s, many nurseries have relied primarily on fumigation with methyl bromide and several other fumigants to control nematodes in forest tree nurseries. The number of rules and regulations regarding the use of fumigants has been increasing in recent years, and forest nurseries are now adjusting to new regulatory changes enacted by the U.S. Environmental Protection Agency that have altered how and where fumigation can be applied (Zasada and others 2010). One of the greatest changes will be the buffer zone requirements, which are likely to reduce the area within nurseries that can be fumigated. The costs associated with fumigation also have been steadily increasing in recent years. Managers will need to rely on integrated strategies for suppressing nematode populations as they face changes in fumigation regulations. Practices such as cover cropping and fallow can be readily used to control many plant-parasitic nematode species, but more biological and ecological information is needed about the specific nematode species that cause problems in forest nurseries.

Address correspondence to:

Michelle M. Cram or Stephen W. Fraedrich, U.S. Department of Agriculture, Forest Service, 320 Green Street, Athens, GA 30602–2044; e-mail: mcram@fs.fed.us or sfraedrich@fs.fed.us.

References

Barham, R.O.; Marx, D.H.; Ruehle, J.L. 1974. Infection of ectomycorrhizal and nonmycorrhizal roots of shortleaf pine by nematodes and *Phytophthora cinnamomi*. Phytophthology. 64: 1260–1264.

Bloomberg, W.J.; Orchard, W.R. 1969. Chemical control of root disease of Douglas-fir seedlings in relation to fungus and nematode populations. Annals of Applied Biology. 64: 239–244.

Bloomberg, W.J.; Sutherland, J.R. 1971. Phenology and fungus-nematode relations of corky root disease of Douglas-fir. Annals of Applied Biology. 69: 265–276.

Caveness, F.E. 1957. Root-lesion nematode recovered from eastern redcedar at Halsey, Nebraska. Plant Disease Reporter. 41: 1058.

Churchill, R.C.; Ruehle, J.L. 1971. Occurrence, parasitism, and pathogenicity of nematodes associated with sycamore (*Plantanus occidentalis* L.). Journal of Nematology. 3: 189–96.

Cram, M.M.; Enebak, S.A.; Fraedrich, S.W.; Dwinell, L.D.; Zarnoch, S.J. 2007. Evaluation of fumigants, EPTC herbicide, and *Paenibacillus macerans* in the production of loblolly pine seedlings. Forest Science. 53: 73–83.

Cram, M.M.; Fraedrich S.W. 2005. Management options for control of a stunt and needle nematode in Southern forest nurseries. In: Riley, L.E.; Dumroese, R.K., tech. coords. National Proceedings: Forest and Conservation Nursery Associations—2004. Proceedings RMRS-P-35. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 46–50.

Cram, M.M.; Fraedrich, S.W. 2009. Stunt nematode (*Tylenchorhynchus claytoni*) impact on southern pine seedlings and response to a field test of cover crops. In: Dumroese, R.K.; Riley, L.E., tech. coords. National Proceedings: Forest and Conservation Nursery Associations–2008. Proceedings RMRS-P-58. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 95–100.

Donaldson, F.S. 1967. *Meloidogyne javanica* infesting *Pinus elliottii* seedlings in Florida. Plant Disease Reporter. 51: 455–456.

Duncan, L.W.; Noling, J.W. 1998. Agricultural sustainability and nematode integrated pest management. In: Barker, K.R.; Pederson, G.A.; Windham, G.L., eds. Plant and nematode interactions. Madison, WI: American Society of Agronomy. Agronomy. 36: 251–287.

Dwinell, L.D.; Sinclair, W.A. 1967. Effects of N, P, K and inoculum density of *Verticillium dahliae* on populations of *Pratylenchus penetrans* in roots of American elm and sugar maple. Phytopathology. 57: 810.

Eisenback, J.D.; Yang, B.; Hartman, K.M. 1985. Description of *Meloidogyne pini* n. sp., a root-knot nematode parasitic on sand pine (*Pinus clausa*), with additional notes on the morphology of *M. megatyla*. Journal of Nematology. 17: 206–219.

Enebak, S.A.; Starkey, T.E.; Quicke, M. 2011. Effect of methyl bromide alternatives on seedling quality, nematodes and pathogenic soil fungi at the Jesup and Glennville Nurseries in Georgia: 2007 to 2008. Journal of Horticulture and Forestry. 3: 150–158.

Esser, R.P. 1977. How soil borne nematodes enter and disperse in Florida nurseries. Florida Department of Agriculture & Consumer Services Division of Plant Industry. Nematology Circular 33. 2 p.

Flegg, J.J.M. 1967. Extraction of *Xiphinema* and *Longidorus* species from soil by a modification of Cobb's decanting and sieving technique. Annals of Applied Biology. 60: 429–437.

Fraedrich, S.W. 1993. Soil fumigation practices in nurseries producing bareroot tree seedlings. In: USDA Workshop on Alternatives to Methyl Bromide; 1993 June 29–July 1; Crystal City, VA. Summary of U.S. Forest Nursery Survey. U.S. Department of Agriculture, Interagency Methyl Bromide Alternatives Committee. 41 p.

Fraedrich, S.W.; Cram, M.M. 2002. The association of a *Longidorus* species with stunting and root damage of loblolly pine (*Pinus taeda* L.) seedlings. Plant Disease. 86: 803–807.

Fraedrich, S.W.; Cram, M.M.; Handoo, Z.A. 2003. Suitability of southern pines, other selected crops, and nutsedge to a *Longidorus* sp. associated with stunting of loblolly pine seedlings. Plant Disease. 87: 1129–1132.

Fraedrich, S.W.; Cram, M.M.; Handoo, Z.A. 2005. The effect of fallow on *Longidorus americanus*, a nematode associated with stunting of loblolly pine seedlings in Georgia, USA. Nematology. 7: 487–493.

Fraedrich, S.W.; Cram, M.M.; Handoo, Z.A.; Zarnock, S.J. 2012. Influence of *Tylenchorhynchus ewingi* on growth of loblolly pine seedlings, and host suitability of legumes and small grains. Nematology. 14(4): 417–425.

Fraedrich, S.W.; Dwinell, D.L. 2005. Effects of dazomet, metam sodium, and oxamyl on *Longidorus* populations and loblolly pine seedling production. Southern Journal of Applied Forestry. 29: 117–122.

Hansbrough, T.; Hollis, J.P. 1957. The effect of soil fumigation for the control of parasitic nematodes on the growth and yield of loblolly pine seedlings. Plant Disease Reporter. 41:1021–1025.

Henry, B.W. 1953. A root rot of southern pine nursery seedlings and its control by soil fumigation. Phytopathology. 43: 81–88.

Hildebrand, D.M. 1989. A review of soil solar heating in Western forest nurseries. In: Landis, T.D., tech. coord. Intermountain Forest Nursery Association. General Technical Report RM-184. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 49–51.

Hopper, B.E. 1958. Plant-parasitic nematodes in the soils of Southern forest nurseries. Plant Disease Reporter. 42: 308–314.

Hopper, B.E. 1959. Three new species of the genus *Tylenchorhynchus* (Nematoda: Tylenchida). Nematologica. 4: 23–30.

Johnson, A.W.; Burton, G.W. 1973. Comparison of millet and sorghum-sudangrass hybrids grown in untreated soil and soil treated with two nematicides. Journal of Nematology. 5: 54–59.

Johnson, A.W.; Ratclifffe, T.F.; Freeman, G.C. 1970. Control of *Meloidogyne incognita* on dogwood seedlings by chemical dips. Plant Disease Reporter. 54: 952–955.

Jones, F.G.W.; Larbey, E.W.; Parrott, D.M. 1969. The influence of soil structure and moisture on nematodes, especially *Xiphinema*, *Longidorus*, *Trichodorus* and *Heterodera* spp. Soil Biology and Biochemistry. 1: 153–165.

Lembright, H.W. 1990. Soil fumigation: principles and application technology. Journal of Nematology. 22(4S): 632–644.

Maggenti, A.R.; Viglierchio, D.R. 1975. *Seguoia sempervirens* and *Sequoiadendron giganteum*: hosts of common plant-parasitic nematodes of California. Plant Disease Reporter. 59: 116–119.

McCain, A.H.; Bega, R.V.; Jenkinson, J.L. 1986. Effect of fall sowing and solar heating of soil on two conifer seedling diseases. Tree Planters' Notes. 37: 17–20.

McElroy, F.D. 1985. Post-plant control of nematodes in bareroot nurseries. In: Landis, T.D., tech. coord. Western Forest Nursery Council-Intermountain Nurseryman's Association. General Technical Report INT-185. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 99–101.

McKenry, M.V.; Thomason, I.J. 1976. Dosage values obtained following pre-plant fumigation for perennials. II. Using special methods of applying methyl bromide and 1,3-dichloropropene nematicides. Pesticide Science. 7: 535–544.

Mihail, J.D.; Alcorn, S.M. 1984. Effects of soil solarization on *Macrophomina phaseolina* and *Sclerotium rolfsii*. Plant Disease. 68: 156–159.

Norton, D.C. 1979. Relationship of physical and chemical factors to populations of plant-parasitic nematodes. Annual Review of Phytopathology. 17: 279–299.

Peterson, G.W. 1962. Root lesion nematode infestation and control in a plains forest tree nursery. Research Note 75. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. p 2.

Peterson, G.W. 1970. Response of ponderosa pine seedlings to soil fumigants. Plant Disease Reporter. 54: 572–575.

Peterson, G.W.; Riffle, J.W. 1986. Root lesion nematodes in junipers and pines. In: Riffle, J.W.; Peterson, G.W., tech. coords. Diseases of trees in the Great Plains. General Technical Report RM-129. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 140–141. Chapter 64.

Ploeg, A.T.; Phillips, M.S. 2001. Damage to melon (*Cucumis melo* L.) variety Durango by *Meloidogyne incognita* in southern California. Nematology. 3: 151–157.

Riffle, J.W. 1970. Nematodes parasitic on *Pinus ponderosa*. Plant Disease Reporter. 54: 752–754.

Riffle, J.W. 1972. Effect of certain nematodes on the growth of *Pinus edulis* and *Juniperus monosperma* seedlings. Journal of Nematology. 4: 91–94.

Riffle, J.W.; Kuntz, J.E. 1967. Pathogenicity and host range of *Meloidogyne ovalis*. Phytopathology. 57: 104–107.

Ruehle, J.L. 1962. Histopathological studies of pine roots infected with lance and pine cystoid nematodes. Phytopathology. 52: 68–71.

Ruehle, J.L. 1966. Nematodes parasitic on forest trees. I. Reproduction of ectoparasites on pine. Nematologica. 12: 443–447.

Ruehle, J.L. 1968a. Pathogenicity of sting nematode on sycamore. Plant Disease Reporter. 52: 523–525.

Ruehle, J.L. 1968b. Plant-parasitic nematodes associated with Southern hardwoods and coniferous forest trees. Plant Disease Reporter. 52: 837–839.

Ruehle, J.L. 1969. Influence of stubby-root nematode on growth of southern pine seedlings. Forest Science. 15: 130–134.

Ruehle, J.L. 1971. Nematodes parasitic on forest trees. III. Reproduction on selected hardwoods. Journal of Nematology. 3: 170–173.

Ruehle, J.L. 1972. Pathogenicity of *Xiphinema chambersi* on sweetgum. Phytopathology. 62: 333–336.

Ruehle, J.L. 1973a. Influence of plant-parasitic nematodes on longleaf pine seedlings. Journal of Nematology. 5: 7–9.

Ruehle, J.L. 1973b. Nematodes and the forest trees—types of damage to tree roots. Annual Review of Phytopathology. 11: 99–118.

Ruehle, J.L.; Sasser, J.N. 1962. The role of plant-parasitic nematodes in stunting of pines in Southern plantations. Phytopathology. 52: 56–58.

Sanzo, C.P.; Rohde, R.A. 1967. *Xiphinema americanum* associated with maple decline in Massachusetts. Phytophthology. 59: 279–284.

Seinhorst, J.W. 1995. The effect of delay of attack of oats by *Heterodera avenae* on the relation between initial nematode density and plant growth, plant weight, water consumption, and dry matter content. Nematologica. 41: 487–504.

Shurtleff, M.C.; Averre, III, C.W. 2000. Diagnosing plant diseases caused by nematodes. St. Paul, MN: The American Phytopathological Society. 189 p.

Sutherland, J.R. 1970. Some forest nursery seedling hosts of the nematode *Xiphinema bakeri*. Canadian Journal of Plant Science. 50: 588–590.

Sutherland, J.R.; Dunn, T.G. 1970. Nematodes in coastal British Columbia forest nurseries and association of *Xiphinema bakeri* with a root disease of Douglas-fir seedlings. Plant Disease Reporter. 54: 165–168.

Sutherland, J.R.; Sluggett, L.J. 1975. Corky root disease: population fluctuations of *Xiphinema bakeri* nematodes, and disease severity in forest nursery soil cropped with different seedling species. Canadian Journal of Forest Research. 5: 97–104.

Timper, P.; Hanna, W.W. 2005. Reproduction of *Belonolaimus longicaudatus*, *Meloidogyne javanica*, *Paratrichodorus minor*, and *Pratylenchus brachyurus* on pearl millet (*Pennisetum glaucum*). Journal of Nematology. 37: 214–219.

Timper, P.; Wilson, J.P.; Johnson, A.W.; Hanna, W.W. 2002. Evaluation of pearl millet grain hybrids for resistance to *meloidoghne* spp. and leaf blight caused by *Pyricularia grisea*. Plant Disease. 86: 909–914.

Viglierchio, D.R. 1979. Response of *Pinus ponderosa* seedlings to stylet-bearing nematodes. Journal of Nematology. 11: 377–386.

Wang, K.H.; McSorley, R. 2008. Exposure time to lethal temperatures for *Meloidogyne incognita* suppression and its implications for soil solarization. Journal of Nematology. 40: 7–12.

Wong, T.K.; Mai, W.F. 1973. Pathogenicity of *Meloidogyne hapla* to lettuce as affected by inoculum level, plant age at inoculation and temperature. Journal of Nematology. 5: 126–129.

Zasada, I.A.; Halbrendt, J.M.; Kokalis-Burelle, N.; LaMondia, J.; McKenry, M.V.; Noling, J.W. 2010. Managing nematodes without methyl bromide. Annual Review of Phytopathology. 48: 311–328.

Development and Distribution of Planted Seedlings, Naturally Regenerated Seedlings, and Competing Vegetation 6 Years After Wildfire

Diane L. Haase, Robin Rose, and Dave Henneman

Western Nursery Specialist, Forest Service, Portland, OR; Professor, College of Forestry, Oregon State University, Corvallis, OR; Reforestation Manager, U.S. Department of the Interior, Bureau of Land Management, Medford, OR

Abstract

Delays in reforestation following wildfire due to insufficient seedling supplies and other factors can result in competing vegetation occupying the area, thereby increasing reforestation costs and decreasing early seedling growth and survival rates. We established plots in 2004 to compare Douglas-fir seedling (*Pseudotsuga menziesii* Mirb. Franco) stocktypes for reforestation within the Biscuit Fire in southwestern Oregon. Because 10 plots were left unplanted, a unique opportunity existed to examine planted and unplanted areas side by side. We intensively surveyed all plots in June 2008 for spatial distribution and growth characteristics of conifer and woody shrub vegetation. The survival rate was high for all planted stocktypes. Container seedlings grew most during the first growing season, but thereafter all stocktypes were very slow growing on this harsh, droughty site. Very low numbers of naturally regenerated seedlings existed (approximately 28 trees per acre) relative to planted seedlings (approximately 400 trees per acre). Distribution and density of woody shrub species varied little across the site. This paper discusses implications for restoration management decisions after a wildfire as well as the potential for Stand Visualization System as a silvicultural tool.

Introduction

Fire suppression and the buildup of fuels have led to an increasing frequency and severity of forest fires in the Western United States often resulting in thousands of acres in need of restoration annually. These wildfires have a profound influence on plant communities (Agee 1993, Frost and Sweeny 2000). In a 2004 survey, Federal reforestation personnel identified documentation, cost, funding, NEPA (National Environmental Policy Act) requirements, delays, salvage, and vegetative competition to be critical issues that affect reforestation after a wildfire (Rose and Haase 2005).

Biscuit Fire

The Biscuit Fire began on July 13, 2002, in southwest Oregon as a result of ignition by lightning strikes. By the time it was declared controlled on November 8, 2002, nearly 500,000 acres (200,000 hectares) were burned. The Biscuit Fire was the largest fire ever recorded in Oregon history, as well as the most expensive fire suppression effort nationally in 2002, at an approximate cost of $150 million in Federal and State funds. Most (97 percent) of the area burned by the Biscuit Fire was in the Siskiyou National Forest. On the northwest end of the fire, nearly 10,000 acres (4,000 hectares) of U.S. Department of the Interior, Bureau of Land Management (BLM) land became involved in the fire approximately 2 months after ignition; many of those acres were burned intentionally as a control measure to establish a containment perimeter.

Natural Versus Artificial Regeneration

Considerable debate has occurred regarding the merits of natural versus artificial forest regeneration after a wildfire (Donato and others 2006, Newton and others 2006, Skinner 2006) and yet too few studies address the long-term implications across diverse environmental conditions. Regardless of the type of regeneration that is chosen, the establishment of a new stand is crucial for wildlife habitat, recreational uses, and timber production associated with a mature forest ecosystem. After a wildfire, the early successional community of rapidly growing broadleaf shrubs and hardwoods provides a vibrant wildlife habitat and soil stabilization. Competition for soil moisture and growing space, however, can be a challenge to the establishment of conifer seedlings. Natural conifer regeneration is a viable option for forest managers when long regeneration periods and high levels of variation are acceptable within the management objectives (Shatford and others 2007). When that is not acceptable, planting seedlings and controlling brush increases tree density, growth, and distribution during the early years of stand development (Hobbs and others 1992, Sessions and others 2004, Zheng and others 2006). Planting seedlings from site-specific seed sources after a wildfire does not adversely affect genetic diversity (Rajora and Plujar 2004) and may hasten the return to a large-conifer-dominated forest ecosystem by as much as 50 years (Sessions and others 2003).

Stocktype Choices

Because the number of acres in need of planting cannot be predicted in advance, it is unlikely that the necessary amount of seedling stock will be available to reforest a burned area after a large wildfire. When using 2-year-old stock for reforestation efforts, planting may be delayed by 3 or more years. This delay period may allow for competing vegetation to occupy the area, thereby increasing reforestation costs and decreasing early seedling growth and survival rates. The use of 1-year-old stocktypes can reduce the length of time until outplanting for an area devastated by fire. Shaw (1996) discussed growth and survival among seedling stocktypes with 1-year-old container stock having lower initial cost and lead time but uncertain performance compared with larger bareroot stock (e.g., 1 + 1 or plug + 1). In the 2004 survey, respondents indicated that relative performance among stocktypes varied considerably depending on site conditions, annual precipitation, seedling species, and location (Rose and Haase 2005).

Vegetative Competition

After a disturbance from wildfire, a declining probability of success over time exists for seedlings that are planted without vegetation control (Newton and Lavender, unpublished in Sessions and others 2003). In a study with container-grown white spruce seedlings planted after wildfire and salvage logging, there was 93 percent survival with scarification site prep and 76 percent without scarification (Densmore and others 1999). In another study, removal of shrubs resulted in increased survival and growth following fire (De las Heras and others 2002). In addition, the use of grass seeding to control erosion and increase forage can result in significant seedling mortality (Lehmkuhl 2002). On the Medford BLM District, 10-year records indicate that delays that allowed for two or more seasons for vegetation to recover after disturbance negatively affected seedling survival and increased the need to interplant and replant from an average of 3 percent of the seedlings when planting in a timely manner to an average of 22 percent of the seedlings when planting delays occurred (D. Henneman, personal communication).

Control of competing vegetation can result in significant gains in conifer seedling stem volume. After 8 years, Douglas-fir (*Pseudotsuga menziesii* Mirb. Franco) grown in plots with 3 years of woody-weed control, herbaceous-weed control, or total weed control had stem volume increases of 81, 172, and 307 percent, respectively, as compared with seedlings grown in plots without control of competing vegetation (Rose and others 1999). In addition, increasing the weed-free area around a seedling results in increased volume and height growth (Rose and Ketchum 2002).

Stand Visualization System

The Stand Visualization System (SVS) generates semirealistic, 2-dimensional and 3-dimensional graphic images depicting individual stand components using detailed geometric models (McGaughey 1997). Robert J. McGaughey (U.S. Department of Agriculture [USDA], Forest Service, Pacific Northwest Research Station) developed SVS, and James B. McCarter (College of Forest Resources, University of Washington) developed an SVS add-in for Microsoft Excel. Both SVS and the Microsoft Excel add-in are available online for free download.

SVS defines each plant in a plot based on species, plant type, and position within the plot. The data can be used to display the overall structural diversity and density present within the stand by enabling differentiation between shrub and tree layers using different plant forms, colors, or other types of marking. The data can be examined using overhead, profile, and perspective views. In addition, tabular and graphical summaries of plot information can be generated to show current and future conditions and to predict effects of silvicultural treatments and other influencing factors on subsequent growth and yield.

Foresters and other land managers can use the visual illustration of forest stand structure and composition generated by SVS to support decisionmaking toward achieving specific land-use goals. SVS can show both commercial and noncommercial species, together or individually, thereby providing useful information applicable to timber, recreation, wildlife, and other forest management resource areas. SVS can be used to generate stand images for various applications, such as prediction of mountain pine beetle effects on lodgepole pine stands (Hawkes and others 2005), evaluation of wildlife habitat relationships (Parisi and others 2007), education of private forest landowners (Roth and others 2006, Roth and Finley 2007), and estimation of stand management activities on fuel loads and potential future fires (Reinhardt and Crookston 2003).

Objectives

The purpose of this study was to compare growth and survival of planted 1- and 2-year-old Douglas-fir stocktypes after the Biscuit Fire and to examine the distribution and development of seedlings and other vegetation through intensive surveys and SVS images of planted and unplanted plots.

Materials and Methods

Site Characteristics

The study site was on Medford BLM land within the 2002 Biscuit Fire area (figure 1), located along Sourgrass Road approximately 25 miles NW of Merlin, OR (N 42° 33.129, W 123° 44.790) at an elevation of 3,800 ft (1,150 m). The site is in the northern extreme of the Mediterranean climate zone and is characterized by hot, dry summers and cool, moist winters with most precipitation falling as snow. The site was logged in 1988 and replanted with a mixture of 76 percent 1 + 1 Douglas-fir, 16 percent 1 + 1 sugar pine (*Pinus lambertiana* Dougl.), 6 percent styro-5 western hemlock (*Tsuga heterophylla* [Raf.] Sarg.), and 2 percent styro-10 Port-Orford-cedar (*Chamaecyparis lawsoniana* [A. Murr.] Parl.). The site was later interplanted in 1994. The portion of the 2002 Biscuit Fire that occurred on this particular site was a nonstand-replacement fire, which led to the development of uneven-aged stands (Agee 1993). In the spring of 2004, after the Biscuit Fire, the area around the study site was planted with Douglas-fir (65 percent), sugar pine (29 percent), and Port-Orford-cedar (6 percent)—all were container seedlings.

Figure 1. Site on the Biscuit Fire chosen for the study. (Photo source: Diane L. Haase 2004).

Planted Seedlings for Stocktype Comparison

Three replications were installed on a relatively flat ridge top on the east side of Sourgrass Road and two replications were installed on a 10- to 15-percent sloping southwest aspect on the west side of the road. On March 23, 2004, three Douglas-fir stocktypes from the same seed lot were planted on the site at a spacing of 10 ft by 10 ft (3 m by 3 m). The three stocktypes were 1 + 1 bareroot seedlings, styro-15 container seedlings (250 cm^3 volume per cavity), and Q-plug transplant seedlings. The Q-plug stocktype is a 1-year-old transplant seedling, sown in a 1 in^3 (16 cm^3) stabilized media plug (International Horticultural Technologies, LLC, Hollister, CA) in midwinter, grown under greenhouse conditions, transplanted to bareroot beds in early spring, and lifted the next winter.

Experimental Design

The three Douglas-fir stocktypes were planted in a randomized complete block design (five blocks). Each plot was approximately 60 ft by 60 ft (18 m by 18m), which is equivalent to approximately one-twelfth of an acre (0.03 hectares). In addition to the three stocktype plots, two additional plots were established in each block and left unplanted.

Seedling Measurements

Seedlings planted in 2004 for stocktype comparison were measured for seasonal height, stem diameter, and survival at the end of the first three growing seasons (September 2004, September 2005, and October 2006, respectively). Seedlings were measured again in June 2008 (for estimate of 2007 growth) and September 2008. Instances of chlorosis, dead tops, and browning were also recorded. No animal damage was noted on any seedlings. Growth was calculated by subtracting initial and annual values.

Application of SVS to the Site

In June 2008, each of the 25 plots was intensively surveyed. The precise location of each conifer seedling and woody shrub in each plot was recorded as an x-y coordinate relative to a reference point using a Criterion Electronic Laser surveying instrument (Laser Technology, Inc., Centennial, CO). One person selected a plant to be surveyed and held a reflector paddle over the plant's center while a second person aimed the laser at the paddle to determine the azimuth and horizontal distance from the instrument (figure 2). Coordinates for larger trees (live and dead) and stumps were also recorded. For each conifer plant, the shoot height, crown ratio, crown radius, stem diameter, and dominance class were recorded. For all shrub species, height and crown radius were recorded. Large clumps of a particular shrub species were surveyed as one plant. After a plant's position and characteristics were recorded, it was marked with paint to ensure that all plants were surveyed and none were surveyed more than once.

Figure 2. The position and characteristics of each woody plant in every plot was surveyed using a reflector paddle (left) and Criterion Electronic Laser surveying instrument (right). (Photo source: Diane L. Haase 2008).

Data from each plot were entered into spreadsheets formatted for the SVS program. The x-y coordinates were generated using sine/cosine formulas from the distance and azimuth readings collected in the field. For each plot, an overhead image of all plants was created using colored solid shapes to show cover and spatial distribution of each species. In addition, a perspective view of each plot was created showing only conifers.

Statistical Analyses

Data were analyzed using analysis of variance (ANOVA) for a randomized complete block. Tests for normality, linearity, and constant variance of the residuals were performed to ensure the validity of these assumptions—no data transformations were deemed necessary. Fisher's Protected Least Significant Difference procedure was used to determine significant differences in growth and survival data among seedling stocktypes at the $\alpha \leq 0.05$ level. To determine vegetative composition and characteristics on the site, planted plots (three plots per block for stocktype comparison as described previously) and unplanted plots (two plots per block) were grouped for comparisons of conifer and brushy vegetation between the two groups.

Results

Stocktype Comparisons

The container stocktypes (Q-plug and styro-15) had significantly more height growth during the first season (2004) than did the 1 + 1 bareroot seedlings (figure 3), which may be explained by the fact that two-thirds of the 1 + 1 seedlings had multiple tops or no terminal bud at the time of planting due to top pruning in the nursery. Styro-15 seedlings also had the greatest average stem diameter growth during the first season (figure 3). During the subsequent four growing seasons, however, height and stem diameter growth were minimal on

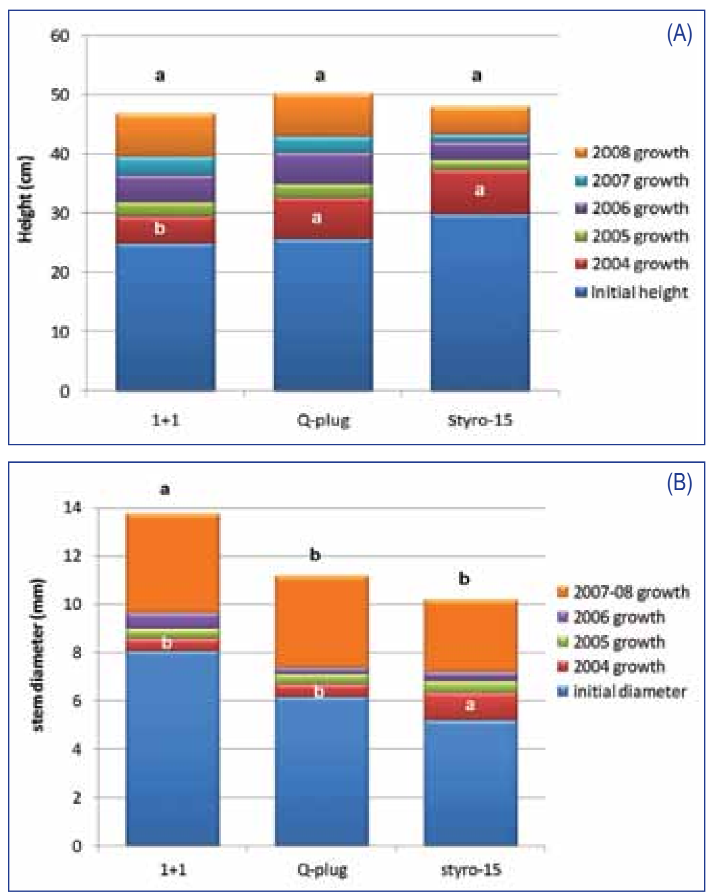

Figure 3. Annual height (A) and stem diameter growth (B) among stocktypes. White letters indicate differences among stocktypes for 2004 growth and black letters indicate differences among total size after five growing seasons. Those with different letters are statistically significant at the $\alpha \leq 0.05$ level.

this relatively harsh site and did not differ among stocktypes (figure 3). Bareroot 1 + 1 seedlings had significantly larger initial stem diameter than the two container stocktypes and that difference continued to be significant for overall diameter in September 2008 (figure 3).

Most seedlings exhibited chlorosis by the end of the second season; this was especially evident for styro-15 seedlings (figure 4), which were clearly stressed by the second season and had an 8-percent drop in survival during the third season. This demonstrates the importance of using a multiyear assessment to accurately evaluate the relative performance among stocktypes or treatments in a given forest regeneration project. Despite the slow growth, survival after five growing seasons was high for all three stocktypes (90.6 percent for styro-15, 95 percent for 1 + 1, and 95.6 percent for Q-plug seedlings).

Conifer Density in Stocktype and Nonplanted Plots

Conifers in the unplanted plots, as well as those in the planted plots that were not part of the stocktype trial, were separated into two size classes. “Large” conifers greater than 3.3 ft (1 m) tall were considered established prefire while “small” conifers less than 3.3 ft tall were considered established postfire. (Note: Because trees are very slow-growing on this site, it is possible that some of the smaller conifers were actually established before the 2002 fire.)

Figure 4. Styro-15 seedling exhibiting severe chlorosis after the second growing season. (Photo source: Diane L. Haase 2004).

The average density of Douglas-fir seedlings planted for stocktype comparison was 33.7 trees per plot (407 trees per acre or 1,006 trees per hectare). In addition, stocktype comparison plots had an average of 2.4 naturally regenerated small conifers and 2.6 large (prefire) conifers per plot (figure 5). In unplanted plots, an average of 12.0 small conifers and 3.2 large conifers existed per plot (figure 5). During survey of the plots, however, it became evident that most of the small Douglas-fir and sugar pine seedlings were not naturally regenerated. These seedlings were of similar age, size, and form, were spaced at regular intervals, and were sometimes planted in rows—indicating that the operational planting crew strayed into the study plots while planting the surrounding area. To confirm this, we excavated a Douglas-fir and a sugar pine seedling and determined that each originated as plug seedlings (in fact, controlled-release fertilizer prills were found within the Douglas-fir root system). As a result, we concluded that approximately 90 percent of the small Douglas-fir and sugar pine conifers in the unplanted plots were actually planted nursery stock. For a more accurate estimate of naturally regenerated seedling density in the study area, the number of small conifer seedlings within the stocktype plots (not planted as part of the study) was used resulting in an estimate of 29 naturally regenerated trees per acre (72 per hectare).

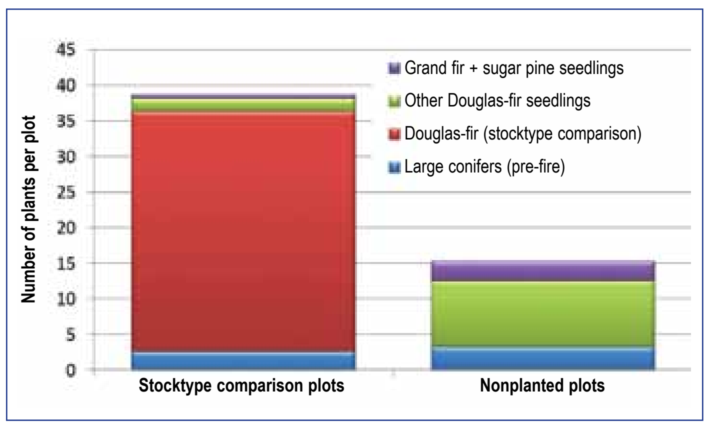

Figure 5. Plots planted for stocktype comparison had approximately 38 conifers per plot and unplanted plots had approximately 15 conifers per plot, although most of Douglas-fir and sugar pine seedlings in the unplanted plots were determined to have been planted during operational planting of the surrounding area resulting in an estimate of 29 naturally regenerated trees per acre (72 per hectare).

Table 1. Eight woody vegetation species were found on the study site (listed in order of abundance).

Common name	Scientific name	Average height cm (in)
Chinkapin	*Chrysolepis chrysophylla* (Douglas ex Hook.) Hjelmqvist	84.1 (33.1)
Deer oak	*Quercus sadleriana* R. Br.	48.1 (18.9)
Pacific rhododendron	*Rhododendron macrophyllum* D. Don ex G. Don	60.6 (23.9)
Pinemat manzanita	*Arctostaphylos nevadensis* A. Gray	13.8 (5.4)
Greenleaf manzanita	*Arctostaphylos patula* Greene	40.6 (16.0)
Whiteleaf manzanita	*Arctostaphylos viscida* Parry	49.3 (19.4)
Salal	*Gaultheria shallon* Pursh	20.6 (8.1)
Canyon live oak	*Quercus chrysolepsis* Liebm.	70.7 (27.8)

Other Woody Vegetation

Nonconifer woody species found on the site are listed in table 1. The average total brush cover per plot was approximately 18 percent. Woody shrubs varied little among plots, although it was noted that pinemat manzanita occurred in greater abundance in Blocks 1 to 3 while whiteleaf manzanita occurred in greater abundance in Blocks 4 to 5. Salal occurred only in Blocks 4 to 5. Relative abundance and coverage of woody shrubs for the site are shown in figure 6.

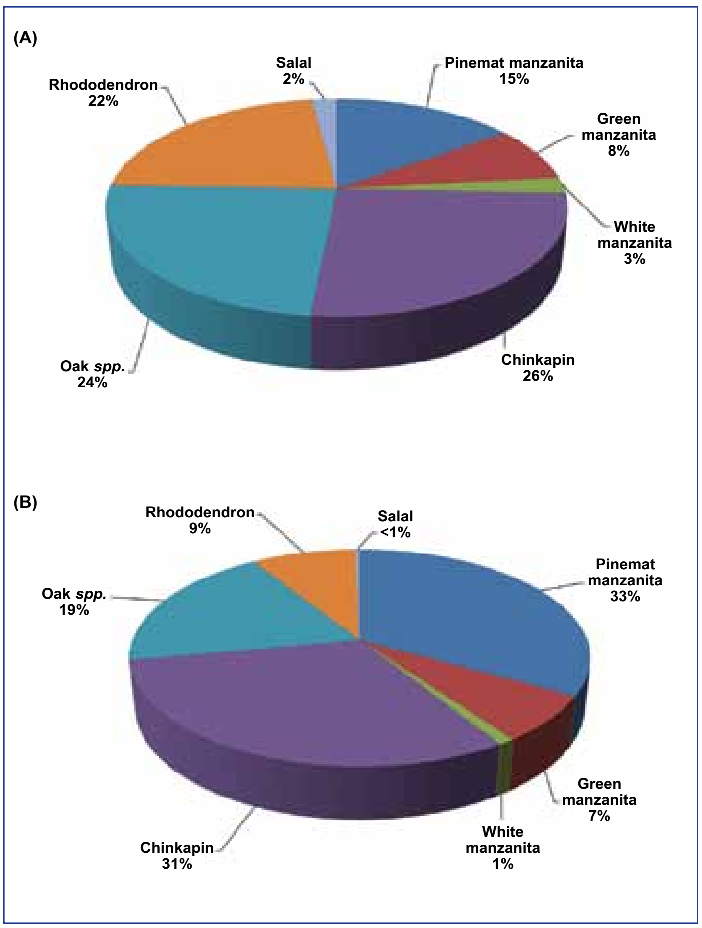

Figure 6. Relative abundance of woody shrub species found on the site by number of plants (A) and by coverage (B).

Stand Visualization System

Graphic images of the spatial distribution and cover for each woody plant on each of the 25 plots were generated with SVS. The perspective view (figure 7) shows the distribution and abundance of conifer seedlings in each plot and the overhead view (figure 8) shows overall cover of all species on each plot.

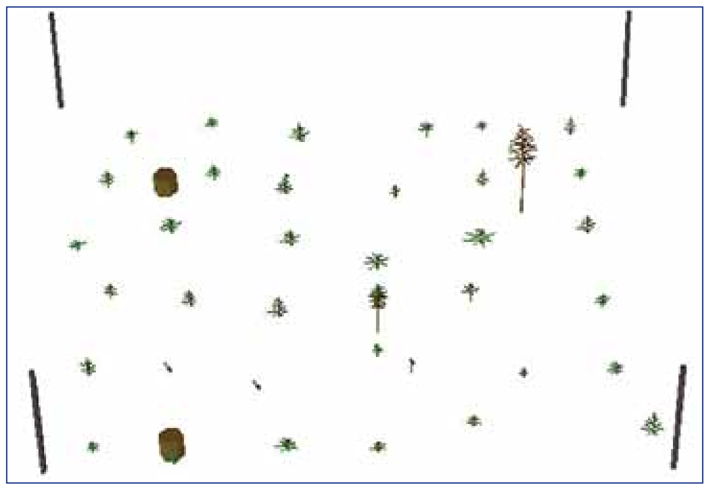

Figure 7. Example of perspective view of conifers in a plot.

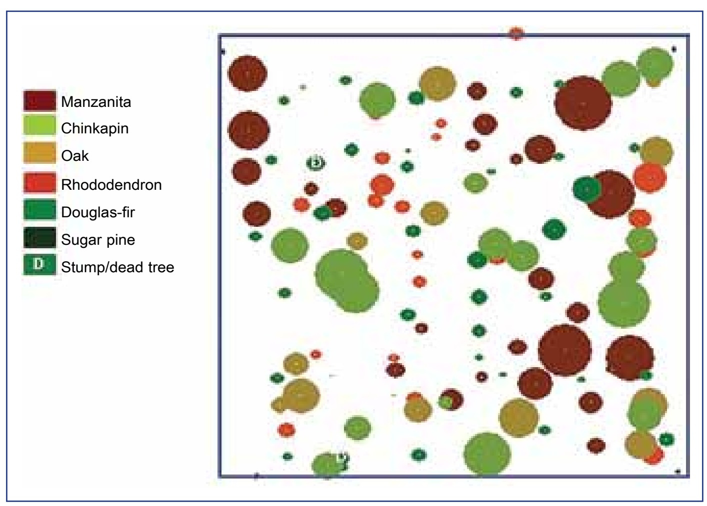

Figure 8. Example of overhead view of all woody plant species in a plot.

Discussion

Stocktype Comparison

After five growing seasons, the two 1-year-old stocktypes had high survival and similar growth to the 2-year-old transplant seedlings indicating that any of these stocktypes would be an appropriate choice for this type of site. It is important to note, however, that none of the stocktypes performed especially well. The arid conditions in this area are extremely limiting for seedling growth regardless of stocktype and are likely the primary factor determining seedling performance. On this site, average cumulative height growth and stem diameter growth were only 7 to 10 in (18 to 25 cm) and 0.4 to 1.0 in (10 to 15 mm), respectively, over the five growing seasons. This is less growth than would be expected in just one season on a site where soil moisture is not limiting. In a similar stocktype comparison study, three Douglas-fir stocktypes were planted in a droughty, skeletal soil in southwest Oregon. After 5 years, annual growth and shoot and root characteristics were similar among stocktypes suggesting that stocktype designation alone may not be adequate for predicting field performance on such sites (Hobbs and others 1989).

Naturally Regenerated Conifers

It was unfortunate and unexpected that operational planting activities resulted in some seedlings planted within the study area. Using the number of small conifers found in the planted plots (not planted for stocktype comparison) resulted in an estimate of two Douglas-fir seedlings and one sugar pine seedling per plot, plus one grand fir (*Abies grandis* [Douglas ex D. Don] Lindl.) seedling per every six plots, for an estimate of 29 naturally regenerated trees per acre. This is less than one-tenth the stocking that resulted from tree planting (approximately 400 trees per acre) and would not be adequate to meet stocking standards (USDI 2003). Using a reforestation model to compare unplanted with planted larch (*Larix gmelinii* [Rupr.] Rupr.) in an area burned by a catastrophic fire, it was found that it would take 30 to 40 years longer for tree abundance to return to prefire levels for unplanted versus planted scenarios (Wang and others 2006).

The proximity of a site to an abundant and viable seed source is an important factor in determining efficacy of natural regeneration (Tappeiner and others 2007). Seed dispersal is influenced by many factors, including physical, climatic, and biotic factors (McCaughey 1986), and lessens as the distance from the source increases. Distance to seed source can strongly influence the rapidity and density of new stand establishment through natural regeneration. In areas where no remaining live trees exist after a large intensive fire such as the Biscuit Fire, the nearest seed source could be several miles away, thereby reducing available seed for natural regeneration and delaying establishment of conifers in the area. One study found that naturally regenerated seedlings were abundant in plots evaluated 9 to 19 years after a wildfire (Shatford and others 2007). All of those plots, however, were within 1,600 ft (500 m) of a seed source.

It is evident that a wide range of factors must be integrated to evaluate forest conditions and management options to meet specific forest regeneration goals. In this study, more than 60 large conifer trees were located in plots established before the Biscuit Fire. The presence of these trees results in a local seed source for natural regeneration; however, the abundance of naturally regenerated seedlings was very low. Droughty soil conditions, animal predation, and occasional high winds are likely inhospitable for abundant seed production, germination, and seedling growth.

Other Woody Vegetation

The drought-tolerant, woody shrub species found on the Biscuit Fire site are typical of the forest vegetation community found in the Klamath-Siskiyou region of southwestern Oregon. Chinkapin was the most abundant species on the plots and accounted for 26 percent of the woody plants and 31 percent of the total brush coverage by area. Chinkapin is an evergreen species and grows primarily in northern California and southern Oregon. It is a minor component in a wide range of forest communities (Eyre 1980) and sprouts rapidly and prolifically after a fire or other injury. Deer oak, rhododendron, and manzanita were the other prevalent brush species on the site and are also evergreen shrub species that regenerate readily after a fire. At the time of planting in 2004, just 17 months after the fire, these species already had a notable presence on the site.

The shrub species covered an average of 18 percent of the surface area. The SVS images show that the shrubs are fairly evenly distributed throughout the site, with many large clumps. It is likely that coverage by these woody shrubs will expand over time and pose a significant competitive factor for available resources.

Stand Visualization System

The images generated by SVS provide far more information to foresters or researchers than can be learned from vegetation data tables alone. The graphic representation of stand characteristics is effectively a real-time visualization of stand composition, structure, and spatial distribution. The images can also be employed as a decision support tool by providing dynamic temporal simulations of stand growth and yield.

For purposes of this project, we used SVS to show the spatial distribution of relatively small plants with equal emphasis on conifer species and woody shrub species. More commonly, SVS is used to visualize older stands with an emphasis on growth and yield of conifer species. Nonetheless, by manipulating the color display for various shrub species, overhead images can give a graphic representation of shrub cover and distribution. In the future, it would be ideal if the color palette selection and plant graphics options were expanded for improved representation of small plants of many species. By taking periodic measurements over time, SVS can be used on any stand to not only evaluate density and distribution but also to simulate temporal effects of available silvicultural management options such as thinning or harvest to develop appropriate stand management plans. As such, the visual format of SVS can be a supplemental tool that is readily understood by foresters and the public.

Conclusions

Natural regeneration is beneficial on some sites and with some species (Thanos and others 1996, Shatford and others 2007). Concern remains among scientists and foresters, however, that it can be too slow and too unpredictable (Kozlowski 2002, Sessions and others 2004). Data from this study indicate a wide distribution of woody competitive species with few conifer seedlings established through natural regeneration during the 6 years since the Biscuit Fire.

Seedling stocking density can be quite variable and slow with natural regeneration, especially for harsher sites like the one examined in this project, where the germination environment and seed source viability were likely inadequate. When there are specific reforestation objectives for a particular level of spatial distribution and density to meet ecological management goals within a specified timeframe, it is recommended that seedlings be planted as soon as possible after a wildfire (or any disturbance) to achieve those goals. Such decisions must also integrate consideration of the local environment, vegetation community, and other factors.

The use of SVS imagery provides an extra tool that enables forest managers to graphically evaluate the spatial distribution, density, cover, and size of specific species within the forest vegetation community. These data can lead to a better understanding of stand recovery after a catastrophic wildfire and can be used as a predictive tool for silvicultural restoration options.

Address correspondence to:

Diane L. Haase, Western Nursery Specialist, USDA Forest Service, P.O. Box 3623, Portland, OR 97208; e-mail: DLHaase@fs.fed.us; phone: 503–808–2349.

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References

Agee, J.K. 1993. Fire ecology of Pacific Northwest forests. Washington, DC: Island Press. 493 p.

De las Heras, J.; Martínez-Sánchez, J.J.; González-Ochoa, A.I.; Ferrandis, P.; Herranz, J.M. 2002. Establishment of *Pinus halepensis* Mill. saplings following fire: effects of competition with shrub species. Acta Oecologica. 23: 91–97.

Densmore, R.V.; Juday, G.P.; Zasada, J.C. 1999. Regeneration alternatives for upland white spruce after burning and logging in interior Alaska. Canadian Journal of Forest Research. 29: 413–423.

Donato, D.C.; Fontaine, J.B.; Campbell, J.L.; Robinson, W.D.; Kauffman, J.B.; Law, B.E. 2006. Response to comments on "Post-wildfire logging hinders regeneration and increases fire risk." Science. 313: 615c.

Eyre, F.H., ed. 1980. Forest cover types of the United States and Canada. Washington, DC: Society of American Foresters. 148 p.

Frost, E.J.; Sweeny, R. 2000. Fire regimes, fire history and forest conditions in the Klamath-Siskiyou region: an overview and synthesis of knowledge. Ashland, OR: Wildwood Environmental Consulting. 59 p. http://newforestry.org/shfsc/info/Klamath-Siskiyou%20 Fire%20Regimes.pdf. (February 2012).

Hawkes, B.C.; Taylor, S.W.; Stockdale, C.; Shore, T.L.; Beukema, S.J.; Robinson, D. 2005. Predicting mountain pine beetle impacts on lodgepole pine stands and woody debris characteristics in a mixed severity fire regime using Prognosis[BC] and the Fire and Fuels Extension. 2005. In: Lagene, L.; Zelnik, J.; Cadwallader, S.; Hughes, B., eds. Mixed severity fire regimes: ecology and management, November 17–19, 2004, Spokane, WA. Vol. AFE MISC03. Pullman, WA: Washington State University Cooperative Extension Service/The Association for Fire Ecology: 123–125.

Hobbs, S.D.; Crawford, M.S.; Yelczyn, B.A. 1989. Early development of three Douglas-fir stocktypes on a droughty skeletal soil. Western Journal of Applied Forestry. 4: 21–24.

Hobbs, S.D.; Tesch, S.D.; Owston, P.W.; Stewart, R.E.; Tappeiner, J.C.; Wells, G.E. 1992. Reforestation practices in southwestern Oregon and northern California. Corvallis, OR: Oregon State University Press. 465 p.

Kozlowski, T.T. 2002. Physiological ecology of natural regeneration of harvested and disturbed forest stands: implications for forest management. Forest Ecology and Management. 158: 195–221.

Lehmkuhl, J.F. 2002. The effects of spring burning and grass seeding in forest clearcuts on native plants and conifer seedlings in coastal Washington. Northwest Science. 76: 46–60.

McCaughey, W.W.; Schmidt, W.C.; Shearer, R.C. 1986. Seed dispersal characteristics of conifers in the inland mountain west. General Technical Report INT-203. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 50-62.

McGaughey, R.J. 1997. Visualizing forest stand dynamics using the Stand Visualization System. In proceedings: 1997 ACSM/ASPRS Annual Convention and Exposition. April 7–10, 1997. Seattle, WA. Vol. 4. Bethesda, MD: American Society for Photogrammetry and Remote Sensing: 248–257.

Newton, M.; Fitzgerald, S.; Rose, R.; Adams, P.W.; Tesch, S.D.; Sessions, J.; Atzet, T.; Powers, R.F.; Skinner, C. 2006. Comment on "Post-wildfire logging hinders regeneration and increases fire risk." Science. 313: 615a.

Parisi, M.D.; Motroni, R.S.; Robards, T.A. 2007. Clarification of the measurement of California wildlife habitat relationships (CWHR) system size classes 5 and 6 for tree habitats. CWHR Technical Report No. 32. Sacramento: California Department of Fish and Game, Resource Management and Policy Division, Biogeographic Data Branch, California Wildlife Habitat Relationships Program. 14 p.

Rajora, O.P.; Pluhar, S.A. 2004. Genetic diversity impacts of forest fires, forest harvesting, and alternative reforestation practices in black spruce (*Picea mariana*). Theoretical and Applied Genetics. 106: 1203–1212.

Reinhardt, E.; Crookston, N.L. 2003. The fire and fuels extension to the forest vegetation simulator. General Technical Report RMRS-GTR-116. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 209 p.

Rose, R.; Haase, D.L. 2005. Rapid response reforestation: studies in fire restoration. In: Dumroese, R.K.; Riley, L.E.; Landis, T.D., tech. coords. 2005. National proceedings: Forest and Conservation Nursery Associations—2004; 2004 July 12–15; Charleston, NC; and 2004 July 26–29; Medford, OR. Proceedings. RMRS-P-35. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 90–93.

Rose, R.; Ketchum, J.S. 2002. Interaction of vegetation control and fertilization on conifer species across the Pacific Northwest. Canadian Journal of Forest Research. 32: 136–152.

Rose, R.; Ketchum, J.S.; Hanson, D.E. 1999. Three-year survival and growth of Douglas-fir seedlings under various vegetation-free regimes. Forest Science. 45: 117–126.

Roth, P.A.; Finley, J.C. 2007. Visualize your forest—using forest simulation software to communicate forest management concepts to private forestland owners. Journal of Forestry. 105: 15–19.

Roth, P.A.; Finley, J.C.; Zobrist, K.W.; Baumgartner, D.M. 2006. Computer technology helps family forest owners in Pennsylvania and Washington. Journal of Forestry. 104: 132–135.

Sessions, J.; Buckman, R.; Newton, M.; Hamann, J. 2003. The Biscuit Fire: management options for forest regeneration, fire and insect risk reduction and timber salvage. Corvallis, OR: Oregon State University, College of Forestry. 63p.

Sessions, J.P.; Bettinger, P.; Buckman, R.; Newton, M.; Hamann, J. 2004. Hastening the return of complex forests following fire: the consequences of delay. Journal of Forestry. 102: 38–45.

Shatford, J.P.A.; Hibbs, D.E.; Puettmann, K.J. 2007. Conifer regeneration after forest fire in the Klamath-Siskiyous: How much, how soon? Journal of Forestry. 105: 139–146.

Shaw, L.S. 1996. Conifer seedling choices in wildfire reforestation—eastside perspectives. In: Landis, T.D.; South, D.B., tech. coords. National proceedings, forest and conservation nursery associations. General Technical Report PNW-GTR-389. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station: 207–210.

Skinner, D. 2006. The Donato-law fiasco: mixing politics & science: alchemy at OSU. Evergreen. Winter 2006–2007: 4–31.

Tappeiner, III, J.C.; Maguire, D.A.; Harrington, T.B. 2007. Silviculture and ecology of Western U.S. forests. Corvallis, OR: Oregon State University Press. 440p.

Thanos, C.A.; Daskalakou, E.N.; Nikolaidou, S. 1996. Early post-fire regeneration of a *Pinus halepensis* forest on Mount Párnis, Greece. Journal of Vegetation Science. 7(2): 273–280.

U.S. Department of the Interior, Bureau of Land Management. 2003. Oregon State Office, Regeneration Stocking Surveys Handbook. H-5705-1, 2003, Release 5-249. Portland, OR: U.S. Department of the Interior, Bureau of Land Management. 37 p.

Wang, X.; He, H.S.; Li, X. 2006. The long-term effects of fire suppression and reforestation on a forest landscape in northeastern China after a catastrophic wildfire. Landscape and Urban Planning. 79(1): 84–95.

Zheng, J.; Oliver, W.W.; Busse, M.D. 2006. Growth and development of ponderosa pine on sites of contrasting productivities: Relative importance of stand density and shrub competition effects. Canadian Journal of Forest Research. 36(10): 2426–2438.

Morphological Grades of Lodgepole Pine Seedlings Compared After 13 Growing Seasons

Steven B. Kiiskila

Forest Agronomy Consultant, New Forest Treeworks, Smithers, British Columbia, Canada

Abstract

The effect of morphological specifications within one stock type of container lodgepole pine grown under conditions that promote secondary foliage was examined. Seedlings were graded into three classes based on height and the tallest stock was further sorted by primary or secondary needles. Root collar diameter was similar among all seedlings except the short treatment group, which had a significantly smaller average diameter. Initial height differences resulted in seedling sturdiness that decreased when height increased. Seedling survival after 13 growing seasons was relatively high for all groups, although that of the mid-height treatment was less at 84 percent because of initial damage from pests, a factor that is unrelated to seedling morphology. After 13 growing seasons, no differences existed in height, diameter at breast height, or stem volume among treatments, suggesting that initial seedling size and needle morphology are not major factors in determining lodgepole pine reforestation success on this type of site in the central interior of British Columbia with low vegetation competition.

Introduction

A number of attributes can be measured to quantify seedling morphology (Grossnickle and others 1991), with the most common being height and root collar diameter (RCD). Indirectly, seedling height provides a measure of photosynthetic (Iverson 1984) and transpirational (Ritchie 1984) area. RCD is a measure of general seedling durability (Cleary and others 1978) and has been regarded as the best single predictor of field survival and growth (Thompson 1984). Along with height and RCD, the height-to-diameter ratio (HTDR) or sturdiness ratio is thought to be an important stock characteristic that influences early plantation performance (Burdett 1983).

These size attributes are the basis for the various stock type sizes currently available for production of reforestation seedlings. Currently in British Columbia (B.C.), reforestation stock is available in a multitude of Styroblock™ (Beaver Plastics, Edmonton, Alberta) containers and grown outdoors, in greenhouses, or a combination of both (Anonymous 1998). For each particular stock type (e.g., species, container size, age), stock is often further graded by assigning specific morphological specifications in the growing contract. For example, container stock grown in B.C. typically has minimum and maximum height and RCD specifications that it must meet, or it is culled (van Steenis 1994). Seedlings that are more than the maximum height are not culled if they meet or exceed a specific target RCD. Reforestation specialists typically prefer a specific seedling size within each stock type. The primary objective of this trial was to determine what effect the seedlings' initial height, within a specific stock type, has on subsequent field performance of lodgepole pine (*Pinus contorta* Dougl. var. *latifolia* Engelm.) seedlings. Specifically, how do seedlings of a target height perform relative to shorter or taller seedlings of the same stock type.

Pine seedlings for reforestation may also be ordered with primary or secondary (i.e., fascicle) foliage (Montville and others 2002). Secondary needle growth can be induced by using nursery cultural techniques such as the use of supplemental lighting, although the physiological basis for converting to secondary needles is still poorly understood (Mustard and others 1998). In addition to fascicle needles, secondary-needle pine has a whorl of buds at the apex instead of the single terminal bud usually found in primary needle pine (Montville and others 2002). In some cases, pine has been culled on the basis of its needle type, although this requirement has varied over the years. The second objective of this trial was to determine if the field performance of primary-needle pine differed from that of similar-sized, secondary-needle pine from a crop grown under extended photoperiods, which induced secondary needles in most of the crop.

Methods

Seedling Size and Needle Classes

The seeds of the lodgepole pine seedlings used in this trial were sourced from a local, wild-stand collection (seedlot 39409) near the planting site. The seedlings for this trial were selected during a lift of a large order of seedlings operationally grown for L&M Lumber Ltd. (Vanderhoof, B.C.) at the PRT Red Rock forest nursery (Prince George, B.C.). These seedlings were grown in CopperBlock™ Styroblocks™ (Beaver Plastics model number 313B/4, 30 mm [1.17 in] diameter with 126 mm [4.97 in] depth) under standard commercial growing regimes similar to those described in Wenny and Dumroese (1991) and Landis and others (1989). This regime entailed sowing the seeds into a double-poly greenhouse in mid-March and growing them under cover until mid-June at which time the poly was removed and the seedlings were exposed to full sunlight. The greenhouse poly was replaced in mid-August and the seedlings remained covered until early November when they were lifted and placed in frozen storage (-2 °C [28.4 °F]) until they were planted the next spring.

The nursery grew the crop to have fascicle foliage, also known as secondary needles (2°), by extending the day length (23 hr) during the first 10 weeks, although some of the taller seedlings produced only primary (1°) needles. The target height and RCD specifications for the stock at time of lifting were 12 cm (4.7 in) and 2.8 mm (0.11 in), respectively. The minimum height and RCD specifications were 5 cm (2.0 in) and 2.2 mm (0.09 in), respectively. The maximum allowed seedling height was 25 cm (9.8 in), unless the seedling had target RCD or greater. At the time of seedling harvest in November, four treatments were selected off the lift line (Short, Mid, Tall with 2° needles, and Tall with 1° needles). All stock used in the trial fell within the specified parameters and thus would have been planted. The average height and RCD (± standard error of the means) of the treatments are presented in table 1.

Outplanting Site

The field site was established approximately 100 km (60 mi) southwest of Vanderhoof, B.C. (Cutting permit 100; block 670, at km 75 off the Kluskus Forest Service Road). The site is in the 04 site series (Sxw Huckleberry-Soopolallie) of the SBSmc3 (Kluskus variant of the moist cold Sub-Boreal Spruce) biogeoclimatic subzone as per DeLong and others (1993). The trial area is relatively flat, at an elevation of 1,115 m (3,658 ft). The soil was classified as a sandy loam containing 15 to 20 percent coarse fragments, with a 14 cm (5.5 in) mor humus (Sinclair and Wilder 1997). The soil moisture regime was classified as submesic (3) and the soil nutrient regime as medium (C). The harvesting method was conventional roadside, and the silviculture system was clear-cut. The site was disk trenched. During the first growing season (1999), there was 23 cm (9.1 in) of precipitation at the trial site. A data logger, buried 5 cm (2.0 in) deep on a favorable planting spot on the berm of a trench, recorded soil temperature every 30 minutes from May 11 to October 18, 1999. Soil temperature was quite low at the time of planting (May 11, 1999), reaching a maximum in the first season of only 16 °C (60.8 °F), and dropping quite quickly towards the end of September (figure 1). At the time of planting, no competing herbaceous vegetation was present. At the end of the seventh growing season (October 2005), minimal to no herbaceous, woody shrub, or broadleaf competition existed (figure 2). The site was manually brushed of aspen (*Populus tremuloides* Michx.) saplings that summer.

Table 1. Mean height and RCD measurements for lodgepole pine seedlings in each treatment at the time of planting. Means followed by the same letter are not significantly different from one another (Tukey HSD multiple comparisons p > 0.05).

Variable	Short 2°	Mid 2°	Tall 2°	Tall 1°	F-ratio	P
Height (cm/in)	7.3/2.9a	13.1/5.2b	21.4/8.4c	23.6/9.3d	800.02	0.00
RCD (mm/in)	2.9/0.11a	3.2/0.13b	3.2/0.13b	3.3/0.13b	27.878	0.00

RCD = root collar diameter. 2° = primary needles. 1° = secondary needles.

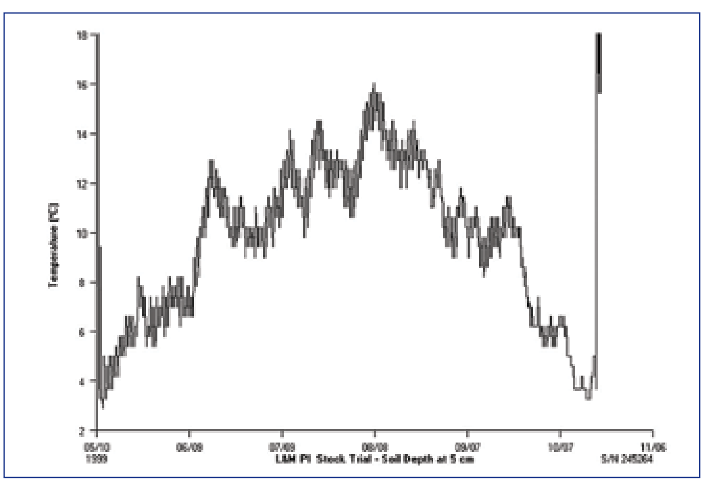

Figure 1. Soil temperature at 5 cm (2.0 in) depth on a favorable planting spot in the berm on a trench from May 11 to October 18, 1999.

Figure 2. The trial site during fall measurement, October 17, 2005. The 2 m (6.6 ft) height pole is leaning against a lodgepole pine tree with an 83 cm (32.7 in) leader. (Photo source: Steven B. Kiiskila).

At the final measurement (October 2011), no vegetation competition existed, although site occupancy was high, with high amounts of naturally regenerated pine ingress.

Study Design

The trial's experimental design was a randomized block design, with four replications (i.e., blocks) established adjacent to each other. Site conditions were relatively homogenous within and among blocks. Each of the four blocks contained four rows of 25 seedlings, one for each treatment, randomly assigned within each block. Cedar posts, placed at the front of each row 2.5 m (8.2 ft) apart and at the end of end of each row, allowed for average spacing of 2.5 m (8.2 ft) within the rows. Two professional planters working in the area planted the seedlings using operational planting practices at the time which involved planting the seedlings on the berm of the trench, approximately one finger deep (distance of container plug beneath the soil surface). Planters were instructed to choose the best seedling microsite, rather than predetermined planting spots. Each seedling was marked by ribboned wire pig tails with a uniquely numbered aluminum tag.

Data Collection and Analyses

Each seedlings was measured for height and stem diameter on the day of planting, and in the fall at the end of the 1st, 2nd, 3rd, 5th, 7th, and 13th growing seasons (October 18, 1999, September 29, 2000, October 18, 2001, October 3, 2003, October 17, 2005, and October 5, 2011). At the end of the second and third growing seasons, vigor was rated with a subjective visual assessment: 1 = poor, 2 = fair, and 3 = good. At the end of the 7th and 13th growing seasons, trees were subjectively rated for vigor using a four-point system: 1 = moribund, 2 = poor, 3 = fair, and 4 = good. Stem volume (cm^3) after the 7th and 13th growing seasons was calculated as a cone: (⅓ by p by [ground level diameter/2]^2 by height).

SYSTAT 10.2 was used to perform the analysis of variance, and Tukey's post hoc multiple range test was performed if treatment differences were found to be significant. The trial was established as a randomized block design, with block as the replication (rep) and rep x treatment as the error term. The level of significance was maintained at $p = 0.05$. A small number of trees (i.e., 10 out of 400) damaged by disease, pests, and other biotic or abiotic factors were removed from the 2011 data set before the height, diameter, and volume were analyzed.

Results

Survival

Shortly after planting, some of the stock sustained frost damage. At the end of the first growing season, however, survival was 100 percent for the Mid 2° treatment and 99 percent for the other treatments. At the end of the third growing season, the survival rate remained at 100 percent and 99 percent for the Mid 2° and Short 2° treatments, respectively, and at 98 percent for both Tall treatments. Four seasons later, the survival rate was at 96 percent or greater for all treatments except the Mid 2° treatment, which was at 89 percent, with most of mortality attributed to Warren's root collar weevil (*Hylobius warren* Wood). At the end of 12 years, survival was still relatively unchanged at 95, 93, 92, and 84 percent for the Tall 1°, Tall 2°, Short 2°, and Mid 2° treatments, respectively. Mortality occurring after the seventh year measurement was primarily the result of Comandra blister rust (*Cronartium comandrae* Pk.) and western gall rust (*Endocronartium harknessii* [J.P.Moore]Y. Hiratsuka).

Vigor

Overall seedling vigor at the end of the second growing season was 2.6, 2.3, 2.1, and 1.9 for the Short 2º, Mid 2º, Tall 2º, and Tall 1º treatments respectively (figure 3). At the end of the third season, treatment ranking remained the same, but visual assessment of all treatments increased from the previous fall to 2.8, 2.7, 2.5, and 2.3 for the Short 2º, Mid 2º, Tall 2º, and Tall 1º treatments, respectively. After seven growing seasons (fall 2005), overall vigor was rated high at 3.7, 3.6, 3.6, and 3.4 for the respective Tall 2°, Tall 1°, Short 2°, and Mid 2° stock. During the fall 2011 measurement, the vigor rating was nearly identical for all four treatments, ranging from 3.6 to 3.7.

Morphology

At the time of planting, statistically significant height differences existed between all four treatments (table 1). As intended, the relative height differences between the Short, Mid, and Tall treatments were substantial, while only a 2 cm (0.8 in) difference in height existed between the Tall 2° and Tall 1° seedlings. At the end of the first and second growing seasons, height rankings among treatments remained the same as the rankings at planting, except that the absolute heights of the Tall 2º and Tall 1º seedlings were no longer significantly different from one another. By the end of the third growing season, absolute height growth had evened out somewhat, with only the Short 2º seedlings being statistically smaller

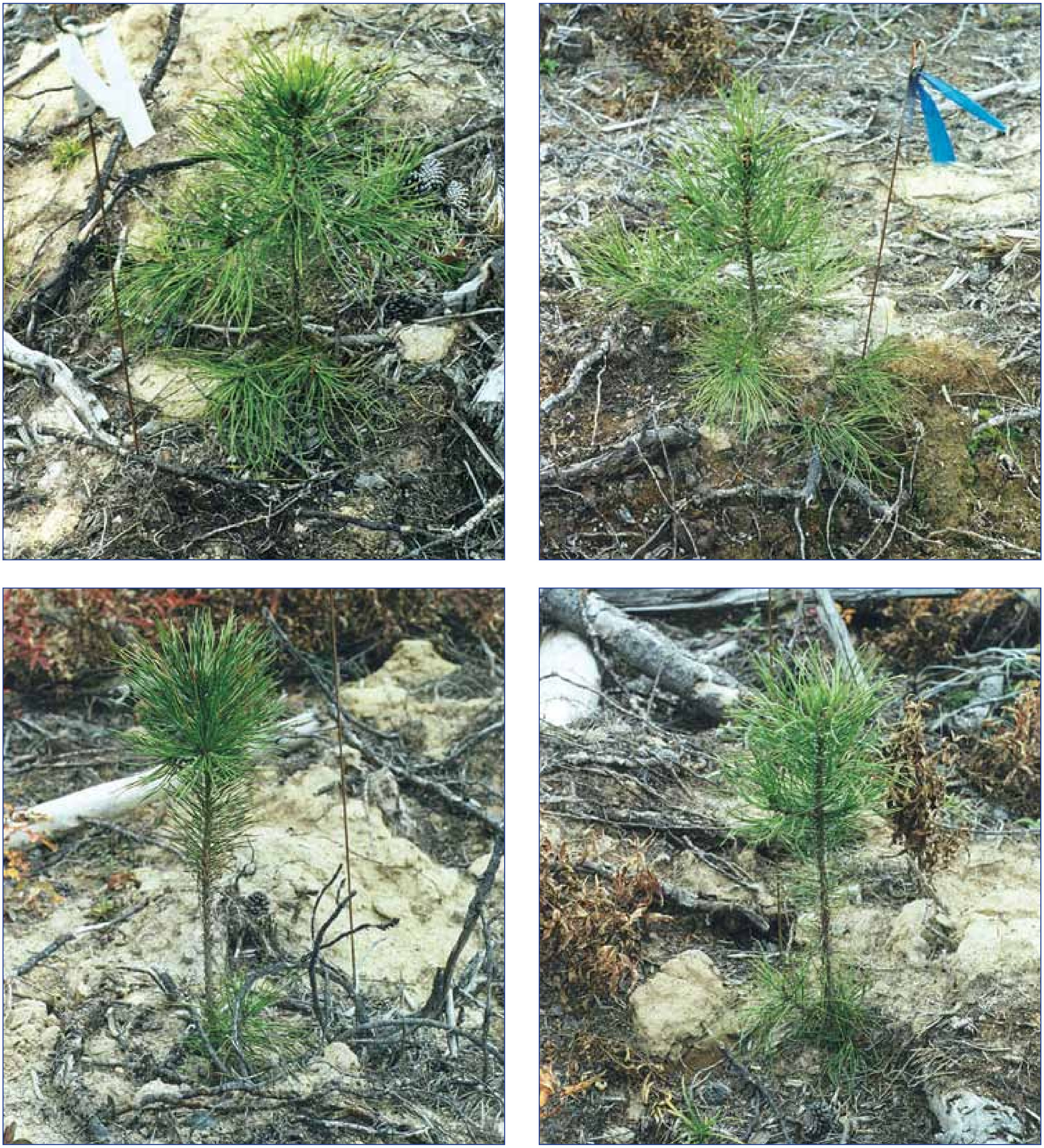

Figure 3. Example of seedlings from each treatment, September 19, 2000. Clockwise from top left: Short 2°, Mid 2°, Tall 2°, and Tall 1°. (Photos source: Steven B. Kiiskila).

than the Tall 2º seedlings. This height difference occurred because height increment during the first three growing seasons ranked among treatments as follows: Short 2º > Mid 2º > Tall 2º > Tall 1º (figure 4). At the end of the 7th and 13th growing seasons, tree height was no longer significantly different among treatments.

At time of planting, RCD of the Short 2º seedlings was significantly less than that of seedlings in the other three treatments (table 1). By the end of the sixth growing season, seedling diameter was similar among all treatments. In the fall of 2011, diameter at breast height (DBH) was measured and was also not significantly different among treatments. Similarly, no statistically significant ($p = 0.05$) treatment differences existed in stem volume calculated after 7 and 13 growing seasons (figure 5).

At the time of planting, seedling height of the various specification classes increased as expected from the Short 2º treatment up to the two Tall treatments. Diameter of the taller specification classes did not follow the same trend, however, which resulted in varied sturdiness or HTDR among treatments. During the first, second, and third growing seasons, the HTDR of the Short 2º and Mid 2º seedlings stabilized at approximately 40 (table 2). The initially high HTDR of the Tall stock also stabilized at 40, but not until the fifth growing season. The HTDR, although similar among treatments, increased substantially by the end of the 13th growing season.

Discussion

The results of this trial show that although specific sizes of reforestation seedlings may look more aesthetically pleasing, that does not necessarily equate to greater field performance. According to the operational contract specifications, the Mid 2° treatment was the desired or target size seedling for this stock type. The presence of smaller stock, such as the Short 2° treatment, often causes concern among silvicultural practitioners (L. Cosman 1999, personal communication), even if the seedlings are well balanced in regard to height and RCD. Under favorable site conditions, large seedlings generally grow better than smaller seedlings (Iverson 1984, Ritchie 1984, Racey and others 1989, Burdett 1990). More specifically, greater initial seedling height is more often advantageous on sites where vegetation competition is a potential problem (Cleary and others 1978, Newton and others 1993). On this site, later competition existed from aspen, but none from herbaceous

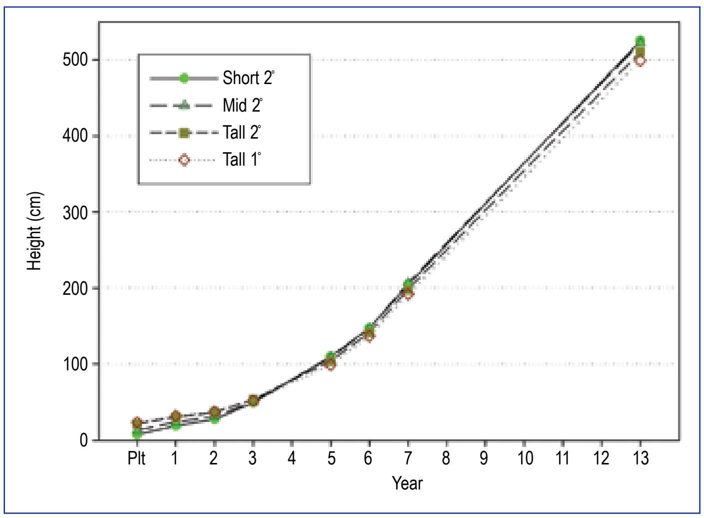

Figure 4. Average height (cm) of seedlings in the four lodgepole pine seedling size/needle morphology treatments from planting (plt = May 1999) through 13 growing seasons (October 2011).

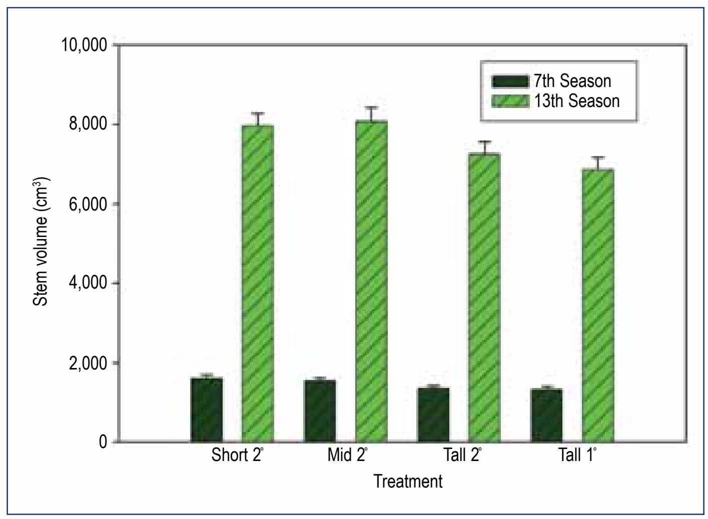

Figure 5. Average stem volume (cm^3) of seedlings in the four lodgepole pine seedling size/needle morphology treatments in October 2005 and October 2011. Vertical bars represent standard errors of the mean.

Table 2. Mean height-to-diameter ratios of seedlings in each treatment during the 13 growing seasons.

Date	Short 2°	Mid 2°	Tall 2°	Tall 1°
At planting	25	41	67	72
Fall 1999	41	51	64	69
Fall 2000	37	41	49	52
Fall 2001	38	39	43	46
Fall 2003	39	39	40	40
Fall 2005	39	41	40	40
Fall 2011	71	70	71	70

2° = primary needles. 1° = secondary needles.

vegetation or woody shrubs during initial seedling establishment. This likely explains the fact that all seedlings were the same height after 3 years, although the Short 2° stock started out two and three times shorter than the Mid 2° and Tall stock, respectively.

Tall, skinny (i.e., high HTDR) seedlings are also not favored by silvicultural practitioners (L. Cosman 1999, personal communication) because they are less able to withstand vegetation, snow press, and other potentially damaging agents compared with more sturdy stock (Noland and others 2001). The initial HTDR of seedlings in the Mid 2° treatment was the same during the first seven growing seasons after planting (table 2), and seedlings in the three other treatments converged around that same HTDR within 3 to 5 years, suggesting that the target height and RCD specifications for this stock type are appropriate. For the first 5 years after planting, the less sturdy Tall seedlings allocated more resources into stem diameter than to height, while in contrast, the Short 2° seedlings initially allocated more resources to height growth. Although Tall seedlings were less sturdy than seedlings in the shorter treatments, it is worth noting that, with an average HTDR of 70, the Tall seedlings were still considered adequately sturdy; the maximum height divided by minimum RCD results in a maximum allowable HTDR of 114 for this stock type. The fact that initial seedling sturdiness had no influence on survival or growth on this site is likely due to the lack of vegetative competition. In addition, Thomson and McMinn (1989) reported that growth rate in northern B.C. was related to size at first measurement for white spruce (*Picea glauca* [Moench] Voss), but not for lodgepole pine.

Although primary-needle pine has less foliage, and thus less transpirational area, secondary-needle pine is often considered more resistant to drought stress. Presently, this assumption is based more on appearance than anything, because no significant evidence in the literature supports enhanced field performance of one needle type over the other (Omni and others 1992, Mustard and others 1998). Either way, this hypothesis was not fully put to the test in this trial since drought was not an issue during establishment on this cold, northern site. Some silviculture practitioners are also concerned that primary needles may have a greater vulnerability to solarization soon after planting in comparison to secondary needles. This greater vulnerability was the case in this trial because solarization was responsible for the initial low vigor ranking of the Tall 1° treatment. Although this lack of vigor initially makes the tree look rather unsightly, frozen-stored, spring-planted stock have bud-flush and grow new secondary foliage within a couple weeks after planting. Primary-needle pine has been shown to have greater shoot growth potential after planting because of the increased stem units in the single, large terminal bud compared with the whorl of buds and smaller terminal bud found on secondary-needle pine (Thompson 1976, 1981). The whorl of buds on secondary-needle pine initially result in a bushier seedling and are also considered to be advantageous on frost or browse prone sites, providing a backup if the terminal bud is damaged.

As a cultural treatment, a more valid comparison of needle types would be between seedlings grown under conditions to maintain primary needles versus conditions to promote secondary needles. The small minority of seedlings in this trial that maintained primary needles under an extended photoperiod may have resulted from variations within the greenhouse environment or from genetic differences among the seedlings (Clapham and others 2002). Although it is not known why some seedlings maintained primary needles in the nursery, it is clear that on this site there was no advantage to cull seedlings that did not have secondary needles at the time of lift.

Along with growth, survival is an important component of meeting the silviculturist's reforestation goals. In this trial, survival rates were relatively high and similar among all treatments except the Mid 2° treatment, which experienced a slight increase in mortality from insects and disease. The reason for the greater mortality from pests on this treatment is not known, although its middle size ranking among treatments suggests that seedling size was not responsible.

This trial was not designed to determine the optimum seedling size, defined by South and Mitchell (1999) as the stock type that will minimize overall reforestation costs while achieving established goals for initial survival and growth. Rather, results from this trial suggest that grading guidelines for lodgepole pine seedlings grown for sites with minimal herbaceous competition in the central interior of B.C. need not be overly conservative. In the nursery, biological limitations exist for what any given container size can produce for each species. Although the nursery grows to the target specifications of the particular stock type, some variation will always exist because seedlings are biological organisms. Ideal seedling specifications reflect what can be reliably grown in the various container sizes in a cost-effective manner (van Steenis 1994). Thus, seedling specifications for a particular species-stock type combination need not be based primarily on field performance, but based more on what can be economically produced in that container in the nursery year after year. In regard to seedling size, field performance is primarily a function of the silvicultural practitioner choosing the correct stock type for a particular site, based on the specific height and RCD specifications in place for that species-stock type combination.

Since the establishment of this trial, two significant factors affecting reforestation in the interior of B.C. have occurred. The first factor being the gradual switch to more expensive, genetically improved seed from seed orchards, and the scarcity of wild natural seed in some areas due to the mountain pine beetle (*Dendroctonus ponderosae* [Scolytidae]) epidemic. The other being the general economic slump in the forest product industry and the resulting cost cutting by forest companies. In response, some lodgepole pine seedlings are now lifted without specifications, a process often termed as a block run with extractable plug. This process results in a savings by not wasting expensive or scarce seed, and the greater seedling recovery results in reduced seedling production costs. Results from this trial support the move towards relaxed seedling specifications in lodgepole pine planted in the central interior of B.C. on sites with minimal vegetation competition.

Conclusions

The lack of difference among morphological grades of a stocktype in height, DBH, or stem volume after 13 growing seasons suggests that initial seedling size or sturdiness is not a major factor in determining lodgepole pine reforestation success on this type of site with minimal vegetation competition. Also, results from this trial give no reason to cull primary needle lodgepole pine from a population of lodgepole pine seedlings grown under conditions promoting secondary needles. Different results are likely to occur with other species and sites with vegetation competition.

Address correspondence to:

Steven Kiiskila, New Forest Treeworks; e-mail: Steven.Kiiskila@telus.net.

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References

Anonymous. 1998. Provincial seedling stock type selection and ordering guidelines. Victoria, British Columbia, Canada: British Columbia Ministry of Forests, Forestry Division Services Branch: 71 p.

Burdett, A.N. 1983. Quality control in the production of forest planting stock. The Forestry Chronicle. 59(3): 132–138.

Burdett, A.N. 1990. Physiological processes in plantation establishment and the development of specifications for planting stock. Canadian Journal of Forest Research. 20: 415–427.

Clapham, D.H.; Ekberg, I.; Eriksson, G.; Norell, L.; Vince-Prue, D. 2002. Requirement for far-red light to maintain secondary needle extension growth in northern but not southern populations of *Pinus sylvestris*. Physiologia Plantarum. 114(2): 207–212.

Cleary, B.D.; Greaves, R.D.; Owston, P.W. 1978. Seedlings. In: Cleary, B.D.; Greaves, R.D.; Hermann, R.K., eds. Regenerating Oregon forests. Corvallis, OR: Oregon State University Extension Service: 63–98.

DeLong, C.; Tanner, D.; Jull, M.J. 1993. A field guide for site identification and interpretation for the southwest portion of the Prince George Forest Region. In: Land management handbook No. 24. Victoria, British Columbia, Canada: British Columbia Ministry of Forests: 290 p.

Grossnickle, S.C.; Major, J.E.; Arnott, J.T.; Lemay, V.M. 1991. Stock quality assessment through an integrated approach. New Forests. 5: 77–91.

Iverson, R.D. 1984. Planting-stock selection: Meeting biological needs and operational realities. In: Duryea, M.L.; Landis, T.D., eds. Forest nursery manual: production of bareroot seedlings. The Hague, The Netherlands: Martinus Nijhoff/Dr. W. Junk Publishers: 261–266.

Landis, T.D.; Tinus, R.W.; McDonald, S.E.; Barnett, J.P. 1989. Seedling nutrition and irrigation. Volume 4. The container tree nursery manual. Agriculture Handbook 674. Washington, DC: U.S. Department of Agriculture, Forest Service. 119 p.

Montville, M.; Richter, P.; Kiiskila, S. 2002. Planting handbook for interior regions, spring 2002 edition. Armstrong, British Columbia, Canada. 25 p. http://www.prt.com/sites/default/files/planting_handbook_for_interior_regions.pdf. (November 2011).

Mustard, J.; Hawkins, C.; Kooistra, C. 1998. Secondary needle lodgepole pine: What do we get? In: Kooistra, C.M., ed. Proceedings of the 1995, 1996, and 1997 annual meetings of the Forest Nursery Association of British Columbia. Vernon, B.C.: Ministry of Forests: 163–167.

Newton, M.; Cole, E.C.; White, D.C. 1993. Tall planting stock for enhanced growth and domination of brush in the Douglas-fir region. New Forests. 7: 107–121

Noland, T.L.; Mohammed, G.H.; Wagner, R.G. 2001. Morphological characteristics associated with tolerance to competition from herbaceous vegetation for seedlings of jack pine, black spruce, and white pine. New Forests. 21: 199–215.

Omi, S.K.; Eggleston, K.L.; Marshall, J.D.; Wenny, D.L. 1993. Primary vs. secondary needle development in lodgepole pine: update on current investigations from Coeur D'Alene nursery. In: Kooistra, C.M., ed. 12th annual meeting of the Forest Nursery Association of British Columbia. Vernon, British Columbia, Canada: Ministry of Forests: 35–42.

Racey, G.D.; Glerum, C.; Hutchison, R.E. 1989. Interaction of stock type and site with three coniferous species. Forest Research Report 124. Ontario: Ministry of Natural Resources, Ontario Forest Research Institute. 12 p.

Ritchie, G.A. 1984. Assessing seedling quality. In: Duryea, M.L.; Landis, T.D., eds. Forest nursery manual: production of bareroot seedlings. The Hague, The Netherlands: Martinus Nijhoff/Dr. W. Junk Publishers: 243–259.

Sinclair, S.; Wilder, N. 1997. Silviculture Prescription, Forest License A55578, L & M Lumber Ltd., Cutting Permit 100, Block 670. Unpublished report.

South, D.B.; Mitchell, R.J. 1999. Determining the "optimum" slash pine seedling size for use with four levels of vegetation management on a flatwoods site in Georgia, U.S.A. Canadian Journal of Forest Research. 29(7): 1039–1046.

Thompson, S. 1976. Some observations on the shoot growth of pine seedlings. Canadian Journal of Forest Research. 6(3): 341–347.

Thompson, S. 1981. Shoot morphology and shoot growth potential in 1-year-old Scots pine seedlings. Canadian Journal of Forest Research. 11(4): 789–795.

Thomson, A.J.; McMinn, R.G. 1989. Height growth rates of young white spruce and lodgepole pine. Canadian Journal of Forest Research. 19: 257–261.

van Steenis, E. 1994. Developing container conifer seedling specifications: A balanced approach? In: Landis, T.D.; Dumroese, R.K., tech. cords. National Proceedings, Forest and Conservation Nursery Associations. General Technical Report RM-257. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 85–92.

Wenny, D.L.; Dumroese, K.R. 1991. A growing regime for container-grown Scotch and Austrian pine seedlings. Moscow, ID: University of Idaho, Idaho Forest, Wildlife and Range Experiment Station, College of Forestry, Wildlife and Range Sciences. 8 p.

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