Tree Planters' Notes

United States Department of Agriculture
Forest Service

Spring 2015
Volume 58, Number 1

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

TPN is sponsored by the Cooperative Forestry Staff of the U.S. Department of Agriculture (USDA), Forest Service, State and Private Forestry Deputy Area, in Washington, DC. The Secretary of Agriculture has determined that the publication of this periodical is necessary in the transaction of public business required by law of this Department.

Editor: Diane L. Haase

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Web site: http://www.RNGR.net/publications/tpn

E-mail: DLHaase@fs.fed.us

Printed on recycled paper.

Spring 2015

Dear TPN Reader

I'm pleased to begin a 5th year as your editor for this long-lasting and unique resource. I know of no other widely distributed publication available that focuses on applied technical information about nursery production and outplanting for reforestation, restoration, and conservation. Because of this, I rarely turn down a submission and work very hard with many authors to turn their manuscripts into good, solid, useful articles worthy of sharing. Recently, a potential author submitted a manuscript that simply was not within the scope of TPN; so, reluctantly, I rejected it. Nonetheless, the author really wanted to publish it in TPN because, as he put it, "much of the info contained is actually useful." Therefore, he is working to rewrite his manuscript in the context of reforestation, and you will likely see it in a future issue. Feedback such as this reaffirms that the many hours I spend on each issue are worth the effort!

This issue includes two articles by Starkey, Enebak, and South with comprehensive information about bareroot (page 4) and container (page 18) forest seedling nursery practices in the Southern United States. The articles are based on a 2012 survey of nurseries in the 13 Southern States. It has been more than three decades since a similar survey was done for bareroot nurseries. A survey, such as this, had never been done for container nurseries. Also in this issue, Hitchcox gives an overview of the phases of pest invasions, the safeguards needed to prevent or contain invasions, and a summary of some exotic insect pests with potential to affect plants in the nursery and in the forest (page 27). In their article, Regan, Apostol, and Davis (page 37) present results from a study that evaluated the effects of two container sizes, with and without copper root pruning, on 6-year field performance of western white pine seedlings. Jetton and colleagues (page 42) describe a project aimed at mitigating the decline of table mountain pine by targeted collections and long-term storage of seeds. (Note: In the Fall 2013 issue of TPN, another article by Jetton and colleagues described a similar project to conserve Eastern and Carolina hemlocks.)

This is the first issue without an addition to TPN's State-by-State series. Since 2011, 19 States have been profiled, and another will be included in the Fall 2015 issue. It can be quite a challenge to persuade authors to write these articles, but I am determined to eventually profile all 50 States and the U.S.-affiliated islands. I highly encourage folks to recruit co-authors and "divide and conquer" so that it is an easier endeavor. If you would like to volunteer to write the paper for your State (or to nominate someone), please contact me.

Best Regards,

Diane L. Haase

The best time to plant a tree was 20 years ago. The next best time is now. ~Chinese Proverb

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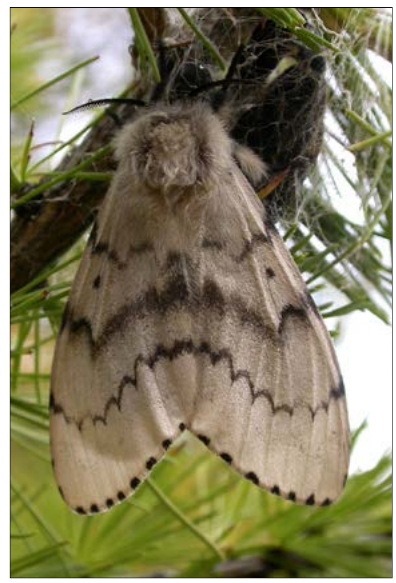

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Forest Seedling Nursery Practices in the Southern United States: Bareroot Nurseries

Tom E. Starkey, Scott A. Enebak, and David B. South

Research Fellow, Southern Forest Nursery Management Cooperative, School of Forestry and Wildlife Sciences, Auburn University, Auburn, AL; Professor of Forest Pathology and Director of the Southern Forest Nursery Management Cooperative, School of Forestry and Wildlife Sciences, Auburn University, Auburn, AL; Professor Emeritus, School of Forestry and Wildlife Sciences, Auburn University, Auburn, AL

Abstract

Nearly 80 percent of the 1.1 billion forest seedlings grown in 2012 in the United States were produced in the 13 Southern States. A survey of current nursery practices for southern bareroot nurseries was compiled and the results presented and compared with a similar survey conducted in 1980. Most notable changes during the past 32 years include reduction in the number of nurseries growing seedlings (including the phase-out of all Federal nurseries), increase in production capacity of industrial nurseries, more seedlings produced by the private sector, a shift in growing more crops under a single fumigation regime, the development of synthetic soil stabilizers, the widespread appearance of the weed spurge, the development of more efficacious fungicides for the control of fusiform rust and other diseases, root and top pruning of seedlings to facilitate the widespread use of full-bed belt lifters, the use polyacrylamide gels to protect roots system after lifting, the use of seedlings bags and boxes for shipping seedlings, and the use of migrant and legal foreign nationals as a source of nonpermanent labor.

Introduction

In 2012, more than 1.1 billion bareroot and container conifer seedlings were produced for reforestation in the United States (Harper et al. 2013), of which nearly 80 percent were produced in the 13 Southern States (table 1).

Table 1. Bareroot seedling (conifer and hardwood) production and percentage of total production by region.

Region	Bareroot seedlings produced	Bareroot percent by region
Southern	755,413,000	82.4
Northeast	8,828,000	1.0
North Central	57,701,000	6.3
Great Plains	5,430,000	0.6
Intermountain	3,301,000	0.4
Pacific Northwest	85,890,000	9.4
Pacific Southwest	—	—
Region Totals	916,563,000	

Source: Harper et al. (2013)

There have been several surveys of forest nursery practices since 1950 (Abbott 1956, Abbott and Eliason 1968, Abbott and Fitch 1977, Boyer and South 1984). These surveys can be used to document changes in technology and method of seedling production. Three surveys included nurseries throughout the entire United States (Abbott 1956, Abbott and Eliason 1968, Abbott and Fitch 1977). In 1917, a detailed report, not a survey, primarily describing equipment, growing techniques, and facilities at five U.S. Department of Agriculture (USDA) Forest Service nurseries was published for the interest and value “to all who are engaged in nursery work with forest trees” (Tillotson 1917:1). Because southern pines account for more than three-fourths of the total seedlings grown for reforestation in the United States, a 1980 survey of production practices for bareroot southern pine seedlings was conducted (Boyer and South 1984). The 1980 survey was the most recent survey of bareroot nursery practices; although annual surveys of seedling production numbers were initiated by the Southern Forest Nursery Management Cooperative (Nursery Cooperative) in 1997.

Since 1972, the Nursery Cooperative has worked with forest seedling nurseries to increase seed efficiency and seedling quality. The area represented by this research-based cooperative includes Alabama, Arkansas, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, (east) Oklahoma, South Carolina, Tennessee, (east) Texas, and Virginia (figure 1). Nurseries that are members of this cooperative grew more than 84 percent of the total seedlings produced in the Southern United States (Enebak 2012). Since the 1980 survey, many changes have occurred in seedling production practices. The purpose of this article is to document current nursery practices employed in southern bareroot conifer nurseries and changes that have occurred in the 32 years since the 1980 survey. Nursery practices in southern container conifer nurseries are documented in a companion manuscript, *“Forest Seedling*

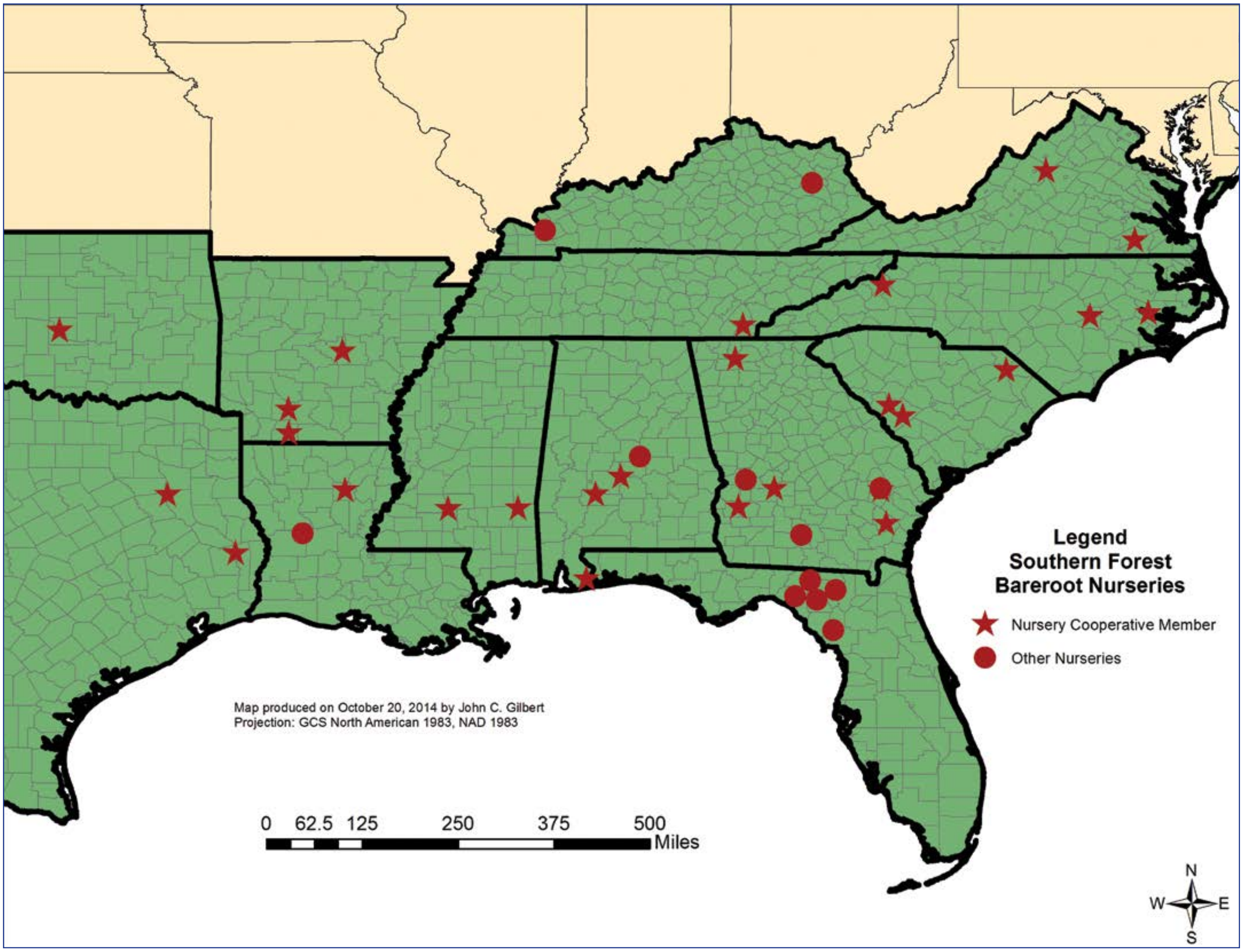

Figure 1. Southern States included in the bareroot survey and location of Nursery Cooperative and nonmember nurseries. (Map by John Gilbert 2014)

Nursery Practices in the Southern United States: Container Nurseries," also appearing in this issue of *Tree Planters' Notes*.

The Nurseries

In June 2012, a 28-page survey of nursery practices was mailed to 40 bareroot forest seedling nurseries in the 13 Southern States (figure 1) with completed returns received from 35 managers of which 26 were Nursery Cooperative members. Because some nursery managers choose not to answer some questions, results are based on the number of nursery managers responding to a question. In 1980, 63 bareroot nurseries received the nursery survey and 50 nurseries participated in the survey (Boyer and South 1984). For our purposes, nursery ownership was categorized as State (nursery owned by the State), industry (nursery owned by a company that also owns land and production facilities such as mills), or private (owned by a company with no land ownership or production facilities). In 1980, the Nursery Cooperative had 19 industry, 12 State, 1 Federal, and 0 private members. The first private nursery joined the Nursery Cooperative in 1988. Nursery closures and mergers have dramatically changed nursery ownership and production capacities. Since 1995, at least 28 nurseries in the Southern Region have shut down with a potential reduction in annual seedling production of more than 617 million (table 2). Some of this lost production has been recovered as remaining nurseries have increased seedling production by either expanding existing production systems or increasing the number of crops per rotation. The net reduction is estimated at 480 million seedlings (Sharp 2014). The effect of these mergers and acquisitions reduced Nursery Cooperative membership (2012) to 16 members (i.e., 3 industry, 4 private, 8 State, and 1 Federal) operating 28 nurseries (figure 1).

Table 2. Southern bareroot forest nursery closures and production losses by ownership type since 1995.

Year	Production
Industry	
1996	40,000,000
1999	10,000,000
2001	32,000,000
2001	25,000,000
2002	30,000,000
2002	22,000,000
2007	35,000,000
2010	30,000,000
2010	35,000,000
2010	30,000,000
2012	22,000,000
Total Industry	311,000,000
Private	
2000	15,000,000
2002	15,000,000
2003	25,000,000
2004	30,000,000
2005	33,000,000
2007	15,000,000
2009	8,000,000
Total Private	141,000,000
State	
1995	18,000,000
1996	15,000,000
1996	18,000,000
1997	25,000,000
2000	20,000,000
2005	12,000,000
2007	20,000,000
2007	5,000,000
2007	20,000,000
Total State	153,000,000
Federal	
2000	12,000,000
Grand Total	617,000,000

Sources: Sharp (2014), South (2014)

The oldest nurseries in the 1980 survey were the Miller State Nursery in Alabama, which operated from 1934 to 1993 and the Ashe Nursery in Mississippi that was operated by the USDA Forest Service from 1936 to 2000 (Boyer and South 1984). In 2012, the oldest reporting nurseries were the State nursery in Goldsby, OK, which began operation in 1947 and the State nursery in Goldsboro, NC, which began operation in 1954. The oldest private nursery was Superior Trees in Lee, FL, which began seedling production operations in 1953.

Seedling Production

In the 2012 season (i.e., the winter of 2011–2012), the total conifer and hardwood seedling production for both stock types (bareroot and container) in the South exceeded 936 million seedlings. This year was the third consecutive year that production fell to less than 1 billion seedlings since the Nursery Cooperative began tracking annual seedling production in 1997, and continues a downward trend in total seedling production that began in 2002. Hardwood production accounted for approximately 4 percent of the total seedling production in the South (Harper et al. 2013) and is not included in this paper.

In the Southern United States, bareroot loblolly pine (*Pinus taeda* L.) accounted for 86 percent of the total conifer production followed by slash pine (*P. elliottii* Engelm.) at 11 percent and longleaf pine at 1 percent (*P. palustris* Mill.) (Enebak 2012). The percentage of loblolly pine production was up since 1980 when it accounted for 77 percent of bareroot conifers (table 3) (Boyer and South 1984). During the early 1930s, longleaf pine and slash pine were the predominant conifers produced; no loblolly pines were grown (Boyer and South 1984). In 2012, 80 percent of seedlings produced in the Southern United States were bareroot whereas, in 1980, 99.8 percent were bareroot (Boyer and South 1984). The choice of stock type differs among the three major southern pine species. More than 91 percent of loblolly pine and 95 percent of slash pine were produced as bareroot stock whereas less than 4 percent of longleaf pines were produced as bareroot stock (Enebak 2012).

In 2012, nurseries in Georgia produced a total of 303.3 million seedlings, more than 2.7 times the seedlings produced by nurseries in South Carolina, the next highest State in production number (Enebak 2012). The largest number of forest seedling nurseries (13 bareroot and container) was found in Georgia, which explains why it has been the top seedling producer for years. The largest individual nursery (based on production) was an industry nursery located in South Carolina.

Private and industry nurseries produced 49 and 38 percent of the seedlings in the Southern United States, respectively. Although the State nurseries produced only 13 percent of conifer seedlings, they produced 40 percent of the bareroot hardwoods (Enebak 2012).

Generally, nursery production per nursery has increased from less than 1 million seedlings in 1934 to 17 million in 1980 (Boyer and South 1984), then decreased to 13 million in 2012. In 1980, State and Federal nursery annual seedling production averaged 22 million while in 2012 State nurseries averaged 6 million. By contrast, industry nurseries averaged 18 million seedlings produced per year in 1980 (Boyer and South 1984) and 29 million in 2012. On a per seedling basis, fixed costs have increased for State nurseries while they have decreased for industry nurseries.

Table 3. Conifer species grown in southern bareroot forest nurseries in 1980 and 2012.

Species	Scientific name	1980 bareroot production	1980 percent of bareroot total	2012 bareroot production	2012 percent of bareroot total
Loblolly pine	*Pinus taeda* L.	965,620,000	77.1	615,588,000	85.7
Slash pine	*P. elliottii* Engelm.	167,214,000	13.4	80,042,000	11.1
White pine	*P. strobus* L.	22,640,000	1.8	1,834,000	0.3
Shortleaf pine	*P. echinata* Mill.	12,914,000	1.0	1,548,000	0.2
Longleaf pine	*P. palustris* Mill.	10,293,000	0.8	5,247,000	0.7
Sand pine	*P. clausa* (Chapm. ex Engelm.) Vasey ex Sarg.	8,175,000	0.7	6,204,000	0.9
Virginia pine	*P. virginiana* Mill.	6,858,000	0.5	1,069,000	0.1
Scots pine	*P. sylvestris* L.	1,220,000	0.1	1,069,000	0.1
Spruce pine	*P. glabra* Walter	157,000	< 0.1	11,000	< 0.1
Pond pine	*P. serotina* Michx	30,000	< 0.1	219,000	< 0.1
Other pines		54,420,000	4.3	1,411,000	0.2
Red cedar	*Juniperus virginiana* L.	1,807,000	0.1	230,000	< 0.1
Baldcypress	*Taxodium distichum* (L.) Rich.	290,000	< 0.1	3,870,000	0.5
Arizona cypress	*Hesperocyparis arizonica* (Greene) Bartel	31,000	< 0.1	0	0.0
Totals		**1,251,669,000**		**718,344,000**	

Sources: Boyer and South (1984), Enebak (2012)

In 2012, a range of genotypes was used for reforestation in the South. Nearly all the longleaf pine sold in 2012 were wild collected, with seed collected from production areas rather than specific families selected for specific traits. Most loblolly and slash pine seedlots sold in 2012 were grown from second-generation improved seed (table 4). Although most loblolly and slash pine seedlots were open pollinated, a portion were from controlled, mass-pollinated selections. The industry and larger private nurseries with access to seed orchards tend to market the advanced genetic seedlots. In addition, a small portion of the 2012 loblolly pine crop was clonal stock produced for CellFor Inc. using somatic embryogenesis (Grossnickle and Pait 2008).

Table 4. Bareroot seedlot genetics sown in 2012 in southern bareroot forest nurseries. More than one genotype was listed for most nurseries.

Species	Genetics	Percent sown
Loblolly pine (n = 29)	1st generation	8
	2nd generation	57
	3rd generation	16
	Advanced	19
Slash pine (n = 14)	1st generation	9
	2nd generation	75
	3rd generation	5
	Advanced	11
Longleaf pine (n = 4)	Wild	91
	Improved	9

Nursery Soils

Texture

In 1980, 74 percent of nurseries were built on soils with more than 75 percent sand (Boyer and South 1984) (table 5). In 2012, this percentage was nearly the same but also reflected a shift toward sandier sites. Since 1980, 7 out of 13 newly established nurseries were located on soils with more than 75 percent sand and 6 nurseries were established on sites with more than 88 percent sand. Soils with high sand content have several advantages, including they (1) are conducive to mechanical lifters; (2) drain quickly following a rain event, thereby allowing for quick access into the fields; (3) warm up faster in the spring for sowing; and (4) have good permeability. A minor disadvantage is that coarse-textured soils may have lower cation exchange capacity and require more fertilizer to achieve seedling growth targets. For at least a century, it has been known that it is much easier to add fertilizer to a sandy soil than to manage seedlings on a clay soil (Tillotson 1917). Likewise, Wakeley (1935:37) said "Fairly sandy soils frequently meet all forest nursery requirements if they are underlain by less pervious soils. The cost of enriching such soils with various fertilizers is offset by greater ease of working, and most pine species develop better root systems in light than heavy soils."

Table 5. Soil types in southern bareroot forest nurseries in 1980 and 2012.

Soil type	Description	Percent in 1980 (n = 51)	Percent in 2012 (n = 31)
Sand/loamy sand	More than 75 percent sand	33	38
Sandy loam	52 to 75 percent sand	41	35
Sandy clay loam	More than 45 percent sand and 20 percent clay	16	15
Loam/silt loam	Less than 52 percent sand to more than 50 percent silt	10	12

Source for 1980 data: Boyer and South (1984)

Organic Matter

Nurseries located in the Coastal Plain are characterized by low soil organic matter when compared with nurseries located in the Piedmont region and more northern portions of the country. The median percent soil organic matter for nurseries with sandy or loamy sand soil in 2012 was 1.6 percent (table 6) compared with 1.7 percent in 1980 (South and Davey 1983). The methodology used to calculate soil organic matter, however, was not queried in either survey. The traditional Walkley and Black or Modified Walkley and Black methods will generally return a lower measure of soil organic matter than the loss on ignition method for soils in the coastal plain region (Tuffour et al. 2014).

In 2012, most managers (85 percent) reported that they have a regular program to increase soil organic matter other than the use of a cover crop as compared with 66 percent in 1980 (Boyer and South 1984). Although many organic amendments are available, 48 percent of the 27 managers responding in 2012 applied sawdust to the production units before fumigation to increase soil organic matter. The median amount of sawdust applied in 2012 was 61 yd^3/ac (115 m^3/ha). Bark was the second most common amendment (table 7).

The level of soil organic matter has become more of an issue because of recent changes in soil fumigation rules. The area of land that can be fumigated at any one time is now determined by "buffer zones" that must surround the fumigated land and cannot be entered for 3 days. Factors such as proximity of neighbors, ownership of adjoining land, and location of nursery buildings dictate the maximum acreage that can be fumigated daily. According to the Environmental Protection Agency (EPA) regulations, these buffer zones can be reduced with the use of new high-barrier plastic tarps such as totally impermeable film and by increasing the level of soil organic matter in the soil. Nurseries with 1 to 2 percent soil organic matter receive a 10-percent reduction credit, those with 2 to 3 percent receive a 20-percent reduction credit, and those with more than 3 percent receive a 30-percent reduction credit.

Table 6. Percent organic matter for southern bareroot forest nurseries in 2012.

Percent organic matter	Percent of nurseries (n = 34)
Less than 1.0	6
1.0 to 1.4	32
1.5 to 2.0	21
2.1 to 2.4	21
2.5 to 2.9	15
More than 3	6

Table 7. Organic matter materials used by southern bareroot forest nurseries to increase soil organic levels. Some managers reported using more than one type of material.

Organic matter	Percent of nurseries in 1980 (n = 50)	Percent of nurseries in 2012 (n = 27)
Sawdust	54	38
Bark	24	32
Gin compost	0	6
Wood chips	12	6
Mill grit	0	3
Other	10	24
None	34	15

Source for 1980 data: Boyer and South (1984)

Cover Crop/Fallow

Nurseries rotate their land with fallow and cover crop for many reasons including improving soil structure, addressing soil microbiology issues, and managing weed or nematode problems. In 2012, nursery land in cover crop or fallow was 53 percent (of the total cropland), which was similar to that in 1980 (Boyer and South 1984). By ownership class, the amount of land in cover crop or fallow in 2012 was 65 percent for State nurseries, 65 percent for private nurseries, and 35 percent for industry nurseries. Industry and larger private nurseries have less land in fallow or cover crop because of changes in production rotation. In 1980, 56 percent of industry nurseries followed a 1:1 seedlings:cover crop rotation while, in 2012, they used either a 2:1 or 3:1 rotation (2 to 3 years of seedling production followed by 1 year of cover crop/fallow). Extending the rotation length reduces fumigation costs and keeps land in production longer. This shift in rotation for industry and larger private nurseries might also help explain why soil organic matter has not increased from 1980 to 2012. In 1980, managers applied organic matter to nonproduction units every other year before fumigation. With a rotation shift to 2:1 or 3:1, organic matter is applied only every 3 to 4 years, which might have decreased the total amount of organic matter added to a field over time (assuming application amounts were not adjusted).

In 2012, 78 percent of nurseries used either millet (*Panicum ramosum* L.) or *Sorghum* spp. as a summer cover crop, which has not changed from the cover crops used in 1980. The application of fertilizer to the summer crop was done regularly in 2012 by more than 90 percent of the nurseries. In both 2012 and 1980 (Boyer and South 1984), a winter cover crop of rye (*Lolium* spp.) was the most popular used by nursery managers. In 2006, a strong relationship between cover crop type and stunt nematode (*Tylenchorhynchus claytoni*) and stubby-root nematode (*Paratrichodorus minor*) populations was reported (Cram and Fraedrich 2009). Since this report, nurseries that traditionally have nematode problems use cover crops other than corn or sorghum, which are hosts for these nematodes. Leaving production land fallow is a method that

45 percent of nurseries in 2012 reported using. The most common reason nurseries use fallow land is the ability to aggressively address weed problems using glyphosate.

Cultural Practices

Sowing

Before 1980, most managers used gravity-drop seed sowers such as Whitfield®, Love Oyjord®, Stanhay®, or Planet Junior® (Boyer and South 1984). Soon afterward, precision vacuum drum sowers became available and several were put into use in nurseries throughout the Southern United States. In the 2012 survey, gravity sowers were the most frequently used method for sowing seed (table 8, figure 2). A study by Boyer et al. (1985) found that a vacuum sower was more precise in seed placement and resulted in less seedling culls relative to gravity sowers. Slower speed and higher maintenance are two reasons vacuum sowers are not more commonly used today, however.

Nursery managers strive to complete sowing in a minimum number of days because uniformity in germination across a nursery greatly facilitates seedling management during the growing season. In 2012, nurseries that produced more than 20 million seedlings sowed an average of 5.4 million seeds per day to complete sowing in an average of 8 days. Nurseries that used a gravity sower sowed 700,000 more seeds per day than those nurseries that used a vacuum sower. Larger nurseries using a vacuum sower will frequently use more than one vacuum sower to complete the sowing operation in a shorter timeframe. Smaller nurseries that produced less than 20 million seedlings sowed an average of 1.8 million seeds per day to complete sowing in an average of 4 days.

Table 8. Sowing machines used in southern bareroot forest nurseries in 2012 to sow conifers. Some managers reported using more than one type of machine.

Machine	Mode of operation	Percent of nurseries (n = 34)
Love/Oyjord®	Gravity	50
Whitfield®	Gravity	38
Summit®	Vacuum	32
Love Vacuum®	Vacuum	6
Silver Mountain®	Vacuum	3

Approximately 60 percent of managers queried in 2012 began sowing in mid-April (table 9). Nurseries with coarse-textured soils tend to sow earlier than nurseries with finer textured soils that tend to warm up later in the spring. Before sowing, seed preparation such as stratification, is done on site at 62 percent of the nurseries in 2012. The remaining nurseries obtained stratified seed from a seed facility operated within their organization or from another nursery. Seed treatments that include fungicides for control of fusiform rust (*Cronartium querccum* f. sp. *fusiforme*) and/or bird or animal repellants were used by 82 percent of nurseries. In addition, 80 percent of nurseries used latex as a chemical sticker. The type of latex used ranged from store-purchased paint to latex from Dow Chemical.

Seedling root collar diameter (RCD) increases as seedbed density decreases. In 2012, the average seedbed density for loblolly and slash pines was 24 seedlings/ft^2 (258 seedlings/m^2)

Table 9. Starting date for sowing conifers in southern bareroot forest nurseries.

Date	Percent of nurseries (n = 31)
Late March	3
Early April	23
Mid April	60
Late April	13

Figure 2. Machines used to sow a bareroot nursery (A) Vacuum precision drum sower (Silver Mountain Equipment®) and (B) Gravity drop sower (Love®). (Photos by Tom Starkey, 2009 and 2014)

and for longleaf pine was 13 seedlings/ft^2 (140 seedlings/m^2). These densities have changed little during the past 32 years in southern bareroot forest nurseries.

Since the 1980 survey, synthetic soil stabilizers (e.g., Agrilock®) have been introduced to reduce bed washout and seed losses soon after sowing. Effective stabilizers also maintain seedbed integrity over most of the growing season. In 2012, 72 percent of nurseries reported using synthetic soil stabilizers. At three nurseries, bark mulch and a soil stabilizer were used either on all production units or on nursery beds adjacent to riser lines to prevent washout from the irrigation system. The use of synthetic soil stabilizers is a major change from 32 years ago. In 1980, hydromulch was a common choice in industrial nurseries whereas other nurseries favored pinestraw, sawdust, or bark (Boyer and South 1984). In 2012, the only mulch reported used to cover seedbeds was bark mulch, although it did little to keep seed in place or maintain seedbed integrity during heavy rainfall events.

Irrigation

In 1980, less than 33 percent of southern bareroot forest nursery managers monitored soil moisture as compared with 100 percent in 2012. In 2012, more than 75 percent used a subjective visual and tactile soil assessment, while 8 percent used objective methods such as tensiometers or electronic soil moisture devices. One manager asserts that an objective method reduces over-watering and increases development of fibrous seedling root systems (Weatherly 2014).

Managers reporting satisfaction with their irrigation systems (70 percent) remained the same for both surveys. In 1980 and in 2012, impact head irrigation systems were the predominant irrigation method. In 2012, one manager reported using a center pivot irrigation system exclusively and another reported using both the center pivot and the impact head systems (figure 3). The riser/nozzle layout for impact head irrigation systems are designed in square/rectangular patterns (62 percent) or a rhomboid pattern (in which nozzles on adjacent riser lines are staggered). In 2012, 55 percent of nurseries used well water for irrigation. Other sources of irrigation water included surface ponds, streams, and rivers. Some nurseries (15 percent) used other water sources, providing a backup in case the primary source runs into problems during the growing season.

The amount of water applied during a growing season varies with soil texture and seedling growing phase. Depending on rainfall, the median amount of water applied in 2012 during germination and seedling growth was 1 in/wk (2.5 cm/wk). As seedlings are hardened off in preparation for lifting, the

Figure 3. Oscillating impact head irrigation system used by nearly all bareroot nurseries in Southeast. (Photo by Tom Starkey 2014)

median amount of water applied per week dropped to 0.5 in/wk (1.3 cm/wk). Many nurseries (88 percent) also used irrigation to cool the seedlings during the summer to avoid heat problems. Short periods of irrigation can reduce bed temperatures by 20 °F (11.1 °C) and ambient air temperatures by 10 to 15 °F (5.6 to 8.3 °C) (May 1984). When air temperatures exceed 93 °F (34 °C) in 2012, most nurseries applied irrigation to reduce bed temperatures regardless of recent precipitation. Despite measures to cool nursery beds and seedlings, 83 percent of responding southern bareroot forest nursery managers indicated they have experienced heat-related problems in seedling growth.

Four nurseries (12 percent) regularly irrigated at night in 2012, and 50 percent have considered night irrigation as an option for their production system. In 2012, lack of labor was listed as the primary concern about night watering and reduced ability to spot problems was the primary concern in 1980 (Boyer and South 1984). Managers also had concerns about disease increases in 2012, but this concern may not be based on scientific data because plants are commonly wet at night from rainfall or heat loss to the atmosphere. Seedling surface moisture (dew) quickly evaporates when the sun rises. In the 1930s, night irrigation was preferable because of reduced evaporative loss, thereby resulting in increasing water penetration into the soil (Wakeley 1935).

Fertilization

In 2012, more than 50 percent of managers used a private consultant for fertilization recommendations of bareroot seedbeds and 25 percent used personnel within their company to determine fertilizer needs. In 2012, both granular and liquid inorganic fertilizers were used. More than 70 percent of managers purchased granular fertilizer by the bag rather than bulk whereas 83 percent use bulk liquid fertilizers. Nearly 60 percent of nurseries used some form of urea as their primary nitrogen source (figure 4). Iron was the most frequent micronutrient used to treat nutrient problems. In 2012, 29 different fertilizers formulations were listed for growing loblolly pine. In 1980, potassium was "often applied" (Boyer and South 1984) to encourage seedling hardening-off; however, little research data support this practice (Boyer and South 1984). In 2012, 55 percent of nurseries continued to apply potassium in late summer to early fall.

Figure 4. Application of liquid fertilizer while irrigating using a nine-bed sprayer to reduce fertilizer burn to seedlings. (Photo by Scott Enebak 2002)

Pruning

Seedling shoot (top) and root pruning are cultural tools commonly used by southern bareroot nurseries in an effort to achieve seedling target specifications, improve shoot:root ratio, increase crop uniformity, control shoot height, and prepare the seedling for shipping (South and Donald 2002). Although commonly used today (2012), these practices were operationally used at several nurseries in 1980 (exact number of nurseries not reported) and were nonexistent in the 1930s (Boyer and South 1984).

In 2012, 91 percent of southern bareroot nurseries top pruned seedlings; the State-operated nurseries were the only respondents that did not top prune. The first top pruning is usually done in July, with 76 percent of nurseries top pruning again two or three times during the summer.

Root pruning is accomplished by (1) undercutting, which cuts the tap root; (2) root wrenching, which tears the roots and improves bed drainage; and (3) lateral pruning, which separates seedlings in adjacent drills to facilitate lifting with mechanical lifters. Undercutting and lateral root pruning are typically done before lifting. Root wrenching is done to encourage root growth, improve bed drainage, and occasionally to loosen seedlings before lifting. In 2012, 89 percent of responding managers root pruned their crop (53 percent undercut, 26 percent undercut and root wrenched, and 82 percent lateral pruned). State nurseries were the only nurseries that did not root prune.

Undercutting is done with either a horizontal fixed or reciprocating blade that cuts the tap root at 6 to 8 in (15 to 20 cm) below the ground line. Root wrenching uses a fixed blade at a slight angle that tends to tear the roots and breakup the bed's soil profile. Managers who do not lateral root prune must hand lift their seedlings using either a Frobro® or similar seedling harvester that undercuts, lifts, and vibrates the seedling bed while minimizing root damage. In 2012, most managers reported that they initiated root pruning in July or October. Those who indicated July were most likely root wrenching, not undercutting. Those who reported root pruning in October were undercutting their tap roots to help meet target seedling specifications in preparation for lifting.

Integrated Pest Management

Mortality

More than two-thirds of nursery managers in 2012 estimated crop mortality of less than 3 percent caused by factors other than weeds, with an average of 2 percent for all nurseries (table 10). This rate is a significant decrease from the 1980 survey where the average mortality was 11 percent (Boyer and South 1984). Average loss because of bird predation in 2012 was 0.21 percent, which was up slightly from 1980 (Boyer and South 1984). Nurseries reporting seedling loss because of bed washout from early spring rains was significantly lower in 2012 (0.02 percent) compared with 2.6 percent in 1980 (table 10). This reduced loss is most likely because of the widespread use of soil stabilizers applied at sowing, which were not available in 1980. The use of soils stabilizers probably also explain the reduction in losses because of rain splash since 1980.

Fumigation

Integrated pest management begins in all bareroot nurseries with soil fumigation (figure 5). The goal of which is to provide broad control of soil borne diseases, insects, weeds, and nematodes without lasting injury to beneficial organisms. Methyl bromide was the most commonly used soil fumigant in both 1980 (Boyer and South 1984) and 2012. A significant effect on the use of methyl bromide occurred in 1993 when

Table 10. Factors contributing to seedling mortality in southern bareroot forest nurseries in 1980 and in 2012.

Factor	Percent of nurseries in 1980 (n = 51)	Percent loss in 1980 (n = 51)	Percent of nurseries in 2012 (n = 31)	Percent loss in 2012 (n = 31)
Pre-emergent damping off	14	0.58	39	0.23
Post-emergent damping off	33	1.00	71	0.42
Fusiform rust	14	0.16	3	0.01
Rhizoctonia foliar blight	—	—	29	0.12
Nematode	4	0.11	13	0.06
Animals	—	—	61	0.25
Herbicide	24	0.52	42	0.30
Insect	10	0.38	48	0.11
Birds	12	0.16	48	0.21
Hail	—	—	13	0.01
Rain splash	22	0.44	42	0.19
Nutrient deficiency	18	0.20	13	0.04
Wind	12	0.40	3	0.01
Bed washout	59	2.60	3	0.02
Drought	18	0.72	3	0.02

Source for 1980 data: Boyer and South (1984)

Figure 5. Fumigation of bareroot nursery with methyl bromide/chloropicrin under plastic. (Photo by Tom Starkey 2008)

the EPA began an incremental phaseout of methyl bromide (EPA 2014). Although the initial goal was a phaseout by 2005, allowable exemptions using the Critical Use Exemption and the Quarantine and Preshipment permitted continued use in tree nurseries. Since its beginning in the 1970s, the Nursery Cooperative researched alternatives that could be effectively substituted for methyl bromide (Starkey 2012). Although many Nursery Cooperative nurseries have participated in alternative fumigant trials, as of 2012, only 16 percent of responding managers have operationally tried an alternative fumigant.

Use of methyl bromide as the primary fumigant rose from 88 percent in 1980 to 97 percent in 2012 (Boyer and South 1984). Chloropicrin is commonly mixed with methyl bromide to act as a warning agent and to increase efficacy on soil fungi. In 1980, the most common mixture ratio was 98:2 methyl bromide:chloropicrin at an average rate of 357 lb/ac (400 kg/ha) and in 2012, 80:20 was the most common ratio applied at 364 lb/ac (408 kg/ha). During the past 32 years, the amount of methyl bromide (active ingredient) applied per nursery-acre has decreased by 17 percent. This reduction is even greater when changes in crop rotation since 1980 are considered. In addition, the total amount of methyl bromide applied on all nursery land has decreased since 1980 because of nursery closures and mergers. The net seedling loss of 480 million seedlings, discussed previously, represents approximately 775 ac (334 ha) of nursery land no longer needing fumigation. The cost of fumigation (including tarp removal), accounting for inflation, has stayed constant during the past 32 years with a 2012 cost of approximately $2,032/ ac ($5,021/ha). Because of changes in crop rotations, the 2012 cost per thousand seedlings is less than 1980 costs because it is now prorated across three to four crops.

Season and frequency of soil fumigation has changed during the past 32 years. In 1980, one-half of nurseries fumigated their soils after February and one-half fumigated in the fall (Boyer and South 1984). In 2012, 68 percent of southern bareroot nurseries fumigated in the fall. Fall fumigation provides a broader biological window in which fumigation can occur. During October and November, nurseries have more days in which to fumigate before the labor-intensive lifting season begins in December. Also, achieving proper soil temperatures is easier in the fall than the spring, which can be a problem in nurseries located in cooler regions. In 1980, 60 percent of nurseries fumigated a production unit every other year (Boyer and South 1984). In 2012, only 17 percent fumigated every other year, 56 percent fumigated the same production area after two seedling crops, and 27 percent fumigated after three or more seedling crops. With the cost of soil fumigation increasing, more nursery managers are considering the option of fumigating after 3 crop years.

Disease Control

Post-emergent damping off caused the greatest mortality loss in nurseries in 2012 (table 10). The percentage of nurseries reporting damping off as a major cause of mortality was nearly double for 2012 compared with 1980 yet the percent loss decreased by 58 percent from 1980 to 2012. The development of more efficacious fungicides is a primary reason for the decrease in seedling loss because of diseases since 1980.

Fusiform rust is the primary stem disease that managers in southern nurseries must address. The fungus is commonly found within a 150-mi (241-km) wide band extending from South Carolina to Texas (Enebak and Starkey 2012). Basidiospores from the rust fungus are produced in early spring to early summer, coinciding with susceptible seedling germination in the nursery. A notable change from the 1980 survey is the class of fungicides available to control fusiform rust. In 1980, 75 percent of southern nurseries applied Fermate® (ferbam). Because of its lack of rain-fastness, nurseries reportedly made up to 54 applications of Fermate® per season to control fusiform rust (Boyer and South 1984). Bayleton® (triadimefon), a relatively new fungicide in 1980 was reported to be as effective or more effective for the control of fusiform rust (Boyer and South 1984) with only four to five applications per season. In the 2012 survey, 71 percent of nurseries used Bayleton® and 29 percent used Proline® (prothioconazole), a fungicide registered in 2011, which also requires four to five applications per season (Starkey and Enebak 2011). The amount of active ingredient applied in 1980 with Fermate® was more than 4 lb/ac/yr (4.4 kg/ha/yr). With the introduction of Bayleton® the rate dropped to less than 1 lb/ac/yr (1.1 kg/ha/yr) active ingredient and 10 oz/ac/yr (0.7 kg/ha/yr) of Proline®. More efficacious fungicides have resulted in a reduction of seedling losses because of fusiform rust (table10). For example, in 1980, a nursery growing 30 million seedlings may have lost 4.8 million seedlings to fusiform rust whereas in 2012, that same nursery, using better fungicides, may have reduced the loss to 300,000 seedlings.

Other diseases addressed less frequently in nurseries are *Rhizoctonia* foliar blight, pitch canker, and tip blight. A total of 27 fungicides were used to control various seedling foliage, stem, and root diseases in 2012 including Cleary 3336F®, (thiophanate-methyl), Bravo® (chlorothalonil), Chipco 26019® (iprodione), and Banner Maxx® (propiconazole).

Insect Control

Nurseries reported annual losses because of insects to be less than 1 percent in 2012, which is less than the 1 to 2 percent reported in the 1980 survey (Boyer and South 1984). Most of the seedlings reported damaged by insects in 2012 (25 percent) were attributed to the tarnished plant bug (*Lygus lineolaris* Miridae and/or *Taylorilygus* spp.). Losses from these insects were not recognized as a problem before 1982 (South 1991). Southern bareroot forest nurseries commonly use Asana® (esfenvalerate) and permethrin-based insecticides to control insects.

Weed Control

Many of the same troublesome weeds appear on the 1980 and 2012 surveys (table 11). The prevalence of certain weed species, however, has changed dramatically during the past 32 years. In 1980, only one nursery mentioned spurge (*Euphorbia* spp.) as a troublesome weed (Boyer and South 1984). In 2012, spurge was mentioned by 22 nurseries (65 percent) (table 11) and considered the most troublesome weed by 19 percent of managers. Managers listed yellow nutsedge (*Cyperus esculentus* L.) and purple nutsedge (*C. rotundus* L.) as troublesome weeds in both 1980 and 2012, although the percentage that indicated nutsedge was the most troublesome weed has decreased since 1980 (table 11). This decrease in "troublesomeness" may be attributed to aggressive weed control during the crop and cover/fallow periods. This approach has been called the "24/7 weed management program" (South 2009).

Table 11. Most troublesome weeds in southern bareroot forest nurseries reported in 1980 and 2012. Some managers listed more than one species.

Weed	Scientific name (genera)	Percent of nurseries in 1980 (n = 47)	Percent of nurseries in 2012 (n = 31)
Crabgrass	*Digitaria*	64	12
Nutsedge	*Cyperus*	62	44
Bermuda grass	*Cynodon*	36	6
Purslane	*Portulaca*	30	—
Morning glory	*Ipomoea*	28	35
Sicklepod	*Arabis*	23	18
Goose grass	*Acrachne*	23	3
Carpetweed	*Mollugo*	17	
Fennel	*Eupatorium*	13	3
Clover	*Dalea* spp.	6	3
Barnyardgrass	*Echinochloa*	6	—
Florida pusley	*Richardia*	4	—
Broomsedge	*Carex; Andropogon*	4	—
Cocklebur	*Xanthium*	4	—
Crowfoot grass	*Dactyloctenium*	4	—
Flathead sedge	*Cyperus*	4	12
Spurge	*Euphorbia*	2	65
Coffee weed	*Senna*	—	15
Water weed	*Eclipta*	—	6
Willow	*Salix*	—	9
Other	—	40	32

Source for 1980 data: Boyer and South (1984)

The most common source of weed seed in 1980 was windblown seed from adjacent areas and mulch used to cover recently sown nursery beds (Boyer and South 1984). In 2012, 82 percent of nurseries reported windblown seed as the most common source of weed seeds followed by irrigation water and mulch. Nursery Cooperative members also cite "lack of chemical efficacy" as a common weed control issue. The lack of chemical efficacy can sometimes be attributed to mixing chemicals with hard water that can tie-up the active ingredients in some herbicides or the use of off-patent chemicals. In 1980, nurseries were still transitioning from the widespread use of mineral spirits to herbicides such as Goal® (oxyfluorfen) and Roundup® (glyphosate). The availability of off-patent herbicides was minimal in 1980. Manufacturers of off-patent pesticides must formulate the inert-ingredient composition resulting in variation among companies and differences in efficacy compared with the original chemical formulation (Capuzzi 2010).

In 1980, 73 percent of nurseries surveyed used Goal® (oxyfluorfen) (table 12) (Boyer and South 1984) and in 2012, 100 percent nurseries used Goal 2XL® (oxyfluorfen). GoalTender® (oxyfluorfen) is a different formulation than Goal 2XL® and allows its application to seedlings earlier after sowing than Goal 2XL®. The Nursery Cooperative has encouraged the use of GoalTender® among members to control weeds early in the growing season before they become established (South et al. 2004). In the 2012 survey, only Nursery Cooperative members used GoalTender®. In 2012, more than one-half (55 percent) of nurseries used shielded sprayers to apply herbicides (primarily in hardwood weed control) and 29 percent used wick-wiper herbicide applicators.

Table 12. Herbicides used in southern barefoot forest nurseries in 2012. Managers listed more than one herbicide.

Herbicide	Percent of nurseries (n = 33)
Goal®	100
GoalTender®	36
Cobra®	58
Sethoxydin	45
Reflex®	29
Fusilade®	21
Others	42

Lift, Pack, and Ship

In 2012, 62 percent of nursery respondents machine lifted their seedlings and 38 percent hand lifted their seedlings (figure 6). In 1980, only 38 percent of nurseries used machine lifting (Boyer and South 1984). The J.E Love Company's (Garfield, WA) full-bed belt lifter is used by more than three-fourths of southern bareroot forest nurseries that use a full-bed belt lifter. More than 75 percent of managers pack their seedling in a packing shed while the rest pack their seedlings in the field. Managers who use a packing shed cull large, small, or deformed seedlings before packing. It is more difficult to cull seedlings during field packing and therefore managers strive to produce a uniform seedling crop to minimize the cull percentage.

Although not specified in the 1980 survey, clay slurries were frequently used to coat seedling roots before shipping. This practice reportedly protected seedling roots before planting (Hamner and Broerman 1967). During the 1980s, managers adopted the operational use of polyacrylamide gels to protect roots because of (1) lower cost, (2) less storage space, and (3) less mess compared with clay. In 2012, 70 percent of managers used polyacrylamide gels while 24 percent still used clay slurries. In 1980, nursery managers most frequently packed

Figure 6. Methods used to lift seedlings for shipping in southern bareroot nurseries include (A) hand lifting seedlings that have been loosened using a Fobro® seedling lifter and (B) machine lifting with a Love® full-bed belt lifter and seedling transport wagon. (Photos by Tom Starkey 2014 and 2011)

seedlings in bundles—seedling root systems were placed on a large piece of wax-coated Kraft paper, rolled, and strapped with a stick to facilitate carrying and lifting. This packing method kept seedling roots protected, but left foliage exposed. In 2012, only 21 percent of nurseries packed seedlings exclusively in bundles while 44 percent packed seedlings in closed bags exclusively, 6 percent used boxes exclusively, and 29 percent packed seedlings in boxes or bags depending on customer requests.

In the Southern United States, most seedlings are lifted from December to February. The accumulated chilling hours is commonly monitored by nursery managers. Although chilling is directly related to freeze tolerance, the relationship between chilling hours and long-term storability of seedlings has not been established (South 2013). In 2012, 67 percent of nursery respondents monitored chilling hours (32 to 46 °F [0 to 8 °C]). The minimum chilling reported for storing bareroot pine seedlings for less than 1 week was 182 hours. Many managers desire about 400 chilling hours when storing loblolly pine seedlings for 4 weeks or more. When lifting seedlings before the end of December, 54 percent of managers hold seedlings less than 1 week in cool storage and 46 percent store for less than 2 weeks. When seedlings are lifted after December 31, nearly 35 percent of managers are comfortable storing them longer than 3 weeks and the remaining 65 percent try to ship seedlings as soon after lifting as possible.

In the Southern United States, seedlings in the nursery bed continue to grow during the winter months (December to February), increasing in both RCD and root biomass. Seedling shoot height does not change during the winter months and remains relatively constant until bud break in late winter. In 2012, the average reported target RCD for loblolly pine shipped in late November is 0.18 in (4.6 mm) while a loblolly pine shipped in February has a target RCD of 0.22 in (5.5 mm). Target seedling size was not reported in the 1980 survey.

Labor

Although not part of the 1980 survey, most nonpermanent nursery labor in 1980 was local labor. In 2012, nursery managers reported that their current labor sources include (1) permanent employees; (2) part-time local labor, including U.S. nationals and legal foreign nationals; (3) migrant labor, including H1A and H2B workers; and (4) prison labor (table 13). Permanent employees were reported to be the primary source of labor for the sowing operation because of the precision and attention to detail required at this critical stage of seedling production and because a large labor force is not needed. Permanent labor is also the primary source of labor during the summer months (June to August) when hand weeding is the major activity. During the lifting season, migrant labor is the major labor source used to lift, sort, and package seedlings. Nurseries indicated that 75 percent of their total temporary labor budget is used during shipping season. This use of temporary labor has not changed during the past 3 years for 90 percent of the nurseries.

Table 13. Sources of labor used in southern bareroot forest nurseries in 2012.

Labor[1]	Nursery Activity (n = 34)		
	Percent of nurseries		
	Sowing	Summer	Lifting
Permanent	81	74	68
Local	55	61	61
Migrant	19	23	65
Prison	10	16	16

Permanent = full-time employees. Local = includes U.S. nationals and legal foreign nationals. Migrant = includes H1A and H2B labor, etc.
[1] More than one labor source was listed for most nurseries.

Managers' top concerns about temporary labor were (1) availability, (2) cost, and (3) consistent attendance. From 2008 to 2011, 48 percent of those surveyed reported labor cost increases of about 8 percent. These concerns, along with changes in labor laws, create uncertainty for nurseries as well as their customers.

Summary

Surveys of this type are important as they document changes in specific cultural activities and development of new equipment, technology, and pesticides. Documenting changes in government regulations can also explain shifts in nursery production. When Abbott (1956) began the first of several surveys of bareroot nursery practices, he established the importance of tracking seedling production and practices in the United States. The survey by Boyer and South (1984) was the most significant because it focused on the Southern Region of the United States where most seedlings are produced. Surveys such as the one presented in this paper and the 1984 survey should be conducted every 10 years.

When the Nursery Cooperative began in 1972, research efforts were directed toward pest management, especially weed control. Although great strides have occurred in this area, new pesticides are still a need. Registering new pesticides has become more difficult in recent years. Government regulations for new pesticides and the failure to reregister current pesticides have reduced the number of pesticides available to nursery managers. Furthermore, chemical companies are reluctant to register new products for a crop, which is grown regionwide on less than 2,000 ac (809 ha).

Advances in seedling production in the future will likely occur as a result of practices that improve seed efficiency and seedling quality. Opportunities exist for cultural activities and changes in the lifting operation that minimize loss of roots during lifting. Improvements in seedling quality uniformity and seedling nutrition at outplanting will help in establishment of seedling plantations. Opportunities exist for advances in seed treatment, seed stratification, and early seed establishment. Biological pesticides and fertilizers are finding widespread use in agronomy and horticulture and may also have applications in bareroot seedling production.

Address correspondence to—

Tom E. Starkey, Southern Forest Nursery Management Cooperative, Auburn University, School of Forestry and Wildlife Sciences, 602 Duncan Drive, Auburn, AL 36849; e-mail: tom.starkey@auburn.edu; phone: 334–844–8069.

Acknowledgments

The USDA Forest Service, Region 8 Cooperative Forestry, Atlanta, GA, provided funds for this survey. The authors thank Stan Bartkowiak, Jeff Chieppa, Joe Clark, Rachel Conley and Ferhat Kara for their assistance in summarizing the survey data.

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Forest Seedling Nursery Practices in the Southern United States: Container Nurseries

Tom E. Starkey, Scott A. Enebak, and David B. South

Research Fellow, Southern Forest Nursery Management Cooperative, School of Forestry and Wildlife Sciences, Auburn University, Auburn, AL; Professor of Forest Pathology and Director of the Southern Forest Nursery Management Cooperative, School of Forestry and Wildlife Sciences, Auburn University, Auburn, AL; Professor Emeritus, School of Forestry and Wildlife Sciences, Auburn University, Auburn, AL

Abstract

The production of container-grown seedlings for reforestation in the Southern United States has increased nearly 5,000 percent since 1980. Current container seedling production in the Southern United States represents 68 percent of the entire U.S. container production. This article describes results from a comprehensive survey of container nursery practices in the Southern United States that includes nursery size, seedlings produced, container type, and growing media. In addition, production methods such as sowing, pest control, irrigation, fertilization, cultural techniques, shipping, and labor sources are also described.

Introduction

The Southern Forest Nursery Management Cooperative (Nursery Cooperative) has worked with forest seedling nurseries in the Southern United States since 1972. The area represented by this research-based cooperative includes (east) Texas, (east) Oklahoma, Arkansas, Louisiana, Kentucky, Mississippi, Tennessee, Alabama, Georgia, North Carolina, South Carolina, Virginia, and Florida (figure 1). The goal of the Nursery Cooperative is to increase seed efficiency and seedling quality using research to develop and disseminate cultural, chemical, and biological technologies in an integrated system for the economical production of seedlings. Since 1997, the Nursery Cooperative has also conducted an annual seedling production survey of member and nonmember nurseries in the Southern Region.

Bareroot seedling culture dominates the production of forest seedlings for reforestation in the Southern United States When combining all forest tree seedling production regions together, container production accounts for 23 percent of total seedlings (bareroot and container) produced (Harper et al. 2013) within the United States. There have been several surveys of forest nursery practices since 1950 (Abbott 1956, Abbott and Eliason 1968, Abbott and Fitch 1977, Boyer and South 1984), but these surveys were limited to bareroot seedling production.

The Nurseries

In June 2012, a 23-page survey was sent to 19 container nurseries in the Southern United States (figure 1) and returns were received from 10 nurseries. These 10 nurseries produce about 61 percent of the total Southern United States container seedling production (Enebak 2012). Because some nursery managers chose not to answer all questions, results in this article are based on the number of nursery managers responding to each question. For the purpose of this article, nursery ownership is categorized as State (nursery owned by the State), industry (nursery owned by a company that also owns land and production facilities, such as mills), or private (owned by a company with no land ownership or production facilities). Container seedlings are grown by all three categories of nursery ownership with most container production (83 percent) occurring in private nurseries (Enebak 2012). Of the nursery managers responding to the survey, 60 percent grew only container stock and 40 percent produced both container and bareroot stock, Of those responding nurseries, 60 percent grew both loblolly and longleaf pine, 30 percent grew only longleaf pine, and one nursery grews only loblolly pine. The oldest State nurseries responding to this survey were in Florida (Herren Nursery) and North Carolina (Griffith Nursery), both of which began growing container seedlings in 1972. The oldest industry and private nurseries, both in Alabama, were Westervelt Corporation and International Forest Company (originally International Forest Seed Company), that began growing container seedlings in 1981 and 1983, respectively.

Seedling Production

Container forest tree seedling production was estimated to be 0.4 million in 1973 (Aycock 1974) and 3.5 million in 1980 (Boyer and South 1984); it now likely exceeds 181 million (Enebak 2012). Accurately quantifying container seedling production is difficult, however, because several small longleaf pine (*Pinus palustris* P. Mill.) nurseries do not participate

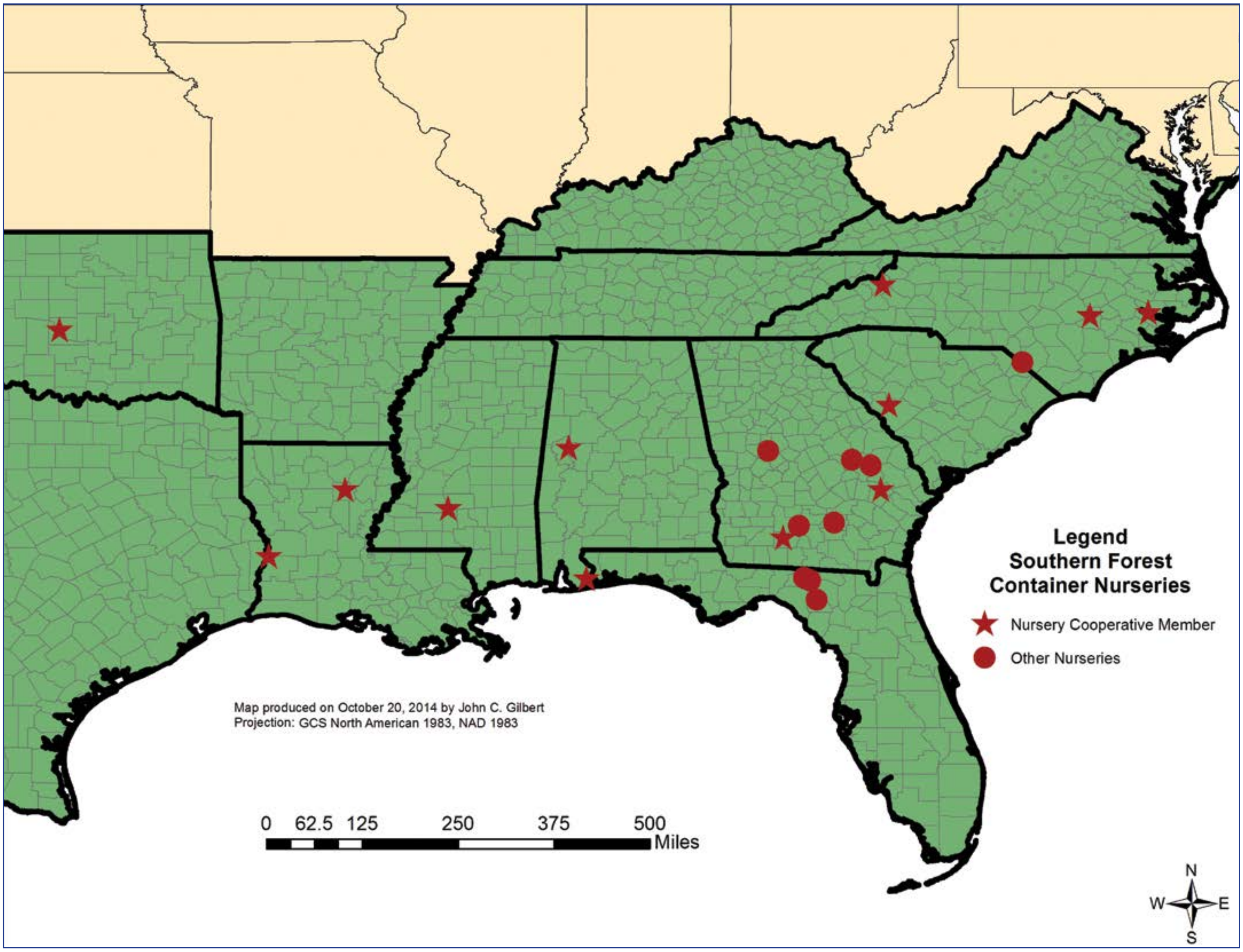

Figure 1. Southern States included in the container survey and location of Nursery Cooperative and nonmember container nurseries. (Map by John Gilbert 2014)

in any type of survey. Nonetheless, container production in the South accounts for more than 68 percent of the total container forest tree seedlings produced in the United States (table 1).

Table 1. Regional container seedling (conifer and hardwood) production in 2012 and percentage of total production by region.

Region	Container seedlings produced	Container percent by region
Southern	181,505,000	68.4
Northeast	1,198,566	0.5
North Central	6,168,565	2.3
Great Plains	1,109,000	0.4
Intermountain	4,879,630	1.8
Pacific Northwest	56,041,800	21.1
Pacific Southwest	14,323,800	5.4
Total	265,226,361	

Source: Harper et al. 2013

The choice of stock type used for reforestation differs dramatically for the three major pine species grown in the Southern United States. Only 9 percent of loblolly pine (*Pinus taeda* L.) and 5 percent of slash pine (*P. elliottii* Engelm.) are produced as container stock seedlings whereas 96 percent of longleaf pine are produced in containers (Enebak 2012) (figure 2). The large difference between loblolly and slash pine when compared with longleaf pine is because of the better survival of container compared with bareroot longleaf pine. Other factors include more efficient use of longleaf pine seed that is frequently in short supply and a broader window for outplanting in the field (Dumroese and Barnett 2003). Longleaf, loblolly, and slash pine account for 99 percent of all conifers grown as container stock in the South (table 2), with longleaf pine accounting for 63 percent of the container total (Enebak 2012). In the South, private, industry and State nurseries produce 83, 11, and 6 percent of container seedlings, respectively (Enebak 2012).

Table 2. Conifer species grown in container forest seedling nurseries in the Southern United States in 2012.

Species	Scientific name	2012 container production	Percent of total
Longleaf pine	*Pinus palustris* Mill.	112,905,000	63.3
Loblolly pine	*P. taeda* L	59,800,000	33.5
Slash pine	*P. elliottii* Engelm.	3,808,000	2.1
Shortleaf pine	*P. echinata* Mill.	1,051,000	0.6
Sand pine	*P. clausa* (Chapm. ex Engelm.) Vasey ex Sarg.	430,000	0.2
Virginia pine	*P. virginiana* Mill.	22,000	< 0.1
Other pines		301,000	0.2
Fraser fir	*Abies fraseri* (Pursh) Poir.	500,000	0.3
Total		178,317,000	

Source: Enebak (2012)

Figure 2. Longleaf pine growing in a container system. (Photo by Tom Starkey 2009)

Annual seedling production in southern container nurseries ranged from 50,000 to 55 million (median annual production was about 6 million). The two largest container nurseries in the South account for 43 percent of the total in the South and nearly 30 percent for all the container production in the United States (Enebak 2012, Harper et al. 2013). Four nurseries also grow a portion of the 2.2 million native plants species used in longleaf pine ecosystem restoration. None of the responding nurseries produced container-grown hardwood seedlings (*Quercus*, *Fraxinus*, etc.) although other nurseries grew at least 2.7 million hardwoods in containers in 2012 (Enebak 2012).

A range of genotypes are sown as container seedlings. Wild sources, harvested from production areas (e.g., Blackwater State Forest, Eglin Air Force Base), represented 73 percent all the longleaf pine seedlots sold in 2012. Slash pine genotypes were equally divided between first- and second-generation families from seed orchards. The largest percentage of loblolly genotypes sold as container seedlings were advanced generation (39 percent) from controlled, mass-pollinated selections or somatic embryogenesis (table 3), which is 20 percent more than in bareroot stock (Starkey et al. 2015). CellFor Inc. produced loblolly pine clonal stock using somatic embryogenesis (Grossnickle and Pait 2008), which were used for container transplants to grow 20 percent of the 2012 container loblolly pine crop. Industry and large private nurseries with access to seed orchards tend to market the advanced genotypes. Loblolly pine rooted cuttings also accounted for a small percentage of the total loblolly production.

Table 3. Pine seedlot genetics sown in 2012 at 10 southern forest seedling container nurseries.

Species	Genetics	Percent sown
Loblolly pine (n = 7)	1st generation	4
	2nd generation	33
	3rd generation	24
	Advanced	39
Slash pine (n = 2)	1st generation	48
	2nd generation	48
	Advanced	4
Longleaf pine (n = 9)	Wild	73
	Improved	27

Cultural Practices

Containers

Container size and composition is an important factor in container nurseries. In the South, 60 percent of surveyed nurseries use hard plastic containers, 10 percent use expanded polystyrene containers, and 30 percent use both container types. Of the 10 responding nursery managers, 4 indicated that they grew seedlings in more than one type of hard plastic container. Based on total seedling production, 82 percent of seedlings are grown in hard plastic containers. Only one size of expanded polystyrene container is used in the Southern United States with a seedling density of 49 seedlings/ft^2 (530 seedlings/m^2) and a cell volume of 6.6 in^3 (108 ml). The median seedling density for the most commonly used hard plastic containers is 52.9 seedlings/ft^2 (569 seedlings/m^2) with a cell volume of 6.7 in^3 (110 ml). One manager grows seedlings in a 4.0 in^3 (66 ml) container, which are typically planted in the fall (i.e., before December) and not sold to nonindustrial private landowners.

Growing Media

All responding managers use growing media composed of peat moss and other soilless amendments. The average growing mix for container nurseries was 68 percent peat moss with vermiculate and perlite used as secondary ingredients by 80 percent of nursery managers. One nursery manager includes composted bark in the nursery's growing medium. One manager mixes growing medium ingredients on site rather than purchasing a custom mix from a distributor. Compressed bales of peat moss, more than 5 ft (1.5 m) in height, are used by 50 percent of managers. At sowing, the average pH of growing media was 4.7. One-half of all responding nursery managers have had to switch growing-media suppliers (2009–2012) because of price and inconsistent mixing.

Sowing

Sowing conifer seed in Southern container nurseries typically begins in March with seedlings extracted from their containers for outplanting about 8 to 9 months later (November to December). Container nurseries begin sowing nearly a month before bareroot nurseries (Starkey et al. 2015), which allows seed germination to be complete before air temperatures exceed 90 °F (32.2 °C). Sowing of container seedlings is slower than sowing of bareroot seedlings. For example, sowing a 20-million capacity bareroot nursery can be done in less than 5 days whereas the same size container nursery may take more than 60 days to complete.

The production of native understory plants for longleaf pine ecosystem restoration is a growing segment in container production. The three most common species grown are wiregrass (*Aristida beyrichiana* Trin. & Rupr.), little bluestem (*Schizachyrium scoparium* (Michx.) Nash), and Indian grass (*Sorghastrum nutans* (L.) Nash). Because of customer requirements and length of time in the nursery, native understory plant sowing occurs March to July with the peak sowing period after conifer sowing is complete.

Vacuum-drum sowers are common in larger container nurseries (production of more than 6 million seedlings) (table 4). Vacuum-drum sowers can efficiently sow 300,000 to 400,000 cavities per day (figure 3). Smaller nurseries, especially those growing primarily longleaf pine, hand-sow their seedling crop. Hand sowing or mixing the seed as a top dress are common methods for sowing native plant species (table 4). One nursery manager commented that investment in mechanization for sowing native understory plant seed will be necessary if production increases.

After sowing, 90 percent of managers cover seed in the containers with a capping material to minimize seed desiccation. The two most common capping materials are vermiculite and sawdust. Following sowing and capping, most nurseries

Table 4. Sowing methods used for conifers and native plant species in container forest nurseries in the Southern United States. Some managers use more than one method.

	Number of nurseries	
Method	**Conifers**	**Native plants**
Vacuum-drum sower	5	1
Needle sower	1	0
Vacuum-drop sower	1	0
Hand sow	5	3
Top dress or cuttings	1	3

Figure 3. Vacuum-drum sowing machines (SK Design, Inc.) are used by larger container nurseries. These sowers are capable of sowing 300,000 to 400,000 cavities a day. (Photo by Tom Starkey 2009)

transport the containers outside to the field production areas. One nursery routinely palletizes the containers under cover and stores them for a short time period to allow the germination process to begin. After this pregermination process, containers are moved to outdoor growing areas. One-half of the nursery respondents germinate the seeds under shade cloth in the outdoor growing areas. Shade cloth protects the young germinants from desiccation and rain splash and deters bird predation. Following germination, the shade cloth is removed for the remainder of the growing season. Covered greenhouses are not used in the South; two nurseries, however, use their uncovered greenhouse structure to supplement their primary growing facilities.

Irrigation

Four of the responding nursery managers (including the two largest nurseries) use center pivot irrigation, with two of these nurseries also using a stationary system (such as oscillating impact head or pop-up irrigators) or traveling boom (figure 4). Six of the responding nurseries use only a stationary head system. The largest nursery has 14 single-span center pivot systems. Wells are the source of irrigation water for seven of eight responding nursery managers. Water usage during the seedling production season is reported to government agencies by 70 percent of the nurseries.

Figure 4. Irrigation systems used in southern container forest nurseries include (A) a center pivot irrigation system on benches and (B) a stationary impact head on a "T"-rail bench system. (Photos by Tom Starkey 2009 and 2010)

All responding nursery managers monitor container plug moisture using a touch-and-feel system as opposed to an electronic moisture device or a container weight system. During the seed germination phase, 80 percent of nurseries irrigate every day with a goal of keeping the top 40 percent of the plug moist. After the germination phase, the goal of irrigation is to keep an average of 93 percent of the plug moist. During shipping season, all managers reduce irrigation frequency and 60 percent also reduce irrigation amount to harden seedlings for extracting, packing, and shipping.

During the summer (June to September), air temperatures in the South regularly exceed 90 °F (32.2 °C) and may exceed 100 °F (37.7 °C). Most nursery managers (80 percent) irrigate their seedlings after temperatures reach 94 °F (34.4 °C) to reduce air and container temperatures. All managers indicated they have experienced heat-related problems with seedling growth.

Fertilization

Fertilization in container nurseries is accomplished by mixing slow-release fertilizer into the growing medium and/or by applying water-soluble fertilizers. The latter method requires a tractor-spray applicator or the ability to inject fertilizers into the irrigation system (fertigation). Tractor-sprayers are most commonly used to address specific nutrient problems during the growing season (e.g., iron chlorosis).

Most nurseries (80 percent) use slow-release fertilizer mixed in the growing medium, one-half of which use a 3- to 4-month formulation and one-half use a full-season formulation. The 3- to 4-month formulation is most common at nurseries that also use fertigation. Slow-release fertilizers with shorter release formulations enable the nursery manager to provide nutrients earlier in the season when excess precipitation can limit the ability to irrigate and to also better control seedlings growth later in the season. A previous Nursery Cooperative survey (Starkey and Enebak 2012) showed that nurseries using only full-season, slow-release fertilizers had the lowest foliar nitrogen levels at the time of shipping (October to January) compared with nurseries using fertigation.

Of container nursery managers, 80 percent use slow-release fertilizer in one of three ways: as a sole source for fertilization (10 percent), in combination with tractor/spray (40 percent), or in combination with an injector and tractor spray (30 percent) (table 5). Nurseries that use an injector apply water-soluble fertilizer with micronutrients or individual nutrients to maintain proper nutrition or correct deficiencies.

Table 5. Fertilization methods used in southern container forest nurseries (n = 10).

Fertilization method	Percent of nurseries
Slow-release fertilizer only	10
Combination of slow-release plus tractor/spray	40
Combination of slow-release, plus injector, plus tractor/spray	30
Only injector-applied	20

Five managers stated that they evaluate nutrient status of their seedlings twice annually, four managers evaluate their seedlings three or more times per growing season, and one manager does not monitor nutrient status at all during the growing season.

Top Pruning

The term "shoot pruning," or "top pruning," is typically associated with pruning of central stem species, such as loblolly and slash pine, where both the needles and shoot are cut, and the term "top clipping" is usually associated with longleaf pine because only the needles are cut. To avoid confusion, top pruning will be used in this paper for both species. Top pruning in container nurseries has become a common practice in the past 15 years (figure 5). Most loblolly container nurseries (86 percent) and most longleaf nurseries (80 percent) top prune their seedlings. Of nursery managers, 40 percent top prune only one time (generally in July), whereas 60 percent top prune more than once. The most common reasons nursery managers top prune are to increase crop uniformity, to control height growth, and to produce better balanced seedlings.

Figure 5. Example of top pruning machine used in southern container forest nurseries. These machines are custom designed and manufactured locally to accommodate individual nursery configuration. (Photo by Tom Starkey 2009)

Integrated Pest Management

Mortality

The average annual seedling loss reported by nursery managers in container nurseries was 3.8 percent. The major problems are associated with pre- and post-emergent damping off and bird predation of seed and young germinants. All other factors listed caused only minor losses of less than 1 percent (table 6).

Bird predation of seed and young germinants had the greatest loss (1.33 percent), which was significantly higher than bird predation reported in southern bareroot nurseries (Boyer and South 1984, Starkey et al. 2015). Despite the rate of bird predation, only three of seven respondents treat their seed with compounds labeled to reduce animal and/or bird predation. One nursery manager reported two interesting observations: first, birds appear to be more of a problem in seedlots with poor or weak germination and, second, shade cloth will sometimes increase losses by not easily allowing birds that enter under the cloth to escape.

Disease Control

Pre- and post-emergent damping off was reported by 70 percent of nursery managers as being a significant problem (table 6). Losses because of damping off most likely correlate with the amount of precipitation during germination; when precipitation is high, damping off problems would also be expected to be high.

Fusiform rust (*Cronartium querccum* f. sp. *fusiforme*) is the primary stem disease in southern pine nurseries. The fungus is commonly found within a 150 mi (241 km) band from South Carolina to Texas (Enebak and Starkey 2012). Basidiospores from the rust fungus are produced in early spring to early summer on oak trees (*Quercus* spp.) present around the nursery, coinciding with presence of susceptible seedling tissue in the nursery. Although losses because of fusiform rust were not

Table 6. Factors contributing to seedling mortality in southern container forest seedling nurseries in 2012 (n = 10).

Factor	Percentage of nurseries	Percentage of loss
Preemergent damping off	70	0.82
Postemergent damping off	70	1.15
Fusiform rust	0	0
Rhizoctonia foliar blight	20	0.04
Rhizoctonia crown blight	20	0.05
Nutrient	10	0.01
Herbicide	20	0.12
Insect	30	0.10
Birds	80	1.33
Rain splash	10	0.17

reported in 2012 (table 6), 86 percent of nurseries use Bayleton® (triadimefon) and/or Proline® (prothioconazole) to control fusiform rust. Fungicides are effective for controlling fusiform rust when used. In 2011, one nursery did not apply fungicides to control fusiform rust and reported a 20-percent infection rate on that year's crop.

The next most common pesticides reported by at least 60 percent of nurseries for controlling damping off, crown rot, and needles blights and spots were thiophanate-methyl, chlorothalonil and Banrot® (Etridiazole, 15 percent, thiophanate-methyl, 25 percent). Several phosphonate fungicides, such as Aliette® (aluminum tris), were used by five nursery managers for the control of damping-off diseases. This class of fungicides (phosphonates) was not used by any bareroot nurseries (Starkey et al. 2015). Phosphonate fungicides are most effective when applied as a root drench, which is easier to achieve in a container nursery than in a bareroot nursery. Other commonly used fungicides include Chipco 26019® (iprodione), azoxystrobin, and propiconazole. When tallying the various products reported from all nurseries, a total of 19 different fungicides were used for disease control.

Insect Control

Annual seedling loss because of insects was reported to be less than 1 percent. Nursery managers reported that tip moth (*Rhyacionia* spp.) and plant bugs (*Lygus lineolaris* Miridae and *Taylorilygus pallidulus* [Blanchard]) cause the greatest container seedling mortality. Of the nursery managers, 60 percent reported regularly monitoring the seedling crop to determine when to apply insecticides. The most frequently used insecticides in container nurseries are chloropyrifos, permethrin, and Asana® (esfenvalerate). When tallying products reported from all nurseries, a total of nine insecticides were used to control insect pests.

Weed Control

Black willow (*Salix nigra* Marshall) was noted as the most troublesome weed in 60 percent of the nurseries. Black willow is found along the margins of the nursery property and produces abundant small, windblown seed during the time of sowing in March and April. Thus, willow seedlings appear only in those container sets that were in the production areas at the time of seed dispersal. The second most troublesome weed was spurge (*Euphorbia* spp.). When queried as to the source of new weeds in their nursery operations, all managers indicated that windblown seed was the primary source. Of the nursery managers responding to the survey, 70 percent use nonpermanent labor for hand weeding, whereas, one nursery manager indicated that he was solely responsible for hand weeding of his entire nursery.

The most commonly used herbicides for broadleaf weeds were Goal® (oxyfluorfen), GoalTender® (oxyfluorfen), and Cobra® (lactofen). Sethoxydim was the most common herbicide used for grasses. Tank mixing of broadleaf and grass herbicides is used at seven nurseries.

Lift, Pack, and Ship

One distinct advantage of container planting stock is that the planting window is longer than for bareroot seedlings (Brissette et al. 1991). Nearly 80 percent of nurseries ship their seedlings between September and January 1 (table 7). In bareroot nurseries, shipping normally does not begin until December.

At the time of shipping, 40 percent of nursery managers bring their seedlings to a packing shed, 30 percent pack only in the field, and the remaining 30 percent pack in both the field and shed. All container seedlings in the South are packed and shipped in wax-coated, cardboard boxes. Depending on tree species and root plug size, these boxes commonly hold 250 to 300 seedlings. The average number of seedlings extracted from the container and packed in shipping boxes is 175,000 per day, with a range of 15,000 to 350,000 per day. Of the container nurseries responding to the survey, 70 percent have a cooler in which to store seedlings and 30 percent store their seedlings in a shed or pole barn before customer pickup or shipping.

In the Southern United States, soil and air temperature conditions are such that pine seedlings continue to grow during the winter months. Therefore, seedlings increase in both root-collar diameter (RCD) and root biomass from December to February with the average reported target RCD for loblolly pine shipped in late November of 4.0 mm (0.16 in) while a loblolly pine shipped in January has a target RCD of 4.5 mm (0.18 in).

Container nursery managers were queried if they believed that container seedlings out-perform bareroot seedlings. Not unex-

Table 7. Percentage of container seedlings shipped by month in 2012 for southern container forest seedling nurseries (n = 10).

Month	Percent seedlings shipped
Before September	3
September	17
October	4
November	27
December	29
January	20
February	9

pectedly, they all answered this question with a "yes" or "sometimes." The reasons for their response included (1) intact root system at shipping, (2) broader planting window, (3) higher initial survival, and (4) early planting to provide more root growth.

Labor

In 2012, southern container tree nursery managers reported that their labor sources included permanent employees, part-time local labor such as U.S. nationals and legal foreign nationals, and migrant labor, which includes H1A and H2B workers (table 8). Local labor is more commonly used throughout the season than any other labor source. Local and migrant labor is used at a higher percentage of total labor during the sowing and shipping seasons. Shipping season (November to February) uses more nonpermanent labor than any other operation. Nursery managers indicated that 30 and 62 percent of their total temporary labor budget is used during sowing and shipping season, respectively. For 50 percent of the nurseries, the use of temporary labor sources from 2008 to 2011 increased from 6 to 10 percent.

Nursery managers' top concerns with temporary labor were cost and lack of attention to details. One interesting comment was that companies or independent contractors that specialize in providing agricultural labor were more reliable than local staffing agencies that supplied temporary, nonspecialized labor.

Table 8. Source of labor used in southern container forest seedling nurseries in 2012 (n = 10). More than one labor source was listed by most nurseries.

Labor	Percentage of nurseries		
	Sowing	Summer	Shipping
Permanent	50	60	40
Local	80	70	70
Migrant	60	40	80

Permanent = Full-time employees.
Local = Includes U.S. nationals and legal foreign nationals.
Migrant = Includes H1A and H2B labor, etc.

Summary

Container seedling production in the Southern United States has increased dramatically since 1974 and currently represents 20 percent of the total regional seedling production. In the future, bareroot will be the primary stock type for the production of loblolly and slash pine and container will continue to be the preferred stock type for the longleaf production. Container seedlings may increase their market share of loblolly and slash pine as companies reserve advanced genetics of these species for container stock.

Container stock can also increase market share by reducing costs and increasing seedling quality. Areas in which costs may possibly be reduced include (1) changing growing media composition by eliminating or reducing high-cost items such as vermiculite and perlite; (2) increasing seeding efficiency of longleaf pine and native plant species; (3) finding more effective herbicides for weed control, especially black willow; and (4) developing mechanization for seedling extraction and packing. Container seedling quality can be improved by (1) use of more efficient seed treatments; (2) greater fill of root mass in the container, especially at shipping; (3) better seedling height management; (4) better seedling nutrition at the time of shipping; and (5) shipping container seedlings as early in the fall or early winter as possible.

Address correspondence to—

Tom E. Starkey, Southern Forest Nursery Management Cooperative, Auburn University, School of Forestry and Wildlife Sciences, 602 Duncan Drive, Auburn, AL 36849; e-mail: tom.starkey@auburn.edu; phone: 334–844–8069.

Acknowledgments

The U.S. Department of Agriculture, Forest Service, Southern Region Cooperative Forestry, Atlanta, GA, provided funds for this survey. The authors thank Stan Bartkowiak, Jeff Chieppa, Joe Clark, Rachel Conley, and Ferhat Kara for their assistance in summarizing the survey data.

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Safeguarding Against Future Invasive Forest Insects

Mark Hitchcox

Pest Survey Specialist, U.S. Department of Agriculture, Animal and Plant Health Inspection Service, Plant Protection and Quarantine, Portland, OR

Abstract

Many nonnative insect species have been introduced into North American forests, sometimes with a detrimental effect on wild and cultivated plants. Prevention of new invasive species depends on improved awareness of the pest and pathway risks, and finding methods to realistically mitigate those risks. Early detection and rapid response strategies aim to prevent new pest introductions. Within the timeline of each new pest introduction is a tenuous period where a population may or may not become established. After a new pest has become established in the landscape, the ability to detect that population before it spreads beyond controllable levels is critical. This article reviews the phases of a pest invasion, the safeguards needed to prevent or contain invasions, and some of the exotic insect pests, which may affect nursery production, forest outplantings, or mature woodlands in the future.

Introduction

Throughout the past century, foreign insect species have established in North America, some populations of which have greatly affected forested landscapes (Pimentel et al. 2005, Krcmer 2008, Aukema et al. 2011). Natural and urban forests are being attacked by exotic woodboring pests, such as emerald ash borer (*Agrilus planipennis* Fairmaire) (EAB) and Asian longhorned beetle (*Anoplophora glabripennis* [Motschulsky]) (ALB, figure 1), and by defoliating pests such as European gypsy moth (*Lymantria dispar dispar* [L.]) (EGM) and the hemlock wooly adelgid (*Adelges tsugae* Annand) (HWA). EAB, ALB, EGM, and HWA are widely considered invasive insect pests. "Invasive," for purposes of this article, refers to a nonnative organism whose introduction and establishment is likely to cause harm to economic and environmental plant resources.

The damage caused by invasive insect pests is considerable. The EAB alone has killed tens of millions of ash trees (*Fraxinus* spp.) since its detection in 2002, and predictive models estimate the cost of removing and replacing ash in urban and forest landscapes will exceed $12.5 billion (Herms and McCullough 2014). One report also indicates that this pest has an indirect effect on human health, with a measured increase in human illness in communities affected by the EAB (Donovan et al. 2013). Costly Federal and State quarantines have been established to attempt to contain EAB, ALB, and EGM and prevent their spread to other communities.

Figure 1. Asian longhorned beetle oviposition and exit hole damage in a maple tree in a southern Ohio quarantined area. (Photo by Helmuth Rogg, Oregon Department of Agriculture)

For example, efforts to contain EGM infestations include State and Federal quarantines, annual monitoring, an ambitious slow-the-spread program, and eradication of outlying satellite populations, have contributed to successfully preventing EGM from become a widespread pest across the Nation.

During the past few decades, an increase in global trade of agricultural products and live plants has increased the risk of new pest introductions (Mack et al. 2000). The initial North American introduction of invasive insect pests, such as HWA, EAB, and ALB, was likely caused by the importation of infested live plants and wood-packing material (Work et al. 2005, Liebhold et al. 2012).

By predicting the next invasive pest, regulatory agencies can focus inspection and survey resources on the highest risk pest pathways. A heightened awareness of new potential invasive pests can also help land managers implement phytosanitary conditions and increase monitoring and plant pest control programs.

Phases of an Invasion

When reviewing historical invasions of forest insect pests, such as EAB, ALB, and HWA, a generalized pattern can be seen, involving introduction, establishment, and integration. The term "introduction" refers to the arrival of a foreign pest and can also be considered adventive. The term "establishment" refers to a species ability to survive and complete at least one reproductive cycle at a given location. "Integration" refers to the success with which a newly established pest population assimilates into the local environment. For purposes of prioritizing safeguarding efforts, this generalized pest invasion timeline can also be described in the following phases (adapted from Krcmar 2008):

- Phase I: Not established; interceptions at ports of entry.
- Phase II: Detected beyond port setting, not known to be established.
- Phase III: Established, integration into the local environment, not causing damage.
- Phase IV: Established, widespread, causing noticeable damage.

Although foreign species may enter a country, a species may not always establish and become invasive. Random events, such as adverse climate conditions or lack of suitable host plants, or prescribed events, such as port inspections, treatments, or pesticide fumigations, reduce the chances that a species will establish. After a pest becomes established, regulatory agencies may have an opportunity to respond if the infestation is detected early. For instance, regulatory response to ALB has included State and Federal quarantines, and intensive surveillance and eradication programs within those quarantined areas. In other instances, a new pest, such as HWA, may remain undetected for years and spread rapidly, thereby allowing the population to establish and disperse to a size beyond which regulatory control is possible.

After an adventive population expands and integrates into a local environment, several factors influence whether it will become a pest on forest and agricultural crops. Presence of vulnerable hosts, absence of naturally occurring predators and parasites, and climatic condition all influence the chances a population may establish and build to outbreak levels (Eschtruth 2013). Some pest invasions go through a period of exponential growth, their populations appearing to suddenly increase in size and effect (figure 2). Loope and Howarth (2003) predicted that, in terms of invasive alien species during the subsequent 5 years, "because of the lag time in invasions, we will be dealing largely with alien species currently present but not yet recognized as problematic." In the time since Loope and Howarth's prediction, U.S. forests have experienced mortality attributed to the exponential rise of exotic pests, such as EAB and HWA.

If a newly introduced pest becomes established, landowners and producers may need to respond to the effects, adapting existing integrated pest management (IPM) programs to control a new pest. Recent economic studies have shown that a large burden from the introduction of invasive species falls on homeowners and municipal governments (Aukema et al. 2011). In addition, timber losses because of reduced tree growth, increased tree mortality, or reduction in viable seed, result in increased management and costs (Krcmer 2008).

Ideally, every step along the invasive timeline has a corresponding safeguarding measure to address the risk. The best way to avoid the effects is to prevent the introduction of new pests using prescribed phytosanitary management, certified inspections, and preventative treatments. If this approach fails, domestic surveillance can help detect a newly established pest population. Field surveys, such as those conducted using the U.S. Department of Agriculture's (USDA) Cooperative Agricultural Pest Surveys (CAPS), strive to detect new infestations of foreign invasive pests in the United States. Early detection of, and rapid response to, new nonindigenous pest introductions can increase our chances of control and eradication of pest populations before they can widely disperse and cause serious damage.

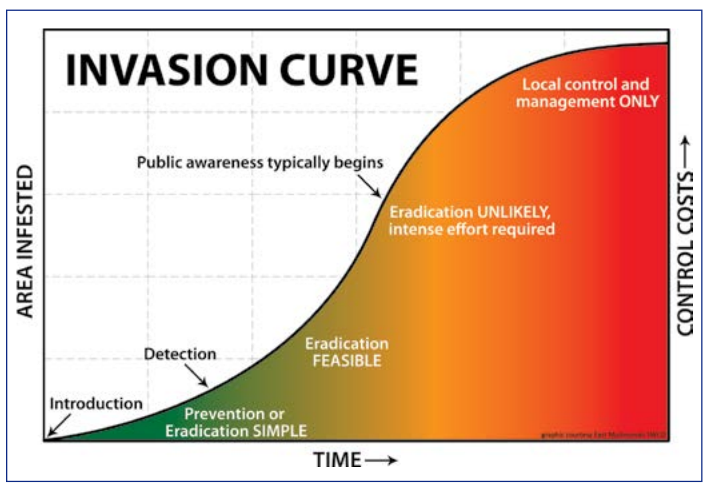

Figure 2. The invasion curve displays a generalized pest population response over time, after the introduction and establishment of a new invasive species into a new environment. As a pest population expands and integrates into the landscape, chances of detecting that pest become greater, yet that pest population also becomes more difficult to eradicate. (Image courtesy of East Multnomah Co. SWCD)

Potentially New Invasive Forest Insects in North America

By reviewing several examples of emerging invasive species, their biology and symptoms, their interception history, their known and preferred plant hosts, and by relaying some concerns about their possible effects, agencies and managers can develop a better understanding of these risks and how to prepare and protect forest nurseries and forested landscapes.

The following sections describe some of the pests that are at varying phases of introduction, establishment, and integration. These species are a representative sample of forest insect pests that are not established in the United States, but have a high likelihood of arrival, establishment, and spread, or have been introduced into the United States and are at varying phases of establishment. None of the following pests are currently regulated under Federal domestic quarantine.

Defoliating Insects

Asian Gypsy Moth, Status: Phase II

European gypsy moth populations are found within quarantined areas of North America, their larvae causing defoliation on forest and agricultural crops in several States. Their rate of natural dispersal is limited by the flightless condition of female EGM, who typically deposit egg masses near or on the same tree on which she developed. Unlike EGM, Asian gypsy moths (AGM, including *Lymantria dispar asiatica* Vnukovskij, *L. dispar japonica* [Motschulsky], *L. albescens* Hori and Umeno, *L. umbrosa* [Butler], and *L. postalba* Inoue) are not so limited in mobility (figure 3). Female AGM typically fly several hundred meters in a night, sometimes traveling up to 12 mi (20 km) to deposit their eggs (Iwaizumi et al. 2010, Molet 2014). Those egg masses, and the emerging larvae, could form the basis of a new infestation. If the AGM were ever to establish in the United States, this female dispersal behavior would be a significant challenge for containment and control of this species. In forested areas of Japan and Russia, AGM populations periodically build to high numbers, at times producing great "swarms" of moths near port areas. This intersection between AGM mating flights and international marine conveyance poses a risk of pest introduction to the United States.

AGM are drawn to bright lights, where they deposit eggs on many substrates, including cargo and marine vessels. Vessels departing Asian ports bound for America are inspected, cleaned, and certified to be free from AGM eggs. Despite such efforts, AGM eggmasses are found during inspections every year at North American ports of entry. When an approaching vessel

Figure 3. Female Asian gypsy moths are capable of long flight, thereby increasing the geographic dispersal of eggs and rapidly spreading a population. (Photo by John H. Ghent, USDA Forest Service)

is found with significant AGM risk, the ship is frequently ordered back out to sea to undergo a cleaning treatment. Additional risks related to AGM eggmasses on imported cargo increase the possibility for the introduction, and establishment of a new population of AGM, not only at the port but also far inland, where the imported cargo may travel. Pheromone trapping surveys are conducted annually to detect new AGM populations that may have established in the United States. The AGM is not known to be established in the United States; the risks, however, are evidenced by interceptions of AGM in inland survey traps in Idaho and Oklahoma (USDA-APHIS 2014b). Response to a new AGM detection includes increased surveillance and, if warranted, control treatments to eradicate the pest population. These response measures have been crucial in keeping this invasive species from establishing in North America.

Pine Sawfly, Status: Phase I

The pine sawfly (*Diprion pini* [L.]) attacks several species of pine (*Pinus* spp.) in areas where it occurs (Albrecht 2014). The larvae are gregarious feeders, feeding in groups and consuming needles and shoots, and then pupating on the twigs, or on understory objects beneath the tree. In Russia, Ukraine, and Belarus, sawfly populations build and decline in natural cycles, occasionally reaching outbreak levels, contributing to tree stress, secondary infection, and mortality. In Finland, these outbreaks have become more frequent, contributing to timber loss (De Somviele et al. 2007).

The pine sawfly is not known to occur in the United States, and queries of U.S. port interception records reveal no significant reports for pine sawfly life stages on imported commodities during the past 20 years (AQAS 1994–2014). Other exotic sawfly species, such as *Diprion similis* (Hartig) and *Gilpinia hercyniae* (Hartig), have been found on imported plant material, and are now established and spreading throughout much of North America (Wilson 2005, LaGasa et al. 2012). The risk of introduction of pine sawfly has likely been minimized using tight phytosanitary measures such as import requirements for pine Christmas trees and increased restrictions on logs with bark; the permissibility of pine boughs, cut branches, and Christmas trees, however, will continue to serve as a potential pathway for pine sawfly introduction (USDA 2014).

Wood Borers

Bamboo Longhorned Beetle, Status: Phase I

The bamboo longhorned beetle (*Chlorophorus annularis* [Fabricius]), or tiger longicorn as it is known in its native Asian territory, is a pest of cut bamboo products but has also been reported in live citrus (*Citrus* spp.), English gurjuntree (*Dipterocarpus tuberculatus* Roxb.), sugarcane (*Saccharum officinarum* L.), grape (*Vitis* spp.), apple (*Malus* spp.), and sweetgum (*Liquidambar* spp.) (Duffy 1968, USDA-APHIS 2014c). In bamboo, the bamboo longhorned beetle larvae feed and pupate internally in the sapwood tissue. The hidden larval lifestages within the wood make this pest difficult to detect. The species is not known to be established in the continental United States; however, live specimens have been intercepted several times in imported bamboo material (AQAS 2014; USDA-APHIS 2014c). In plant nursery settings, bamboo stakes are sometimes used as stays or vertical supports for young trees. The coincidental integration of infected bamboo stakes with exposed host material could allow the bamboo longhorned beetle to damage nursery stock or spread through nursery trade to other regions of the United States where the beetle could establish in the landscape. Imported dried bamboo is required to undergo treatment before entry; ineffective treatment, or mismanifested imports of dried bamboo stakes, furniture products, and possibly bamboo nursery stock could serve to transport the bamboo longhorned beetle to new regions.

Pine Cone Cerambycid, Status: Phase II

The pine cone cerambycid (*Chlorophorus strobilicola* [Champion]) is another woodboring beetle not known to be established in the United States. The species is native to India, where the larvae infest pine cones and cause as much as 80 percent seed loss (Singh 2007) (figure 4). In late 2003 and early 2004, U.S. regulatory agencies issued a recall notice after finding imported shipments of scented pine cones and potpourri from India infested with pine cone cerambycid (Albrecht et al. 2014). Detection surveys conducted immediately following this incident did not detect any established populations of this pest. Although the pine cone cerambycid is a priority for surveys under the CAPS program, only five States have surveyed for it during the past few years (USDA-APHIS 2014b). Pine cone cerambycid has no known attractants, and, therefore, surveys involve visual inspection of host trees and cones for evidence of this pest. Pine cone damage is described as dust-filled, with oval-shaped emergence holes (USDA-APHIS 2014c).

Figure 4. The adult *Chlorophorus strobilicola* (A) and pine cone with larval damage caused by this pest (B). (Photos courtesy of Pennsylvania Department of Conservation and Natural Resources—Forestry Archive [A] and Steven Valley, Oregon Department of Agriculture [B])

Japanese Pine Sawyer, Status: Phase I

Japanese pine sawyer beetles (*Monochamus saltuarius* [Hope] and *M. alternatus* [Hope]) typically attack dead or downed timber in their native habitat. Introduction of Japanese pine sawyer beetles along with associated foreign wood nematodes (*Bursaphelenchus* spp.), however, may have invasive impacts on North American pine forests. The beetles use strong mandibles to chew into the bark, where they deposit eggs. Pine sawyer larvae bore extensive tunnels throughout the tree, while the associated pine wood nematodes feed on epithelial cells and disrupt water transport within the tree, causing wilt within a few weeks of infestation. Wood nematodes cannot travel independently and rely on beetles, such as the Japanese pine sawyer, to transport them to a new tree host in the beetle's trachea. Although neither species of Japanese pine sawyer is currently established in the United States, Japanese pine sawyer beetle larvae have been frequently intercepted in imported wood pallets and dunnage.

Velvet Longhorned Beetle, Status: Phase III

The velvet longhorned beetle (*Trichoferus campestris* [Faldermann]) is an exotic insect native to Asia. The species feeds mainly on dry, dead wood; however, occasional reports record the species feeding on living hosts, such as birch (*Betula* spp.), mulberry (*Morus* spp.), spruce (*Picea* spp.), and pine (Smith 2009). The velvet longhorned beetle has been intercepted several times at U.S. ports of entry between 1997 and 2014, mostly as live larvae in wood packing material (dunnage, crates) from Asia (USDA-APHIS 2014c). This risky pathway is likely the vector that introduced velvet longhorned beetle populations to limited areas of Utah and Illinois. In Salt Lake City, UT, these beetles have been trapped since 2010, and intensive surveys have discovered specimens in local hardwood trees. Widespread damage has not been confirmed; however, early indications suggest larva of the species may be surviving in living tree tissue, raising concerns that the velvet longhorned beetle may become a plant pest. Woodborer surveys continue to monitor for this pest in several States.

Bark Beetles and Ambrosia Beetles

Although small in size, bark and ambrosia beetles can build to such high population densities that their attacks overwhelm a tree and introduce pathogens. In outbreak conditions, these pests can cause widespread mortality. For instance, the native mountain pine beetle (*Dendroctonus ponderosae* Hopkins) has been a major cause of pine mortality in North America in recent years. Although outbreaks of native beetles occur, the episodes are usually part of a natural cycle in the ecosystem of a forest. Nonnative species, however, may establish and integrate into the environment in unpredictable ways and can threaten coniferous and hardwood forests.

Mediterranean Pine Engraver, Status: Phase III

Native to Europe, northern Africa, and Asia, the Mediterranean pine engraver (*Orthotomicus erosus* [Wollaston]) is a bark beetle that attacks several species of conifer host trees (USDA-APHIS 2014c). The beetle and larvae feed internally, tunneling through cambium and phloem layers, creating a reddish-brown dust, and on occasion, if a healthy tree is attacked, pitch tubes may extend from the bark. Blue staining may also be present on the sapwood. As an internal feeding insect, this bark beetle species can be spread through the movement of untreated pallets, crates, and firewood containing bark. In 2004, Mediterranean pine engraver was first detected in Fresno, CA, when 50 beetles were intercepted in funnel traps at a municipal zoo. Beetles were detected again in 2006, indicating a population had established (USDA-APHIS 2014c). Delimitation survey is being conducted using the USDA Forest Service's Early Detection Rapid Response program (EDRR). In 2011, an additional detection of a single Mediterranean pine engraver was reported from a trap near Raleigh, NC. It is still unclear whether this single detection was an interception of a new accidental introduction from wooden pallets, or if a new population has indeed established in the landscape (NAPIS 2014). Continued monitoring and research will define its presence, the distribution of the pest population, and its integration into the environment.

Woodboring Ambrosia Beetle, Status: Phase I

The woodboring ambrosia beetle (*Megaplatypus mutates* [Chapuis]) is a species whose larvae bore internally into the trunk of walnut (*Juglans* spp.), apple, poplar (*Populus* spp.) and several other species of hardwood trees. Most ambrosia beetles, as the name suggests, carry a fungus, which inoculates the tunnels and galleries created by the larvae (Figure 5). The larvae feed on the fungus, and under native conditions, this group of insects is not considered a major pest. In Argentina and Italy, however, the woodboring ambrosia beetle is known to attack live and vigorous trees. In Argentina, this beetle has infested commercial poplar plantations, weakening the trees, impeding growth, and introducing a fungus, which decays and downgrades the wood quality (Gimenez 2003). The species is not known to occur in North America, although it has been found as a hitchhiker on infested wood packing material (Alfaro et al. 2007).

Figure 5. Tunneling "galleries" made by the exotic ambrosia beetle *Megaplatypus* mutates. (Photo by Gianni Allegro, CRA-PLF Unita di Ricerca per le Produzioni Legnose Fuori Foresta, Casale Monferrato, Italy)

Woodwasps

Also known as horntails, so named for the sturdy spike on their posterior, woodwasps (Hymenoptera: Siricidae) are exclusively plant feeders. They reproduce by injecting eggs with a long ovipositor into the sapwood of trees. The emerging larvae bore tunnels and holes as they develop inside the tree. Many native species of woodwasps occur in North America, attacking dead and declining trees, and sometimes becoming secondary pests. These native populations are usually kept in check by natural predators and parasites that have coevolved. Exotic introductions of woodwasp species, however, may find an arena void of ecological checks. Populations may establish and pose a potential threat to urban and rural forests.

Sirex Woodwasp, Status: Phase IV

The exotic Sirex woodwasp (*Sirex noctilio* Fabricius) larvae feed internally in the sapwood of the trunk and limbs of several pine species. Damage symptoms include resin beads, weeping sap, and discolored, wilting foliage (figure 6). Adult female Sirex woodwasps carry a symbiotic fungus (*Amylostereum* spp.) and mucoid substance which, when injected into the tree during oviposition, hastens wood decomposition and softens the tree tissue for the young woodwasp larvae to develop

Figure 6. Weeping sap is one symptom that may indicate a pine tree is infested with the exotic woodwasp *Sirex noctilio*. (Photo by Dennis Haugen, Bugwood.org)

(Fundazioa 2012). The fungus is typically a weak pathogen, but in high titer, can reduce sap flow, and hasten a tree's decline. In its native habitat in Europe, Asia, and North Africa, Sirex woodwasp populations are usually kept in check by native predators and parasites, although they can sometimes become secondary pests. Sirex woodwasps have established in Australia, New Zealand, and South America, sometimes with significant effects. Historic outbreaks in southeastern Australia have killed more than 1.8 million pines in a single year, and in South America, the woodwasps, and their fungal associate, have caused up to 80 percent tree mortality in pine stands (Rawlings 1954, Coutts 1968, Carnegie 2007).

Sirex woodwasp has been found in New York, Connecticut, Michigan, New Jersey, Ohio, Pennsylvania, Vermont, and Ontario, Canada (USDA-APHIS 2014b). Recent research has shown that both native and exotic woodwasp species can coexist in the same tree (Hajek et al. 2013), and that each species may carry the exotic fungal symbiont. This “fungal swapping” may be a concern, where both exotic and native woodwasp outbreaks may be accompanied by an exotic fungal symbiont. Although no Federal quarantine regulates Sirex woodwasp in the United States, several States maintain exclusionary quarantines to prevent artificial spread in wood materials, such as logs and firewood. Detection surveys continue to monitor for the pest in areas of high pine production, and ongoing research aims to manage the pest in pine plantations.

Tremex Woodwasp, Status: Phase II

The Tremex woodwasp (*Tremex fuscicornis* [Fabricius]) is native to Europe and Asia where it typically attacks mainly dead and declining trees (figure 7). The species has moved to other regions, likely from imported wooden crates, where it has affected hardwood tree plantations and agricultural windbreaks. In Chile, infestations have been observed on healthy maple (*Acer* spp.), willow (*Salix* spp.), and poplar trees. In these cases, the Tremex woodwasp begins its attack by ovipositing in the branches of the tree. The emerging larvae bore through the wood and develop inside the tree for 1 to 3 years, consequently weakening the tree (Ciesla 2003, Parra et al. 2005). Adult emergence holes are round and 5 to 6 mm (about 0.2 in) in diameter. Other symptoms of an infested tree include branch and crown dieback, yellowing and wilted leaves, leaf and trunk necroses, bubble-like tyloses formation in the cells, loosened bark, sapwood discoloration, and general structural weakening. As with Sirex woodwasps, Tremex woodwasps also carry fungal symbionts, which soften and degrade the wood (Ciesla 2003, Parra et al. 2005, CABI 2011). Tremex infestations in Chile have also affected agricultural crops through destruction of forested windbreaks that shelter agricultural fields (Palma et al. 2005). Despite increased safeguarding measures for imported wood packing material, live larvae, pupae, and adults of Tremex woodwasps are still intercepted with imported commodities, including reports of adult Tremex woodwasps flying from a shipping container when opened. Given the difficulty in inspecting for internal-feeding woodwasps, the detection of an emerging adult in a shipping container can be considered a chance find. Unfortunately, the high number of adult wasp interceptions suggests that insufficient safeguards are in place to adequately reduce the risk of Tremex woodwasp introduction.

Figure 7. Tremex woodwasp deposits eggs, a fungus, and a mucoid substance into the wood of hardwood trees. (Photo by Jiří Berkovec, Plzni, Czech Republic)

Preventing the Next Invasion

Over the past few decades, as global trade has increased, so has the need to better understand pest risks and safeguards against invasive species (Work et al 2005, Krcmar 2008, Liebhold et al. 2012). Through governmental regulations, such as the Plant Protection Act of 2000 (Library of Congress 2000), or global treaties such as the International Plant Protection Convention (IPPC), agencies regulate the movement of commodities to protect native plants and the production of agricultural and silvicultural resources. Preventative safeguarding measures have been adopted by many countries, in the form of sanitary treatments and certification, improved inspection at ports, and an improved ability to detect nonnative species beyond ports of entry.

Sometimes referred to as the “safeguarding continuum,” this network of pest exclusion efforts includes components aimed at reducing the overall risk of pest introduction and establishment. This safeguarding network involves several components including overseas preinspection of commodities, import inspections at U.S. ports of entry, domestic surveys, and pest eradication and management programs. These safeguarding programs are typically conducted by Federal, State, and municipal government agencies, universities, and private industry. In the United States, the USDA Animal and Plant Health Inspection Service (APHIS) and State agricultural agencies provide guidance and certification for the import and export permitting of plant products. Likewise, when U.S. commodities are destined for international trade, importing countries have certain phytosanitary requirements. A phytosanitary certificate may be required by the importing country to certify that the product has been inspected and found free of regulated pests (FAO 2011). Field and greenhouse propagative plants are subject to import requirements depending on the country of origin. Propagative plant material that originates in Canada is also subject to inspection (USDA 2014). For help reviewing plans for international movement of plants, contact the USDA’s permit unit (http://www.aphis.usda.gov/permits).

The USDA's Cooperative Agriculture Pest Survey program conducts annual detection surveys targeting specific insect and disease species that pose a significant threat to agriculture. Using this program, States select from a list of target pests that are considered high-risk for their region. Although some pests are considered to be the highest risk for introductions, the frequency with which a pest is monitored depends on several challenges. For example, States frequently survey for AGM and the Mediterranean pine engraver beetle, whereas the velvet longhorned beetle and Tremex woodwasp are not as frequently selected as target pests for surveys (USDA-APHIS 2014b). This avoidance may be partly because of challenges in the development and deployment of effective lures and traps for some target pests. Research continues to make scientific advances in developing new survey tools to strengthen our pest monitoring programs.

Regulatory agencies and port inspections are unable to completely mitigate all risk. Safeguarding also relies greatly on the vigilance of businesses and citizens, especially when considering international commerce and movement of plant material. Horticultural professionals, especially those with import and export businesses, are also a critical part of biosecurity. It is important to be aware of phytosanitary issues and safeguard nursery sites, ensuring only healthy stock is brought into an active productive area (Landis et al. 2010). Nursery owners who desire to import new tree varieties may be required to obtain an import permit and may qualify for post-entry quarantine arrangements to minimize risks for introduction of new plant pests. For instance, routine inspections of imported nursery stock, and staging new plant materials separately from the main growing area for a period of observation, help prevent any new insect or disease pests from establishing in the nursery or the surrounding environment.

Another critical component of the safeguarding net is the inclusion of education and recruitment of citizens. Private citizens, or citizens engaged in nonsurvey activities, are reporting new nonnative species and playing an important role in the detection of new invasive species populations. Between 1991 and 2001, Washington State logged 57 new records for invasive pests never before found in the State. Nearly one-third of those new detections were made during random encounters by private citizens or off-duty biologists (Looney et al. 2011). The importance of public education has been critical in detecting new populations of ALB in the United States and has led to an extensive outreach program (http://www.beetlebusters.info/). Beyond outreach, new initiatives to train and include citizen scientists in surveys can further improve chances of finding new infestations of exotic plant pests.

Many pests discussed in this article are representative of nonnative insects that have the potential to be introduced into North America and become new invasive forest pests. Other pests not discussed here, such as nonnative pathogens, nematodes, mollusks, and weeds, also represent important plant health risks. Although governmental regulations, monitoring, and control programs greatly reduce the risk of establishment of new foreign pests, these steps are not solely effective at prevention. The pest safeguarding system also relies heavily on a vigilant citizenry and an attentive marketplace.

Address correspondence to—

Mark Hitchcox, U.S. Department of Agriculture, Animal and Plant Health Inspection Service, Plant Protection and Quarantine, Oregon Field Office, 6135 NE 80th Avenue, Suite A-5, Portland, OR 97218; e-mail: mark.e.hitchcox@aphis.usda.gov; phone: 503–820-2745.

Acknowledgments

The author thanks Paul Chaloux and Abbey Powell (U.S. Department of Agriculture, Animal and Plant Health Inspection Service) for providing comments on an earlier draft of the manuscript.

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Stocktype Influences Western White Pine Seedling Size 6 Years After Outplanting

Donald J. Regan, Kent G. Apostol, and Anthony S. Davis

Assistant Nursery Manager, Center for Forest Nursery and Seedling Research, College of Natural Resources (CNR), University of Idaho (UI), Moscow, ID; Research Scientist, Center for Forest Nursery and Seedling Research, CNR, UI, Moscow, ID; Director and Associate Professor, Center for Forest Nursery and Seedling Research, CNR, UI, Moscow, ID

Abstract

In container seedling nurseries, copper coating that promotes root pruning and varying container volumes are often used to manipulate seedling size in an effort to optimize outplanting success. Western white pine seedlings were grown with or without copper root pruning in two container sizes. Seedling height and root-collar diameter were significantly different at outplanting and after six growing seasons. Seedlings grown in larger containers (130 ml [8 in^3]) outperformed their smaller (80 ml [5 in^3]) counterparts, and copper root pruning resulted in approximately 10 percent more height and root-collar diameter growth. With relatively few studies investigating the longer-term performance of western white pine seedlings of different stocktypes, these results should aid in identifying appropriate seedlings for meeting outplanting objectives.

Introduction

A target seedling is a plant that has been cultured to survive and grow on a specific outplanting site. The specific outplanting objective(s) will have a critical influence on the target seedling characteristics. Stocktype selection is an important tool used to meet certain management objectives (e.g., reforestation, saw logs or pulp production, and restoration or conservation projects) and overcome obstacles to reforestation success such as site conditions, cost constraints, and the silvics of the species of interest. For example, stock grown in large containers require more growing medium, more fertilizer, and more growing space than those grown in smaller containers; therefore, stocktypes with larger, more robust root systems have higher production costs than those grown in smaller containers (Bowden 1993). Stocktype selection is described in detail in Landis (2009), Davis and Brusven (2010), and Pinto et al. (2011a).

The "Target Plant Concept" promotes quantification of the relationship between seedling quality, in terms of morphology and physiology, and outplanting success (Landis 2009). Use of that information to refine propagation protocols and outplanting practices should then yield higher seedling establishment success. In a container seedling nursery, cavity size and cultural practices are commonly managed to manipulate seedling growth to meet objectives and achieve morphological (e.g., height, stem diameter, shoot to root ratio, and root volume) and physiological (e.g., root growth potential, tissue electrolyte leakage, tissue water potential, tissue moisture content, gas exchange, and mineral nutrition) targets (Landis 2009). The stocktype characteristics that are linked to outplanting success will vary depending on the sites where they will be outplanted. For instance, where seedlings experience drought in the field, stocktypes with larger and longer root systems have better survival or growth as they have better access to water and nutrients. Large shoots can create water deficits through large transpirational surface areas, while small shoots may have small surface areas for photosynthetic activity, resulting in low carbohydrate reserves to endure long periods of drought (Pinto et al. 2011b). Larger container size is well correlated with larger seedling size at the end of the nursery production cycle (Pinto et al. 2011a). Typically, larger seedlings cost more initially (Davis and Brusven 2010) but can outperform smaller seedlings in the field (Pinto et al. 2011a).

Given concerns about container seedlings having poor root egress and poor field survival following outplanting (Wenny et al. 1988), techniques to promote post-planting root growth were developed. One such treatment involves copper coating (copper oxychloride) on container walls. Because copper is toxic to roots, roots will self-prune on contact. After outplanting, seedlings treated in this manner tend to grow more lateral roots, particularly in the upper profile of the root plug (Burdett et al. 1983, Dumroese 2000, Campbell et al. 2006). This improved lateral root development can result in altered, and potentially improved, seedling water and nutrient acquisition (Burdett et al. 1983).

Western white pine (*Pinus monticola* Douglas ex D. Don) is an important component of forests in the Inland Northwest; however, white pine blister rust (*Cronartium ribicola* Fisch. VonWaldh.) is diminishing its range and stature, resulting in the colonization of these forests by less economically and ecologically desirable species (Kinloch Jr. 2003). After the extent and cause of western white pine decline were understood, scientists initiated efforts to restore the species using blight-resistance breeding programs were undertaken (Kim et al. 2003). Local and government nurseries across the species' range currently produce and distribute blight-resistant seedlings and encourage plantings for forest health improvement. For this reason, continued interest exists in refining nursery production and early stand silviculture practices to promote western white pine seedling establishment.

South et al. (2005) and Sword Sayer et al. (2009) observed an increase in seedling size and substantial allocation of root system dry weight to the taproot in longleaf pine (*Pinus palustris* Mill.) when seedlings were grown in copper-coated containers. In addition, Dumroese et al. (2013) reported increased taproot biomass in longleaf pine but no changes to shoot or total root biomass when grown in copper-coated containers. On the other hand, Wenny et al. (1988) reported the use of copper-coated containers resulted in no benefit to western white pine seedling growth 3 years after planting; while Campbell et al. (2006) reported the same for lodgepole pine (*Pinus. contorta* ex Loudon) after two growing seasons.

The objective of this study was to compare the growth and survival of outplanted western white pine seedlings grown in two sizes of containers with and without copper coating. It was hypothesized that seedlings grown with copper treatment would out-perform non-copper seedlings by exhibiting increased growth because of improved water and nutrient uptake, and that seedlings grown in larger containers would maintain their size difference over time.

Materials and Methods

Western white pine seeds (Moscow Seed Orchard seed source) were sown in March 2004. Seedlings were grown under standard operational practices (per Wenny and Dumroese 1987) at the University of Idaho's Franklin H. Pitkin Forest Nursery. Two sizes (120/80 and 91/130) of Styroblock containers (Beaver Plastics, Acheson, Alberta, Canada) either without a copper treatment (Superblock©) or with a copper oxychloride coating (Copperblock©) were included in the study. Containers were identical except for a proprietary application of copper oxychloride made to the surface of each cavity in the Copperblock®, which serves as the root-pruning mechanism. 120/80 containers have a growing density of 120 seedlings per container and a cavity volume of 80 ml (5 in^3), while 91/130 containers have a growing density of 91 seedlings per container and a cavity volume of 130 ml (8 in^3). Following lifting from containers in December 2004, seedlings were placed in cold storage at 2 °C (28 °F) until May 2005, at which time they were thawed and outplanted on a mesic site in Elk River, ID (46°78' N, 116°18' W, elevation 945 m [3,100 ft]), using hoedads (figures 1 and 2).

Figure 1. A general view of the field study site in Elk River, ID. (Photo by D. Regan 2014)

Figure 2. Western white pine seedlings outplanted from (A) Superblock© and (B) Copperblock©. (Photo by D. Regan 2014)

The field study site was generally an ash cap mix in the upper horizons with the habitat type of western redcedar (*Thuja plicata* Donn ex D. Don) and wild ginger (*Asarum caudatum* Lindl.) The soil is in the threebear series, medial over loamy, amorphic over mixed, superactive, frigid oxyaquic udivitrands (Soil Survey Staff 2006). Historic mean maximum and minimum air temperatures were13.6 °C (56.5 °F) and -0.3 °C (31.4 °F), respectively (http://www.wrcc.dri.edu). Mean annual precipitation at the site is 950 mm (37.4 in) with 2,515 mm (99 in) occurring as winter precipitation.

Four replications were established as a randomized complete block design with 20 seedlings per treatment replication. The study was a 2 × 2 factorial (copper coating × container size). Initial height and root-collar diameter (RCD) were measured after outplanting and again at the end of the sixth growing season (September 2010), at which point survival was tallied. Data were analyzed with two-way Analysis of Variance using SAS software version 9.2 (SAS Institute, Cary, NC) and significant differences ($\alpha = 0.05$) were determined using Tukey's HSD.

Results

No significant interactions occurred between copper coating and container size, allowing for analysis of main effects. At outplanting, seedlings grown in the Copperblock® containers had shorter height ($p = 0.0002$) and more RCD ($p < 0.0001$) than those grown in the Styroblock® (no copper) containers and seedlings grown in 91/130 containers were taller ($p < 0.0001$) and had larger RCD ($p < 0.0001$) than those grown in 120/80 containers (table 1).

Six years after outplanting, seedling survival was not influenced by container size ($p = 0.1790$) or copper treatment ($p = 0.5011$) and ranged from 52 to 59 percent across all treatments (data not shown). Height growth ($p = 0.0009$), total height ($p = 0.0002$), RCD growth ($p = 0.0008$), and total RCD ($p = 0.0001$) were significantly more for seedlings grown in larger cavities (91/130 containers) compared with those grown in smaller cavities (120/80 containers) (table 1). Seedlings grown in the Copperblock® containers had more height growth ($p = 0.0048$), RCD

Table 1. Western white pine seedling size (means ± standard errors) at outplanting and after six growing seasons. Different letters indicate significance at $\alpha = 0.05$ between container sizes or between container types. Seedlings were grown in two sizes of Styroblocks either without a copper treatment (Superblock©) or with a copper oxychloride coating (Copperblock©).

Stocktype	Initial (May 2005)	Growth (Sept. 2010)	Total (Sept. 2010)
Height (cm)			
80 ml (5 in³)	11.8 ± 0.1 B	105.3 ± 3.6 B	117.1 ± 3.5 B
130 ml (8 in³)	13.7 ± 0.2 A	122.1 ± 3.6 A	136.8 ± 3.6 A
Superblock©	13.2 ± 0.2 A	107.3 ± 3.9 B	120.5 ± 4.0 B
Copperblock©	12.3 ± 0.2	121.2 ± 3.6 A	133.5 ± 3.7 A
Diameter (mm)			
80 ml (5 in³)	3.9 ± 0.1 B	27.4 ± 0.8 B	31.3 ± 0.8 B
130 ml (8 in³)	4.6 ± 0.1 A	31.3 ± 0.9 A	35.9 ± 0.9 A
Superblock©	4.1 ± 0.1 B	28.0 ± 0.9 B	32.1 ± 1.0 B
Copperblock©	4.4 ± 0.1	30.8 ± 0.8 A	35.2 ± 0.9 A

Conversions: 1 mm = 0.061 in; 1 cm = 0.394 in.

growth ($p = 0.0120$), total height ($p = 0.0079$), and total RCD ($p = 0.0061$) than those grown in the Styroblock® (no copper) containers (table 1).

Discussion

Western white pine seedlings grown in larger containers were initially larger and grew more in height and RCD than seedlings in smaller containers after six growing seasons (table 1). These size and growth differences are not surprising given plant use of growing space and resource acquisition (Sword Sayer et al. 2009, Pinto et al. 2011). Although statistically significant, however, it is important for foresters to determine on a case-by-case basis whether the 62.5-percent increase in container cavity volume, yielding a roughly 10 percent gain in size, is operationally or economically significant. In addition, it is possible that nursery cultural practices could have been adjusted to tailor growing regimes for each container size used. Pinto et al. (2011a) identified that stocktype studies are often limited in scope by using operational practices on experimental stocktypes. Under that premise, stocktype differences in the present study may be underestimated.

Although seedlings grown in copper-treated containers were initially shorter, the < 1 cm (0.4 in) difference was overcome by more growth in those seedlings during six growing seasons. RCD was more throughout the study for seedlings grown in Copperblock® containers compared with those grown in Styroblock® (no copper) containers. Given that RCD tends to be positively correlated with root volume, this increased RCD suggests increased root mass as well. Studies have shown greater lateral root egress resulting from copper pruning treatments (Burdett et al. 1983, Wenny et al. 1988, Dumroese 2000, Campbell et al. 2006, Sword Sayer et al. 2009), so it is anticipated that seedling development can be enhanced following outplanting when using such stock. Aldrete et al. (2002) found that seedling root morphology was improved in smooth-bark Mexican pine (*Pinus pseudostrobus* Lindl.) and Montezuma pine (*P. montezumae* Lamb.) following copper root pruning in the nursery, and postulated that seedling establishment could be improved in an economical manner using this treatment. Our results agree with Burdett et al. (1983), who found that longleaf pine height growth 4 years after outplanting was significantly greater in seedlings that had received copper root pruning compared with those that did not. Nonetheless, other studies have shown ambiguous results in the effect of copper treatment on seedling development after outplanting. Wenny et al. (1988) reported no difference in western white pine seedling growth as a result of copper root pruning 3 years following outplanting. Campbell et al. (2006) reported the same for lodgepole pine after two field seasons. Haywood et al. (2012) did not observe a significant increase in survival for longleaf pine 5 years after outplanting, while Sword Sayer et al. (2009) found no improvement in longleaf pine seedling morphology 1 year after outplanting or in survival 5 years after outplanting for seedlings grown in copper-treated containers, but stated that improved root architecture could yield longer term benefits. Given this variability in results across time, species, and sites, future studies must better quantify seedling quality at outplanting, site conditions, and post-planting environmental conditions.

Container size and copper root pruning each resulted in approximately 10 percent gains in height and RCD. The gains yielded by copper coating may provide a greater economic incentive than those achieved through using larger container use. The long-term nature of this study demonstrates that gains in seedling establishment may be interactive with environmental conditions and indicates that stocktype studies should be continued beyond 3 years to provide useful information on the long-term efficacy of such treatments. Furthermore, while most studies have solely investigated morphological attributes of seedlings associated with copper root pruning, effects on seedling physiological status should be carefully examined. For example, Davis et al. (2011) found that longleaf pine seedling cold hardiness was unaffected by copper root pruning and Arnold and Struve (1993) found seedling Ca, Cu, Mg, N, and Zn levels were higher in seedlings grown with copper root pruning compared with seedlings grown in non-copper containers.

Address correspondence to—

Kent G. Apostol, Research Scientist, Center for Forest Nursery and Seedling Research, College of Natural Resources, University of Idaho, PO Box 441133, Moscow, ID 83843; e-mail: kapostol@uidaho.edu; phone: 208–885–3770.

Acknowledgments

Potlatch Corporation and the University of Idaho Center for Forest Nursery and Seedling Research funded this study. Dave Wenny, Kasten Dumroese, Daniel L. Miller, Abbie Acuff, John Mandzak, and Raini Rippy provided field and technical support. Kea Woodruff and Diane Haase provided helpful comments on the manuscript.

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Genetic Resource Conservation of Table Mountain Pine (*Pinus pungens*) in the Central and Southern Appalachian Mountains

Robert M. Jetton, Barbara S. Crane, W. Andrew Whittier, and William S. Dvorak

Research Assistant Professor, Camcore, Department of Forestry & Environmental Resources, North Carolina State University (NC State), Raleigh, NC; Regional Geneticist, U.S. Department of Agriculture, Forest Service, Southern Region National Forest System, Atlanta, GA; Research Forester, Camcore, Department of Forestry & Environmental Resources, NC State, Raleigh, NC; Professor and Director Emeritus, Camcore, Department of Forestry & Environmental Resources, NC State, Raleigh, NC

Abstract

Table Mountain pine (*Pinus pungens* Lambert) was historically a widespread pine species native to the central and southern Appalachian Mountains, but, in recent decades, its current natural distribution has been reduced to less than 30,000 ac (12,000 ha). Reasons for this decline include wildfire suppression programs of the early 20th century, southern pine beetle outbreaks, and recent climate fluctuations. Part of the effort to mitigate this decline is a 5-year, cooperative, genetic-resource conservation effort being conducted by Camcore (International Tree Breeding and Conservation, North Carolina [NC] State University) and the U.S. Department of Agriculture (USDA), Forest Service, Southern Region National Forest System. The goal of the project was to target seed collections from up to 300 mother trees in 30 populations distributed across the natural range of the species. During five field seasons, cones were collected from a total of 262 mother trees in 38 populations and yielded a total of 390,530 seeds. Seeds have been distributed to the USDA Agricultural Research Service-National Center for Genetic Resources Preservation for long-term storage, the USDA Forest Service Ashe Nursery Facility for seed orchard and reforestation activities, and the Camcore Seed Bank for research and field plantings. Collectively, the seed stored at these three facilities represents the largest genetic resource of Table Mountain pine that exists outside of natural stands.

Introduction

Table Mountain pine (*Pinus pungens* Lambert; TMP) is an Appalachian Mountain endemic species that has a fragmented distribution within a main range extending from central Pennsylvania south into northern Georgia (Farjon 2005, figure 1). A number of geographically disjunct populations occur to the east and west of this main distribution, with those in the Piedmont regions of Virginia and North and South Carolina associated with small isolated mountains. The typically small, geographically isolated populations occur mostly along south- and west-facing ridgelines and outcroppings at elevations between 1,000 and 4,000 ft (300 and 1,200 m). Soils are inceptisols that are low in productivity, shallow, stony, and highly acidic and have poor profile development (Zobel 1969). Trees growing on these sites have a stunted, gnarled, wind-sculpted appearance, but the species can grow taller and straighter on better quality sites (figure 2).

Table Mountain pine is a member of the pine subsection *Australes* and is most closely related to pitch pine (*Pinus rigida* Mill.), pond pine (*P. serotina* Michx.), and loblolly pine (*P. taeda* L.) (Gernandt et al. 2005). Common pine associates in its native habitats are Virginia pine (*P. virginiana* Mill.) at the low end of the elevation range and pitch pine at middle elevations (Camcore 2010). At the high end of its elevation range TMP tends to occur in pure stands or intermixed with oak (*Quercus* spp.). Across much of its distribution, TMP exhibits a fire-adapted regeneration strategy, possessing highly serotinous seed cones (figure 3) and requiring periodic, low-intensity wildfires to eliminate competition, prepare the seedbed, and release seeds from cones (Zobel 1969). At the northern edge of the species' range in Pennsylvania, cones are less serotinous and typically open naturally in the absence of fire every fall to release seeds (Brose et al. 2010). The species has occasionally been used commercially as a source of pulpwood, low-grade sawtimber, and firewood when harvested opportunistically, but it is most valuable for the ecosystem services it provides. The serotinous seed cones are a year-round source of food for wildlife, and the trees and their root systems help to stabilize soils along ridgelines, minimizing erosion and runoff (Della-Bianca 1990).

Across most its range, TMP populations have declined significantly during the past several decades. This previously widespread species is now limited to less than 30,000 ac

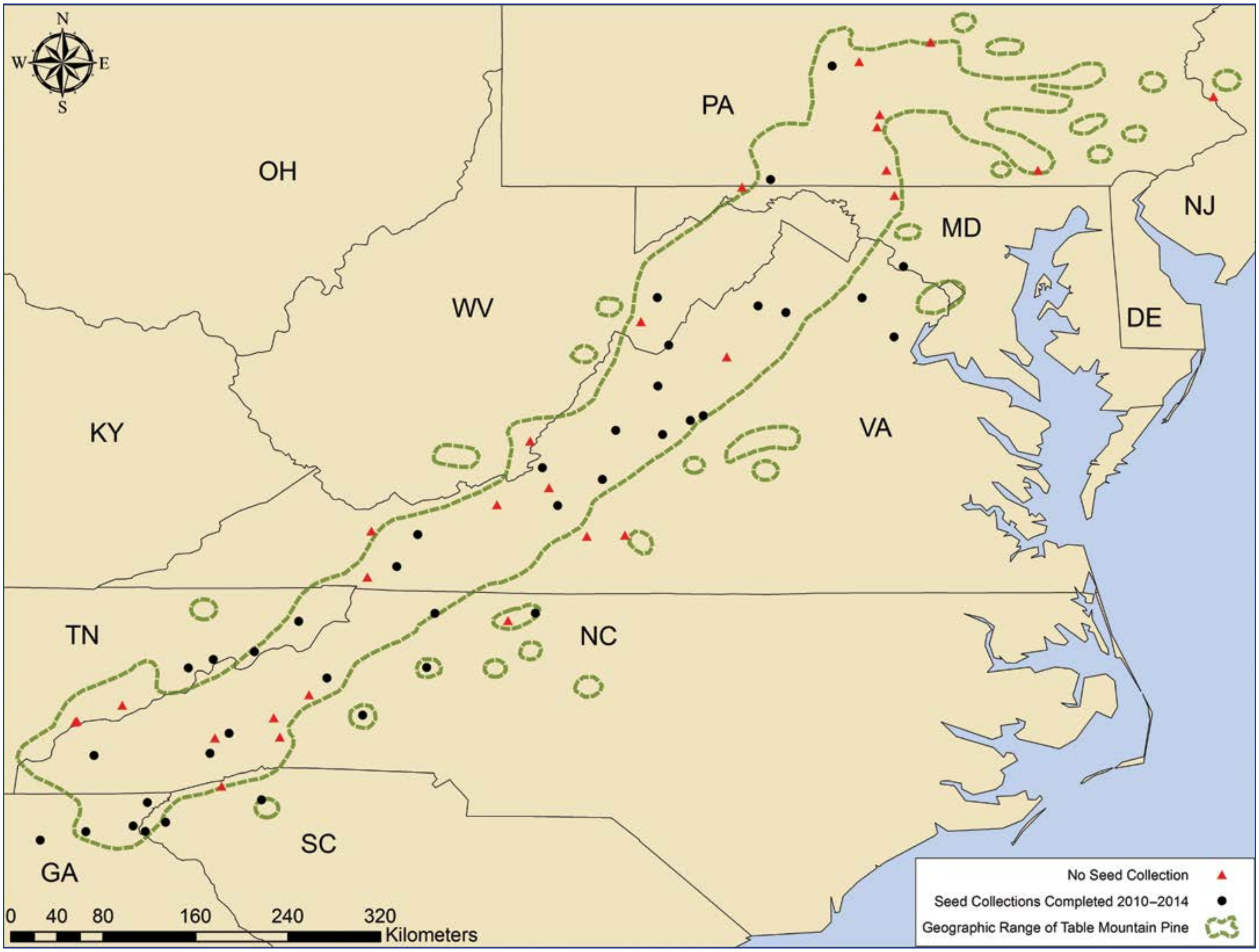

Figure 1. The geographic distribution of Table Mountain pine in the central and southern Appalachian Mountains and the locations of 65 known population occurrences identified by Camcore. Seed collections were completed in those indicated by black circles. No seed collections were attempted in those indicated by red triangles.

(12,000 ha). The primary cause of this decline is early 20th century wildfire suppression programs that reduced the frequency of low-intensity fires the species needs to regenerate (Williams 1998). In the absence of fires, the natural process of stand succession has allowed hardwoods to take over in many sites previously dominated by TMP. Use of prescribed fire to regenerate declining TMP populations has been researched (Welch and Waldrop 2001), but it remains unclear what intensities and frequencies of controlled burning are best (Waldrop and Brose 1999, Randles et al. 2002). Secondary causes of decline are periodic infestations of the southern pine beetle (*Dendroctonus frontalis* Zimm.) (Knebel and Wentworth 2007), outbreaks of which in mountainous regions are typically associated with periods of prolonged drought. Climate change has also been identified as a potential cause of TMP decline (Erickson et al. 2012), buts its role and the ability of the species to adapt has not been studied in depth.

Given TMP's decline, its ecological role in soil stabilization along high-elevation ridges, its importance as a source of food for wildlife, and the absence of consistently reliable methods for regenerating declining stands, the species was identified by the USDA Forest Service as a good candidate for seed conservation to secure the genetic resources of the species before additional populations were lost. A gene conservation project was initiated in late 2009 as a collaborative effort between Camcore (International Tree Breeding and Conservation, NC State University) and the USDA Forest Service Southern Region National Forest System to conserve seed resources of TMP during a 5-year period (2010–2014). The objectives of the project were to (1) make representative seed collections from 30 populations and up to 300 mother trees (10 per population) distributed across the geographic range of the species, (2) place seeds into cold storage at the USDA Forest Service Ashe Nursery Facility (Brooklyn, MS) and the Camcore Seed

Figure 2. Where Table Mountain pine grows on low productivity soils typical of the species, trees tend to have a stunted, gnarled, wind-sculpted appearance (A), but can grow taller and straighter on better quality sites (B). (Photos courtesy of Camcore, Department of Forestry & Environmental Resources, North Carolina State University)

Figure 3. Serotinous seed cones of Table Mountain pine at Hanging Rock State Park in North Carolina. (Photo courtesy of Camcore, Department of Forestry & Environmental Resources, North Carolina State University)

Bank (Raleigh, NC) to support seed orchard establishment and reforestation activities, and (3) submit seed samples from each mother tree to the USDA Agricultural Research Service-National Center for Genetic Resources Preservation (Fort Collins, CO) for long-term preservation. This article describes the results of the seed collection and the TMP genetic resources now available.

Seed Collection Strategy and Protocols

The first phase of this project was to identify candidate populations for seed collection. Through conversations with both Federal and State resource managers and surveys of the available scientific literature, 65 occurrences of TMP were identified (table 1, figure 1). Camcore personnel visually confirmed the existence of trees at 53 of the sites. The remaining 12 sites were not visited because of time and funding constraints.

The next phase was to design an effective gene conservation strategy to capture a representative number of alleles, or different forms of the same gene on a chromosome. As an example,

Table 1. Location, climate, ecological subregion, and seed collection data for 65 Table Mountain pine populations identified by Camcore as candidates for seed collection.

Provenance	County, State	Elev. (m)	Lat. (D.d)	Long. (D.d)	Ann. min./max. temp. (°C)	Total ann. precip. (mm)	Plant hardiness zone	Ecological subregion	Seed collection
Climate/Seed Zone 1									
Cades Cove	Blount, TN	851	35.56	– 83.83	4.7/17.7	1,592	6b	Blue Ridge Mountains	No
Camp Merrill	Lumpkin, GA	606	34.63	– 84.12	6.2/19.1	1,671	7a	Blue Ridge Mountains	Yes
Cherokee Orchard	Swain, TN	1,534	35.68	– 83.48	4.6/18.1	1,461	6b	Blue Ridge Mountains	No
Looking Glass Rock	Transylvania, NC	1,186	35.30	– 82.79	4.7/17.4	1,740	6b	Blue Ridge Mountains	Yes
Middle Gregory	Blount, TN	740	35.55	– 83.85	5.3/18.7	1,525	6b	Blue Ridge Mountains	No
Mount Pisgah	Buncombe, NC	1,742	35.43	– 82.76	4.2/16.6	1,643	6b	Blue Ridge Mountains	No
Nolton Ridge	Graham, NC	1,097	35.29	– 83.70	4.6/18.3	1,667	6b	Blue Ridge Mountains	Yes
Paris Mountain	Greenville, SC	470	34.94	– 82.39	8.7/21.2	1,465	7b	Southern Appalachian Piedmont	Yes
Pine Mountain	Oconee, SC	507	34.70	– 83.30	8.3/21.6	1,519	7b	Southern Appalachian Piedmont	Yes
Poor Mountain SC	Oconee, SC	479	34.77	– 83.14	7.8/21.0	1,615	7b	Southern Appalachian Piedmont	Yes
Smithgall Woods	Habersham, GA	535	34.69	– 83.76	9.2/22.2	1,360	7a	Southern Appalachian Piedmont	Yes
Table Rock Mountain SC	Pickens, SC	886	35.05	– 82.71	7.3/20.6	1,674	7a	Blue Ridge Mountains	No
Tallulah Gorge	Rabun, GA	445	34.74	– 83.39	7.2/20.5	1,675	7b	Blue Ridge Mountains	Yes
Walnut Fork	Rabun, GA	702	34.92	– 83.28	5.8/19.2	1,850	7a	Blue Ridge Mountains	Yes
Climate/Seed Zone 2									
Bent Creek	Buncombe, NC	876	35.46	– 82.65	5.2/18.5	1,338	6b	Blue Ridge Mountains	Yes
Black Mountain	Buncombe, NC	971	35.58	– 82.30	4.7/17.5	1,448	6b	Blue Ridge Mountains	No
Chimney Rock	Rutherford, NC	679	35.43	– 82.25	6.0/19.3	1,383	7a	Blue Ridge Mountains	No
Graveyard Mountain	Haywood, NC	622	35.76	– 82.02	6.4/20.0	1,307	7a	Blue Ridge Mountains	No
South Mountains	Burke, NC	677	35.60	– 81.61	7.3/20.4	1,319	7a	Central Appalachian Piedmont	Yes
Table Rock Mountain NC	Burke, NC	1,181	35.89	– 81.88	4.7/17.5	1,424	6a	Blue Ridge Mountains	Yes
Climate/Seed Zone 3									
Bald Mountain	Nelson, VA	867	37.90	– 79.05	4.1/16.2	1,202	6b	Blue Ridge Mountains	Yes
Briery Branch	Rockingham, VA	1,133	38.48	– 79.22	2.4/14.2	1,149	5b	Northern Ridge & Valley	Yes
Brush Mountain	Montgomery, VA	747	37.24	– 80.56	4.6/17.9	959	6b	Northern Ridge & Valley	No
Buena Vista	Rockbridge, VA	748	37.79	– 79.27	4.7/17.2	1,148	6b	Blue Ridge Mountains	Yes
Cliff Ridge	Unicoi, TN	850	36.10	– 82.45	5.3/18.8	1,189	6b	Blue Ridge Mountains	Yes
Clinch Mountain	Tazwell, VA	1,254	37.04	– 81.54	4.1/17.0	1,112	6a	Northern Ridge & Valley	No
Dragon's Tooth	Roanoke, VA	490	37.38	– 80.16	5.1/18.2	1,009	6b	Northern Ridge & Valley	No
Elliott Knob	Augusta, VA	1,203	38.16	– 79.31	3.3/15.6	1,142	6a	Northern Ridge & Valley	Yes
Greene Mountain	Greene, TN	726	36.03	– 82.77	4.9/18.0	1,191	6b	Blue Ridge Mountains	Yes
Hanging Rock	Stokes, NC	648	36.40	– 80.26	6.6/19.2	1,246	7a	Central Appalachian Piedmont	Yes
Iron Mine Hollow	Botetourt, VA	716	37.44	– 79.74	5.9/18.5	1,077	7a	Blue Ridge Mountains	Yes
Iron Mountain TN	Johnson, TN	883	36.33	– 82.10	5.1/18.3	1,230	6b	Blue Ridge Mountains	Yes
Iron Mountain VA	Grayson, VA	1,019	36.68	– 81.57	3.2/14.7	1,330	5b	Blue Ridge Mountains	No
Kates Mountain	Greenbrier, WV	822	37.74	– 80.30	3.2/16.2	1,065	6a	Allegheny Mountains	No
Little Walker Mountain	Wythe, VA	751	37.01	– 81.18	3.8/16.7	1,053	6a	Northern Ridge & Valley	Yes
Meadow Creek	Cocke, TN	739	35.97	– 82.96	5.9/19.2	1,157	7a	Blue Ridge Mountains	Yes
North Fork	Pendelton, WV	1,166	38.67	– 79.44	2.4/14.4	1,150	5b	Northern Ridge & Valley	No
North Mountain	Rockbridge, VA	927	37.82	– 79.63	4.4/17.2	1,110	6b	Northern Ridge & Valley	Yes
Pigg River	Franklin, VA	287	37.00	– 79.86	6.8/19.7	1,120	7a	Central Appalachian Piedmont	No
Pilot Mountain	Surry, NC	737	36.34	– 80.47	6.8/20.0	1,212	7a	Central Appalachian Piedmont	No
Poor Mountain VA	Roanoke, VA	673	37.23	– 80.09	5.3/18.1	1,054	7a	Blue Ridge Mountains	Yes
Potts Mountain	Craig, VA	600	37.53	– 80.21	4.9/18.4	979	6a	Northern Ridge & Valley	Yes
Ravens Roost	Augusta, VA	974	37.93	– 78.95	4.0/16.0	1,205	6b	Blue Ridge Mountains	Yes
Rocky Face	Alexander, NC	536	35.97	– 81.11	6.8/20.5	1,247	7b	Central Appalachian Piedmont	Yes
Smith Mountain	Pittsylvania, VA	295	37.00	– 79.56	6.6/19.4	1,116	7a	Central Appalachian Piedmont	No
Snake Den Mountain	Smyth, VA	1,064	36.76	– 81.34	3.7/16.3	1,180	6a	Blue Ridge Mountains	Yes
Stone Mountain	Wilkes/Alleghany, NC	680	36.39	– 81.04	5.4/19.1	1,206	6b	Blue Ridge Mountains	Yes
Climate/Seed Zone 4									
Abraitys Pine Stand	Hunterdon, NJ	34	40.42	– 74.98	4.8/16.7	1,179	6b	Northern Appalachian Piedmont	No
Bald Eagle	Union, PA	351	40.84	– 77.18	3.3/15.3	1,077	6a	Northern Ridge & Valley	No
Blue Mountain	Cumberland, PA	517	40.18	– 77.60	3.9/14.7	1,075	6b	Northern Ridge & Valley	No

Table 1. Location, climate, ecological subregion, and seed collection data for 65 Table Mountain pine populations identified by Camcore as candidates for seed collection. (continued)

Provenance	County, State	Elev. (m)	Lat. (D.d)	Long. (D.d)	Ann. min./max. temp. (°C)	Total ann. precip. (mm)	Plant hardiness zone	Ecological subregion	Seed collection
Climate/Seed Zone 4 *(continued)*									
Buchanan	Bedford, PA	371	39.77	– 78.43	3.8/16.3	955	6b	Northern Ridge & Valley	Yes
Bull Run	Fauquier, VA	412	38.85	– 77.72	6.0/18.1	1,045	7a	Northern Appalachian Piedmont	Yes
Catoctin Mountain	Frederick, MD	438	39.65	– 77.46	4.4/15.4	1,115	6b	Blue Ridge Mountains	No
Edinburg Gap	Shenandoah, VA	525	38.79	– 78.53	3.0/16.8	1,001	6a	Northern Ridge & Valley	Yes
Kelly's Run Susquehanna	Lancaster, PA	160	39.85	– 76.35	5.9/16.8	1,054	7a	Northern Appalachian Piedmont	No
Massanutten Mountain	Rockingham, VA	867	38.39	– 78.77	4.5/17.2	1,026	6b	Northern Ridge & Valley	No
Michaux	Franklin, PA	429	39.85	– 77.53	4.4/15.5	1,105	6b	Northern Ridge & Valley	No
Quantico	Stafford, VA	76	38.55	– 77.47	6.8/18.9	1,027	7a	Central Appalachian Piedmont	Yes
Rocky Gap	Allegany, MD	424	39.72	– 78.65	3.3/15.8	975	6b	Northern Ridge & Valley	No
Rothrock	Huntingdon, PA	398	40.69	– 77.74	3.2/14.1	1,042	5b	Northern Ridge & Valley	No
Shenandoah	Madison, VA	1,110	38.74	– 78.31	6.8/19.2	1,136	6a	Blue Ridge Mountains	Yes
Smoke Hole	Pendelton, WV	877	38.85	– 79.31	4.9/18.5	965	5b	Northern Ridge & Valley	Yes
Stone Valley Forest	Huntingdon, PA	351	40.66	– 77.95	4.2/15.7	974	6a	Northern Ridge & Valley	Yes
Sugarloaf Mountain	Frederick, MD	472	39.10	– 77.39	6.3/18.5	998	6b	Northern Appalachian Piedmont	Yes
Tuscarora	Perry, PA	526	40.28	– 77.58	4.3/15.4	1,042	6b	Northern Ridge & Valley	No

Elev. = elevation. Lat. = latitude. Long. = longitude. Ann. min./max. temp. = annual minimum/maximum temperature. ann. precip. = annual precipitation.

alleles in humans are those that control eye color. Designing this strategy successfully is dependent on a good understanding of population genetic structure and environmental adaptability for the species of concern. Understanding these characteristics helps answer common questions that arise for gene conservation concerning how many populations and mother trees per population to sample, and how to choose provenance seed collection sites across a species' range to capture maximum levels of diversity and broad adaptability. The benchmark goal for most plant genetic resource programs is to capture 95 percent of genes occurring in target populations at frequencies of 5 percent or greater (Marshall and Brown 1975). For conifers of low to moderate genetic diversity, a seed sample from 6 to 10 populations distributed across the range of a species and from 10 to 20 mother trees per population is sufficient to obtain this goal (Dvorak et al. 1999, Dvorak 2012). This approach has been used successfully by Camcore to conserve the genetic resources of 11 pine species native to Central America and Mexico (Dvorak et al. 2000), and eastern hemlock (*Tsuga canadensis* [L.] Carriére) and Carolina hemlock (*T. caroliniana* Engelmann) in the Eastern United States (Jetton et al. 2013).

Available data on genetic structure and diversity across 20 populations of TMP distributed from Pennsylvania to Georgia indicates that the species has a high level of genetic diversity compared with the average for most conifers and woody plants in general (Gibson and Hamrick 1991). The highest levels of diversity are concentrated at the northern and southern extremes of the range. Populations were also found to be highly differentiated from each other (13.6 percent genetic variation among populations compared with 6.8 percent for most conifers), a characteristic indicative of the isolated nature of most populations.

While these genetic parameters are useful for understanding how genetic variation is structured across the range of the species, they are not necessarily informative as to the environmental adaptability of TMP. Adaptability was assessed by evaluating the USDA ecological subregions (McNab et al. 2007) and plant hardiness zones (USDA 2012), across which the TMP range occurs, and identifying the number and locations of seed zones for the species. ArcMap Version 10 (ESRI 2010) was used to overlay the TMP range on the ecological subregion and hardiness zone data layers to identify the subregions and zones occupied by the species. Table Mountain pine was found to occupy eight ecological subregions (Southern Appalachian Piedmont, Central Appalachian Piedmont, Northern Appalachian Piedmont, Lower New England, Central Ridge and Valley, Allegheny Mountains, Blue Ridge Mountains, Northern Ridge and Valley), of which six are represented in the 65 candidate populations (table 1). The range of TMP was found to occur across six plant hardiness zones (5a to 7b). All but one zone (5a) is represented in the 65 candidate populations (table 1).

Seeds zones were identified using a cluster analysis to assess climate similarity among the 65 known TMP occurrences (table 1, figure 1). Climate data consisted of the 19 bioclimatic variables available in the WorldClim Version 1.4 database

(Hijmas et al. 2005) and were derived for each of the 65 populations using DIVA-GIS Version 7.5 (Hijmas et al. 2012). These data were then subjected to a cluster analysis using the average linkage method in SAS Version 9.4 (SAS 2012), and each cluster of populations with similar climatic characteristics was then assumed to represent a seed zone for TMP. This analysis indicated that 90 percent of the variation in climate among the 65 populations was explained by four clusters resulting in four seed zones (figure 4). These seed zones are defined by decreasing average annual minimum temperature (Zone 1 = 43.3 °F [6.3 °C]; Zone 2 = 42.2 °F [5.7 °C]; Zone 3 = 40.6 °F [4.8 °C]; Zone 4 = 40.4 °F [4.7 °C]), average annual maximum temperature (Zone 1 = 66.6 °F [19.4 °C]; Zone 2 = 65.8 °F [18.9 °C]; Zone 3 = 63.7 °F [17.6 °C]; Zone 4 = 61.8 °F [16.6 °C]), and total annual precipitation (Zone 1 = 63 in [1,604 mm]; Zone 2 = 53 in [1,369 mm]; Zone 3 = 45 in [1,142 mm]; Zone 4 = 41 in [1,043 mm]) moving from south to north across the TMP range.

Using Gibson and Hamrick's (1991) genetic diversity data and results of the ecological subregion, plant hardiness zone, and seed zone analyses, a seed collection strategy was designed for TMP. Given the species' relatively high level of genetic variation and the fact that the populations tend to have a high level of genetic differentiation, 30 populations were targeted for seed collection. At least 5 of the disjunct populations that have a high probability of harboring unique alleles were to be included in these 30 populations. To account for environmental adaptability, the 30 targeted populations were to be spread across the four seed zones and stratified to account for the ecological subregions and plant hardiness zones represented in the 65 candidate populations. The seed collection protocol in each population called for the sampling of 10 mother trees per population while maintaining a distance of 328 ft (100 m) between each tree selected, recognizing that some populations may be so small that either sampling a smaller number of trees or maintaining a shorter distance between selected trees might

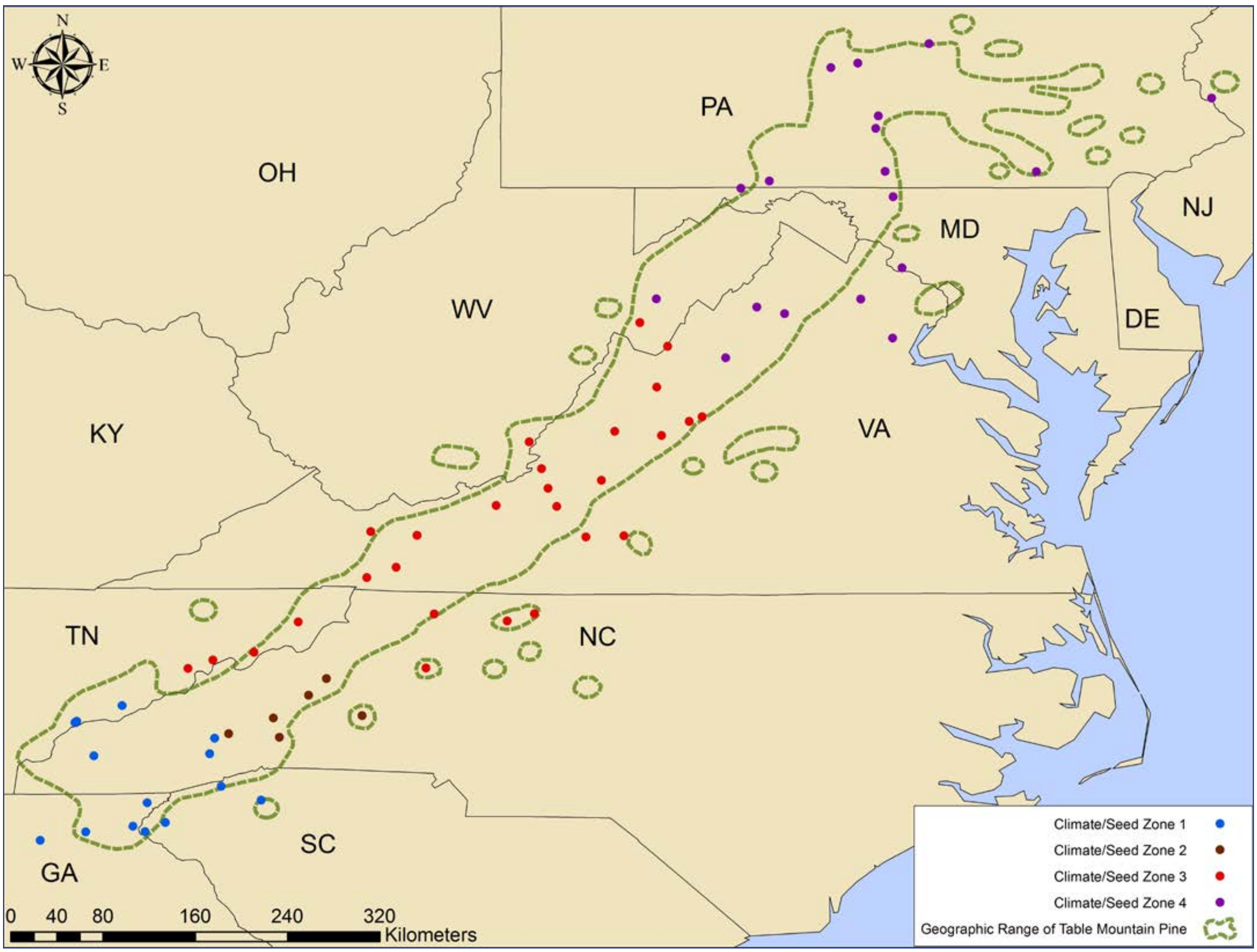

Figure 4. The four climate/seed zones identified for Table Mountain pine following the climate similarity cluster analysis.

be necessary. When available, 50 seed cones were collected from each tree. In total, this collection strategy should yield seeds from up to 300 individual mother trees. Additional details on field protocols used for seed collection are available in Jetton et al. (2009).

Provenance Seed Collections and Seed Distribution

During the 5-year duration of this project, seed collections were made from 262 mother trees distributed across 38 TMP populations from central Pennsylvania to northern Georgia (table 1, figure 1). The number of mother trees sampled in each population ranged from as few as 1 in 2 populations to 10 in 12 populations. On average, 35 cones and 1,490 seeds were collected per tree, yielding a total of 390,530 TMP seeds placed into storage (figures 5 and 6). Based on 30-day Petri dish germination assays conducted at 72 °F (22 °C), under a 16:8 light:dark photoperiod, and with two 50-seed replications per population, average seed viability was 52 percent. Results from x ray tests conducted on 200 seeds per population by the USDA Forest Service National Seed Laboratory (Dry Branch, GA) indicated 61 percent filled seed. With 26 filled seeds per cone and an average seed potential of 50 seeds per TMP cone (Farjon 2005), the seed efficiency (filled seeds per cone/seed potential x 100) of mother trees sampled in this project was 52 percent. Tree, seed, and cone traits for each TMP population sampled are summarized in table 2.

Well represented in the seed collections are populations in the central and southern portions of the TMP range (figure 1). Less well represented are populations in the most northern portion of the range in Pennsylvania, an area of high genetic diversity for the species, where time and resources allowed for sampling in only two of the nine populations identified in the region. Disjunct populations to the east of the main species distribution are also well represented, with a total of seven sampled in Maryland, Virginia, North Carolina, and South Carolina (figure 1). Disjunct populations to the west were not sampled. Collections also captured TMP genetic resources from five of the ecological subregions and five of the plant hardiness zones occupied by TMP (table 1). Areas not sampled include the Lower New England, Central Ridge and Valley, and Allegheny Mountains subregions and hardiness zone 5a. Populations from all four TMP seed zones were sampled.

Of the 390,530 seeds collected, 193,395 representing 242 mother trees and 36 populations have been stored at the USDA Forest Service Ashe Nursery Facility for use in seed orchard and reforestation activities. An additional 55,828 seeds representing 257 mother trees and 38 populations have been stored at the USDA Agricultural Research Service National Center for Genetic Resources Preservation for long-term preservation. The Camcore Seed Bank at NC State University has retained 135,361 seeds representing all 262 mother trees and 38 populations as a backup collection for conservation. An additional 5,946 seeds were used for germination testing and genetic diversity studies (figure 7).

Figure 5. Cloth collection bags with Table Mountain pine cones from Briery Branch in Virginia before drying and seed extraction. (Photo courtesy of Camcore, Department of Forestry & Environmental Resources, North Carolina State University)

Figure 6. Table Mountain pine seeds with wings from Briery Branch in Virginia following extraction from cones. (Photo courtesy of Camcore, Department of Forestry & Environmental Resources, North Carolina State University)

Table 2. Tree, seed, and cone traits for 38 Table Mountain pine populations where seed collections were conducted 2010–2014.

Provenance	Seed year	Trees (#)	Height (m)[a]	DBH (cm)[1]	Cones (#)	Seeds (#)	Seed weight (g)	Seeds per cone (#)	Seeds per gram (#)	Filled seed (%)	Germination (%)
Bald Mountain	2010	10	8.26 (±0.69)	36.78 (±1.77)	50.40 (±7.06)	2,550.00 (±369.26)	34.53 (±4.93)	52.65 (±4.90)	75.30 (±4.65)	68.60 (±4.15)	72.00 (±4.00)
Bent Creek	2010	2	9.14 (±1.52)	31.55 (±12.55)	39.00 (±12.00)	5,177.00 (±3,238.00)	44.90 (±25.20)	118.40 (±46.59)	109.23 (±10.80)	4.50 (±0.50)	31.00 (±5.00)
Briery Branch	2010	10	12.74 (±0.75)	37.52 (±1.75)	55.60 (±9.57)	2,454.00 (±450.64)	31.46 (±4.99)	45.02 (±5.08)	75.02 (±5.29)	66.10 (±6.01)	67.00 (±1.00)
Buchanan	2011	6	11.88 (±3.73)	24.31 (±4.43)	31.00 (±5.46)	753.66 (±424.61)	12.50 (±7.54)	21.38 (±9.24)	70.83 (±6.96)	64.83 (±4.70)	56.00 (±6.00)
Buena Vista	2010	10	9.35 (±0.86)	39.55 (±2.98)	30.50 (±3.48)	1,443.40 (±191.26)	21.83 (±3.11)	49.61 (±6.01)	68.46 (±2.90)	60.80 (±6.51)	32.00 (±4.00)
Camp Merrill	2010	4	8.38 (±0.43)	37.77 (±3.58)	75.00 (±18.12)	2,078.50 (±1,132.70)	21.52 (±10.53)	22.48 (±8.21)	88.28 (±7.97)	42.25 (±13.75)	39.00 (±13.00)
Cliff Ridge	2011	8	9.14 (±0.80)	19.43 (±1.85)	24.37 (±3.60)	765.37 (±87.96)	10.13 (±1.60)	35.61 (±4.85)	79.47 (±5.43)	69.50 (±4.85)	63.00 (±1.00)
Edinburg Gap	2011	1	8.53 (±0.00)	19.70 (±0.00)	10.00 (±0.00)	118.00 (±0.00)	1.20 (±0.00)	11.80 (±0.00)	98.33 (±0.00)	28.00 (±0.00)	not tested
Elliott Knob	2011	10	9.20 (±1.11)	33.33 (±1.58)	43.50 (±6.23)	2,552.80 (±669.41)	30.92 (±7.46)	53.99 (±6.48)	83.98 (±7.81)	67.70 (±4.59)	50.00 (±6.00)
Hanging Rock	2010	8	5.71 (±0.85)	24.46 (±2.71)	35.37 (±4.37)	1,255.50 (±255.95)	12.52 (±2.86)	33.96 (±3.02)	107.31 (±9.67)	37.75 (±6.27)	36.00 (±6.00)
Greene Mountain	2011	10	7.10 (±1.01)	20.91 (±2.69)	34.10 (±4.53)	1,835.71 (±380.02)	22.85 (±4.73)	53.38 (±7.27)	80.32 (±7.61)	60.20 (±7.82)	53.00 (±3.00)
Iron Mine Hollow	2010	3	7.21 (±1.13)	37.16 (±7.22)	59.33 (±9.82)	3,143.67 (±999.84)	46.24 (±13.86)	49.78 (±9.77)	67.57 (±3.63)	47.33 (±16.29)	49.00 (±1.00)
Iron Mountain TN	2011	5	11.58 (±0.87)	30.50 (±5.35)	31.80 (±4.87)	1,123.00 (±165.60)	14.08 (±1.37)	35.81 (±3.09)	78.33 (±3.95)	64.40 (±9.43)	33.00 (±3.00)
Looking Glass Rock	2010	8	5.05 (±0.44)	23.42 (±2.59)	40.00 (±7.20)	1,336.63 (±489.51)	12.66 (±3.91)	28.11 (±6.15)	105.37 (±7.16)	63.37 (±5.30)	56.00 (±2.00)
Meadow Creek	2011	7	10.72 (±0.70)	26.58 (±3.50)	37.00 (±7.30)	1,729.18 (±385.88)	21.52 (±4.80)	47.95 (±6.26)	80.32 (±6.51)	57.28 (±8.45)	70.00 (±0.00)
Nolton Ridge	2010	6	5.33 (±0.62)	15.61 (±1.80)	21.16 (±5.83)	1,430.00 (±415.21)	17.60 (±5.53)	69.40 (±6.68)	83.21 (±1.33)	65.16 (±9.84)	66.00 (±6.00)
North Mountain	2010	10	9.57 (±0.92)	29.82 (±2.61)	52.30 (±4.33)	2,622.20 (±322.87)	34.84 (±4.63)	53.44 (±8.01)	75.95 (±2.72)	78.40 (±6.73)	58.00 (±4.00)
Paris Mountain	2012	4	15.45 (±0.35)	39.82 (±1.57)	37.50 (±5.95	136.00 (±73.88)	1.67 (±0.91)	4.30 (±2.70)	81.25 (±1.33)	26.25 (±12.48)	53.00 (±4.00)
Pine Mountain	2010	7	15.79 (±1.32)	36.81 (±1.19)	51.85 (±6.59)	3,021.14 (±539.42)	42.81 (±7.12)	57.78 (±4.63)	70.45 (±1.97)	70.16 (±6.51)	41.00 (±13.00)
Poor Mountain SC	2010	6	12.31 (±0.32)	34.40 (±4.19)	56.16 (±14.96)	1,945.33 (±511.16)	24.28 (±6.10)	35.25 (±4.53)	77.25 (±3.46)	50.00 (±7.86)	22.00 (±10.00)
Poor Mountain VA	2011	10	10.85 (±0.79)	27.46 (±2.25)	21.40 (±1.73)	964.10 (±152.22)	13.66 (±2.40)	44.89 (±6.12)	71.95 (±3.09)	85.40 (±2.40)	66.00 (±0.00)
Quantico	2011	3	16.25 (±1.34)	39.66 (±3.93)	34.33 (±14.89)	1,601.33 (±986.14)	21.03 (±11.84)	35.66 (±16.39)	113.29 (±41.31)	46.33 (±21.98)	18.00 (±14.00)
Ravens Roost	2010	2	5.94 (±1.37)	27.15 (±0.85)	34.50 (±1.50)	1,743.00 (±614.00)	17.15 (±6.05)	49.84 (±15.63)	101.65 (±0.06)	25.00 (±11.00)	49.00 (±11.00)
Rocky Face	2012	5	8.22 (±2.08)	28.56 (±1.45)	28.00 (±3.63)	355.40 (±58.73)	4.37 (±0.72)	13.62 (±2.59)	81.25 (±1.32)	64.00 (±7.07)	51.00 (±7.00)
Smithgall Woods	2012	1	12.20 (±0.00)	38.00 (±0.00)	37.00 (±0.00)	410.00 (±0.00)	5.05 (±0.00)	11.08 (±0.00)	81.25 (±0.00)	28.00 (±0.00)	25.00 (±4.16)
Smoke Hole	2011	7	9.62 (±1.16)	28.65 (±1.46)	42.42 (±2.65)	2,495.29 (±326.19)	36.04 (±5.51)	59.34 (±7.79)	71.06 (±2.26)	46.42 (±6.32)	51.00 (±5.00)

Table 2. Tree, seed, and cone traits for 38 Table Mountain pine populations where seed collections were conducted 2010–2014. (continued)

Provenance	Seed year	Trees (#)	Height (m)[a]	DBH (cm)[1]	Cones (#)	Seeds (#)	Seed weight (g)	Seeds per cone (#)	Seeds per gram (#)	Filled seed (%)	Germination (%)
Snake Den Mountain	2011	10	11.00 (±1.33)	31.43 (±2.87)	37.20 (±5.41)	2,556.40 (±449.41)	31.15 (±5.86)	65.73 (±4.55)	86.44 (±6.72)	58.00 (±9.43)	54.00 (±2.00)
South Mountains	2011	10	12.25 (±0.77)	32.76 (±2.34)	29.40 (±2.71)	1,022.30 (±147.99)	13.07 (±2.07)	37.36 (±5.62)	81.72 (±4.52)	57.40 (±6.09)	59.00 (±7.00)
Stone Mountain	2011	10	7.22 (±7.22)	28.38 (±1.77)	32.20 (±2.29)	931.60 (±158.31)	10.04 (±2.03)	27.76 (±4.01)	98.43 (±7.16)	65.50 (±5.41)	51.00 (±5.00)
Table Rock Mountain NC	2010	10	9.72 (±0.74)	26.93 (±1.32)	34.60 (±5.46)	1,584.90 (±223.26)	21.72 (±3.22)	49.45 (±5.17)	75.06 (±5.39)	44.90 (±9.12)	56.00 (±4.00)
Walnut Fork	2010	10	12.19 (±2.32)	23.57 (±2.30)	29.90 (±3.43)	1,418.30 (±348.99)	21.57 (±5.23)	44.22 (±9.47)	68.06 (±4.47)	82.50 (±5.71)	86.00 (±4.00)
Bull Run	2013	6	6.60 (±1.60)	24.00 (±5.39)	14.66 (±3.73)	557.16 (±104.63)	8.17 (±1.69)	48.43 (±14.86)	73.51 (±5.88)	68.33 (±6.43)	78.00 (±6.00)
Little Walker Mountain	2013	6	9.09 (±0.53)	29.23 (±3.38)	45.66 (±20.74)	1,079.17 (±278.65)	17.29 (±4.71)	39.52 (±9.01)	64.15 (±3.08)	78.33 (±4.41)	92.00 (±2.00)
Potts Mountain	2013	10	7.43 (±0.94)	22.65 (±1.98)	13.30 (±2.39)	721.70 (±133.40)	10.53 (±1.78)	61.58 (±9.38)	66.87 (±2.01)	60.40 (±5.75)	56.00 (±4.00)
Shenandoah	2013	10	9.29 (±0.85)	40.31 (±4.51)	31.40 (±2.69)	398.10 (±165.39)	5.71 (±2.25)	11.99 (±4.59)	74.47 (±6.24)	64.55 (±4.35)	62.00 (±8.00)
Stone Valley Forest	2013	6	11.22 (±2.39)	21.05 (±4.62)	13.33 (±1.62)	261.66 (±143.67)	3.77 (±2.23)	20.82 (±10.67)	60.59 (±21.52)	62.66 (±12.71)	76.00 (±0.00)
Sugarloaf Mountain	2013	3	7.62 (±1.52)	24.15 (±0.85)	24.33 (±2.96)	33.33 (±9.38)	0.31 (±0.14)	1.50 (±0.53)	125.99 (±24.01)	70.00 (±15.27)	20.00 (±0.00)
Tallulah Gorge	2014	8	11.87 (±1.59)	24.78 (±3.85)	8.50 (±1.74)	160.12 (±31.53)	2.40 (±0.47)	25.95 (±8.14)	66.67 (±0.00)	48.75 (±6.15)	60.00 (±2.00)
Overall Means		7	9.66 (±0.25)	29.32 (±0.61)	34.85 (±1.29)	1,490.57 (±81.94)	19.32 (±1.02)	42.13 (±1.55)	79.46 (±1.29)	61.14 (±1.41)	52.69 (±2.26)

DBH = diameter at breast height.

Figure 7. Table Mountain pine seedlings grown from collected seed for genetic diversity analysis. (Photo courtesy of Camcore, Department of Forestry & Environmental Resources, North Carolina State University)

Conclusions

The cooperative program between Camcore and USDA Forest Service on the conservation of Table Mountain pine has been successful. The program acquired 390,530 seeds for gene conservation and reforestation purposes and amassed the largest genetic base for the species that exists outside of natural stands. Although additional seed collections are needed to sample the underrepresented northern extreme of the TMP range and unsampled ecological subregions and plant hardiness zones, the genetic resources that have been acquired thus far represent a genetically diverse and broadly adaptable seed resource that can be used effectively to aid reforestation efforts with the species. The USDA Forest Service plans to use a portion of the seed to establish a seed orchard to support planned reforestation efforts, and has already sown seeds to produce seedlings for stand restoration following tornado damage on the Nantahala National Forest in North Carolina. Ongoing research includes a genetic diversity study using microsatellite molecular markers to compare the levels of genetic diversity captured in the seed sample to that of the natural stands where the seed originated. This study will also consider how 20 years of additional stand management and decline have affected the fine-scale genetic structure and integrity of natural TMP stands since the last thorough genetic assessment of the species by Gibson and Hamrick (1991).

Address correspondence to—

Robert M. Jetton, Research Assistant Professor, Camcore, Department of Forestry & Environmental Resources, North Carolina State University, Raleigh, NC 27695; e-mail: rmjetton@ncsu.edu; phone: 919–515–6425; fax: 919–515–6430.

Acknowledgments

The authors thank the numerous Federal, State, and local land managers and resource professionals who provided permits and access to the field sites where seed collections were made and Joseph Lawdanski and Christopher Tharp who assisted with seed cleaning and processing. They also thank Victor Vankus and Becky Loth at the U.S. Department of Agriculture (USDA), Forest Service National Seed Laboratory for providing the x ray seed viability data. The USDA Forest Service Joint-Venture Agreement 09-JV-11083160-001 and Camcore Research Project 624 supported this project.

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