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Fall 2016

Dear TPN Reader

This issue is perhaps the longest issue of TPN ever! This Fall 2016 issue is long because it includes proceedings papers from the 2015 annual nursery meetings:

- Joint Meeting of the Northeast Forest and Conservation Nursery Association and Southern Forest Nursery Association (Kent Island, MD, July 20-23, 2015)
- Annual Meeting of the Western Forest and Conservation Nursery Association (Eugene, OR, October 26-27, 2015)

Starting with the 2014 nursery meetings, proceedings papers are being published in *Tree Planters' Notes.* The papers are still identified as papers that were presented at the nursery meetings, and they are still listed online in the National Nursery Proceedings section of the Reforestation, Nurseries and Genetics Resources (RNGR) Web site, but their citation is now in TPN. All issues of the nursery proceedings, dating back to the 1949 "Meeting of Forest Tree Nurserymen" (held in Seattle, WA) are available online at http://www.rngr.net/publications/proceedings/.

This issue contains five articles from each of the above-mentioned nursery meetings plus another three articles. These 13 articles cover a wide range of new information on topics including plant propagation, reforestation and restoration strategies, tree physiology, and new technology. I expect you will find something useful that you can apply to your own operation.

As usual, I'm looking for more articles to fill future issues of TPN. Please consider submitting your paper for publication. You can also send suggestions for topics or authors you would like to see included in TPN. Guidelines for authors can be found online at http://www.rngr.net/publications/tpn.

May you all enjoy the fall and winter seasons!

Diane L. Haase

Don't judge each day by the harvest that you reap
but by the seeds that you plant.
~ Robert Louis Stevenson

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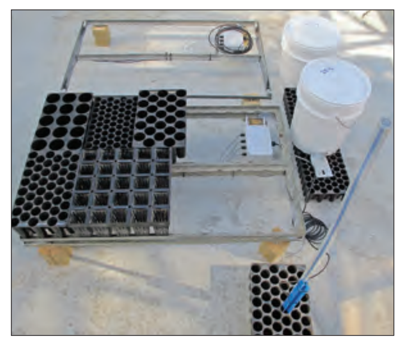

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Papers Presented at the Annual Meeting of the Western Forest and Conservation Nursery Association (Eugene, OR, October 26-27, 2015)

Tree Planting in the South, 1925 to 2012

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Abstract

Historic tree planting records were actively maintained throughout the United States until 1999. Since then, incomplete public records in the South have created some confusion in the number of acres planted during the first decade of the 21st century. The U.S. Department of Agriculture (USDA) Forest Service, Forest Inventory and Analysis, in coordination with the USDA Forest Service, Southern Region, State and Private Forestry and the Auburn University Southern Forest Nursery Management Cooperative collaborated to fill the gap from 2000 to 2012. This report is an update of the 1986 publication *A Statistical History of Tree Planting in the South 1925-1985* (Williston 1986). Tree planting has contributed significantly to the productivity and wood supply sustainability of the southern forests. Tree planting has offered options to enhance the southern forests while maintaining a balance of wood supply, jobs, a variety of wood products, and quality of life. This article describes the major influences on and from tree planting, and the associated online tables (http://www.rngr.net/publications/tpn/treeplanting-tables) provide the historic journey of tree planting in the South.

Historical Overview

Tree planting in the South (i.e., five Southeastern States plus eight South Central States) has significantly contributed to the productivity and wood supply for more than a century. At the end of the 19th century, Carl Schenck, a professionally trained forester from Germany, grew pine and hardwood seedlings in nurseries and, with the help of his students, established several plantations near Asheville, NC. In 1897, Schenck planted 500,000 white pine (*Pinus strobus* L.) seedlings (shipped from Germany) on three compartments of the Biltmore Estate (Schenck 2011). In 1921 and 1922, the Great Southern Lumber Company established a small pine nursery in Bogalusa, LA. This nursery was likely the first pine nursery (larger than one-third ac [0.13 ha)) in the South (Barnett 2013). By the end of 1925, about 3,000 ac (1,214 ha) of plantations had been established in the South (Zillgitt 1958).

As a continuum of forest land protection and restoration policy at the turn of the 20th century, Section 4 of the 1924 Clarke-McNary Act provided for Federal and State governments to furnish seeds and plants for reforestation in the United States. With the first-year allocation of funds in 1926, so began the first records of tree planting in the South (Hitt 1969). By 1929, official records of tree planting showed almost 10,000 ac (4,046 ha) planted that year in seven Southern States. Tree planting did not begin in earnest, however, until the New Deal reforestation and conservation programs occurred from 1935 to 1942. During those seven years, more than 1 million ac (404,000 ha) were planted in the South by Civilian Conservation Corps enrollees (Williston 1968). The U.S. Department of Agriculture (USDA) Forest Service, State and Private Forestry program collected tree planting data from State forestry agencies annually until 1999, when funding was discontinued.

Leaders in the southern forestry community increasingly recognized the value of tree planting programs as harvesting and reforestation needs increased during the post-World War II economic boom. Between 1956 and 1965, 4.3 million ac (1.7 million ha) were planted on public, forest industry, and private, nonindustrial lands in the South. An additional 1.9 million ac (769,000 ha) were planted during this same period through the Soil Bank Program, a USDA cost-share program to reforest and stabilize unproductive cropland (Williston 1968).

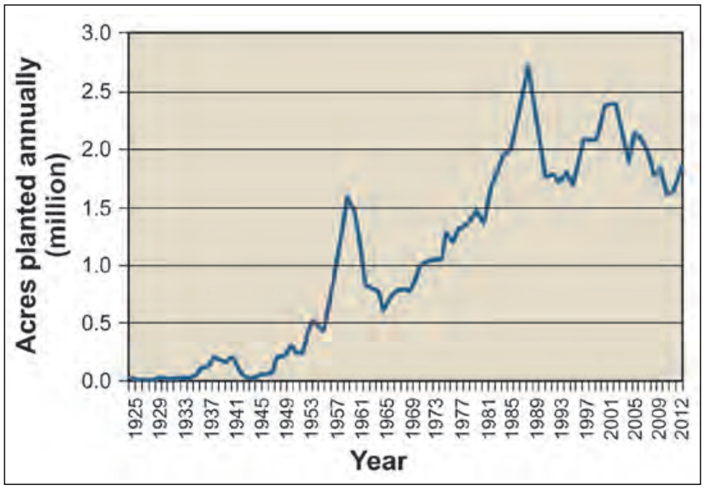

Figure 1. Acres of timberland planted annually in the South, 1925 to 2012.

After the peak of 1.6 million acres planted in 1959, the area planted annually in the South declined sharply to the low of 555,511 ac (224,807 ha) in 1966 (figure 1). For the next 22 years, acres planted each year steadily increased to 2.7 million ac (1.1 million ha) planted in 1988. This steady increase was the result of several factors, including Federal and State cost-share programs, strong primary wood markets, and landowner assistance programs provided by the forest industry and State agencies, and also because of land-grant universities' extension education programs.

Since 1982, an average of about 2 million ac (809,000 ha) per year has been planted in the South. Tree planting cost-share incentives (1985 to 2012) contributed about 9 million ac (3.6 million ha) in the South. The most recent major Federal program, the Conservation Reserve Program (CRP), began as part of the 1985 U.S. Farm Bill. CRP continues in various farm bill appropriations and contributed nearly 6 million ac (2.4 million ha) of tree planting in the South through 2008. In addition to CRP planted acres, an estimated 3 million ac (1.2 million ha) were planted in the South under other Federal and State incentive funding programs during this same period, although no complete records were found for the South (Hoge 2014).

Planted Forests in the South

Viable timber markets that provide economic returns from growing timber are the best incentives for landowners to replant after harvest. Of the 57 million ac (23 million ha) planted by tree planters from 1985 to 2012 in the South (figure 1), 84 percent received no Federal or State incentive payment. The continued cooperative research and development efforts among forest industry, government natural resource agencies, and university research and extension departments in the South have led to improved cultural practices and seedling survival, genetic improvement of planting stock, and better wood utilization (Carter et al. 2015). Increased wood yields of planted stands resulting from these improvements and a ready market for timber have made planting trees an economically attractive proposition for landowners and forest managers.

The South contributes about 18 percent of the world's roundwood production (logs delivered to the mills) from less than 2 percent of the world's total forested area (FAO 2011, Prestemon and Abt 2002) across various ownerships (table 1). The many incentives for tree planting have clearly helped the South become a primary player in the global market for wood products while also maintaining a sustainable wood supply. According to a recent report (South and Harper 2016), pine plantations in the South in 2012 comprise approximately 44.6 million ac (18 million ha). These planted acres are truly the working forests of the South.

Table 1. Acres of pine and hardwood plantations by ownership group in the South, 2005 to 2012.

Ownership	Million acres	Percent
Public	2.7	6
Corporate	17.8	38
Industry	8.7	18
Individual	18.0	38
Total	**47.2**	

Source: Forest Inventory and Analysis data query 2014.

What is the contribution of the planted forests to the total southern forests? The 47 million acres of planted forest in table 1 represent only 22 percent of the total timberland area in the South and 16 percent of the timber volume. Nonetheless, this acreage contributes 38 percent of the average annual biological net growth for the region and 40 percent of the harvested volume each year. These working forests represent 46 percent of the harvested area and grow nearly 50 percent more wood than is being harvested (FIA data query 2014). Tree planting is a major contribution to the fact that the South has more standing tree inventory volume today (both softwood and hardwood) than it had in 1952 (McGuire and Dickerman 1958).

Planted forests also have nontimber benefits. The open, early successional planted forest areas provide habitat for neotropical migratory birds and protective cover for small mammals while offering browse for deer and other grazing wildlife. When effectively managed long term with a prescribed fire regime, planted stands provide improved habitat for threatened and endangered flora and fauna species (Yarrow and Yarrow 1999). To improve these nontimber benefits, cost-share programs have established forest restoration projects and stabilized eroded farmland (Carter et al. 2015). An increase in forest cover typically improves water quality in streams and lakes (Yarrow and Yarrow 1999).

A key point that is often overlooked is how tree planting and these working forests remove pressure from the other areas of southern forests, thereby allowing landowners to reserve and conserve areas for other uses (e.g., hunting, recreation, and aesthetics) or to enhance sensitive areas for long-term conservation.

Methodology To Estimate Annual Tree Planting in the South

Williston (1986) summarized statistics published annually by the USDA Forest Service, the Agricultural Stabilization and Conservation Service (now the USDA Natural Resource and Conservation Service), and the Tennessee Valley Authority (TVA) from 1925 through 1985. The data for the earliest years come from the files in the USDA Forest Service Washington Office, the TVA, various State forestry agencies, and some industrial organizations that planted trees before World War II. These data were sometimes fragmented and incompatible, especially where more than one source of data was used for the same period. Very few records were kept between 1942 and 1944 because of World War II (Williston 1986). The USDA Forest Service began publishing nursery production data in 1950 (Anonymous 1950) and, a few years later, began estimating planted acres (Rotty 1953). To estimate acres planted before 2000, historical tree planting records were reviewed and corrected. Typos and inconsistencies among sources were reconciled and are available online (http://www.rngr.net/publications/tpn/treeplantingtables).

After official Federal recordkeeping was discontinued in 1999 from lack of funding and personnel, the USDA Forest Service, State and Private Forestry, in collaboration with Auburn University, produced empirical tree planting data in the South from 2000 to 2012. Auburn developed the survey form, contacted the forest and conservation nurseries that grow forest tree seedlings in the South, and collected forest tree seedling production data directly from those nurseries. Survey forms were mailed to 72 nurseries in 12 States in the South. The response rate averaged close to 90 percent and represented 95 percent of the total production. Nursery data collected were reported by the number of hardwood and conifer seedlings produced and by the number of bareroot and container seedlings produced. From those data, the number of acres planted was estimated. Assumptions used to estimate seedlings per acre (SPA) from 2000 to 2012 are detailed in Harper et al. (2014).

Forest tree seedlings remain in the general area where they are produced; however, seedlings are routinely shipped across State borders and, at times, across international borders. Due to the closing of many State nurseries and the consolidation of privately owned nurseries, it is clear that an imbalance of exports and imports is reported for acres planted in some States. Therefore, State-level values are not reported from 2000 to 2012 in the online database; values for the entire region should be a reasonable estimate.

Estimating the number of acres planted from nursery production is a problematic computation. With improved nursery handling and shipping practices, genetically improved seedlings, and containerized seedlings, the necessary SPA by some forest land managers are less today than they were 20 years ago because the objectives of many landowners have changed. For example, some landowners now want to optimize value production (either economic or ecological) as opposed to maximizing volume production. The estimated SPA from 2000 to 2012 is based on the Cost of Practices survey that the Auburn University Cooperative Extension conducted and published in Forest Landowner biennially (table 2). The estimated SPA values (table 2) are based on a range of 5 to 29 percent sample of the area planted for the year (http://www.rngr.net/publications/tpn/treeplantingtables). Odd-year values result from an interpolation of the two even years before and after the odd year. Excel tables available online (http://www.rngr.net/publications/tpn/treeplantingtables) list the values used to estimate acres planted. The reader can adjust the SPA on these working tables to conduct additional analyses.

Table 2. Estimated average seedlings per acre planted in the South.

Survey year	Seedlings per acre	Percent of total	Source
2000	631	5	Dubois et. al. 2001
2001	617*		
2002	602	8	Dubois et. al. 2003
2003	594*		
2004	585	7	Smidt et al. 2005
2005	542*		
2006	499	11	Folegatti et al. 2007
2007	549*		
2008	599	29	Barlow et al. 2009
2009	552*		
2010	504	14	Barlow et al. 2011
2011	507*		
2012	510	7	Dooley and Barlow 2013
2013	488*		
2014	465	7	Barlow and Levendis 2015

Note: Values with an asterisk (*) are interpolated.

Conclusions

During the past 60 years, nearly 94 million ac (38 million ha) of trees have been planted across the South, with some acres planted more than once. This acreage is equivalent to an area covering Alabama, Georgia, and South Carolina, plus nearly 2 million additional ac (809,000 ha). With a demand for approximately 5,000 consumer wood products, it is unlikely that southern forests could provide a sustainable wood supply and be competitive in local, national, and global markets without a viable tree planting program.

Maintaining an annual assessment of tree planting in the South provides a prediction of future production and estimates of surplus versus shortfall. Without these data, foresters and nursery managers must speculate on current and future conditions with limited information. This project reinstitutes a long history of collecting tree planting data and attempts to bridge a 12-year gap of tree planting data. It is anticipated that the project will produce annual updates for the online tables (http://www.rngr.net/publications/tpn/treeplantingtables).

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REFERENCES

Anonymous. 1950. Forest tree nurseries of the United States. Tree Planters' Notes. 1(1): 1–21.

Barlow, R.; Levendis, W. 2015. 2014 cost and cost trends for forestry practices in the South. Forest Landowner. 74(5): 22–31.

Barlow, R.J.; Smidt, M.F.; Morse, J.Z.; Dubois, M.R. 2009. Cost and cost trends for forestry practices in the South. Forest Landowner. 68(5): 5–12.

Barlow, R.J.; Smidt, M.F.; Morse, J.Z.; Dubois, M.R. 2011. Cost and cost trends for forestry practices in the South. Forest Landowner. 70(4): 14–24.

Barnett, J.P. 2013. Early history of tree seedling nurseries in the South. In: Haase, D.L.; Pinto, J.R.; Wilkinson, K.M., tech. coords. National proceedings, forest and conservation nursery associations—2012. Proceedings RMRS-P-69. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 42–46.

Carter, M.C.; Kellison, R.C.; Wallinger, R.S. 2015. Forestry in the U.S. South. Baton Rouge, LA: Louisiana State University Press. 386 p.

Dooley, E.; Barlow, R.J. 2013. Special report: 2012 cost and cost trends for forestry practices in the South. Forest Landowner. 72(4): 22–28.

Dubois, M.R.; Erwin, C.B.; Straka, T.J. 2001. Cost and cost trends for forestry practices in the South. Forest Landowner. 60(2): 3–8.

Dubois, M.R.; Straka, T.J.; Crim, S.D.; Robinson, L.J. 2003. Cost and cost trends for forestry practices in the South. Forest Landowner. 62(2): 3–9.

Folegatti, B.S.; Smidt, M.F.; Dubois, M.R. 2007. Cost and cost trends for forestry practices in the South. Forest Landowner. 66(5): 11–16.

Food and Agriculture Organization (FAO) of the United Nations. 2011. Global forest resources assessment 2010: main report. FAO Forestry Paper No. 140. Rome, Italy: Food and Agriculture Organization of the United Nations. 378 p.

Forest Inventory and Analysis (FIA) data query. 2014 (March). (PLSQL used to query data from the Forest Inventory and Analysis database). 1p. Unpublished report. On file with: U.S. Department of Agriculture, Forest Service, Southern Research Station, Forest Inventory and Analysis, 4700 Old Kingston Pike, Knoxville, TN 37919.

Harper, R.A.; Hernández, G.; Arseneault, J; Woodruff, K.J.; Enebak, S.; Overton, R.P. 2014. Forest nursery seedling production in the United States: fiscal year 2013. Tree Planters' Notes. 57(2): 62–66.

Hitt, R.G. 1969. So what have we accomplished? Presentation at the Northeastern Area Nurseryman's Conference. 13 p. http://www.rngr.net/publications/proceedings/1969/northeastern-area-nurserymen-s-conference. (February 2014).

Hoge, D.A. 2014. (Personal communication). Agricultural Program Specialist, U.S. Department of Agriculture, Farm Service Agency, Deputy Administrator Farm Programs, Conservation and Environmental Programs Division, USDA/FSA/DAFP/CEPD STOP 0513, South Building, Room 4768, 1400 Independence Avenue, SW, Washington, DC 20250.

McGuire, J.R.; Dickerman, M.B. 1958. Forest land and timber. In: Crafts, E.C, ed. Timber resources for America's future. Forest Resource Rep. 14. Washington, DC: U.S. Department of Agriculture, Forest Service. 113–142.

Prestemon, J.P.; Abt, R.C. 2002. The southern timber market to 2040. Journal of Forestry. 100(7): 16–22.

Rotty, R. 1953. Forest and shelterbelt planting in the United States during 1952. Tree Planters' Notes. 13: insert. 10 p.

Schenck, C.A. 2011. Cradle of forestry in America: The Biltmore Forest School, 1989-1913. Butler, O. ed. Durham, NC: Forest History Society. 224 p.

Smidt, M.F.; Dubois, M.R.; Folegatti, B.S. 2005. Cost and cost trends for forestry practices in the South. Forest Landowner. 64(2): 25–31.

South, D.B.; Harper, R.A. 2016. A decline in timberland continues for several southern yellow pines. Journal of Forestry. 114(2): 116–124.

Williston, H.L. 1986. A statistical history of tree planting in the South 1925–1985. Misc. Rep. SA-MR 8, September 1986. Atlanta, GA: U.S. Department of Agriculture, Forest Service, Southern Region, State and Private Forestry. 23 p. http://www.rngr.net/publications/statistical-history. (February 2014).

Yarrow, G.K.; Yarrow, D.T. 1999. Managing wildlife. Birmingham, AL: Sweet Water Press. 588 p.

Zillgitt, W.M. 1958. Forest tree planting. In: Crafts, E.C. ed. Timber resources for America's future. Forest Resource Rep. 14. Washington, DC: U.S. Department of Agriculture, Forest Service. 273–286.

Wireless Network of Electronic Scales To Monitor the Substrate Volumetric Water Content for Managing Irrigation of Containerized Seedlings Produced in Forest Nurseries

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Abstract

An automated monitoring system of substrate volumetric water content (VWC) based on gravimetry has been developed to measure several seedling containers at a time. This tool is a wireless sensor network (WSN) using field stand-alone electronic scales that transmit data to the nursery office. At the office, computer software automatically estimates the fresh mass of any seedling crop, at any moment of the season, and then calculates the substrate VWC. This system, specifically designed for forest nurseries, is, to our knowledge, the first in which gravimetry is automatically monitored by using field stand-alone WSN technology to improve irrigation management and reduce water and nutrient losses and groundwater contamination.

Introduction

Of the 133 million containerized and bareroot forest seedlings produced in the 19 forest nurseries in Québec (Canada) in 2015, the majority (94 percent) were containerized (Arseneault 2015). In these nurseries, the growing season duration ranges between 150 and 200 days (end of April to the beginning of November). Containerized seedlings are usually produced in 2 years, and the final seedling dry mass ranges from 1.5 to 13 g (0.05 to 0.43 oz). These seedlings are grown in low-density, peat moss-based substrates (0.08 to 0.12 g/cm^3 [0.0018 to 0.0026 oz/in^3]) in cavities having volumes ranging from 50 cm^3 (3.05 in^3) up to 350 cm^3 (21.36 in^3).

For every nursery that grows containerized seedlings in such low-density substrates, water represents most of the measured mass. Thus, weighing containers (gravimetry) is an excellent way to measure volumetric water content (VWC) of the substrate. The monitoring of substrate VWC is essential to successfully managing the irrigation of containerized seedlings produced in forest nurseries and will lead to a more rational use of water, fertilizers, and pesticides and to improved protection of groundwater.

Two main technologies are used for substrate VWC measurements: (1) gravimetry (Prehn et al. 2010) and (2) reflectometry, which is based on the dielectric properties of the substrate. Two examples of the latter technology are time-domain reflectometry (TDR) (Topp and Davis 1985) and capacitance-based sensors (Burnett and van Iersel 2008). A third technology in addition to those of gravimetry and reflectometry is tensiometry, which refers to the effort needed by the seedling to take up water regardless of the substrate's nature (Boudreau et al. 2006).

In Québec forest tree nurseries, TDR has been manually employed at an operational level using an MP-917 (E.S.I. Environmental Sensors Inc., Victoria, BC, Canada) fitted with probes specifically adapted to small cavities and peat substrates (Gagnon and Girard 2001; Lambany et al. 1996, 1997; Lamhamedi et al. 2001). At an experimental level, a wireless sensor network (WSN) of microtensiometers (Hortau, Saint-Romuald, QC, Canada), usable in cavities having a volume higher than 300 cm^3 (18.3 in^3), was also tested (Boudreau et al. 2006). In a forest nursery context, TDR and tensiometry are expensive and provide a poor sampling rate (1 to 10 small cavities per measurement). As a result, the measurement of substrate VWC in Québec forest nurseries is currently carried out by manually weighing individual containers with a fish scale. By using this method, each gravimetric measurement takes into account between 25 and 67 cavities, depending on the container type.

In Québec, the seasonal evolution of dry mass of conifer seedlings has been monitored since the 1980s for almost every crop, creating a robust database. Thus, a representative profile of the seasonal dry mass evolution has been established for most seedling crop types. For conifer species produced in Québec, the fresh mass of seedlings follows a seasonal profile that is relatively close to that of their dry mass, with a "fresh/dry" ratio of between 3 and 5 (Girard et al. 2011). Using the IRREC software (Girard et al. 2011), the final substrate VWC is obtained by subtracting every known mass that is not substrate water.

Because any manual measurement consumes both time and money, it would be profitable to have an automatic system to reduce monitoring costs. Capacitance sensors, like the EC-5 (Decagon Devices, Inc., Pullman, WA), produce a direct measurement of substrate VWC. They are adapted for the large pots over 1,000 cm^3 (61 in^3) used in ornamental nurseries, where they can be used in conjunction with WSN (Hoskins et al. 2012). These sensors, however, are not appropriate for the small cavities used in forest nurseries (50 to 350 cm^3 [3.05 to 21.36 in^3]). Considering the small market and specificity of forest nurseries, a "do it yourself" (DIY) option, incorporating WSN, seems to be an efficient option for substrate VWC monitoring.

Arduino (Ivrea, Italy), a relatively new open-source tool, provides an opportunity to easily develop an efficient solution for forest tree nurseries. Arduino is a popular development platform based on a microcontroller (a kind of "nano" computer that analyzes and generates electrical signals) that can be connected to many peripherals (like weight sensors and radios used in our application). For example, this technology has been used to build a low-cost automated system for monitoring soil moisture and controlling irrigation designed for greenhouses in an ornamental nursery context (Ferrarezi et al. 2015, van Iersel et al. 2013). Arduino technology and Fritzing software (Potsdam, Germany) for printed circuit board (PCB) design have been used to conceive a homemade PCB that respects the constraints intrinsic to a system developed for use in forest tree nurseries.

Those constraints include the following:

- Scales must be powered by cells that can last for a growing season.
- Scales must provide precise measurements, regardless of ambient temperature, while being stable throughout the season.
- Data transmission capacity must extend over the entire area of a large nursery.

The development context shown here is an example that is specific to the operational constraints of Québec forest nurseries. It can be easily adapted to any other context just by choosing adapted load cells (mass sensors) and container support beds, with an appropriate microcontroller programming.

Hardware Development

Wireless Network

The network uses three kinds of devices (figure 1).

1. Up to nine stand-alone electronic scales at the source of substrate VWC measurement (figure 2) can be grouped into a cluster (like children of a family).
2. Routers at the center of each cluster (powered by a solar shield [figure 3]) act as a parent for the scales of the cluster and broadcast the data from each individual scale over the network. Each router also relays data from nearby routers in the network (even if no scale is attached to it) to a single receiver.
3. A single receiver at the office (figure 4) is connected to a computer that uses weight data to calculate a substrate VWC for each scale and shows the substrate VWC monitoring results. The receiver also acts as a stand-alone datalogger that stores the basic weight values on a Secure Digital (SD) memory card.

All devices of the network (scales, routers, and the receiver) are linked together using the same model of radio modem for each device (XBP-24-BZ7SIT-004,

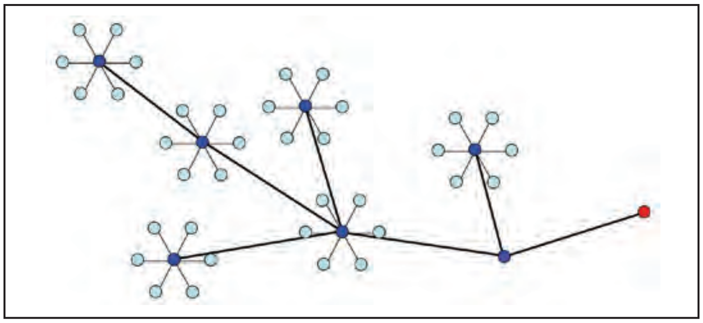

Figure 1. Example sketch of a wireless network (cluster tree type). Stand-alone scales (light blue) are powered by cells, and routers (deep blue) are powered using a solar shield. Each router relays the scale data in multiple hops (of no more than 200 m [610 ft] each) to expand the global network range to a single receiver (red) located at the nursery office.

Figure 2. A stand-alone field scale with different container types used in Québec forest nurseries. A watertight enclosure fixed under the scale contains the power source for one growing season and all electronic scale components (microcontroller, amplifier, radio modem, etc.). The only external component is the radio antenna (in front, mounted in a flexible tube that bends when the irrigation boom passes over it) connected to the radio via a 3 m (9 ft) cable, allowing for optimal positioning for radio transmission efficiency. After the scales are installed in the field, they will work without maintenance for the entire growing season, producing real-time weight data at regular intervals determined by the grower (between 15 and 120 minutes). On the right of the scale are two identical 25 kg (55 lb) homemade weights used for initial calibration. In the back is a scale without an upper bed. (Photo by Daniel Girard, 2016)

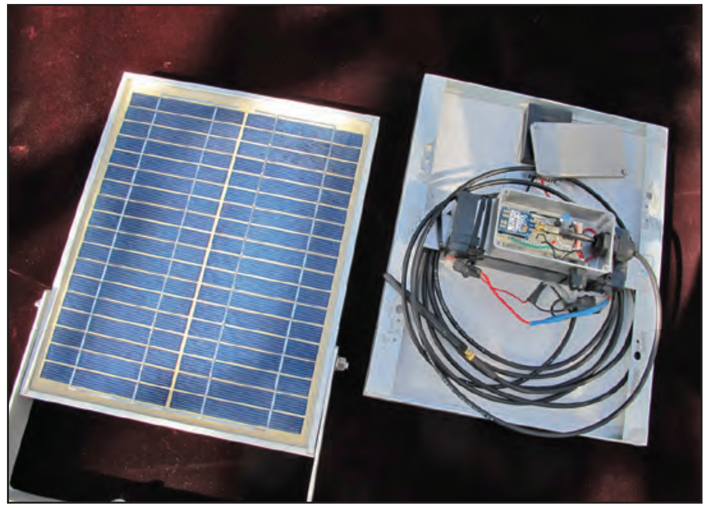

Figure 3. A low-cost, stand-alone, solar-powered router (both top and bottom) that uses a 2.3 Ah lead acid 12 V battery charged by a basic 10 W solar shield. The solar shield uses no costly charging regulator, only a diode to avoid battery discharge into the solar shield during the night. With the constant power demand from the radio, the battery will never be overcharged. (Photo by Daniel Girard, 2016)

Figure 4. Receiver (stand-alone datalogger) connected to a computer to show in real time the incoming weighing data. (Photo by Daniel Girard, 2016)

Digi International, Inc. [Digi] Minnetonka, MN), programmed using X-CTU software (Digi, Minnetonka, MN), which is the only proprietary computer software used in our design (but which is available free to download for use with Digi radio modems for Windows, Mac, or Linux). After the radio modems are programmed suitably for each kind of device, they manage transparently the data routing over the network to the receiver using ZigBee protocol (ZigBee Alliance).

Wireless Range

With the low measurement rate (from 15 to 120 minutes for a scale) used in our application, it is preferable to use the lowest possible baud rate to maximize the wireless range. Therefore, the slowest possible baud rate for the Digi radio modems was chosen (1,200 baud).

For the scales and routers in the field, antennas are usually located 1.0 to 1.5 m (3.3 to 5.0 ft) above ground (figure 2). Therefore, the 2.4 GHz band is preferable for our application because it performs well close to the ground. Moreover, 2.4 GHz radios are usually less expensive than 900 MHz radios (the other common alternative). Based on the results obtained from a field test at Grandes-Piles governmental forest nursery (ministère des Forêts, de la Faune et des Parcs, MFFP du Québec, Québec, Canada, 46°43’56” N., 72°42’06” W.) with a basic network (figure 5), a range of 200 m (656 ft) between router antennas—and between child scales and their parent router—can be effective if no more than one windbreak is located between the antennas. This distance takes into account the fact that wireless transmission efficiency can vary considerably, depending on the surrounding environment (temporary obstructions like vehicles, weather, etc.). Regardless of field configuration, 100 percent efficiency cannot be guaranteed. So, it is a good idea to consider using extra routers to secure data transmission.

One of the most basic considerations is the positioning of the antenna to account for the physical configuration of the field for an optimal efficiency of radio transmissions. Antennas ideally should be placed to get a direct view from one antenna to the next. To obtain the best possible place for wireless transmission, scale antennas can be placed from 3 to 5 m (10 to 16.6 ft) around the scale. Suitably positioned antenna devices result in the highest probability of efficient wireless data transmission.

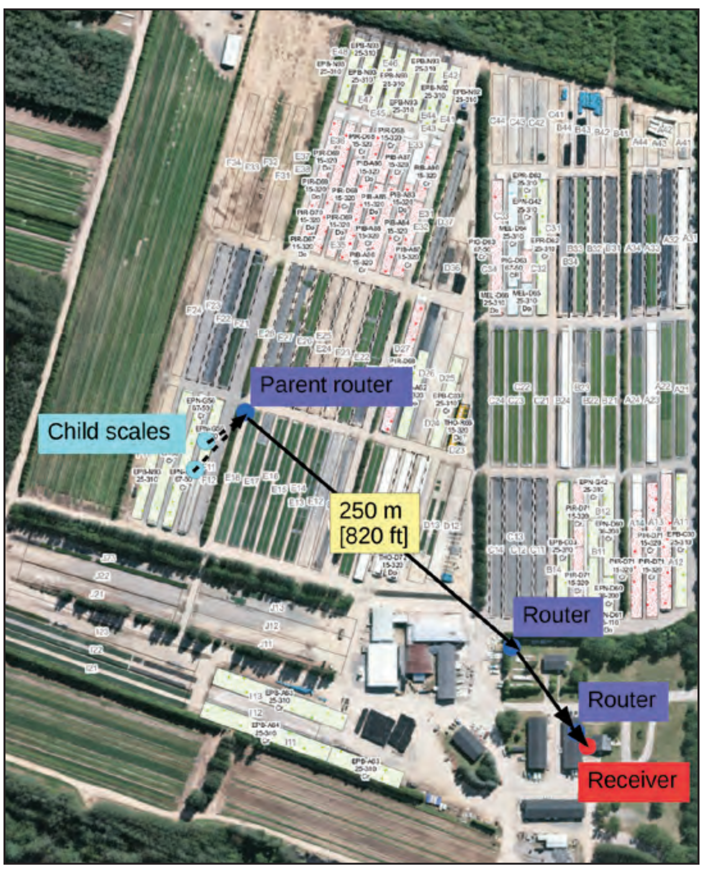

Figure 5. Aerial view of Grandes-Piles nursery, Québec, Canada, depicting wireless network scale range obtained in the field. (Extracted from ArcGis by Chantal Pelletier, Grandes-Piles nursery, 2014).

Electronic Scale

At the locations of substrate VWC measurement in the nursery, each scale uses two identical steel nursery beds (commonly used to support containers in Québec forest nurseries) placed on top of each other and separated by four load cells of 50 kg (110 lb) capacity each (figure 2). The lower bed is supported by four adjustable feet for height setting and horizontal adjustments. The four load cells are fixed at each corner of the lower bed (figure 6). The upper bed that supports the containers is placed on the four load cells. The theoretical maximum load is 200 kg (440 lb), but the maximum load in the field does not exceed 75 kg (165 lb), with a usual load of around 40 kg (90 lb). Depending on the container type, each scale can sample 150 to 670 cavities, having volumes ranging between 50 and 350 cm^3 (3.05 and 21.36 in^3) (figure 2). Figure 7 illustrates the basic components and operation of a scale and also shows how it can produce a basic weight value using an Arduino-based microcontroller (Ivrea, Italy). Figure 8 shows the assembled electronic components that convert the analog signal from the load cells into a digital wireless signal with the process shown in figure 7.

Figure 6. One of the four low-cost load cells used for a scale (bending beam type, protected by a simple coat of aluminum-based paint) after a growing season in the forest nursery. A 3.2 mm (0.125 in) spacer is needed between the lower bed and the load cell, and a 19 mm (0.75 in) spacer is required between the other side of the load cell and the upper bed to mechanically insulate the beam from any unwanted contact. Mass applied on the upper bed induces invisible deformations on the beam that are perceptible by strain gauges applied on it. The initial result is a variable electrical signal (voltage) that is linearly related to the containers’ mass. (Photo by Daniel Girard, 2014)

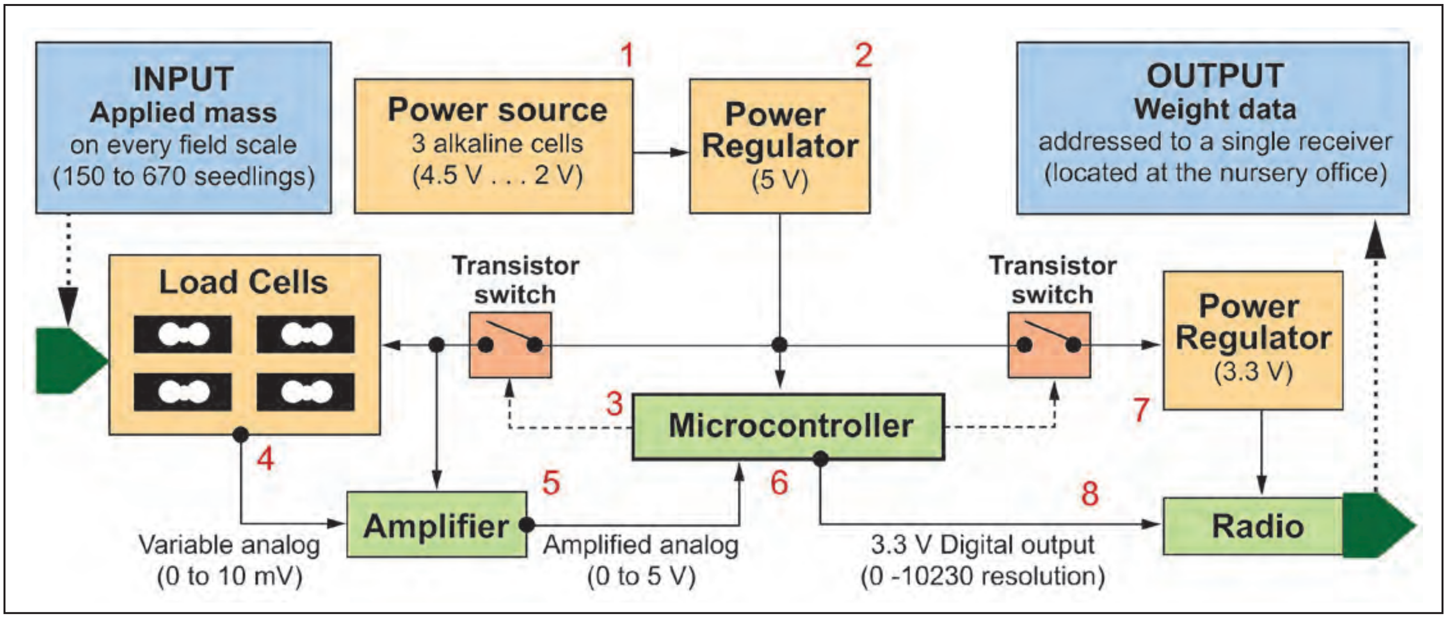

Figure 7. Simplified sketch of scale operation: (1) the scale is powered by three alkaline cells; (2) using a step-up regulator, cell power is boosted to a regulated 5 V to provide a stable analog measurement for the load cells and proper operation of the microcontroller; (3) the microcontroller, which drives all measurement processes, turns on the load cells and instrument amplifier using a transistor switch momentarily to save power; (4) load cells return a small variable output ranging from 0 to 10 mV, depending on the mass applied on the scale; (5) this small output is multiplied proportionally by the amplifier to a 0 to 5 V analog signal that is readable by the microcontroller; (6) the microcontroller converts the analog incoming signal into a basic digital form and, according to internal calibration values (easily set by the user once a year), to a common weight unit (decagrams for our example); (7) then, the microcontroller powers the radio for the few seconds that are needed for the data transmission process via another transistor switch and a step-down 3.3 V regulator (power level needed for radio); (8) at the same time, the microcontroller sends the digital weight value (in decagrams) to the radio, which broadcasts the data through the wireless network. Thereafter, to save power, the microcontroller shuts everything off and falls into a deep sleep mode until the next measurement. Thus, three alkaline cells can last for an entire growing season (references for scale components are provided in table 1).

Load Cells

Low-cost load cells (sensors at the source of measurement) offer a typical accuracy sufficient for substrate VWC monitoring in forest tree nurseries. Also, at less than $10 (U.S.) each, they are 10 to 50 times less expensive than calibrated load cells. Because they are delivered without significant quality control, however, quality control is necessary before assembly (it takes only few minutes per load cell). Up to half of the load cells may be rejected, in part, because of the use of oversized load cells to reduce creeping for our nursery application (see subsequent section on Laboratory Tests). After the quality control steps are rigorously completed, the scale can be assembled and its function should be successful, while keeping a low overall cost.

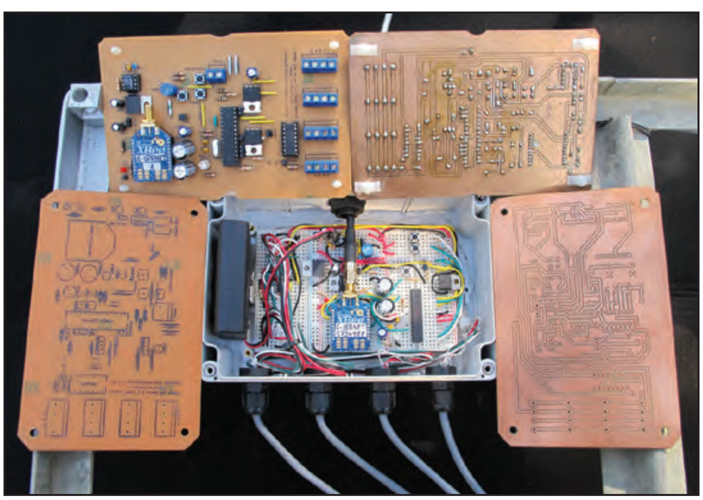

Figure 8. The stand-alone scale uses a homemade printed circuit board (PCB) based on Arduino (Ivrea, Italy). First, a draft circuit (in the grey box) was made and tested under field conditions using a solderless board. Thereafter, a homemade PCB was designed and assembled (around the grey box: different production phases). (Photo by Daniel Girard, 2016)

Scale Calibration

Scales that use low-cost load cells must be calibrated individually. Because the relationship between the electrical output of the load cells and applied load is almost linear, a manual calibration can be simply performed by using two identical calibrated weights of 25 kg (55 lb) each (figure 2). The calibration process is guided by blinking light-emitting diodes (better known as LEDs) on the scale assembly. The result is recorded in the microcontroller's permanent memory. During this process, ambient temperature reference is also recorded using an inboard

LM335 thermistor (Texas Instruments, Inc., Dallas, TX) to adjust future readings under different temperature conditions.

Laboratory Tests

Because temperature can affect load cell measurement (Prehn et al. 2010) and other electronic scale components, a stable mass of 25 kg (55 lb) was measured in a temperature-controlled environment at 24 °C (75 °F) and 4 °C (39 °F) over 48 hours (figure 9). An inboard temperature sensor (LM335, Texas Instruments, Dallas, TX) and microcontroller programming serve to reduce the temperature effect on electronic components to a nonsignificant variation.

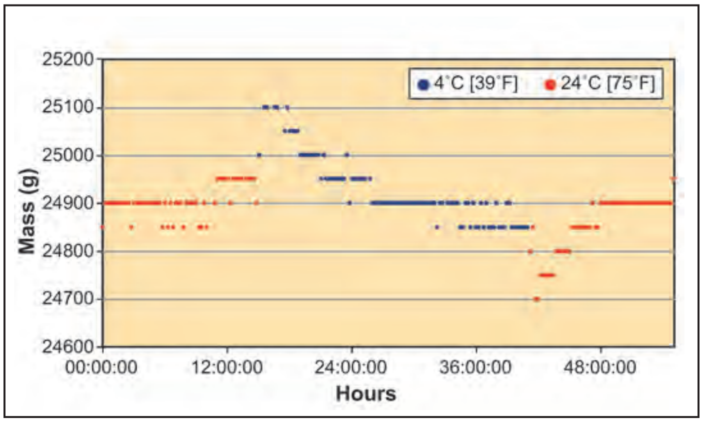

Figure 9. An abrupt temperature change under laboratory conditions (from 24 °C to 4 °C [75 °F to 39 °F] and back to 24 °C) shows the need for compensation. Using the onboard mounted thermistor, the temperature compensation leads to a maximal instant drift of 200 g (6.6 oz) (meaning around 0.5 percent of substrate volumetric water content). Because of different thermic characteristics of the scale components, however, complete temperature compensation after an abrupt change may need up to 6 hours to reduce drift under 0.5 percent. In the field, however, temperature changes are expected to be progressive.

Creeping is a progressive overestimation of the mass resulting from a structural fatigue of the load cell under application of a constant mass. In the load cell data sheet (Phidgets, Inc., Calgary, AL, Canada), creeping is expressed hourly, when the load is close to the maximum capacity. Because scales have to support a significant load for an entire growing season, this phenomenon was measured by applying a stable mass of 68.2 kg (151 lb) (representing around 175 percent of the usual load of a scale during a 7-day period). The selected load cells have an oversized capacity that is around 300 percent of the maximum anticipated load, which reduces the creeping effect to a nonsignificant 0.25 percent of substrate VWC per season (figure 10).

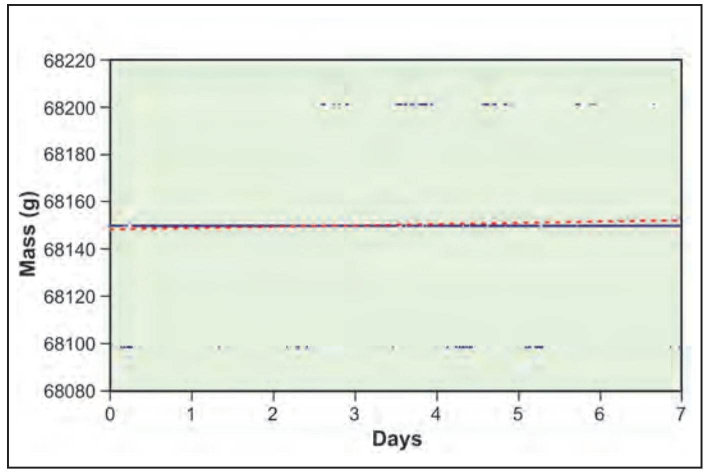

Figure 10. The mass overestimation that is generated by creeping represents 0.546 g (0.0182 oz) per day (red dashed line) meaning around 100 g (3.33 oz) for a 200-day growing season. This estimation represents less than 0.3 percent of substrate volumetric water content and is nonsignificant. Thus, the scale has to be calibrated only once a year. (Note that steps between levels of the blue dots represent the resolution of the scale.)

Power Autonomy of Stand-Alone Scales

Scale power consumption was reduced by programming the shortest possible use of power-draining devices (load cells and radio) using JeeLib Arduino library (JeeLabs, Houten, Netherlands). For scales that perform one measurement every 15 minutes, three AA alkaline cells last approximately 3 months, at an average temperature of 16 °C (61 °F). If more autonomy is needed, C alkaline cells can be used. Programming a larger elapsed time (up to 120 min) between measurements is also a solution to using AA cells. For scales, cell powering is a low-cost solution compared with the use of solar shields with 12 V battery or of an outlet with a long cord.

Routers

Routers must be awakened to receive a signal from a scale. A 2.3 Ah 12 V battery with a 10 W-12 V solar shield with a diode (that avoids battery discharge into solar shield during night) can maintain enough power for a standard cluster (up to 9 scales) and a small network (up to 24 scales), while keeping the battery integrity (figure 3). For larger scale networks, the use of 20 W (or more) solar shields and costly power regulators should be considered. Thus, if AC power is available in the nursery, it is preferable for routers.

Receiver

The receiver, located at the nursery office (figure 4), gives a time stamp (date-hours-minutes) to each incoming weight datum, using a real-time clock, and associates it with each individual scale of the network before recording all data on an SD memory card. The receiver is a stand-alone datalogger but it can be connected to a personal computer (PC) (Windows, Mac, or Linux) to show incoming data in real time using the Arduino serial monitor (Ivrea, Italy) and companion software.

Field Considerations

Installing a scale network in the field requires some precautions. Electronic components must be protected using desiccant inside watertight enclosures. Also, to provide an efficient protection against lightning, grounded metallic enclosures are recommended. For battery-powered scales, installation of an individual ground is highly recommended. In some environments, cables also need to be protected against rodents.

Assembly and Cost

All the components needed to build the wireless network of electronic scales (table 1) are easily available at a relatively low cost. Some specific components, which are not available at a local electronics shop, can be easily ordered from Web sites of electronic hardware providers. Specialized manufacturers can produce a basic PCB at a relatively low cost based on standardized instruction files generated by PCB design software (called Extended Gerber RS-274X). Assembling is accessible to a good tinkerer, but, obviously, this is not a "plug-and-play" solution. Most growers may not feel comfortable with assembling this system. Because hardware and software designs are "open source," however, growers can freely get help from local resources that can build the hardware for them. Most of the needed resources are available on a file transfer protocol—FTP—site (ftp://ftp.mrn.gouv.qc.ca/Public/Drf/IRREC/) or by contacting the first author of this article.

Table 1. Main electronic components used by each of the three types of devices of the wireless network of electronic scales. Note that these components also need many secondary generic components (antenna cable, resistor, capacitor, diode, inductor, etc.), which are not listed in this table. The total material cost for each device is approximately $150 (U.S.).

Component	Model	Manufacturer
Scale		
Printed circuit board (PCB)	Home design	Miscellaneous
Switching step-up 5 V regulator	LT-1302	Linear Technology Corporation, Milpitas, CA
50 kg load cell	P/N 3135_0	Phidgets, Inc., Calgary, AL, Canada
Microcontroller	Atmega328P-PU	Atmel Corporation, San Jose, CA; Arduino, Ivrea, Italy
Instrument amplifier	INA125P	Texas Instruments, Dallas, TX
Transistor switch (MOSFET)	IRF520	International Rectifier (Infineon), El Segundo, CA
Linear step-down 3.3 V regulator	LM3940	Texas Instruments, Dallas, TX
Radio modem (XBee)	XBPBZ7SIT-004	Digi International, Inc., Minnetonka, MN
Antenna	A24-HASM-450	Digi International, Inc., Minnetonka, MN
Router		
PCB	Home design	Miscellaneous
Switching step-down 3.3 V regulator	LM2675	Texas Instrument, Dallas, TX
Radio modem (XBee)	XBPBZ7SIT-004	Digi International, Inc., Minnetonka, MN
Antenna	A24-HASM-450	Digi International, Inc., Minnetonka, MN
Solar shield	10W	Miscellaneous
Receiver		
Microcontroller board	Arduino UNO,R3	Arduino, Ivrea, Italy
Shield	Arduino XBee-SD	Arduino, Ivrea, Italy
Radio modem (XBee)	XBPBZ7SIT-004	Digi International, Inc., Minnetonka, MN
Antenna	A24-HASM-450	Digi International, Inc., Minnetonka, MN
Real-time clock	BB-DS3231	Cytron Technologies, Pulau Pinang, Malaysia

In 2015, a scale was assembled for around $150 (U.S.) of materials and 4 hours of labor. The material cost for the other individual devices (routers and the receiver) was also $150 (U.S.) each, and each required 2 hours of labor. For a global DIY network like the one shown in figure 1 (36 scales, 7 routers, and a receiver), the material cost is around $6,600 (U.S.) and requires about 160 hours of labor.

Despite the initial material and labor costs, wireless electronic scales can be profitable, because they greatly reduce labor and skills required in the forest nursery. In addition, risks of injuries to workers (including chronic injuries caused by repetitive movements like container lifting) can be reduced and data quality improved.

Operational Use

Calculating VWC From Container Weights

To obtain the substrate VWC (based on the water mass [1 g = 1 cm^3]), everything that is not substrate water mass must be subtracted from the basic container weight. First, the stable mass (container, dry substrate, and protective grit placed over the seeds at sowing) can be easily determined. Establishing the seedlings' fresh mass is more complicated, which is why tools based on the seasonal evolution of the standard for seedling dry mass have been developed for the IRREC irrigation software (Girard et al. 2011). These tools are used to reliably estimate the mass (stable and variable) that has to be subtracted from the total weight. Figure 11 shows how the mass that is not attributable to substrate water is established using automatic calculations. These calculations provide an automatic seedling fresh mass estimation over the growing season, simply by providing a sampling date. Using this calculation method, the error percentage is usually smaller than +/- 2.5 percent of VWC, even with large seedlings.

Here is an example for large white spruce (*Picea glauca* [Moench] Voss) seedlings produced in a 15-320 container (15 cavities of 320 cm^3 [19 in^3] each):

1. For a final dry mass target of 10 g (0.33 oz), an error of +/- 20 percent (8 to 12 g [0.27 to 0.4 oz]) is equivalent to +/- 2 g (0.067 oz) per seedling.
2. Applying an oversized fresh/dry ratio of 4 times results in an error of +/- 8 g (0.27 oz) per seedling.

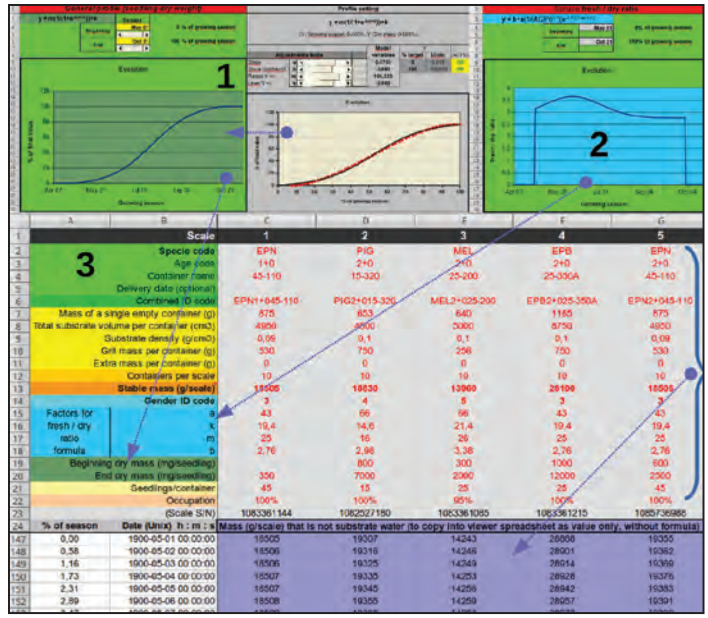

Figure 11. For each scale, the mass that is not substrate water is predicted by simulation for each day of the upcoming growing season. (1) A general profile is set for the seasonal evolution of dry mass, from 0 to 100 percent of the final value, using tools in the grey section. Thereafter, the beginning and the end of the growing season are established to fix the x-axis for the nursery. (2) To obtain the fresh mass, a standard "fresh/dry" ratio of 3.5 can be used, but up to five seasonal evolution profiles of fresh/dry ratios can be established according to the genus of seedling crop (*Picea*: EPN, *Pinus*: PIG, *Larix*: MEL, etc.) to give more precise results. (3) The profile of the dry mass is adjusted according to the targeted dry mass values for the crop of each scale (y-axis). All other parameters (grey zone, red characters) are taken into account to calculate the mass that is not substrate water for every scale and for each day of the growing season (purple zone). Note that all values shown in the third section are given by spreadsheet formulas. In the next step (figure 12), these data will be used to easily produce and show the volumetric water content of the substrate.

3. With 320 g (10.67 oz) of water mass per cavity, the usual error is 8/320 = +/- 2.5 percent of the final substrate VWC result.

With no significant seedling mass, the error is under 1 percent of substrate VWC.

Companion Software Used To Show the Substrate VWC

Until now, we have kept the system as simple as possible in terms of programming, compatibility, and stability. The receiver can act as a stand-alone datalogger, keeping the WSN separate from the PC for daily use. The use of an SD memory card to store incoming data provides an easy way to transfer data to the PC. Stability is an important consideration if the network has to operate for many months without intervention. To get the best stability possible, watchdog functions have been programmed to reset the

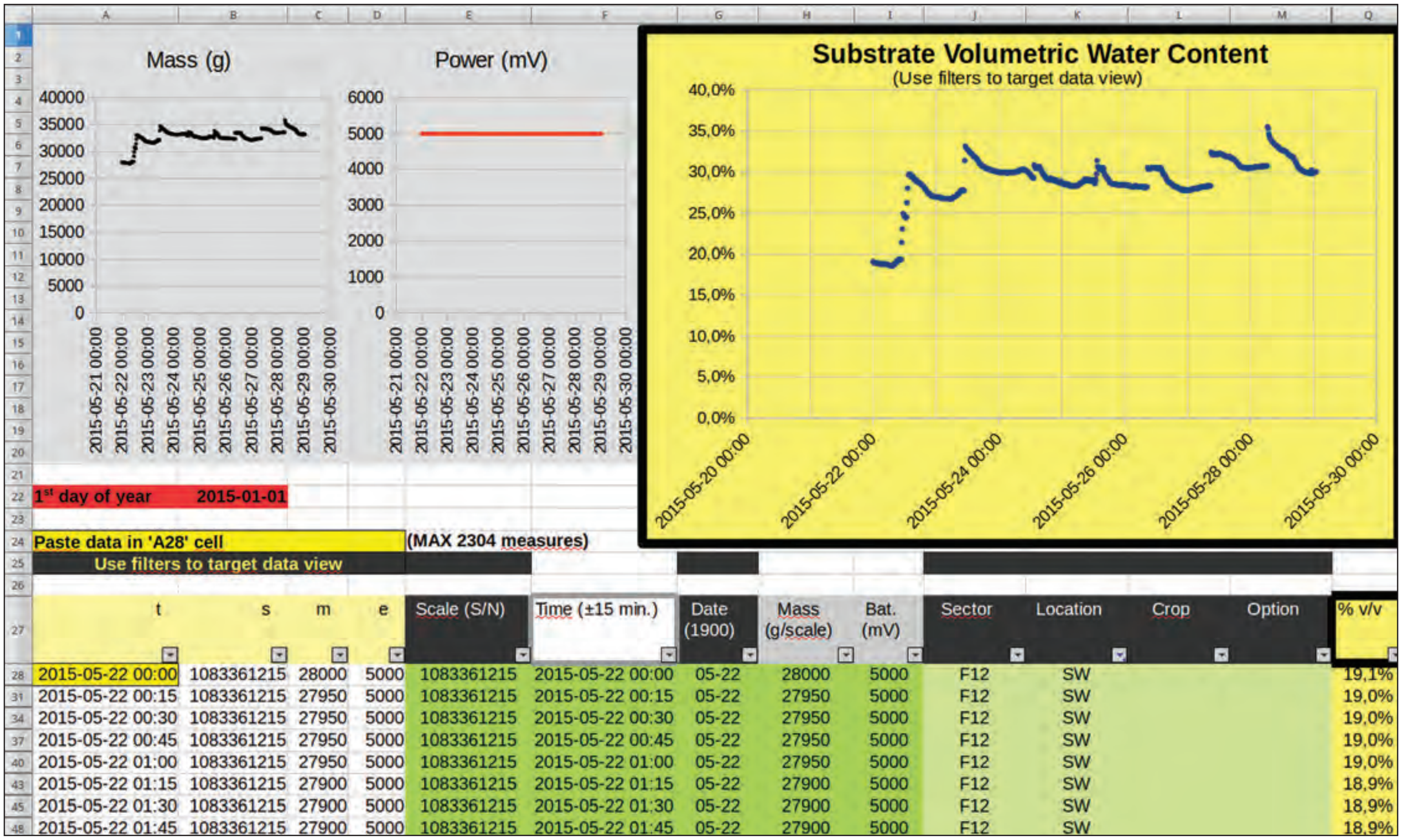

Figure 12. An example graph of substrate volumetric water content monitoring (yellow) obtained at Normandin nursery (Québec, Canada). Other graphs (from left to right) represent basic weight (in g) and cell power level (in mV), respectively. All graphs are based on the individual values shown in the table.

microcontroller in case of an infinite loop generated by an unexpected bug. To date, direct communication between the receiver's microcontroller and the PC via a USB cable is possible only under Linux and requires some basic skills to use.

Spreadsheets used for companion software permit easy computer software development, but they are not efficient for daily calculations. Thus, the companion software uses two spreadsheets (based on LibreOffice Calc spreadsheet software, Berlin, Germany) to provide faster daily calculations. The role of the first spreadsheet (figure 11) is to build a table of the mass values that are not attributable to substrate water for each scale (associated with a crop) and for each day of the growing season. These calculations are complex and time consuming, but they have to be done only once, at the beginning of the season (or only if parameters change significantly during the season). The "non water" table numeric values are copied to the second spreadsheet (figure 12) to be used in a quick calculation process to determine substrate VWC.

Advantages of Container Weighing

The sampling rate of hundreds of seedlings using gravimetry (figure 13) is more statistically adapted to the forest nursery context than using other methods

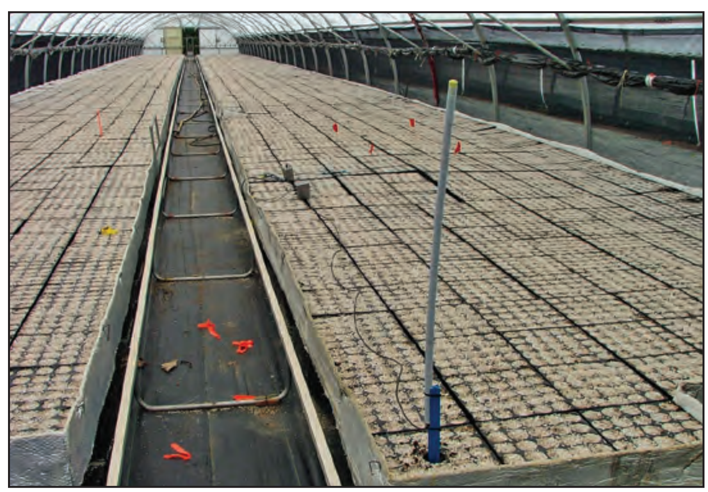

Figure 13. A scale (between the red flags) installed in a crop of seedlings grown in "25-310" type containers (25 cavities with a volume 310 cm^3 (19 in^3) each, IPL 25-310 (Saint-Damien, Québec, Canada) at Grandes-Piles nursery. In front is the same antenna that was shown in figure 2. Few scales may be needed to obtain a robust statistical base for efficient irrigation management in a crop area. (Photo by Daniel Girard, 2014)

(TDR, tensiometry, or capacitance) that usually sample only single seedlings or never more than 10 seedlings per measurement.

For seedlings in the active growth phase, accuracy depends more and more on the fresh weight of seedlings, but for germinating seedlings (with no significant added mass), small variations in substrate VWC are easily detectable using container weighing. Detecting these variations can be a major help in reducing fungal disease while increasing germination efficiency.

Conclusions

This article describes development of a low-cost, automated monitoring system for determining substrate VWC. Although hardware and software proposed for wireless electronic scales are very basic, scales can operate well and will allow growers to improve the irrigation management of their crops. Open source electronic design and software provide an interesting way for markets like forest nurseries to access these new technologies. The principles used for this development can be adapted to other field configurations (other bed types or individual container sampling) by using other load cells and adapted microcontroller programming.

With this system specifically designed for forest nurseries, it is possible to use WSN technology for gravimetric measurements. Indeed, the overall measurement accuracy is the best that can be obtained today for monitoring substrate VWC in forest nurseries. A DIY automated electronic scale can easily give a +/- 1 percent (v/v) resolution of substrate VWC. Even when the bias generated by seedling wet weight estimation (no more than +/- 2.5 percent, using calculation methods of the IRREC irrigation software; Girard et al. 2011) is taken into consideration, gravimetry is still the best method for measuring substrate VWC because it allows a great sampling rate (more than 100 seedlings at a time). Wireless electronic scales can be considered as a necessary evolution, leading to more efficient irrigation scheduling and the production of better quality seedlings with less impact on environmental quality by avoiding excess irrigation (water economy) and reducing nutrient leaching.

Acknowledgments

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REFERENCES

Arseneault, J. 2015. Personal communication regarding the number and species of containerized and bareroot seedlings produced in 2015 in forest tree nurseries of Québec. Forest Technician, Ministère des Forêts, de la Faune et des Parcs (MFFP), Direction générale de la production de semences et de plants forestiers (DGPSPF), Québec City, Québec, Canada.

Boudreau, J.; Jobin, P.; Bettez, M. 2006. Nouvel outil de gestion de la tension et de la température du substrat. Affiche présentée au 4e atelier sur la production de plants forestiers au Québec : Facteurs et techniques culturales influençant le développement racinaire des plants en pépinière forestière. 15-16 mars 2006, Hôtel Clarion, Sainte-Foy, Québec.

Burnett, S.E.; van Iersel, M.W. 2008. Morphology and irrigation efficiency of *Gaura lindheimeri* grown with capacitance sensor-controlled irrigation. HortScience 43(5): 1555–1560.

Ferrarezi, R.S.; Dove, S.K.; van Iersel, M.W. 2015. An automated system for monitoring soil moisture and controlling irrigation using low-cost open-source microcontrollers. HortTechnology. 25(1): 110–118.

Gagnon, J.; Girard, D. 2001. Bilan des pertes saisonnières de nitrates (NO_3^-) et d'eau sous une culture d'épinette blanche 2+0 produite dans le récipient 25-350A. Ministère des Ressources naturelles, Direction de la recherche forestière. Rapp. Int. no 466. 36 p.

Girard, D.; Gagnon, J.; Lamhamedi, M. 2011. IRREC: Un système informatisé de calcul des besoins en irrigation pour les plants en récipients produits dans les pépinières forestières du Québec. Mémoire de recherche forestière no 162, Sainte-Foy, Québec, Canada: Ministère des Ressources naturelles, Direction de la recherche forestière. 54 p.

Hoskins, T.; Owen, J.; Stoven, H. 2012. Monitoring from a distance: using a remote moisture monitoring system to manage irrigation. Digger. 56(7): 41–44.

Lambany, G.; Renaud, M.; Beauchesne, M. 1997. Control of growing medium water content and its effect on small seedlings grown in large containers. Tree Planters' Notes. 48(3/4): 48–54.

Lambany, G.; Robidas, L.; Ballester, P. 1996. Measurement of soil water content in a peat-vermiculite medium using time domain reflectometry (TDR): a laboratory and field evaluation. Tree Planters' Notes. 47(3): 88–93.

Lamhamedi, M.S.; Lambany, G.; Margolis, H.; Renaud, M.; Veilleux, L.; Bernier, P-Y. 2001. Growth, physiology and leachate losses in *Picea glauca* seedlings (1 + 0) grown in air-slit containers under different irrigation regimes. Canadian Journal of Forest Research. 31(11): 1968–1980.

Prehn, A.E.; Owen, J.S.; Warren, S.L.; Bilderback, T.E.; Albano, J.P. 2010. Comparison of water management in container-grown nursery crops using leaching fraction or weight-based on demand irrigation control. Journal of Environmental Horticulture. 28(2):117–123.

Topp, G.C.; Davis, J.L. 1985. Measurement of soil water content using time-domain reflectometry (TDR): a field evaluation. Soil Science Society of America Journal 49(1): 19–24.

van Iersel, M.W.; Chappell, M.; Lea-Cox, J.D. 2013. Sensors for improved efficiency of irrigation in greenhouse and nursery production. HortTechnology. 23(6): 735–746.

Forest Nursery Seedling Production in the United States—Fiscal Year 2015

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Abstract

Forest nursery production for the 2015 planting season was more than 1.3 billion forest tree seedlings with an estimated 2,367,705 ac (958,175 ha) of trees planted. Annual seedling production and acres of trees planted nationwide have increased steadily from 2013 to 2015.

Background

This annual report summarizes forest nursery seedling production in the United States. The number of seedlings reported is used to estimate the number of acres of forest planting per year. Prepared by the USDA Forest Service, Forest Inventory and Analysis (FIA) and State and Private Forestry (S&PF), this report includes State-by-State breakdowns, regional totals, and an analysis of data trends. Universities located in the southern, northeast, and western regions of the United States made an effort to collect data from all the major producers of forest and conservation seedlings in the 50 States. Forest and conservation nursery managers provided the information presented in this report. As far as we know, it is the most complete compilation of such data in the country. Because all data are provided voluntarily by outside sources and some data are estimated, however, caution must be used in drawing inferences.

Methodology

The empirical data for this report were produced by S&PF in collaboration with Auburn University, the University of Idaho, and Purdue University. All these universities collected forest tree seedling production data directly from the forest and conservation nurseries that grow forest tree seedlings in their region of the United States (Auburn University collected from 12 States in the Southeast, the University of Idaho collected from 17 States in the West, and Purdue University collected from 21 States in the Northeast and Midwest). The approximation of planted acres for each State is derived from FIA estimates of tree planting area based on ground plots collected by States during 5-, 7-, or 10-year periods and compiled as an average annual estimate for the associated period. FIA estimates of acres of trees planted by State may not correlate with the estimates produced by nursery production surveys because nurseries do not report shipments across State lines. Total acres by region, however, provide a reasonable comparison between the two methods. Data collected are reported by hardwood and conifer seedlings produced and acreage planted of each (table 1) and by bareroot and container seedlings produced (table 2). A complete list of the assumptions used in compiling this report appear in the *Forest Nursery Seedling Production in the United States—Fiscal Year 2013* (Harper et al. 2014).

Data Trends

A total of 1,302,237,795 forest tree seedlings were shipped from forest and conservation nurseries in the United States in fiscal year (FY) 2015. This total is an increase of 43,487,975 more than the forest nursery seedling reported for FY 2014 and is the

Table 1. Hardwood and conifer tree seedling production and acres planted for each state and each region during the 2014-2015 planting year.

State	Hardwood seedlings produced	Hardwood acres planted[1]	Conifer seedlings produced	Canadian conifer imports	Conifer acres planted[1]	Total seedlings produced	Total acres planted[1]	FIA data acres planted[10]
Southeast								
Florida[2]	1,832,000	3,331	34,770,870	—	63,220	36,602,870	66,551	140,247
Georgia[2]	5,265,000	9,573	336,420,272	—	611,673	341,685,272	621,246	196,602
North Carolina[2]	300,300	546	66,091,000	—	120,165	66,391,300	120,711	108,286
South Carolina[2]	2,104,629	3,827	128,406,645	—	233,467	130,511,274	237,293	55,479
Virginia[2]	834,800	1,518	29,521,000	—	53,675	30,355,800	55,192	92,707
Regional Totals	**10,336,729**	**18,794**	**595,209,787**	—	**1,082,200**	**605,546,516**	**1,100,993**	**593,320**
South Central								
Alabama[2]	223,450	406	123,250,223	—	224,091	123,473,673	224,497	263,720
Arkansas[2]	12,070,120	21,946	95,132,875	—	172,969	107,202,995	194,915	156,973
Kentucky[3]	143,500	330	11,500	—	21	155,000	351	1,479
Lousiana[2]	1,813,700	3,298	20,371,000	—	37,038	22,184,700	40,336	166,984
Mississippi[2]	1,356,900	2,467	79,996,000	—	145,447	81,352,900	147,914	192,746
Oklahoma[2]	482,725	878	2,389,754	—	4,345	2,872,479	5,223	25,434
Tennessee[2]	1,716,000	3,120	5,267,000	—	9,576	6,983,000	12,696	22,489
Texas[2]	79,100	144	81,505,000	—	148,191	81,584,100	148,335	113,125
Regional Totals	**17,885,495**	**32,589**	**407,923,352**	—	**741,678**	**425,808,847**	**774,267**	**942,949**
Northeast								
Connecticut	—	—	—	—	—	—	—	—
Deleware	—	—	—	—	—	—	—	—
Maine[5,9]	—	—	—	18,680,000	31,133	18,680,000	31,133	—
Maryland[2]	765,325	1,392	720,625	—	1,310	1,485,950	2,702	—
Massachusetts	—	—	—	—	—	—	—	8,284
New Hampshire[3]	14,200	33	74,730	—	172	88,930	205	—
New Jersey[3]	157,400	362	—	—	168	230,275	530	—
New York[5]	173,000	288	—	—	860	689,000	1,148	203
Pennsylvania[3]	1,167,086	2,683	—	—	2,260	2,149,986	4,943	1,391
Rhode Island	—	—	—	—	—	—	—	—
Vermont	—	—	—	—	—	—	—	—
West Virginia[3]	521,325	1,198	143,050	—	329	664,375	1527	—
Regional Totals	**2,798,336**	**5,956**	**2,510,180**	**18,680,000**	**36,232**	**23,988,516**	**42,188**	**9,878**
North Central								
Illinois[3]	971,075	2,232	175,100	—	403	1,146,175	2,635	5,062
Indiana[4]	2,921,714	4,495	439,881	—	677	3,361,595	5,172	1,331
Iowa[5]	702,735	1,171	122,075	—	203	824,810	1,374	—
Michigan[2,9]	2,065,774	3,756	39,536,346	480,000	72,757	42,082,120	76,513	11,899
Minnesota[2,9]	813,300	1,479	6,955,500	4,300,000	12,646	12,068,800	14,125	20,059
Missouri[3]	1,359,450	3,125	841,755	—	20,465	2,201,205	23,590	—
Ohio[3]	13,000	30	—	—	—	13,000	30	3,775
Wisconsin[6,9]	1,100,807	1,376	6,330,958	2,300,000	7,914	9,731,765	9,290	9,413
Regional Totals	**9,947,855**	**17,664**	**54,401,615**	**7,080,000**	**115,065**	**71,429,470**	**124,922**	**51,540**

State	Hardwood seedlings produced	Hardwood acres planted[1]	Conifer seedlings produced	Canadian conifer imports	Conifer acres planted[1]	Total seedlings produced	Total acres planted[1]	FIA data acres planted[10]
Great Plains								
Kansas[2]	222,675	405	114,150	—	—	336,825	405	—
Nebraska[2]	82,395	150	1,539,430	—	—	1,621,825	150	—
North Dakota[2]	8,800	16	742,250	—	—	751,050	16	—
South Dakota[2]	800,017	1,455	372,783	—	—	1,172,800	1,455	—
Regional Totals	**1,113,887**	**2,026**	**2,768,613**	—	—	**3,882,500**	**2,026**	—
Intermountain								
Arizona[2]	200,000	364	20,000	—	36	220,000	400	—
Colorado[2]	209,041	380	201,852	—	367	410,893	747	—
Idaho[2]	3,470,160	6,309	5,922,595	1,500,000	13,495	10,892,755	19,804	4,287
Montana[2]	130,768	238	725,916	—	1,320	856,684	1,558	5,142
Nevada[2]	85,453	155	1,705	—	3	87,158	158	—
New Mexico[2]	28,420	52	33,957	62	—	62,377	114	—
Utah[2]	1,125,000	2,045	650,175		1,182	1,775,175	3,227	—
Wyoming	—	—	—	—	—	—	—	—
Regional Totals	**5,248,842**	**9,543**	**7,556,200**	**1,500,000**	**16,465**	**14,305,042**	**26,008**	**9,429**
Alaska								
Alaska[2]	4,000	7	3,200	620,000	1,127	627,200	1,134	806
Pacific Northwest								
Oregon[7,9]	32,461,904	92,748	61,357,066	1,850,000	180,592	95,668,970	273,340	88,379
Washington[7,9]	1,554,267	4,441	45,936,574	150,000	131,676	47,640,841	136,117	54,179
Regional Totals	**34,016,171**	**97,189**	**107,293,640**	**2,000,000**	**312,268**	**143,309,811**	**409,457**	**142,558**
Pacific Southwest								
California[8]	100,835	224	12,936,000	—	28,747	13,036,835	28,791	29,535
Hawaii[8]	272,353	605	30,705	—	68	303,058	673	—
Regional Totals	**373,188**	**829**	**12,966,705**	**—**	**28,815**	**13,339,893**	**29,464**	**29,535**
Totals	**81,720,503**	**184,590**	**1,190,630,092**	**29,880,000**	**2,332,723**	**1,302,237,795**	**2,510,459**	**1,779,209**

[1] Acres planted were estimated assuming:
[2] 550 stems/acre
[3] 435 stems/acre
[4] 650 stems/acre
[5] 600 stems/acre
[6] 800 stems/acre
[7] 350 stems/acre
[8] 450 stems/acre
[9] Totals include an estimate of conifers produced in Canada for distribution to neighboring States; bareroot imports for Maine and containers for other States.
[10] FIA = Forest Inventory and Analysis; average annual acreage planted estimated for all States (2012) on 5-year cycles, except for Alaska, Louisiana, Mississippi, and North Carolina, which are on 7-year cycles, and for Arizona, California, Colorado, Hawaii, Idaho, Montana, Nevada, New Mexico, Oregon, and Washington, which are on 10-year cycles. Data generated by R. Harper.

Table 2. Bareroot and container tree seedling production for each state and each region during the 2014-2015 planting year.

State	Bareroot	Container[1]	Total Seedlings Produced
Southeast			
Florida	28,374,470	8,228,400	36,602,870
Georgia	180,937,000	160,748,272	341,685,272
North Carolina	51,274,300	15,117,000	66,391,300
South Carolina	129,282,658	1,228,616	130,511,274
Virginia	30,355,800	—	30,355,800
Regional Totals	**420,224,228**	**185,322,288**	**605,546,516**
South Central			
Alabama	116,710,673	6,763,000	123,473,673
Arkansas	107,202,995	—	107,202,995
Kentucky	155,000	—	155,000
Louisiana	14,052,700	8,132,000	22,184,700
Mississippi	72,831,000	8,521,900	81,352,900
Oklahoma	2,753,850	118,629	2,872,479
Tennessee	6,983,000	—	6,983,000
Texas	81,584,100	—	81,584,100
Regional Totals	**402,273,318**	**23,535,529**	**425,808,847**
Northeast			
Connecticut	—	—	—
Delaware	—	—	—
Maine[5,9]	—	—	—
Maryland	1,485,950	—	1,485,950
Massachusetts	-	—	-
New Hampshire	88,930	—	88,930
New Jersey	230,275	—	230,275
New York	655,000	34,000	689,000
Pennsylvania	1,438,986	711,000	2,149,986
Rhode Island	—	—	—
Vermont	—	—	—
West Virginia	664,375	—	664,375
Canada	—	18,680,000	18,680,000
Regional Totals	**4,563,516**	**19,425,000**	**23,988,516**
North Central			
Illinois	1,145,225	950	1,146,175
Indiana	3,198,345	163,250	3,361,595
Iowa	804,810	20,000	824,810
Michigan	40,936,000	666,120	41,602,120
Minnesota	4,978,800	2,790,000	7,768,800
Missouri	2,201,205	—	2,201,205
Ohio	—	3,000	13,000
Wisconsin	7,429,115	2,650	7,431,765
Canada	—	7,080,000	7,080,000
Regional Totals	**60,693,500**	**10,735,970**	**71,429,470**
Great Plains			
Kansas	134,175	202,650	336,825
North Dakota	695,000	56,050	751,050
Nebraska	765,810	856,015	1,621,825
South Dakota	1,145,891	26,909	1,172,800
Regional Totals	**2,740,876**	**1,141,624**	**3,882,500**
Intermountain			
Arizona	—	220,000	220,000
Colorado	410,893	—	410,893
Idaho	5,619,934	3,772,821	9,392,755
Montana	110,049	746,635	856,684
New Mexico	—	62,377	62,377
Nevada	—	87,158	87,158
Utah	—	1,775,175	1,775,175
Wyoming	—	—	—
Canada	—	1,500,000	1,500,000
Regional Totals	**6,140,876**	**8,164,166**	**14,305,042**
Alaska			
Alaska	—	7,200	7,200
Canada	—	620,000	620,000
Regional Totals	—	**627,200**	**627,200**
Pacific Northwest			
Oregon	46,828,146	46,990,824	93,818,970
Washington	36,867,000	10,623,841	47,490,841
Canada	—	2,000,000	2,000,000
Regional Totals	**83,695,146**	**59,614,665**	**143,309,811**
Pacific Southwest			
California	—	13,036,835	13,036,835
Hawaii	—	303,058	303,058
Regional Totals	—	**13,339,89**	**13,339,893**
Totals	**980,331,460**	**321,906,335**	**1,302,237,795**

[1] Alaska, Idaho, Maine, Michigan, Minnesota, Oregon, Washington, and Wisconsin received container seedlings produced in Canada.

second consecutive year with a 3-percent increase in the number of seedlings produced compared with the number produced in the previous fiscal year (Harper et al. 2014, Hernández et al. 2015). Some of the increases are attributable to a concerted effort to increase the response rate of forest and conservation nurseries to the production survey, especially in the Western and Northeastern States.

Using the total number of seedlings shipped and the average number of seedlings planted per acre in each State, we estimate that approximately 2,367,705 ac (958,176 ha) of trees were planted during the fall 2014 through spring 2015 planting season, a 3-percent increase compared with the number of acres reported for the previous planting season (Hernández et al. 2015). Trends by regions (table 3) are as follows:

Table 3. Total forest nursery seedling production, including region, by year, from FY 2012 through FY 2015.

Year	Total seedling production	West	East	South
FY 2015	1,302,237,795	175,464,446	95,417,986	1,031,355,363
FY 2014	1,217,607,888	115,620,820	85,684,417	1,015,564,370
FY 2013	1,181,554,535	96,344,063	102,066,671	983,143,801
FY 2012	1,190,552,819	170,975,830	81,672,547	936,918,542

FY = fiscal year.
Sources: This report, Harper et al. (2013, 2014), and Hernández et al. (2015).

West

The 17 States in the USDA Forest Service western regions produced more than 175 million seedlings, 59 million more than in the FY 2014 planting season and 13 percent of the U.S. total.

East

The 20 States in the USDA Forest Service Northeastern Area reported 95 million seedlings, an increase of more than 15 million seedlings compared with the FY 2014 planting season and 5 percent of the U.S. total.

South

The 13 States in the USDA Forest Service Southern Region produced more than 1 billion forest tree seedlings (82 percent of the U.S. total) with an increase of nearly 16 million during the FY 2014 planting season.

Overall, forest nursery seedling production increased steadily during the past 4 years (figure 1; table 3). This steady increase could reflect the continuing high volume of timber product exports and a slight increase in new home construction starts.

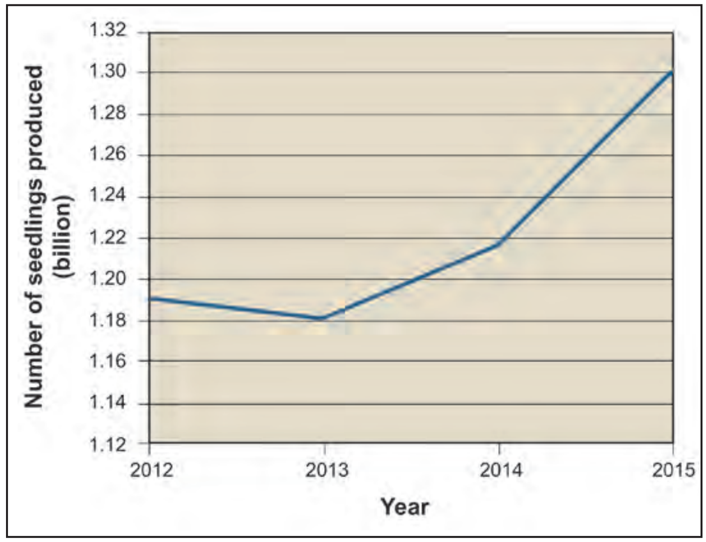

Figure 1. Seedling production in the United States has increased during the past 4 years.

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REFERENCES

Harper, R.A.; Hernández, G.; Arsenault, J.; Bryntesen, M.; Enebak, S.; Overton, R.P. 2013. Forest nursery seedling production in the United States—fiscal year 2012. Tree Planters' Notes. 56(2): 72–75.

Harper, R.A.; Hernández, G.; Arsenault, J.; Woodruff, K.J.; Enebak, S.; Overton, R.P.; Haase, D.L. 2014. Forest nursery seedling production in the United States—fiscal year 2013. Tree Planters' Notes. 57(2): 62–66.

Hernández, G.; Harper, R.A.; Woodruff, K.J.; Enebak, S.; Overton, R.P.; Lesko, J.; Haase, D.L. 2015. Forest nursery seedling production in the United States—fiscal year 2014. Tree Planters' Notes. 58(2): 28–32.

Maryland's New Approach To Increasing Urban Tree Canopy

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Abstract

The 2013 Forest Preservation Act requires Maryland to maintain the existing 40-percent forest canopy coverage statewide. The 2014 amended Chesapeake Watershed Agreement establishes a goal to expand urban tree canopy in the Chesapeake Bay watershed by 2,400 ac (970 ha) by 2025, with Maryland's target being 540 ac (220 ha) (45 ac [18 ha] per year). To achieve these goals, Maryland created two new programs. Marylanders Plant Trees, a $25 coupon reimbursement program, targets individuals wishing to plant a native tree; 33,324 coupons were reimbursed between fiscal year (FY) 2009 and FY 2015. The Lawn to Woodland program, a partnership with the Arbor Day Foundation, targets small-lot owners with 1 to 5 ac (0.4 to 2.0 ha) of plantable space. The Foundation conducts outreach and the Maryland Forest Service handles the tree planting at no cost to the lot owner. In the spring of 2014, the Maryland Forest Service conducted a pilot with 14 ac (5.7 ha) planted on 12 lots. In the spring of 2015, 100 ac (40 ha) on 84 lots were planted statewide and, during the spring of 2016, planting approximately 60 ac (24 ha) on approximately 56 lots statewide was proposed. This paper was presented at a joint meeting of the Northeast Forest and Conservation Nursery Association and Southern Forest Nursery Association (Kent Island, MD, July 20–23, 2015).

Introduction

The State of Maryland has numerous urban forestry laws as well as forest landowner assistance programs to protect and enhance the State's forests. In addition, these laws and programs assist in Maryland's efforts to restore and protect the Chesapeake Bay. During the past few years, new forestry laws were passed, such as No Net Loss of Forest Policy of 2009 and the Forest Preservation Act of 2013, which require the Maryland Forest Service to maintain the statewide forest base. The 2014 Chesapeake Bay Watershed Agreement also created additional goals and outcomes. These new goals created the need for the Maryland Forest Service to evaluate the existing programs' ability and capacity to maintain and also expand the existing canopy coverage. It was determined that the existing programs could not achieve both. Therefore, two new programs were created: Marylanders Plant Trees and Lawn to Woodland.

Marylanders Plant Trees

In late 2008, then Governor Martin O'Malley tasked the Maryland Forest Service to develop a program that would engage the citizens of Maryland to plant trees and to remove barriers that the small, urban landowner may have in purchasing and planting a tree. The barriers were identified as tree cost and available planting space. The Maryland Forest Service looked at the State's counties and towns to see if one or more had already determined a means for addressing one or both of these barriers. Baltimore County was found to have addressed the cost barrier by creating a coupon reimbursement program for county residents. This concept was used as the framework for developing a statewide program. The statewide Marylanders Plant Trees coupon reimbursement program addresses both barriers: the cost factor by lowering the price through use of a coupon and the planting space factor by empowering citizens to plant just one native tree on their townhouse lot. This program was the first effort that engaged urban and suburban landowners to plant native trees to help Maryland achieve no-net-loss of forest statewide.

The Marylanders Plant Trees program enables people to use a $25 coupon on any native tree purchase of

$50 or more at one of the 85 participating nurseries statewide. The nursery then submits the coupon for a $20 reimbursement from the Maryland Forest Service. Information about the program, including the coupon and list of participating nurseries, is online at http://dnr2.maryland.gov/forests/Pages/MarylandersPlantTrees/Introduction.aspx.

The initial funding for the Marylanders Plant Trees program came from the Office of the Attorney General (OAG), which, at the time, had received a partial settlement from a multistate lawsuit regarding air pollution. The OAG agreed to fund a program that would plant trees in urban areas, which would help clean the air. The Maryland Forest Service received two $400,000 payments between 2009 and 2014. From fiscal year (FY) 2009 to FY 2015, 33,324 coupons were reimbursed (one coupon can be used on multiple trees purchased at one time). The program seems to have influenced the nursery businesses in an unexpected way. Local private nurseries are now carrying more native tree species, presumably in response to demand by customers wishing to use the coupon.

Lawn to Woodland Program

In early 2013, the Maryland Forest Service was tasked again with determining ways to engage the urban and suburban landowner to plant trees as a means for addressing an emerging issue of decreasing statewide urban forest canopy coverage. Three events occurred within a short time that spurred this need. The first event was the adoption of the 2010–2015 Maryland Forest Action Plan. This plan identifies numerous State strategies for addressing the three national priorities as identified by the U.S. Department of Agriculture, Forest Service, State and Private Forestry organization. The State strategies included two that addressed canopy cover: Goal I. A—Keep Forests as Forests, Strategy 1.A.3 (Provide incentives to maintain forest cover) and Strategy I.A.5 (Pursue no-net-loss of forests) (Maryland Department of Natural Resources, Forest Service 2010). The second event was the adoption of Maryland's 2013 Forest Preservation Act. This piece of legislation makes Maryland the first State in the Nation to adopt a policy statement requiring the maintenance of 40 percent tree canopy coverage statewide (Section §5-101(i) and §5-102 (b)(1), HB 706 Natural Resources—Forest Preservation Act of 2013, adopted 2013). The third event was the adoption of the 2014 Chesapeake Bay Watershed Agreement that amends the previous agreement to include goals and outcomes to "advance restoration and protection of the Chesapeake Bay ecosystem and watershed" (Chesapeake Bay Program 2014: pg 3). The agreement requires the establishment of specific, measurable targets for each goal. One goal requires an expansion of urban tree canopy cover by 2,400 ac (970 ha) by 2025 (Chesapeake Bay Program 2014). Maryland has been given the targets of 45 ac (18 ha) per year or 540 ac (220 ha) by 2025 (Chesapeake Bay Program 2015).

Upon review of the Maryland Forest Service's existing landowner assistance programs, within both the Forest Management and Urban and Community Forestry programs, it was determined that the existing programs with traditional cooperators were capable of maintaining the required statewide 40-percent tree canopy coverage and acreage but may not have the capacity to increase the canopy coverage at the desired yearly rate. Around this time, the Maryland Department of Planning had determined that Maryland had more than 1 million ac (404,685 ha) of mowed turf (Chesapeake Stormwater Network 2010; Maryland Department of Natural Resources, Forest Service 2013), which spurred the decision to develop a program that targets the small-lot landowner (i.e., the owner of the mowed turf).

A new planting program always presents two hurdles to overcome. One is the funding source and the other is outreach to the targeted audience. Funding for the Lawn to Woodland program came from an unexpected source—the Maryland Reforestation Law. The Maryland Reforestation Law (NRA 5-103), adopted in 1988, requires that any highway construction work conducted by a highway construction agency utilizing State funds and disturbing at least 1 ac (0.4 ha) of forest must replant 1 ac (0.4 ha) of forest (a 1:1 ratio of disturbance to replanting). If replanting cannot occur, then the agency must pay fee-in-lieu of $0.10 per ft^2 ($1.08 per m2) of the required mitigation amount to the Maryland Forest Service, which then must accomplish the planting (Section §5-103, Natural Resources Article, Annotated Code of Maryland [2012 replacement volume as amended]). The Maryland Department of Transportation mitigated with roughly $1 million in fee-in-lieu for highway construction work that disturbed approximately 266 forested acres (108 ha). Outreach was accomplished through a partnership with the Arbor Day Foundation.

The Lawn to Woodland program targets the small lot with 1 to 5 ac (0.4 to 2.0 ha) of plantable space. It is a partnership with the Arbor Day Foundation, which handles the outreach, and the Maryland Forest Service, which manages the tree planting at no cost to the lot owner. In the summer of 2013, the Maryland Forest Service initiated a pilot project within a targeted area just west of Baltimore County (figure 1). The Foundation mailed 1,000 flyers to its members within this area and received a 10-percent response rate. The Maryland Forest Service wrote the planting plan and handled the site preparation work, the planting contracts, the seedling orders, the shelters/stakes, and the post-planting mowing. In the spring of 2014, the pilot project was planted on a total of 14.3 ac (5.8 ha) on 12 sites using 4,300 seedlings purchased from John S. Ayton State Tree Nursery (table 1). It was determined that the seedlings needed 5-ft (1.5-m) shelters and stakes and also tree mats. The planting cost, including nursery purchase and planting contract, was approximately $815.64 per ac ($2,014.63 per ha).

Tubes, stakes, and tree mats were purchased in bulk for multiple planting sites that season and are not included in the cost per acre. Pilot area survival rate was determined to be 85 to 90 percent in the summer and fall of 2015 (figure 2).

Table 1. Spring 2014 seedling order for Maryland's Lawn to Woodland pilot project.

Species		Quantity
Common name	**Scientific name**	
Black oak	*Quercus velutina* Lam.	550
Chestnut oak	*Q. montana* Willd.	550
Northern red oak	*Q. rubra* L.	550
White oak	*Q. alba* L.	550
Common ninebark	*Physocarpus opulifolius* (L.) Maxim., orth. cons.	450
American hazelnut	*Corylus americana* Walter	550
Common persimmon	*Diospyros virginiana* L.	550
Eastern redbud	*Cercis canadensis* L.	550
Total		**4,300**

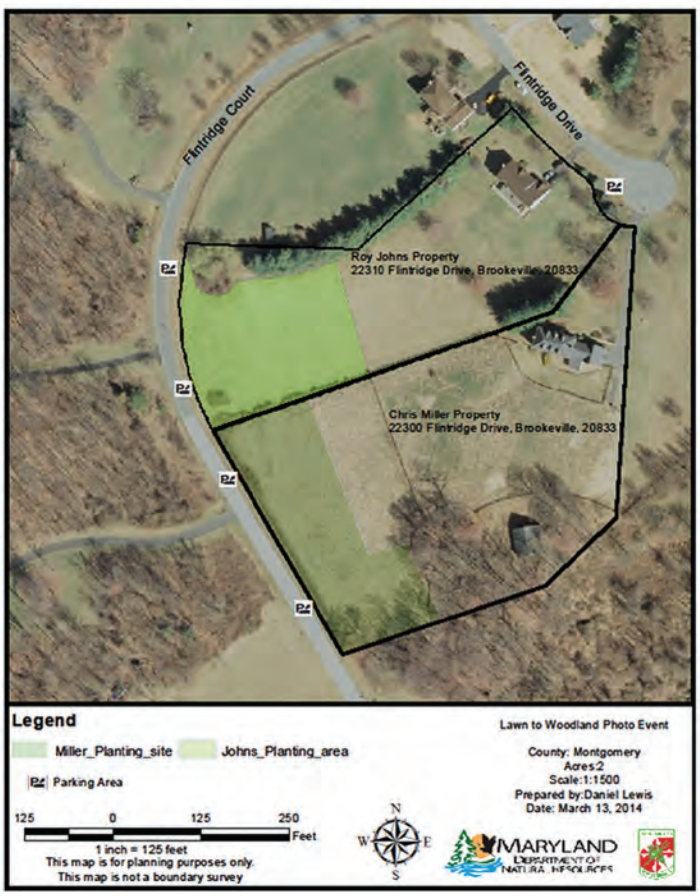

Figure 1. Aerial plan of two neighboring 2014 planting sites for Maryland's Lawn to Woodland pilot project.

Figure 2. Seedling survival was excellent during the 2014 pilot project for Maryland's Lawn to Woodland program. (Photo by Marian Honeczy, 2014)

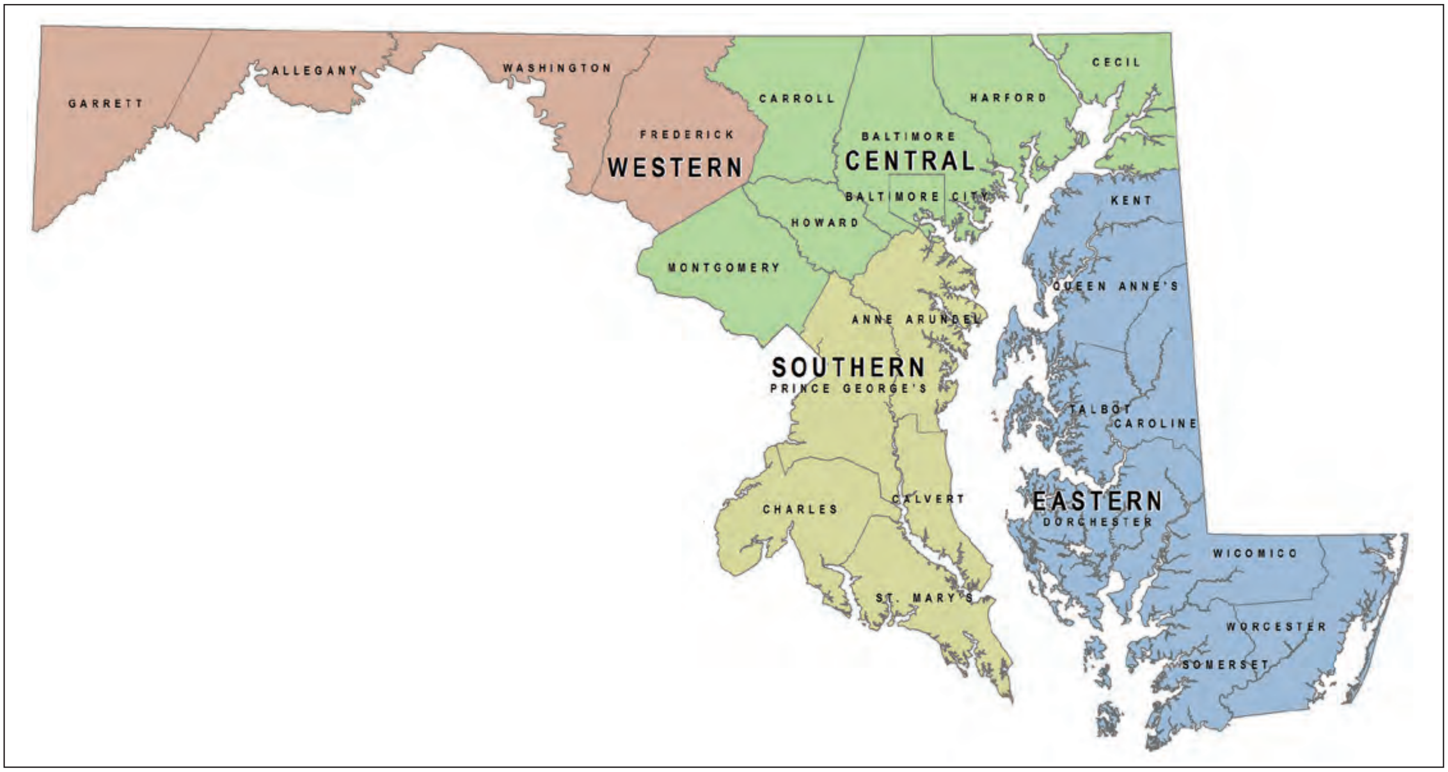

Figure 3. Maryland's Forest Service regions.

After a review of the pilot project, the Maryland Forest Service decided to roll out the program statewide. The Arbor Day Foundation again mailed approximately 100,000 brochures to both active and lapsed Maryland members statewide. The response was huge; at first glance, it seemed beyond the program's capacity to handle. Upon reviewing the responses, it was determined that most who responded did not meet the lot size criteria. Those lot owners who did not fall within the Lawn to Woodland program's available planting space criteria were directed to other more appropriate Maryland Forest Service landowner assistance or tree planting programs. In the spring of 2015, 100 ac (40.4 ha) were planted on 84 sites within all four Maryland Forest Service regions (figure 3) with 41,220 seedlings purchased from John S. Ayton State Tree Nursery (table 2). It was determined that some planting sites needed 4- to 5-ft-tall (1.2- to 1.5-m-tall) shelters and stakes, depending on location (figure 4). Tree mats were also purchased for most planting locations. The total planting cost was $264,163.48, or $2,622.49 per ac ($6,477.55 per ha), including four planting contracts, seedling orders, shelters, staples, and tree mats. The statewide survival rates in the fall of 2015 were 85 to 90 percent.

Table 2. Spring 2015 seedling order by region for Maryland's Lawn to Woodland program.

Region	Number of seedlings	Number of acres	Number of lot owners
Central	10,500	35.0	32
Eastern	10,670	24.5	20
Southern	12,650	27.4	22
Western	4,200	13.8	10
Totals	**41,220**	**100.7**	**84**

Figure 4. During the 2015 planting season, it was determined that tall tree shelters were needed on some sites. (Photo by Chris Peters, Maryland Forest Service, 2015)

Table 3. Spring 2016 seedling order by region for Maryland's Lawn to Woodland program.

Region	Number of seedlings	Number of acres	Number of lot owners
Central	14,100	47	47
Eastern	3,375	7	3
Southern	1,350	3	3
Western	3,750	13	9
Total	**22,575**	**70**	**62**

Because some funding was still available and a number of landowners remained who had not been contacted during the 2015 outreach effort, the Maryland Forest Service decided to conduct the program again in 2016 (table 3). The plantings used the remaining tree tubes, stakes, and tree mats from the 2015 planting. The estimated costs for planting 70 ac (28 ha) on 62 sites include seedling orders and four planting contracts for an approximate total of $131,711, or $1,881 per ac ($4,648 per ha).

Conclusion

To achieve two new statewide canopy goals, the Maryland Forest Service developed two new tree planting assistance programs targeting landowners within the urban and suburban areas of Maryland. Together, these programs help the Maryland Forest Service meet goals set forth in the Maryland Forest Action Plan. According to Donald VanHassent, Maryland State Forester, "These two programs have allowed the Maryland Forest Service to reach out to non-traditional cooperators to help achieve our urban tree canopy goals" (as quoted in Honeczy 2016). As with all planting programs, funding determines the lifespan of the program. Both programs have limited funding and the Maryland Forest Service is examining various options to continue these programs.

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REFERENCES

Chesapeake Bay Program. 2014. Chesapeake Bay watershed agreement. Annapolis, MD: Chesapeake Bay Program. 17 p. http://www.chesapeakebay.net/publications/title/chesapeake_bay_watershed_agreement. (May 2016).

Chesapeake Bay Program. 2015. Tree canopy outcome management strategy 2015-2025, v.1. Annapolis, MD: Chesapeake Bay Program. 27 p. http://www.chesapeakebay.net/publications/title/urban_tree_canopy_management_strategy. (May 2016).

Chesapeake Stormwater Network. 2010. The Clipping Point: Turf Cover Estimates for the Chesapeake Bay Watershed and Management Implications. SCN Tech. Bull. No. 8. Ellicott City, MD: Chesapeake Stormwater Network. 6 p. http://chesapeakestormwater.net/2012/03/technical-bulletin-no-8-the-clipping-point/. (May 2016).

Maryland Department of Natural Resources, Forest Service. 2010. Maryland's forest action plan. Annapolis, MD: Maryland Department of Natural Resources. 62 p. http://www.stateforesters.org/forest-action-plans/maryland. (May 2016).

Maryland Forest Service. 2013. Analysis of turf areas for tree planting in Maryland. Annapolis, MD: Maryland Department of Natural Resources. 3 p.

Honeczy, M. 2016. Maryland's new approach to increasing urban tree canopy. National Association of State Foresters blog, January 28, 2016.http://www.stateforesters.org/news-events/blog/maryland%E2%80%99s-new-approach-increasing-urban-tree-canopy#sthash.psmaxbhG.dpbs

Bigtooth and Quaking Aspen Propagation From Roots Versus Seed

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Abstract

With increased demand for trembling or quaking aspen (*Populus tremuloides* Michx.) and bigtooth aspen (*P. grandidentata* Michx.), the Wisconsin Department of Natural Resources, F.G. Wilson State Nursery has been conducting operational trials to determine the most efficient and effective way to propagate these plants for reforestation and afforestation activities. Seed propagation trials have been mostly unsuccessful because of the nursery's coarse, sandy soils. Root propagation trials with varying cutting sizes and with hand and machine planting has resulted in better success than seed propagation, with maximum yields to date of 8 to 9 salable trees per ft^2 (86 to 97 per m^2). The nursery continues to refine both seed and root propagation techniques to improve efficiency and quality. This paper was presented at a joint meeting of the Northeast Forest and Conservation Nursery Association and Southern Forest Nursery Association (Kent Island, MD, July 20–23, 2015).

Background

The Wisconsin Department of Natural Resources, F.G. Wilson State Nursery is located along the Wisconsin River in southwestern Wisconsin and has been producing seedlings since 1952. In recent years, there has been an increased demand for trembling or quaking aspen (*Populus tremuloides* Michx.) and bigtooth aspen (*P. grandidentata* Michx.). The nursery has had little demand for these species until recently, mainly because of their common presence on the landscape and the fact that they easily regenerate following a harvest by root sprouting. The forests of Wisconsin have been maturing, however, and aspen now make up a smaller percentage of the forest than in the past. Landowners' objectives are also changing. For many landowners, timber production is a secondary goal, and wildlife habitat is the primary goal, especially for whitetail deer. Wildlife biologists are recognizing the decline in aspen and its impact on ruffed grouse habitat. All these factors lead to an increased demand for aspen for both afforestation and reforestation. At the F.G. Wilson State Nursery, the demand for aspen is estimated to be 50,000 to 100,000 seedlings annually.

Seed Propagation Trials

Our first attempts to grow aspen were from seed. Because aspen number about 3 million seed per pound (6.6 million seed per kg), we added wheat germ, corn meal, or a similar carrier to the seed so it would flow better through the LOVE/Oyjord seeder (J.E. Love Company, Garfield, WA). The seed was planted just below the surface (less than 0.15 in [0.38 mm] deep). Several cultural treatments were used, including shading, straw mulch, frequent misting, and hydromulching. Efforts to propagate by seed continued for 5 years, with results ranging from total failure to mediocre success. The best results came from spreading a 0.5- to 1.0-in (12- to 25-mm) straw layer over the seedbed and then watering up to four times daily to maintain moisture. The nursery's coarse, sandy soil with low organic matter made maintaining moisture on the surface difficult, even with the straw. Keeping the straw in place was also a challenge with the wind blowing the straw off the seedbed.

Root Propagation Trials

After talking with staff at the Iowa State Forest Nursery in Ames, Iowa, we learned they were successful at propagating aspen from root cuttings harvested from aspen stands, but it was cost prohibitive to get enough cuttings from wild aspen stands. So our challenge was how to make root propagation cost effective and acquire sufficient quantities of root cuttings. We had plenty of questions to work through.

- Stool beds work well for producing cottonwood cutting, but would they work for aspen?
- We had a supply of both quaking aspen and bigtooth aspen seeding into our oak seedbeds that we considered weeds. Could we harvest these seedlings when the oak seedlings were lifted and produce enough roots from these seedlings?
- How would we care for these seedlings until we could prepare the cuttings?
- How were we going to section the roots?
- What size roots did we need?
- How would we store the roots until we planted?
- How and when would we need to plant?

Year 1

We started our first year of aspen root propagation by lifting the aspen seedlings with the oak seedlings in early April to mid-April 2013 and separating those on the grading belt. We were able to gather about 1,000 aspen seedlings. The seedlings were then stored in the cooler for 3 to 4 weeks. In early May, we began to process the aspen roots. To make the operation more efficient, we bundled the seedlings with aligned root collars, and cut the roots using paper cutters (figure 1). Not knowing which root cuttings would produce sprouts, we saved all the roots and cut them into approximately 4-in (10-cm) lengths, with most root cuttings having diameters ranging from fine hair roots (<0.04 in [<1mm]) to 0.2 in (5 mm) and a few with diameters between 0.2 and 0.4 in (5 and 10 mm). The root cuttings were then placed into seedling boxes and stored in the cooler until planting in early May to mid-May.

Figure 1. Root cuttings from bundles of aspen seedlings were created using a paper cutter. (Photo by Joseph Vande Hey, 2016)

To plant the seedlings, we used the Whitfield hardwood seeder (R.A. Whitfield Manufacturing Co., Mableton, GA) to produce five furrows across the 48-in-wide (1.2-m-wide) bed that had been prepped the same as if we were going to seed. The furrows were about 1-in (2.5-cm) deep. The roots were then placed into the furrows by hand and covered with 0.25 to 0.50 in (6 to 13 mm) of soil. Bundles of root cuttings were placed lengthwise down the row with each bundle against the previous one. Bundle diameters were approximately 0.50 to 0.75 in (13 to 19 mm), with varying numbers of roots in each. With this method, we had enough roots to plant about a 400-ft (122-m) bed. The target density was about 8 to 10 salable trees per ft^2 (86 to 108 per m2). After planting was complete, the bed was watered well.

It took about 3 weeks for the first sprouts to break the soil surface and about 2 more weeks to complete sprouting. Sprout density ranged from 10 to 20 sprouts per square foot. All root-cutting sizes produced sprouts, with the most vigorous sprouts coming from the larger cuttings (0.13 to 0.19 in [3 to 5 mm] diameter range). Some of the roots had multiple sprouts, which we monitored to see what would happen. As the growing season went on, the sprouts grew slowly at first but, by mid-July, were growing well (figure 2), with most root cuttings having good root development and only one sprout left (figure 3). By fall, the sprouts were 16 to 24 in (40 to 60 cm) tall, with stem diameters of 0.13 in (3 mm) or larger. The density had thinned to about 3 to 4 trees per ft^2 (32 to 43 per m2). That bed density was less than the target, but it was still encouraging. Seedlings were lifted and graded the next spring for distribution. During grading, roots were pruned to 8 in (20 cm). The surplus roots were then saved to be used to produce the next crop, along with more aspen roots that were weeded out of the oak seedling beds.

Year 2

After evaluating year-1 production of aspen with root cuttings, we concluded that it was mostly successful. Objectives for the second year were to improve bed

Figure 2. By mid-July, aspen root cuttings were growing well in the nursery beds. (Photo by Joseph Vande Hey, 2015)

Figure 3. Aspen cuttings show good root development by mid-July. (Photo by Joseph Vande Hey, 2015)

densities and determine how short a root we could cut and still produce a salable tree. In year 2, we planted about 500 ft (152 m) of bed with 120 feet of the bed having root cuttings that were about 1 to 2 in (2.5 to 5.0 cm) long and the remainder having cuttings that were 3 to 4 in (7 to 10 cm) long. We also varied the number of roots by planting 0.5-in to 1.0-in-diameter [1.3- to 2.5-cm-diameter] bundles to determine the minimum needed to reach our target density. Planting was done similarly to the previous year.

The longer roots produced the most sprouts and the most saleable trees (4 to 7 per ft^2 [43 to 75 per m2]), but the shorter roots still had very good sprouting and also produced salable trees (3 to 4 per ft^2 [32 to 43 per m^2]). The best beds of salable trees and bed densities (5 to 7 per ft^2 [54 to 75 per m^2]) were grown from the 3- to 4-in (7- to 10-cm) long roots with root bundles of about 1-in (2.5-cm) in diameter at planting; this size is about the most root that can be packed into the furrow using the Whitfield hardwood seeder. These densities were still less than our target, but they were much closer and far better than any yields we had with seed propagation. Again, these seedlings were lifted, graded, and root pruned the next spring. The roots produced from root pruning were about 1.5 times more than in the previous year, resulting in a net gain on root cuttings each year.

Year 3

Hand-planting the root cuttings was labor intensive during the first 2 years, so staff looked at ways to allow for machine planting. They modified our Whitfield hardwood planter by removing the seed hopper and installing larger drop tubes. Each drop tube needed to have the root cuttings hand fed. All root cuttings were 2 to 4 in (5 to 10 cm) long. Two rows were planted using the modified Whitfield hardwood planter (figure 4.) It took four people to hand feed the roots down the drop tubes. A third row was hand-planted as in previous years, with about 1-in (2.5-cm) size root bundles. The machine planting required about the same amount of labor as did the hand-planting. The two rows that were machine planted had five to six salable trees per ft^2 (54 to 65 per m^2). In the hand-planted row, we reached the target bed density of eight to nine salable trees per ft^2 (86 to 97 per m^2).

Figure 4. The nursery's Whitfield hardwood tree planter was modified with drop tubes to hand-feed bundles of aspen roots for planting. (Photo by Joseph Vande Hey, 2015)

Lessons Learned

After producing three crops of aspen from root cuttings, we learned many lessons as we worked through determining if this propagation method could be a viable and cost-effective way to produce aspen.

- Root lengths of 2 to 4 in (5 to 10 cm) long work well.
- Best root-cutting diameters are 0.06 to 0.25 in (1.5 to 6.4 mm); larger cuttings result in too few roots in the ground to reach desired bed density.
- Beds need to be kept moist, similar to other seedlings during germination.
- Some exposed roots do not appear to be a problem.
- Planting depth is critical and should not exceed 1 in (2.5 cm) deep with 0.25 to 0.50 in (6.4 to 12.7 mm) of soil covering.
- Modified machine planting is possible and reduces planting time, but this technique still needs improvement to achieve adequate bed density.

Conclusions

The F.G. Wilson State Nursery will continue propagating aspen from root cuttings. After 3 years, we reached target salable bed densities by hand-planting the root cuttings. Staff believe it is possible to increase yield using the modified Whitfield hardwood planter, but it will require additional modifications to the planter to be able to feed more roots. The nursery also plans to do more aspen propagation from seed. Seed propagation is more cost effective if we can overcome the hurdles of keeping the seed and, ultimately, the small seedling moist in coarse, sandy soils.

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Mid-Atlantic Native Woody Plants in Need of Propagation

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Abstract

In spite of centuries of interest in North American flora, it was not until the 20th and 21st centuries that a concentrated focus on cultivation of native plants has emerged. This focus has been spurred, in part, by a proliferation of environmental regulations and support of Federal, State, and local programs. In the Mid-Atlantic States, only 20 to 30 percent of the thousands of native plant species are produced in nurseries. The table included with this article provides a brief list of plants that are in need of propagation to increase the diversity of available plant material for restoration, conservation, and landscaping. This paper was presented at a joint meeting of the Northeast Forest and Conservation Nursery Association and Southern Forest Nursery Association (Kent Island, MD, July 20–23, 2015).

History

Interest in North American flora was paramount in the 17th and 18th centuries. Explorers of the New World, including John Bannister (1689–1692, Virginia), Mark Catesby (1731–1743, Carolinas), John Clayton (1743–1773, Virginia), Peter Kalm (1748–1751, New Jersey, New York to Ontario), John Bartram (1720s, Pennsylvania, Ohio, Virginia), Andre Michaux (1746–1800, Florida north to Hudson Bay and west to Missouri), and many others, collected specimens for identification, description, and cataloging by their counterparts in Europe. Andrea Wulf's books, The *Brother Gardeners* (2009) and *Founding Gardeners* (2012), document the transition from initial plant description to collection by English gardeners and the further evolution into an obsession for commercial production. The English nursery trade in North American flora flourished into the 19th century. By contrast, North American plant exploration and cultivation during the 19th century focused on Asian and European species. It appears that cultivation of exotic plants was a driving force in both the New World and the Old World.

It was not until the 20th and 21st century development of environmental regulations that a new focus on cultivation of our own hometown flora developed. These species were not particularly difficult to propagate nor was propagule availability a problem, but a new stewardship ethic once espoused by Aldo Leopold in *A Sand County Almanac* (1949) and by Ian McHarg in *Design with Nature* (1969) finally matured. By 1989, 300 years after John Bannister's exploration of Virginia and 50 years after Leopold's new land ethic, Americans awoke to a renewed interest in our own ecosystems and their restoration and stewardship.

Current Needs

With the last 25-year proliferation of environmental regulation involving wetlands, floodplains, and upland forests, the interest in use of native trees and shrubs in the Mid-Atlantic States has exploded. While the primary market of reforestation historically may have been dominated in the forestry and mine reclamation markets, new emerging markets have developed through the Federal Clean Water Act/Wetland Mitigation (1972), the U.S. Department of Agriculture's Conservation Reserve Program (+/- 1995), and other State and local environmental programs, such as stormwater management and water quality retrofits in urban and suburban environments (1979–2009) and enhancement of private properties in support of pollinators (Executive Orders 13693, October 2014; 13514 [archive], October 2009).

Of the several thousand native species documented in eastern floras, perhaps only 20 to 30 percent are available in cultivation. Many native woody and herbaceous plants are still in need of propagation (table 1). The list in table 1 is not meant to be exhaustive, nor has it fully explored the wildlife

Table 1. Mid-Atlantic native plants in need of propagation for the Mid-Atlantic States.

Common name(s)	Scientific name	Site	Wildlife use
Indigo bush	*Amorpha fruticosa* L.	Well drained/xeric-mesic	Sparrows, quail
Black birch, sweet birch	*Betula lenta* L.	Well drained/mesic Cove hardwood species	Dusky birch sawfly (host)
Gray birch	*B. populifolia* Marshall	Well drained/hydric Mountains and Northeast	Grouse
Hornbeam, blue beech	*Carpinus caroliniana* Walter	Mesic-hydric/floodplains	–
Allegheny chinquapin	*Castanea pumila* (L.) Mill.	Well drained Throughout woodland borders	Wild turkey
Fringetree	*Chionanthus virginicus* L.	Mesic-hydric Coastal Plain and Piedmont floodplains	Thrushes, small mammals
American hazelnut	*Corylus americana* Walter	Mesic Chiefly Piedmont	Wild turkey
American beech	*Fagus grandifolia* Ehrh.	Mesic/rich woods and gravel deposits Sometimes circum neutral	Wild turkey, deer
Blue huckleberry	*Gaylussacia frondosa* (L.) Torr. & A. Gray ex Torr.	Mesic or dry Common Coastal Plain	Thrushes, small mammals
Black huckleberry	*G. baccata* (Wangenh.) K. Koch	Dry forests Throughout the Mid-Atlantic	Thrushes, small mammals
Possumhaw	*Ilex decidua* Walter	Mesic Southern Maryland	Thrushes, small mammals
Coastal winterberry	*I. laevigata* (Pursh) A. Gray	Mesic-hydric Chiefly Coastal Plain	Thrushes, small mammals
Maleberry	*Lyonia ligustrina* (L.) DC.	Hydric Throughout the State	–
Staggerbush	*L. mariana* (L.) D. Don	Hydric-mesic-xeric/sandy soils Chiefly Coastal Plain	–
Ironwood	*Ostrya virginiana* (Mill.) K. Koch	Mesic-xeric calcareous Piedmont and Mountains	Wild turkey
Pitch pine	*Pinus rigida* Mill.	Xeric, sandy, or rocky Throughout the State	Crossbills and pine siskins
Pond pine, marsh pine	*Pinus serotina* Michx.	Hydric, sandy, or peaty Coastal Plain	Crossbills and pine siskins
American plum	*Prunus americana* Marshall	Well drained/xeric Ridge and Valley	Thrushes, small mammals
Allegheny plum	*Prunus alleghaniensis* Porter	Xeric, shaly soils Ridge and Valley	Thrushes, small mammals
Wafer ash	*Ptelea trifoliata* L.	Mesic to xeric soils Chiefly Mountain zones	Giant swallowtail, Eastern swallowtail
Southern red oak, Spanish oak	*Quercus falcata/pagodifolia* Michx.	Mesic to hydric Chiefly Coastal Plain	Wild turkey, deer
Chinquapin, yellow oak	*Q. muehlenbergii* Engelm.	Xeric, shaly, calcareous Ridge and Valley	Wild turkey, deer
Chestnut, rock oak	*Q. prinus* L.	Xeric to Mesic soils Throughout the State	Wild turkey, deer
Mountain, red elderberry	*Sambucus racemosa* L.	Mesic to hydric Appalachian Mountains	Thrushes, small mammals
Sassafras	*Sassafras albidum* (Nutt.) Nees	Mesic to xeric soils Throughout the State	Spicebush swallowtail, thrushes, and small mammals
American bladdernut	*Staphylea trifolia* L.	Mesic, floodplains and rich woods/circumneutral Ridge and Valley/Mountain	–
Basswood, American linden	*Tilia americana* L.	Mesic, cove hardwood Mountains	–
Early sweet blueberry	*Vaccinium vacillans* Aiton	Xeric soils Throughout the State	Thrushes, small mammals
Blackhaw	*Viburnum prunifolium* L.	Mesic to xeric Throughout the State	Thrushes, small mammals

use, pollinator use, and hosts for arthropods. The purpose of this article is to stimulate interest of State and private forest tree nurseries in the Mid-Atlantic United States to develop more robust inventories with a wide range of seed provenance. Some examples of the diversity of eastern flora plantings can be seen at the Dolly Sods Wilderness Area (figure 1), Frostburg Reservoir (figure 2), and Mount Storm (figure 3) restoration projects.

Figure 1. Bog restoration following a peat fire at Dolly Sods Wilderness Area, West Virginia. (Photo by Mike Hollins, Ecosystem Recovery Institute, 2010)

Figure 2. Frostburg Reservoir scrub shrub wetland mitigation. (Photo by Mike Hollins, Envirens Inc., 1990)

Figure 3. Mount Storm power plant bog restoration and mitigation. (Photo by Mike Hollins, Envirens Inc., 1995)

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REFERENCES

Leopold, A. 1949. A sand county almanac. Oxford, United Kingdom: Oxford University Press. 240 p.

McHarg, I. 1969. Design with nature. New York: John Wiley and Sons. 208 p.

Wulf, A. 2009. The brother gardeners: botany, empire and the birth of an obsession. New York, NY: Vintage Books. 369 p.

Wulf, A. 2012. The founding gardeners: the revolutionary generation, nature, and the shaping of the American Nation. New York, NY: Knopf Doubleday. 380 p.

Top Pruning of Bareroot Hardwood Seedlings

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Abstract

There are two schools of thought (prune or no-prune) regarding top pruning bareroot hardwood seedlings. Those who recommend top pruning usually consider the economic advantages of top pruning. In some locations, the total cost of establishing hardwoods might be 7 percent lower for top-pruned stock compared with nonpruned stock. Top pruning can reduce the production of cull seedlings (e.g., those that are too tall for shipping), reduce the cost of lifting and shipping, decrease the chance of dieback, and increase growth after planting. Benefits of top pruning appear greater when nonpruned seedlings have low root-weight ratios (root dry weight to total seedling dry weight) and experience stress after planting. In most studies, height growth is stimulated so that, after 3 years in the field, top-pruned seedlings have caught up to the heights of nonpruned seedlings. This paper was presented at a joint meeting of the Northeast Forest and Conservation Nursery Association and Southern Forest Nursery Association (Kent Island, MD, July 20–23, 2015).

Introduction

Top pruning (also known as shoot clipping) has been used to improve the "transplantability" of hardwood seedlings for more than 300 years. John Evelyn (1677) gave a prescription of cutting 1-0 oak (*Quercus* spp.) seedlings in the nursery to a height of 3 cm. He also indicated that, after resprouting for 1 year, some growers recut the seedlings to a height of 15 cm. Two-hundred years later, Fuller (1884: p. 67) reported that "All kinds of forest trees may be, and nearly all should be pruned at time of transplanting." Brisbin (1888) observed that many planting failures could be explained by not pruning enough. Fernow (1910: p. 98) stated that "…pruning is to be done at the time of planting, when it is needful to restore the balance between the branch system and the root system, the latter often having been curtailed in the operation of transplanting the tree." Toumey (1916) stated that the more severely the root system is injured in lifting the trees, the greater the necessity for pruning the tops. Meginnis (1940: p. 35) said "… in horticultural practice, it is customary in transplanting deciduous trees to cut back part of the top in order to reduce transpiration losses pending the time that the root system becomes sufficiently established to restore water balance." Later, Duruz (1953: p. 125) commented that "Usually the amateur is disinclined to cut back a plant for fear of injuring it, but this pruning is essential in order to promote vigor, and better growth will follow." Koller (1977: p. 239) said that "…pruning is essential to the transplant operation" and that the minimum to be removed is "one-third of the growing stems." Kozlowski and Davies (1975: p. 4) said that "Probably the most useful, least expensive, and easiest way of assuring decreased transpirational loss of transplants is by pruning 15 to 40 percent of the bud-bearing branches."

Even though we have centuries of recommendations and decades of studies, there is a continued belief that top pruning will result in stunted growth (Meginnis 1940, Schnelle and Klett 1992), poor establishment (Chalker-Scott 2015, Schlarbaum et al. 1997), or poor stem quality (Dobkowski 1997), or that it will encourage animal depredation (Dey et al. 2006, Nugent 1974). Some claim that top pruning to reduce shipping costs is counterproductive (Schlarbaum et al. 1997). Others say that top pruning is not "natural." This assertion, however, is not entirely true, because various animals browse hardwood seedlings (Clark et al. 2009, Dey et al. 2006, Stanturf et al. 2000) and, on some sites, dieback occurs after planting. In addition, terminal bud abortion is a natural occurrence for many angiosperms (Romberger 1963). By contrast, proper top pruning has an economic justification, can increase seedling vigor (DesRochers and Tremblay 2009, Spetich et al. 2002), and, for some species, has no long-term effect on forking and stem quality (Briscoe 1969, Dierauf and Garner 1996, Jacobs 1969, Stout 1986, Thomas 2009).

Top-Pruning Methods and Application

Most managers top prune before lifting. They use a variety of tractor-powered top pruners, but two common types are rotary mowers and sickle bar mowers (figure 1) (Lowman et al. 1992, South 1996). In the past, a few managers pruned seedlings after lifting. When top pruning is conducted in the packing shed, paper cutters or hand shears have been used.

Figure 1. Top pruning *Quercus* seedlings using a sickle bar mower at the SuperTree Nursery (Shellman, GA). Only a few, well-replicated top-pruning trials have been conducted in operational hardwood seedbeds. (Photo by Robert Cross, 2008)

Timing

Some nursery managers top prune hardwoods two or three times during the growing season (Rentz 1997, Vanderveer 2005), while others top prune seedlings only once (table 1). The timing for top pruning depends on growing-season length. In some northern locations, the growing season is only 3 to 4 months long, with germination beginning in early May, allowing for top pruning in late summer. For example, at the Griffith State Nursery in Wisconsin, 1-0 northern red oak (*Quercus rubra* L.) seedlings are top pruned in September if they are taller than 43 cm (Storandt 2002). The growing season at this nursery is about 140 days with the first frost typically occurring about the third week of September. By contrast, the growing season in southern locations can be 6 to 7 months long. For example, at the Columbia Nursery in Louisiana, the growing season is about 230 days, and, therefore, top pruning (at 28 cm) begins when seedlings reach a height of 46 to

Table 1. Results from a 2006 nursery survey of hardwood nurseries (unpublished data collected by Amy Ross-Davis). Of the 26 returned questionnaires, 17 managers (65 percent) said they top pruned hardwood seedlings. Species, timing, pruning height, and reasons for pruning are listed in this table. The North region is between the 39th and 49th parallels and the South region is between the 49th and 25th parallels.

Species	Time of top pruning	Pruning height (cm)	Reason for top pruning
North region			
Quercus rubra L.	July 1–15	25	Increase root-weight ratio (RWR)
Populus and *Salix*	February	30–38	Reduce shipping cost
Liriodendron tulipifera L.	Several times	Increasing	Increase RWR; allow smaller seedlings to grow
Cornus sericea L.	Late June	25–28	Reduce shoot height
Alternate branched species	Late July	36–38	Decrease top growth
Quercus and *Prunus*	March–April	46	Reduce shipping cost
All hardwoods	Late fall to end of March	25–30	Increase RWR
Quercus, Fraxinus, and *Acer*	Early to mid-September	43	Facilitate packaging
All hardwood species	October	30–36	Reduce top height for packing
All shrub species	At harvest in April	15–30	Improve uniformity and force lateral growth
South region			
All hardwood species	Twice	30–61	Increase RWR
All hardwood species except *Fraxinus pennsylvanica* Marshall	August	47	Increase RWR
Quercus rubra L.	July 27	36	Increase RWR
All hardwood species except *Quercus*	Late October to December	30–46	Increase RWR; uniformity
Quercus	June—38 cm; Sept—58 cm	36–61	Improve root collar diameter
All hardwood species except *Juglans nigra* L. and *Carya*	July–August	61	Increase RWR

51 cm (Rentz 1997). A second top pruning (at 48 cm) is done in August, when the seedlings reach a height of 60 to 66 cm. The manager prefers not to top prune after August. At lifting, the final height may be about 70 to 76 cm. Thus, the second top pruning in Louisiana is about a month earlier than the first (and only) top pruning in Wisconsin.

Target Height at Lifting

The target height for hardwood seedlings at lifting varies by species, box length, and customer specifications. For oaks, recommended height at lifting varies from 15 to 20 cm (Dey et al. 2008, Johnson et al. 1986, Spetich et al. 2002) to 45 to 60 cm (McLeod 2000, Stanturf et al. 2000, Williams et al. 1993) and 60 to 120 cm (Allen et al. 2001, Kormanik et al. 1994). Differing opinions about economics, probability of dieback, and seedling "vigor" explain, in part, why the target seedling height varies among researchers. Although removing almost the entire shoot might achieve the desired results for a few species (DesRochers and Tremblay 2009, Meadows and Toliver 1987, Wightman et al. 2001, Williams 1974), this degree of pruning is rarely practiced by nursery managers.

A cull seedling can be defined, in part, as one that is either too short or too tall (Rose et al. 1990). Therefore, one simple way for nursery managers to increase the production of shippable seedlings is to top prune so that no seedlings exceed the maximum height limit. At some nurseries, maximum height is determined by the length of the shipping box or by the size of the tractor. Because tall, lignified stems can be injured when the tractor passes over the seedbed, top pruning allows for seedlings to pass under the tractor unscathed.

Effects of Top Pruning on Hardwood Seedlings

Top pruning is "improper" when it does not meet the objectives of the nursery manager (e.g., reducing seedling height so that all seedlings fit into a standard shipping box), reforestation manager (e.g., increasing seedling vigor), and landowner (e.g., reducing establishment cost per hectare). For example, removing only 1 cm of the shoot would be considered improper because it does not reduce shipping costs and may not reduce the percentage of cull seedlings (i.e., exceed a maximum height). Likewise, for some species, pruning to a final height of 15 cm would be considered improper when it results in a reduction in survival after outplanting.

Root-Weight Ratio

There are at least four definitions of shoot-root ratio. Some foresters define shoot-root ratio as the shoot length divided by taproot length (Weaver et al. 1982), but most researchers divide the shoot dry weight by the root dry weight (Bernier et al. 1995, Haase 2011, Thomas 2009). Some researchers avoid the drying process and calculate a shoot-root ratio based on fresh weights (Stoeckeler 1937, Wilde and Voigt 1949) or volume displacement (Haase 2011, Racey et al. 1983). I prefer the term root-weight ratio (root dry weight divided by total seedling dry weight [RWR]) because it is easy to understand, cannot be confused with ratios involving lengths or volumes, and has a slightly lower coefficient of variation than a shoot-root ratio (based on dry weights). An RWR of 0.6 simply means the roots make up 60 percent of a seedling's total dry mass.

Top pruning increases the RWR of hardwoods. For example, when a 130-cm-tall oak seedling has an RWR of 0.46, then removing one-half of the shoot mass with top pruning would increase the RWR to 0.63. In one study, removing one-third of the stem increased the RWR from 0.21 to 0.27 and delayed mortality in a greenhouse (Thomas 2009). It is unfortunate that few top-pruning studies report the dry mass of hardwood seedlings before and after clipping. Even so, top pruning (to increase RWR) might increase height growth in the field. Therefore, both greenhouse and field trials suggest that increasing the RWR may indeed reduce the amount of transplant shock and dieback.

Dieback After Outplanting

Top pruning can reduce dieback (Davies 1987). Under stressful field conditions, tall, nonpruned hardwood seedlings may die back during the first or second year after outplanting (Dey et al. 2006). For example, northern red oak seedlings (45 to 66 cm in height) exhibited dieback on three sites for 2 years after planting (Kaczmarek and Pope 1993a). On one site, the amount of dieback was equal to almost one-half the original height. In another study, 34 percent of tall (≈107 cm) northern red oak seedlings exhibited dieback 2 years after planting (Heitzman and Grell 2006).

Tall sweetgum (*Liquidambar styraciflua* L.) may die back when planted on sandy soils. When the initial height of grade 1 bareroot sweetgum seedlings averaged more than 100 cm, stem dieback ranged from 35 to 66 percent (Kormanik 1986). When average height was 84 cm (for grade 1 seedlings inoculated with *Glomus deserticola* Trappe, Bloss & J.A. Menge), however, dieback was only 18 percent. This and other findings (Jacobs et al. 2012) suggest that stem dieback is related to seedling height. Dieback is nature's way of letting foresters know they planted unbalanced hardwood seedlings.

Survival After Outplanting

Because of variations in pruning intensity, outplanting sites, rainfall amounts, and species, top-pruning effects on survival can be variable. Even so, I conducted a statistical test using survival data in table 2. Each treatment mean (pruned or nonpruned survival) was an observation, and each trial was a replication (n = 26). An ANOVA test revealed no overall top-pruning effect on survival ($p > F = 0.26$; least significant difference = 3 percent; $\alpha = 0.05$).

Table 2. Effect of top pruning of bareroot seedlings on field survival of hardwood seedlings. Treatments with less than 10 cm of stem remaining (after top pruning) are not included.

Genus	Years after outplanting	Survival (%)		Difference %)	Reference
		Not pruned	Top pruned		
Carya	5	94	83	– 11	Toliver et al. 1980
Eucalyptus	0.29	94	91	– 3	Thomas 2009
Prunus	1	80	78	– 2	Anonymous 1984
Quercus	1	100	99	– 1	Smith 1992
Liriodendron	2	69	68	– 1	Limstrom et al. 1955
Liquidambar	3	98	98	0	McNabb and VanderSchaaf 2005 (large stock)
Carya	3	91	91	0	Meadows and Toliver 1987
Carya	3	100	100	0	Wood 1996
Liriodendron	2	92	92	0	Dierauf and Garner 1996
Liriodendron	2	0	0	0	Kelly and Moser 1983
Quercus	3	87	87	0	Zaczek et al. 1993 (2-0)
Quercus	1	98?	98?	0?	Russell 1973
Juglans	5	74?	74?	0?	Russell 1979
Juglans	5	66?	66?	0?	Russell 1979
Fraxinus	3	96?	96?	0?	Woessner and van Hicks 1973
Liriodendron	1	> 90?	> 90?	0?	Sterling and Lane 1975
Liquidambar	3	90	93	+3	South 1999
Liquidambar	3	95	98	+3	McNabb and VanderSchaaf 2005 (large stock)
Robinia	2	79	82	+3	Meginnis 1940
Quercus	5	90	93	+3	Toliver et al. 1980
Quercus	5	64	69	+5	Stanturf and Kennedy 1996 (2-0)
Quercus	5	82	87	+5	Toliver et al. 1980
Betula	3	50	58	+8	Godman and Mattson 1971
Carya	3	85	94	+9	Meadows and Toliver 1987
Fraxinus	1	80	97	+17	Anonymous 1984
Carya	2	75	100	+25	Smith and Johnson 1981
	Average	**82**	**84**	**+2**	

? = values not reported by treatment.

When rainfall is adequate after outplanting and survival of nonpruned hardwood stock is greater than 90 percent, there appears to be no relationship between seedling survival and top pruning (Davies 1987, South 1998). Even so, six trials reported a survival benefit of 5 to 25 percent for top-pruned seedlings (table 2). The objective of increasing the RWR by top pruning is to increase the probability of survival after outplanting. When survival of nonpruned stock is less than 90 percent, top pruning may increase survival 45 percent of the time (table 2). In one study, top pruning 10 cm off the shoot reduced mortality, seedling moisture stress, and leaf area (Thomas 2009). Top pruning can reduce total water use for 5 weeks or more after planting (Abod and Webster 1990). For some hardwood species, top pruning to a height of 15 or 30 cm might increase new root growth (Kelly and Moser 1983). Reduced moisture stress and increased root growth have been attributed to increased field survival of hardwoods (Grossnickle 2011, Thomas 2009).

Weed competition and seedling size can affect the survival of top-pruned seedlings. In one study, seedlings were sorted into two size classes (initial diameter of 12 to 16 mm [large stock] or 4 to 8 mm [small stock]) and outplanted on a weedy site and a site with low weed competition (McNabb and VanderSchaaf 2005). The top-pruning treatments involved removing either 50 percent of the stem length (≈40 cm removed) or 94 percent of the length (≈75 cm removed). On both sites, the large stock had better survival and grew more than the small stock. Severe top pruning (i.e., leaving less than 6 cm of stem) reduced survival on both sites, which likely explains why nursery managers do not top prune sweetgum to a height of less than 20 cm. On the site with minimal weed competition, survival was high (more than 97 percent) and 50 percent top pruning had no overall effect on survival. On the weedy site, however, 50 percent top pruning reduced survival of the small stock by 10 to 12 percent compared with nonpruned seedlings.

Height After Outplanting

Top pruning typically stimulates height growth so that, after 3 years in the field, top-pruned seedlings equal the heights of nonpruned seedlings. For example, a study to examine top pruning of sweetgum (figure 2) was installed in January 1996 with seedlings grown at the Westvaco Nursery in South Carolina (South 1999). After 2 years of growth, there was no difference in height between nonpruned and top-pruned seedlings (table 3).

To provide additional evidence, a statistical test was conducted on height data from numerous top-pruning trials (table 4). This analysis included 22 trials (replications), with each replication containing two observations (pruned and nonpruned mean heights

Figure 2. On average, tall, nonpruned *Liquidambar styraciflua* L. seedlings (left) grew only 112 cm during the 3 years after planting, whereas seedlings top pruned to 45 cm (middle) or 30 cm (right) in the nursery grew 144 cm or 157 cm, respectively. More details are provided in table 3. This photo was taken 5 months after planting. (Photo by David South, 1996)

Table 3. Effect of top pruning on seedling morphology and survival of sweetgum (*Liquidambar styraciflua* L.) (South 1999).

Treatment	April 1996 leaf-out (%)	November 1996 leaf length (mm)	Height (cm) January 1996	Height (cm) September 1996	Height (cm) December 1997	Height (cm) December 1998	December 1998 groundline diameter (mm)	December 1998 survival (%)
None	49 a	55 c	81 a	86 a	162 a	193 a	26 a	90 a
Tip removed	62 a	61 b	73 b	75 b	157 a	192 a	26 a	92 a
45 cm	52 a	71 a	45 c	57 c	156 a	189 a	26 a	93 a
30 cm	28 b	71 a	30 d	49 d	159 a	187 a	25 a	93 a
(LSD)	(15)	(4.9)	(2.6)	(3.3)	(5.7)	(8.1)	(2.8)	(8.5)

LSD = least significant difference.

Note: Means in a column followed by the same letter are not statistically different (α = 0.05).

2 to 11 years after outplanting). The ANOVA test found no difference between pruned and nonpruned heights ($p > F = 0.19$; least significant difference = 12.6 cm; $\alpha = 0.05$), indicating that height of pruned seedlings after several years in the field is, on average, no different than that of nonpruned stock. This finding suggests overall height growth was greater for the top-pruned seedlings, given that the initial height of nonpruned seedlings was significantly taller than that of top-pruned seedlings.

Economics

Top pruning might add $0.50 to the cost of producing 1,000 seedlings (table 5). Proper top pruning, however, not only reduces shipping cost, but it makes

Table 4. Effect of top pruning hardwood seedlings on subsequent height (cm) after 2 or more years in the field. Treatments with less than 10 cm of stem remaining (after top pruning) are not included.

Genus	Years after outplanting	Height (cm)		Difference (%)	Reference
		Not pruned	Top pruned		
Carya	5	121	147	+ 21	Toliver et al. 1980
Quercus	2	55	55	0	Smith 1992
Liquidambar	3	250	217	– 13	McNabb and VanderSchaaf 2005 (large stock)
Carya	3	75	81	+ 8	Meadows and Toliver 1987
Carya	4	400	380	– 5	Wood 1996
Liriodendron	2	103	106	+ 3	Dierauf and Garner 1996
Quercus	6	268	300	+12	Zaczek et al. 1997 (2-0 stock)
Quercus	5	134	134	0	Russell 1973
Juglans	5	183	201	+10	Russell 1979
Juglans	5	61	85	+39	Russell 1979
Fraxinus	3	320	328	+2	Woessner and van Hicks 1973
Liquidambar	3	193	189	– 2	South 1999
Liquidambar	3	224	218	– 3	McNabb and VanderSchaaf 2005 (large stock)
Robinia	2	92	81	–12	Meginnis 1940
Quercus	5	371	385	+4	Toliver et al. 1980
Quercus	11	719	744	+3	Stanturf 1995 (2-0 stock)
Quercus	5	336	321	– 4	Toliver et al. 1980
Betula	3	31	46	+48	Godman and Mattson 1971
Carya	3	52	56	+8	Meadows and Toliver 1987
Carya	2	197	309	+57	Smith and Jonson 1981
Quercus	2	85	77	– 9	Adams 1985
Quercus	6	131	122	– 7	Russell 1973
	Average	**200**	**208**	**+ 4**	

Table 5. An example of how top pruning in the nursery can reduce the cost per thousand planted hardwood seedlings. At this nursery, a bag contains either 100 tall seedlings or 200 top-pruned seedlings.

Treatment	Seedling height (cm)	Growing cost ($)	Lifting cost ($)	Bag cost ($)	Shipping cost ($)	Planting cost ($)	Total cost ($)
Not pruned	90	275.00	25	10	17.00	330	657
Top pruned	50	275.50	19	5	8.50	300	608

hand-planting easier, thereby increasing productivity and lowering planting costs. When considering all costs, planting nonpruned hardwood seedlings might increase overall costs by 8 percent when compared with planting top-pruned seedlings (table 5).

Shipping

The economic advantages of top pruning hardwoods vary by nursery. At some nurseries, shipping cost is based on weight, and top-pruned seedlings weigh less than nonpruned stock. In one trial, top pruning reduced seedling weights by 14 percent (McNabb and Vander-Schaaf 2005). This reduction could save the landowner about $2.80 per thousand seedlings (assuming no savings in packaging or planting costs). At other nurseries, shipping cost is based on volume. Therefore, a longer box with 50 percent more volume to accommodate taller, nonpruned stock will cost the nursery 50 percent more to ship (plus the extra cost of the box). If it costs $8.50 per thousand seedlings to ship top-pruned stock and $17 to ship taller stock (table 5), then the savings to the landowner would be $8.50 per thousand seedlings.

Packing Materials

Top pruning also affects the cost of packing materials. At one nursery in Georgia, 200 top-pruned hardwoods can be placed in a bag that normally would hold only 100 nonpruned seedlings (Cross 2015). As a result, the cost of bags would be $5 per thousand for top-pruned stock and $10 per thousand for nonpruned stock.

Planting

Oak seedlings that weigh more (Spetich et al. 2009, Williams et al. 1993) and are taller than 90 cm (Allen et al. 2001) typically will take longer to plant by hand than shorter seedlings. Although small hardwood seedlings are easier to plant, top pruning late in the season typically does not increase the number of seedlings that can be carried by planters, because tree planters' bags are open and, therefore root mass, not height, is the limiting factor for carrying capacity (figure 3).

Tree-planting costs for hardwoods vary by region, species, and tree size. For some regions in the South, the cost of hand-planting a top-pruned hardwood seedling might be near $0.25 and the retail cost of a seedling might be $0.40. In other places, planting costs may exceed the cost of seedlings (Allen et al. 2001, Manatt et al. 2013). For example, a 20-cm-tall top-pruned 2-0 hardwood seedling might cost $0.65 to plant (Spetich et al. 2009) and a 90-cm-tall hardwood seedling might cost $0.70 to plant.

Figure 3. Planting tall, hardwood seedlings in Issaquena County, MS. (Photo by Mike Oliver, 1999)

Seedling Price

Some nurseries base seedling prices on seedling height. For example, a horticultural nursery might have four different price classes for 1-0 seedlings. Tall seedlings may sell for $1.40 each and 50 cm seedlings may sell for $1.05 each (figure 4). When price is based on tree height, a manager would not top prune when demand is high for tall seedlings. In this example, removing 50 percent of the shoot would lower the profit by $0.35 per seedling. By contrast, in years when demand for 50 cm seedlings exceeds supply (and demand for taller stock is low), the manager might consider top pruning to increase seedling sales and avoid carrying unwanted stock over to the next year. Therefore, the economic incentive to top prune is driven, in part, by customer demand.

Future Research Needs

It is surprising that only a few published top-pruning studies (Dierauf and Garner 1996, Toliver et al. 1980) have been conducted in hardwood nursery beds (figure 1). Researchers typically top prune seedlings after lifting and before planting. Future research needs to determine if proper top pruning in hardwood nurseries will affect (1) the number of cull seedlings, (2) survival under moisture-limiting conditions, and (3) diameter growth of seedlings in the seedbed understory (i.e., those that are too short to be affected by the top-pruning equipment).

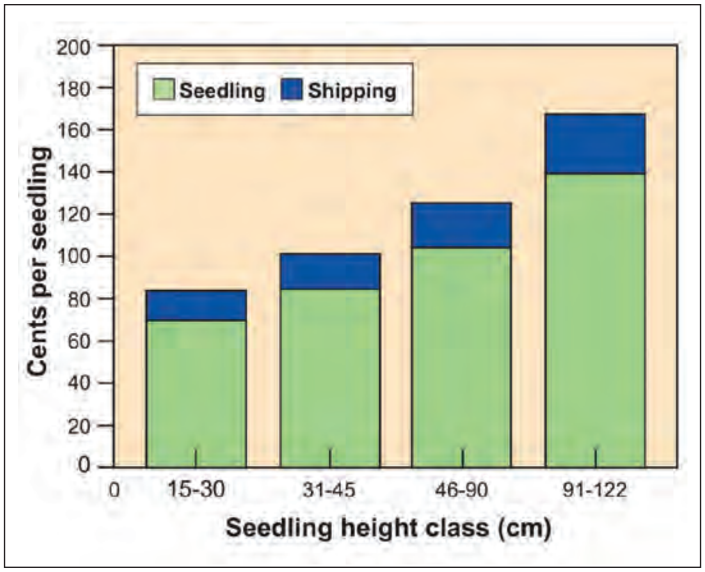

Figure 4. In this example, both shipping cost ($0.14, $0.17, $0.21, and $0.28 per seedling) and seedling price ($0.70, $0.85, $1.05, and $1.40 per seedling) increase with seedling height class.

Treatment plots should be designed to ensure that growth of nonpruned seedlings does not adversely affect the growth of adjacent top-pruned seedlings. It is very important to replicate treatments and to eliminate confounding (Haase 2014). In one study, top pruning was confounded with seedling age (Kaczmarek and Pope 1993b), which casts doubt on the researchers' conclusions regarding new root growth. In another study, a "suppression effect" was confounded with treatment (Kormanik et al. 1995) because rows of nonpruned seedlings were adjacent to rows of top-pruned seedlings. By mid-December, top-pruned seedlings were 3 to 6 cm shorter than the nonpruned stock, suggesting that the taller, nonpruned seedlings likely suppressed the growth of adjacent top-pruned seedlings. As a result, top-pruned seedlings were statistically smaller in height and stem diameter for the fastest growing family but not for the slower growing families.

The number of trees planted per treatment is also important (Haase 2014). In some tests, fewer than 40 nonpruned trees are planted per species (Crunkilton et al. 1992, Johnson et al. 1984, Shoup et al. 1981). This number is insufficient to test for treatment differences in survival. In fact, in some locations, even 100 (Stanturf and Kennedy 1996) or 200 trees per treatment (Meginnis 1940) were not enough to declare an 11-percent improvement in survival as statistically significant.

Because properly planted hardwoods have high survival when rainfall is adequate (table 1), researchers should consider using greenhouse trials when they investigate the effects of top pruning on survival. When rainfall is excluded, soil moisture levels can be controlled so that mortality rate can eventually reach 50 percent or more. In one greenhouse trial, 50 percent mortality of nonpruned seedlings occurred on day 25, whereas top-pruned seedlings did not reach that level of mortality until 10 days later (Thomas 2009). By contrast, field survival from both treatments was greater than 90 percent. Research efforts may be wasted when rainfall masks inherent differences in seedling quality.

Research conclusions need to be based on the scientific method. The scientific process follows a pattern: define the problem, review the literature, make observations and collect data, analyze data and form a generalization, formulate a null hypothesis, design a study to test the null hypothesis, draw conclusions, accurately report and publish results, and reevaluate the generalization. The null hypothesis is rejected only if data from a well-designed nursery study can be used to reject the hypothesis (Fisher 1971, Hurlbert 1984, Snedecor and Cochran 1978). For example, a null hypothesis can be stated as—top pruning sycamore seedlings has no effect on disease infection after planting. I know of no data that can be used to reject this hypothesis. Even so, some claim that top-pruned seedlings make an avenue for disease infection and encourage animal depredation. It is unscientific to reject a null hypothesis using only intuition and assumptions about top pruning (no matter how often the intuition is accepted as fact).

Conclusions

Top pruning hardwood seedlings has several benefits: reduced lifting, packaging, and shipping costs; increased RWR; reduced shoot dieback after outplanting; reduced planting time; and increased shoot growth after planting. In addition, top pruning in the nursery might increase survival on sites with limited rainfall. Unless customers are willing to pay more for taller seedlings or unless nonpruned seedlings are below a critical height, nursery managers may realize economic benefits from proper top pruning of seedlings.

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REFERENCES

Abod, S.A.; Webster, A.D. 1990. Shoot and root pruning effects on the growth and water relations of young *Malus, Tilia* and *Betula* transplants. Journal of Horticultural Science. 65(4): 451–459.

Adams, J.C. 1985. Severe top pruning improves water oak seedling growth. In: Shoulder, E., ed. Proceedings, third biennial southern silvicultural research conference. Gen. Tech. Rep. SO-54. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station: 1–3.

Allen, J.A.; Keeland, B.D.; Stanturf, J.A.; Clewell, A.F.; Kennedy, H.E., Jr. 2001. A guide to bottomland hardwood restoration. Gen. Tech. Rep. SRS-40. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 132 p.

Anonymous. 1984. Outplanting performance of pruned and nonpruned green ash and choke cherry seedlings. In: 1984 report PFRA tree nursery. Indian Head, SK: Agriculture Canada, Prairie Farm Rehabilitation Administration: 17.

Bernier, P.Y.; Lamhamedi, M.S.; Simpson, D.G. 1995. Shoot:root ratio is of limited use in evaluating the quality of container conifer stock. Tree Planters' Notes. 46(3): 102–106.

Briscoe, C.B. 1969. Establishment and early care of sycamore plantations. Res. Pap. SO-50. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 18 p.

Brisbin, J.S. 1888. Trees and tree-planting. New York: Harper and Brothers. 296 p.

Chalker-Scott, L. 2015. The myth of top-pruning transplanted material. Puyallup, WA: Washington State University, Puyallup Research and Extension Center. http://puyallup.wsu.edu/wp-content/uploads/sites/403/2015/03/transplant-pruning.pdf. (August 2015).

Clark, S.L.; Schweitzer, C.J.; Schlarbaum, S.E.; Dimov, L.D.; Hebard, F.V. 2009. Nursery quality and first-year response of American chestnut (*Castanea dentata*) seedlings planting in the Southeastern United States. Tree Planters' Notes. 53(2): 13–21.

Cross, R. 2015. Personal communication. Nursery Manager. Arborgen, Shellman, GA.

Crunkilton, D.D.; Pallardy, S.G.; Garrett, H.E. 1992. Water relations and gas exchange of northern red oak seedlings planted in a central Missouri clearcut and shelterwood. Forest Ecology and Management. 53(1): 117–129.

Davies, R.J. 1987. Tree establishment: soil amelioration, plant handling and shoot pruning. In: Patch, D., ed. Advances in practical arboriculture. Forestry Comm. Bull. 65. London, United Kingdom: Her Majesty's Stationery Office: 52–58.

DesRochers, A.; Tremblay, F. 2009. The effect of root and shoot pruning on early growth of hybrid poplars. Forest Ecology and Management. 258(9): 2062–2067.

Dey, D.C.; Jacobs, D.; McNabb, K.; Miller, G.; Baldwin, V.; Foster, G. 2008. Artificial regeneration of major oak (*Quercus*) species in the Eastern United States: a review of the literature. Forest Science. 54(1): 77–106.

Dey, D.C.; Kabrick, J.M.; Gold, M. 2006. The role of large container seedlings in afforesting oaks in bottomlands. In: Conner, K.F., ed. Proceedings, thirteenth biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-92. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station: 218–223.

Dierauf, T.S.; Garner, J.W. 1996. Effect of initial root collar diameter on survival and growth of yellow poplar seedlings over 17 years. Tree Planters' Notes. 47(1): 30–33.

Dobkowski, A. 1997. Perspectives and outplanting performance with deciduous forest seedlings. In: Landis, T.D.; South, D.B., tech. coords. Proceedings, forest and conservation nursery associations—1996. Gen. Tech. Rep. PNW-389. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station: 215–219.

Duruz, W.P. 1953. The principles of nursery management. New York: De La Mare. 176 p.

Evelyn, J. 1677. Sylva: or a discourse of forest-trees and the propagation of timber. London, England: John Martyn for the Royal Society. 335 p.

Fernow, B.E. 1910. The care of trees. New York: Henry Holt. 392 p.

Fisher, R.A. 1971. The design of experiments. 9th ed. New York: Hafner. 250 p.

Fuller, A.S. 1884. Practical forestry. New York: Orange Judd. 299 p.

Godman, R.M.; Mattson, G.A. 1972. Top pruning may benefit yellow birch planting stock. Tree Planters' Notes. 22(1): 24–25.

Grossnickle, S.C. 2011. Why seedlings survive: influence of plant attributes. New Forests. 43(5): 711–738.

Haase, D.L. 2011. Seedling root targets. In: Riley, L.E.; Haase, D.L.; Pinto, J.R., tech. cords. Proceedings, forest and conservation nursery associations—2010. Proceedings RMRS-P-65. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 80–82.

Haase, D.L. 2014. Beyond cowboy science: simple methods for conducting credible and valid research. Tree Planters' Notes. 57(2): 32–43.

Heitzman, E.; Grell, A. 2006. Planting oaks in group selection openings on upland sites: two case studies from Arkansas. Southern Journal of Applied Forestry. 30(3): 117–122.

Hurlbert, S.H. 1984. Pseudoreplication and the design of ecological field experiments. Ecological Monographs. 54(2): 187–211.

Jacobs, D.F.; Goodman, R.C.; Gardiner, E.A.; Salifu, F.; Overton, R.P.; Hernandez, G. 2012. Nursery stock quality as an indicator of bottomland hardwood forest restoration success in the Lower Mississippi River Alluvial Valley. Scandinavian Journal of Forest Research. 27(3): 255–269.

Jacobs, R.D. 1969. Growth and development of deer-browsed sugar maple seedlings. Journal of Forestry. 67(12): 870–874.

Johnson, P.S.; Dale, C.D.; Davidson, K.R.; Law, J.R. 1986. Planting northern red oak in the Missouri Ozarks: a prescription. Northern Journal of Applied Forestry. 3(2): 66–68.

Johnson, P.S.; Novinger, S.L.; Mares, W.G. 1984. Root, shoot and leaf area growth potentials of northern red oak planting stock. Forest Science. 30(4): 1017–1026.

Kaczmarek, D.J.; Pope, P.E. 1993a. Covariate analysis of northern red oak seedling growth. In: Brissette, J.C., ed. Proceedings, seventh biennial southern silvicultural research conference. Gen. Tech. Rep. SO-93. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station: 351–356.

Kaczmarek, D.J.; Pope, P.E. 1993b. The effects of pruning treatments and initial seedling morphology on northern red oak seedling growth. In: Proceedings, ninth central hardwood forest conference—1993. Gen. Tech. Rep. NC-161. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station: 436–446.

Kelly, R.J.; Moser, B.C. 1983. Root regeneration of *Lirodendron tulipifera* in response to auxin, stem pruning and environmental conditions. Journal of American Society of Horticultural Science. 108(6): 1085–1090.

Koller, G.L. 1977. Transplanting stress: a view from the plant's perspective. Amoldia. 37(5): 230–241.

Kormanik, P.P. 1986. Lateral root morphology as an expression of sweetgum seedling quality. Forest Science. 32(3): 595–604.

Kormanik, P.P.; Sung, S.S.; Kormanik, T.L. 1994. Irrigating and fertilizing to grow better nursery seedlings. In: Landis, T.D., tech. coord. Proceedings, Northeastern and Intermountain forest and conservation nursery associations—1993. Gen. Tech. Rep. RM-243. St. Louis, MO: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station: 115–121.

Kormanik, P.P.; Sung, S.S.; Kormanik, T.L.; Zarnoch, S.J. 1995. Effect of apical meristem clipping on carbon allocation and morphological development of white oak seedlings. In: Edwards, M.B., ed. Proceedings, eighth biennial southern silvicultural research conference. SRS-1. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 332–337.

Kozlowski, T.T.; Davies, W.J. 1975. Control of water balance in transplanted trees. Journal of Arboriculture. 1(1): 1–10.

Limstrom, G.A.; Finn, R.F.; Deitschman, G.H. 1955. Planting stock grades for yellow-poplar. Journal of Forestry. 53(1): 28–32.

Lowman, B.J.; Landis, T.D.; Zensen, F.; Holland, B.J. 1992. Bareroot nursery equipment catalog. 9224-2839-MTDC. Missoula, MT: U.S. Department of Agriculture, Forest Service, Missoula Technology and Development Center. 204 p.

Manatt, R.K.; Hallam, A.; Schulte, L.A.; Heaton, E.A.; Gunther, T.; Hall, R.B.; Moore, K.J. 2013. Farm-scale costs and returns for second generation bioenergy cropping systems in the US corn Belt. Environmental Research Letters. 8(3): 035037.

McLeod, K.W. 2000. Species selection trials and silvicultural techniques for the restoration of bottomland hardwood forests. Ecological Engineering. 15(Supplement 1): S35–S46.

McNabb, K.; VanderSchaaf, C. 2005. Growth of graded sweetgum 3 years after root and shoot pruning. New Forests. 29(3): 313–320.

Meadows, J.S.; Toliver, J.R. 1987. Three-year response of pecan to six methods of seedling establishment. Southern Journal of Applied Forestry. 11(1): 56–59.

Meginnis, H.G. 1940. Effect of top pruning on survival and early growth of black locust. Journal of Forestry. 38(1): 30–36.

Nugent, J.A. 1974. Cold storage of tree seedlings. McConnell, J.L., tech. coord. Proceedings, southeastern nurserymen's conferences. Macon, GA: U.S. Department of Agriculture, Forest Service, Southeastern Area: 1–3.

Racey, G.D.; Glerum, C.; Hutchison, R.E. 1983. Practicality of top-root ration in nursery stock characterization. Forestry Chronicle. 59(5): 240–243.

Rentz, R. 1997. Bottom-land hardwoods for today's market. In: Landis, T.D.; South, D.B., tech. coords. Proceedings, forest and conservation nursery associations—1996. Gen Tech. Rep. PNW-389. Portland, OR: U.S. Department of Agriculture. Forest Service, Pacific Northwest Research Station. 38–40.

Romberger, J.A. 1963. Meristems, growth, and development in woody plants. Tech. Bull. 1293. Beltsville, MD: U.S. Department of Agriculture, Forest Service. 214 p.

Rose, R.; Carlson, W.C.; Morgan, P. 1990. The target seedling concept. In: Rose, R.; Campbell, S.J.; Landis, T.D., ed. Proceedings, combined meeting of the western forest nursery associations—1990. Gen. Tech. Rep. RM-200. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 1–8.

Russell, T.E. 1973. Survival and growth of bar-slit planted northern red oak studied in Tennessee. Tree Planters' Notes. 24(3): 6–9.

Russell, T.E. 1979. Planting methods for black walnut on Cumberland plateau sites. Tree Planters' Notes. 30(1): 11–13.

Schlarbaum, S.E.; Kormanik, P.P.; Tibbs, T.; Barber, L.R. 1997. Oak seedlings: quality improved available now: genetically improved available soon. In: Meyer, D.A., ed. Proceedings, twenty-fifth annual hardwood symposium—1997. Cashiers, NC: National Hardwood Lumber Association: 128–130.

Schnelle, M.A.; Klett, J.E. 1992. Effects of pruning and bark ringing on total nonstructural carbohydrates in crabapple. Journal of Arboriculture. 18(4): 192–196.

Shoup, S.; Reavis, R.; Whitcomb, C.E. 1981. Effects of pruning and fertilizers on establishment of bare-root deciduous trees. Journal of Arboriculture. 7(6): 155–157.

Smith, H.C. 1992. Development of red oak seedlings using plastic shelters on hardwood sites in West Virginia. Res. Pap. NE-672. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 9 p.

Smith, M.W.; Johnson, J.L. 1981. The effect of top pruning and root length on growth and survival of transplanted pecan trees. Pecan Quarterly. 15(2): 20–22.

Snedecor, G.W.; Cochran, W.G. 1978. Statistical methods. Ames, IA: Iowa State University Press. 503 p.

South, D.B. 1996. Top-pruning bareroot hardwoods: a review of the literature. Tree Planters' Notes. 47(1): 34–40.

South, D.B. 1998. Effects of top-pruning on survival of southern pines and hardwoods. In: Waldrop, T.A., ed. Proceedings, ninth biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-20. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station: 3–8.

South, D.B. 1999. Top pruning sweetgum: an update. Tech. Note 99-3. Auburn, AL: Auburn University, Southern Forest Nursery Management Cooperative. 4 p.

Spetich, M.A.; Dey, D.; Johnson, P. 2009. Competitive capacity of *Quercus rubra* L. planted in Arkansas' Boston Mountains. Southern Journal of Applied Forestry. 33(4): 182–187.

Spetich, M.A.; Dey, D.C.; Johnson, P.S.; Graney, D.L. 2002. Competitive capacity of *Quercus rubra* L. planted in Arkansas' Boston Mountains. Forest Science. 48(1): 504–517.

Stanturf, J.A. 1995. Survival and growth of planted and direct-seeded cherrybark oak in the Santee River floodplain after 11 years. In: Edwards, M.B., ed. Proceedings, eighth biennial southern silvicultural research conference. SRS-1. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 489–494.

Stanturf, J.A.; Gardiner, E.S.; Hamel, P.B.; Devall, M.S.; Leininger, T.D.; Warren, M.E. 2000. Restoring bottomland hardwood ecosystems in the lower Mississippi Alluvial Valley. Journal of Forestry. 98(8): 10–16.

Stanturf, J.A.; Kennedy, H.E. 1996. Survival and growth of planted and direct-seeded cherrybark oak in South Carolina. Southern Journal of Applied Forestry. 20(4): 194–196.

Sterling, K.A.; Lane, C.L. 1975. Growth and development of shoot and root pruned yellow-poplar seedlings at two sites. Tree Planters' Notes. 26(3): 1–2, 25.

Stoeckeler, J.H. 1937. Relation of size of deciduous nursery stock to field survival in the Great Plains. Journal of Forestry. 25(8): 773–777.

Storandt, J. 2002. Red oak propagation at the Griffith State Nursery, Wisconsin Rapids, Wisconsin. In: Dumroese, R.K.; Riley, L.E.; Landis, T.D., tech. coords. Proceedings, forest and conservation nursery associations—1999, 2000, and 2001. Proceedings RMRS-P-24. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 120–121.

Stout, S.L. 1986. 22-year growth of four planted hardwoods. Northern Journal of Applied Forestry. 3(2): 69–72.

Thomas, D.S. 2009. Survival and growth of drought hardened *Eucalyptus pilularis* Sm. seedlings and vegetative cuttings. New Forests. 38(3): 245–259.

Toliver, J.R.; Sparks, R.C.; Hansbrough, T. 1980. Effects of top and lateral root pruning on survival and early growth on three bottomland hardwood species. Tree Planters' Notes. 31(3): 13–15.

Toumey, J.W. 1916. Seeding and planting. New York: John Wiley and Sons. 455 p.

Vanderveer, H.L. 2005. Survey of root and shoot cultural practices for hardwood seedlings. In: Dumroese, R.K.; Riley, L.E.; Landis, T.D., tech. coords. Proceedings, forest and conservation nursery associations—2004. Proceedings RMRS-P-35. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 21–23.

Weaver, G.H.; Izlar, B.; Zydias, K.; Broerman, F.S. 1982. Southwide pine plantation survival and nursery practices. Rep. 82-A-10. Jackson, MS: American Pulpwood Association. 42 p.

Wightman, K.E.; Shear, T.; Goldfarb, B.; Haggar, J. 2001. Nursery and field establishment techniques to improve seedling growth of three Costa Rican hardwoods. New Forests. 22(1): 75–96.

Wilde, S.A.; Voigt, G.K. 1949. Absorption-transpiration quotient of nursery stock. Journal of Forestry. 47(8): 543–645.

Williams, H.M.; Kleiss, B.A.; Humphery, M.N.; Klimas, C.V. 1993. First-year field performance of oak species with varying flood tolerance planted on hydric and non-hydric soils. In: Brissette, J.C., ed. Proceedings, seventh biennial southern silvicultural research conference. Gen. Tech. Rep. SO-93. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station: 409–414.

Williams, R.D. 1974. Planting methods and treatments for black walnut seedlings. Res. Pap. NC-107. St. Paul, MN: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 6 p.

Woessner, R.; van Hicks, Jr. 1973. Three-year height of green ash not affected by root and top pruning. Tree Planters' Notes. 24(4): 13–17.

Wood, B.W. 1996. Establishing pecan transplants. HortTechnology. 6(3): 276–279.

Zaczek, J.J.; Steiner, K.C.; Bowersox, T.W. 1993. Performance of northern red oak planting stock. Northern Journal of Applied Forestry. 10(3): 105–111.

Zaczek, J.J.; Steiner, K.C.; Bowersox, T.W. 1997. Northern red oak planting stock: 6-year results. New Forests. 13(1): 177–191.

Growing and Marketing Woody Species To Support Pollinators: An Emerging Opportunity for Forest, Conservation, and Native Plant Nurseries in the Northeastern United States

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Abstract

The decline of insects that pollinate flowers is garnering more attention by land managers, policymakers, and the general public. Nursery managers who grow native trees, shrubs, and woody vines have a promising opportunity to showcase these species, marketing their contributions to pollinator health and other ecosystem services in urban and wild landscapes. Species either not currently in production or in demand may benefit from niche markets that can be created around specific pollinators, especially butterflies and moths with their showy coloration. This is particularly true in the Northeastern United States because of the high diversity of woody species. Nursery catalogs can take advantage of free, online sources of images to highlight woody species and their pollinators. Marketing "pollinator packages," suites of plants that combine different flowering times, forest canopy types, and plant forms (trees, shrubs, and vines), has potential to increase sales and improve habitat for native pollinators. This paper was presented at a joint meeting of the Northeast Forest and Conservation Nursery Association and Southern Forest Nursery Association (Kent Island, MD, July 20–23, 2015).

Introduction

The general public is well aware of the pollinator crisis in North America. Honey bee colony collapse disorder, suspected to be caused by a complicated interaction of parasites and pathogens and other factors, exacerbated by pesticide use, including neonicotinoids, has resulted in steep and often sudden population declines (Alaux et al. 2010; Cox-Foster et al. 2007; Dainat et al. 2012; Johnson et al. 2009, 2010). Reduction and fragmentation of habitat and pesticides have negatively affected abundance and species richness of wild, unmanaged bees (Gill et al. 2012, Whitehorn et al. 2012, Winfree et al. 2009) and the iconic monarch butterfly (*Danaus plexippus* L.; Lepidoptera: Nymphalidae; see table 1 for more details on insect nomenclature). These declines have triggered discussion about the immediate need to reverse these population trends to protect food production, native flora and fauna, and other ecological services necessary for environmental health and economic stability. As a result, the White House (2015) released an initiative to support pollinators, and it includes language that supports using native plants as a key strategy to assist in pollinator recovery.

Thus, an opportunity and a crucial national need exist for managers of forest and conservation nurseries to highlight, produce, and promote native woody species that support pollinators. This article focuses on the Northeastern United States, which we define as Minnesota south to Missouri and east to the Atlantic, although the general concepts are applicable anywhere.

Insects that pollinate plants come in myriad shapes and sizes and are represented by four taxonomic orders: (1) Coleoptera (beetles), (2) Diptera (flies), (3) Hymenoptera (bees and wasps), and (4) Lepidoptera (butterflies and moths) (table 1). On one hand, native bees and bumble bees, with their hairy legs and bodies that come in close contact with floral stamens and with their purposeful collection, transport, and consumption of pollen, are very efficient pollinators (figure 1). On the other hand, most butterflies have smooth bodies and long legs that elevate them above the stamens, and they

Table 1. Common insect pollinators mentioned in this publication: a who's who in the language[a] of entomologists.

Order / *Family* / *Genus*	Common names
Coleoptera	beetles
Diptera	true flies
Syrphidae	syrphid flies, flower flies, hover flies
Hymenoptera	ants, bees, wasps
Andrenidae	
Andrena	mining bees
Apidae	
Apis	honey bees
Bombus	bumble bees
Xylocopa	carpenter bees
Lepidoptera	butterflies, skippers, and moths
Geometridae	ankerworms, geometers, measuringworms
Hesperiidae	skippers
Limacodidae	saddleback caterpillars
Lycaenidae	gossamer-winged butterflies, blues, coppers, hairstreaks, harvesters
Noctuidae	cutworms, dagger moths, noctuid moths, owlet moths, underwings
Nymphalidae	admirals, anglewings, brush-footed butterflies, checkerspots, crescents, fritillaries, mourningcloaks
Papilionidae	swallowtail butterflies
Saturniidae [b]	giant silkworm moths, royal moths
Sphingidae	hawk moths, sphinx moths

[a] From Integrated Taxonomic Information System (June 2015).

[b] Members of the Saturniidae are not pollinators, because adults do not feed (they generally live less than 7 days), but many woody species host their larvae.

Figure 1. Native bumble bees (*Bombus* species; Hymenoptera: Apidae) with their hairy bodies and legs that drag across floral stamen are efficient pollinators (top). Brightly colored butterflies, such as this painted lady (*Vanessa cardui* L.; Lepidoptera: Nymphalidae) (bottom), are generally less efficient pollinators but may provide nursery managers with better marketing options when describing woody plants important to "pollinators" in general. (Photos by R. Kasten Dumroese, 2014)

primarily consume nectar as their energy source; thus, contact with pollen is more accidental, which makes them less efficient pollinators. Some moths and flowers have an obligate pollination strategy. For butterflies and moths, their lack of pollination prowess is often compensated, from a home gardener's perspective, by beautiful colors in striking patterns (figure 2). Other animals, such as bats and hummingbirds, are important pollinators, too. While many native woody plants provide pollen and nectar sources for all pollinators, they are particularly important host plants for the larvae of many species of butterflies and moths. Thus, much of the focus of this article is on the role of woody native plants whose flowers support a broad palette of pollinators in general and, specifically, support butterfly and moth larvae.

The Potential To Grow Northeastern Native Woody Species for Pollinators

The Northeastern United States is a region of exceptional native woody plant diversity. Many of these woody plant genera are currently in the nursery trade; however, additional native species could be introduced and promoted. Some of these, for example, *Cladrastis* Raf. (yellowwood), *Cephalanthus* L. (buttonbush), *Oxydendrum* DC. (sourwood), Sassafras Nees & Eberm. (sassafras), and *Viburnum* L. (viburnum) have unusual foliage or flowers that make them worthy of greater use in natural and more formal landscapes (Harrison 2006). Although a number of eastern native forbs have been identified as important for supporting pollinator populations, native woody species have been largely left out of the discussion. That oversight is most unfortunate because nearly all native tree, shrub, and

Figure 2. A monarch butterfly (*Danaus plexippus*) feeding on *Philadelphus* L. (mock orange). (Photo by Tanya Harvey, Native Plant Society of Oregon, 2012)

woody vine genera of the Eastern United States are known larval hosts and important nectar sources for native lepidopteran (butterfly and moth) species (Tallamy and Shropshire 2009) and support native and domesticated bees. Fragmentation and reduction of eastern forests and shrub-dominated communities, along with the prevalence of exotic ornamental plants for use in urban and rural communities, are important contributing factors to pollinator declines.

Supplying native eastern woody species important to pollinators is an important way to conserve and enhance pollinator populations, especially in urban areas where exotic ornamental genera are widely planted. Most popular ornamental woody genera have native North American counterparts that can be planted and promoted in nursery markets and through public awareness campaigns. Exotic ornamentals may be visited by bees, but most ornamentals do not serve as larval hosts for native Lepidoptera (Tallamy 2007). Similarly, natural communities invaded by invasive woody exotics host fewer native woody plants (in terms of species and abundance), resulting in concomitant declines in the species richness, composition, and abundance of butterflies and moths (Burghardt et al. 2010). Informing and educating the public, restoration biologists, and other land managers about the benefits of native woody species to pollinators will be an important component in supporting pollinator populations that may also yield economic benefits to forest and conservation nurseries. Nurseries should consider working together to inform citizens about the benefits of these plants, because wide-scale public perception and knowledge are important to reversing declining population trends and generating new nursery markets (Meyer 2005).

Woody Species and Pollinators

The work by Tallamy and Shropshire (2009) shows that 15 times more native lepidopteran species use native woody plant species as larval hosts than those that use nonnative ornamental woody species, and, when herbaceous plants and woody plants were compared, woody species supported 10 times more lepidopteran species. Because all flowering native woody species produce nectar, pollen, or both, these species are critical to bee populations as well.

Native woody species are used as larval food sources, for shelter during larval development, and for pupation, and adults use trees, shrubs, and forbs as nectar sources. Native shrub communities in the Northeastern United States are important for Lepidoptera of conservation concern (Wagner et al. 2003). Varying stratum or canopy layers of nectar sources in shrub and forested communities coincide with lepidopteran flight patterns and feeding habits, and the lack or absence of taller feeding layers can lead to decreased habitat use and reduced species richness of butterflies and moths. Native woody plant diversity ensures that a range of nectar availability is present throughout the multigenerational life cycles for this group of pollinators. At the same time, a range of alternate and highly important nectar and pollen sources need to be available for native honey bee and bumble bee populations throughout the growing season. As a consequence, restoration and urban pollinator-supportive landscapes will require multiple native woody species that exhibit a range of flowering phenology.

On one hand, native lepidopteran species that are specialist feeders have coevolved with certain plant lineages or species; are adapted to the flowering phenology, tissue chemistry, and physical structure of the host; and, thus, require the presence of this specific native plant species or a very close relative for reproductive success (Wardhaugh 2014). Native generalists, on the other hand, are able to use a range of woody plants as larval hosts, and, as a consequence, are often more common or have broader geographic distributions. Reduction of natural habitat, use of pesticides, and the effects of climate change, however, have resulted in pollinator population reduction, range shifts, and changes in the flowering phenology of larval host plants. As a result, many of the more common native butterflies and moths require consideration in wildland and urban landscape restoration plans. Recent and rapid decline of monarch butterfly populations (figure 2) exemplify the need to restore native nectar sources, larval host plants, and shelter sites for more common species, including those that exhibit wide migratory patterns or geographic ranges.

Combinations of woody plant species, with a range of early spring to fall flowering phenology, can assist in the recovery of declining bee and butterfly populations. Native shrub combinations can be used for urban landscapes; these landscapes can provide other wildlife benefits such as food, shelter, and nesting sites while reducing maintenance costs. Examples of native eastern trees, shrubs, and woody vines that support bees, butterflies, and moths and that also exhibit a range of desirable ornamental characteristics are shown in table 2. The Pollinator Partnership has a handy online tool that provides ecoregional planting guides (http://www.pollinator.org/guides.htm); entering a ZIP Code provides a link to a summary of plants for pollinators, including woody species, for that area.

Riparian Species

This section about riparian species discusses some of these native woody plants and their benefits to native pollinators in more detail.

It is surprising that native wetland- and riparian-dependent Salicaceae species, such as *Salix* L. (willow) and *Populus* L. (cottonwood), serve as larval hosts for more than 700 butterfly and moth species, including those that are largely found only in wetland habitats. These habitats are also preferential nesting and brooding habitat to numerous migratory songbirds, in part, due to the abundance of insect larvae necessary for raising successful broods. Many willows flower during early spring. Male and female flowers have nectar glands, and pollen from male flowers is often the only available pollen source when native bees (Hymenoptera: Apidae) and flower flies (Diptera: Syrphidae) first emerge after winter (Ostaff et al. 2015).

Table 2. Woody plants, their form (shrub, tree, vine), their floral phenology and pollinators, and the lepidopteran larvae they host.

Genus/ species[a]	Family	Plant form[b]	Flowering	Pollinators (HB = hummingbirds)	Host native Lepidoptera family (species)	Sources[c]
Acer L.	Aceraceae	T	Mid-spring	*Apis*	*Limacodidae* (287)	1,4,9
Aesculus L.	Hippocastanaceae	T	Summer	*Bombus*, Nymphalidae, HB	*Nymphalidae* (33)	1,2,4
Alnus Mill.	Betulaceae	T	Spring	Wind	(248)	1
Amelanchier Medik.	Rosaceae	S/T	Mid-spring	*Apis*, *Bombus*	6+ families (119)	1,3,4,7
Amorpha L.	Fabaceae	S	Summer	*Bombus*, HB	*Hesperiidae* (23)	1,3,4,
Arctostaphylos uva-ursi (L.) Spreng.	Ericaceae	S	Spring	*Apis*, *Bombus*	*Lycaenidae* (15)	1–4
Aristolochia L.	Aristolochiaceae	S	Summer	*Papilionidae*	*Papilionidae* (1)	1,3,4
Aronia Medik.	Rosaceae	S	Spring	*Apis, Bombus*	(5)	1,4
Asimina Adans.	Annonaceae	S/T	Spring	*Coleoptera*	*Papilionidae* (12), *Limacodidae*	1–4, 9
Baccharis L.	Asteraceae	S	Summer/fall	*Nymphalidae*	*Lycaenidae* (20)	1–4
Betula L.	Betulaceae	T	Spring	Wind	(400)	1,2,4
Bignonia capreolata L.	Bignoniaceae	V	Spring	*Bombus*, HB	*Sphingidae*	3
Callicarpa americana L.	Verbenaceae	S	Summer	*Apis, Bombus, Nymphalidae*	(1)	1,2,4
Campsis radicans (L.) Seem. Ex Bureau	Bignoniaceae	V	Summer	*Bombus*, HB	*Sphingidae* (7)	1–4
Carpinus L.	Betulaceae	T	Spring	Wind	*Lycaenidae* (66)	1,2,4
Carya Nutt.	Juglandaceae	T	Early summer	Wind	*Lycaenidae, Limacodidae* (233)	1,2,4,9
Castanea Mill.	Fagaceae	T	Early summer	Wind	(125)	1,2,4
Catalpa Scop.	Bignoniaceae	T	Late spring	*Bombus, Sphingidae*, HB	*Sphingidae* (7)	1,2,4
Ceanothus americanus L.	Rhamnaceae	S	Summer	*Apis, Bombus*	*Lycaenidae* (43)	1,4
Celastrus scandens L.	Celastraceae	S	Summer	*Apis, Bombus*	*Geometridae* (5)	1,4
Celtis L.	Ulmaceae	T	Spring/summer	Wind	(41)	1,4

Genus/ species[a]	Family	Plant form[b]	Flowering	Pollinators (HB = hummingbirds)	Host native Lepidoptera family (species)	Sources[c]
Cephalanthus occidentalis L.	Rubiaceae	S/T	Early summer	*Bombus, Nymphalidae, Sphingidae*	*Sphingidae* (19)	1,3
Cercis canadensis L.	Fabaceae	T	Early spring	*Apis, Bombus*, HB	*Lycaenidae* (19)	1,2,4
Chamaedaphne calyculata (L.) Moench	Ericaceae	S	Early spring	*Bombus*	*Lycaenidae* (15)	1,4
Chionanthus virginicus L.	Oleaceae	S	Late spring	*Apis, Bombus*	*Sphingidae* (8)	1,3,4
Cladrastis kentukea (Dum. Cours.) Rudd	Fabaceae	T	Late spring	*Apis, Bombus*	–	1–5
Clethra L.	Clethraceae	S	Mid-summer	*Apis, Bombus*, HB	*Geometridae* (9)	1,2
Cornus L.	Cornaceae	S/T	Summer	*Apis, Bombus*	*Lycaenidae* (115)	1,2,4
Corylus L.	Betulaceae	T	Early spring	Wind	(124)	1,4
Cotinus obovatus Raf.	Anacardiaceae	T	Summer	Wind	(4)	1,4
Crataegus L.	Rosaceae	T	Early summer	*Apis, Bombus*	10 families (158)	1–5
Diervilla Mill.	Caprifoliaceae	S	Late spring	*Bombus*	*Sphingidae* (4)	1,3
Diospyros L.	Ebenaceae	T	Early summer	*Apis*	*Saturniidae* (44), *Limacodidae*	1–4,9
Elaeagnus commutata Bernh. ex Rydb.	Elaeagnaceae	S	Summer	*Apis, Syrphidae*	*Saturniidae* (22)	1,3
Eubotrys racemosa (L.) Nutt.	Ericaceae	S	Early spring	*Apis, Bombus*	–	1,4
Fagus L.	Fagaceae	T	Spring	Wind	9 families (124)	1,2,4
Fothergilla gardenii L.	Hamamelidaceae	S	Spring	*Apis, Bombus*	–	2,4
Fraxinus L. (black, blue, green)	Oleaceae	T	Late spring	*Apis*	29 families (141)	1,2,4
Gaylussacia Kunth	Ericaceae	S	Early summer	*Apis, Bombus*	*Lycaenidae* (42)	1,3,4
Gleditsia triacanthos L.	Fabaceae	T	Summer	*Apis, Bombus*	*Hesperiidae* (42)	1,2
Gymnocladus dioicus (L.) K. Koch	Fabaceae	T	Late spring	*Apis, Bombus, Papilionidae*, HB	*Sphingidae* (4)	1,4
Halesia Ellis ex L.	Styracaceae	S	Spring	*Apis, Bombus*	(7)	1,4
Hamamelis L.	Hamamelidaceae	S	Spring, fall	*Apis, Syrphidae*	*Lycaenidae* (62)	1,3,4
Hydrangea L. (fertile)	Hydrangeaceae	S	Early spring	*Apis, Bombus*	*Sphingidae* (5)	1,4
Ilex L.	Aquifoliaceae	S	Mid-spring	*Apis*	*Lycaenidae* (34)	1,2,3,4
Itea virginica L.	Grossulariaceae	S	Early summer	*Apis, Bombus, Nymphalidae*	*Lycaenidae* (1)	8
Juglans L.	Juglandaceae	T	Spring	Wind	(123)	4
Kalmia L.	Ericaceae	S	Mid-spring	*Apis, Bombus*	*Noctuidae* (31)	1,2,4
Leucothoe D. Don	Ericaceae	S	Early spring	*Apis, Bombus*	(3)	1,4,6
Lindera benzoin (L.) Blume	Lauraceae	V	Mid-spring	*Nymphalidae*	*Papilionidae, Lycaenidae* (9), *Saturniidae, Geometridae*	1,2,3,4,9
Liquidambar styraciflua L.	Hamamelidaceae	T	Spring	*Apis, Syrphidae*	*Papilionidae* (33)	1
Liriodendron tulipifera L.	Magnoliaceae	T	Spring	*Apis, Bombus, Coleoptera, Syrphidae*	*Papilionidae* (19)	1
Lonicera L.	Caprifoliaceae	S/V	Early summer	*Bombus, Nymphalidae*, HB	*Geometridae, Noctuidae, Nymphalidae* (33)	1–4
Lyonia L.	Ericaceae	S	Early summer	*Apis, Bombus*	*Lycaenidae*	8
Magnolia L.	Magnoliaceae	T	Summer	*Coleoptera*	*Saturniidae* (21)	1,2
Mahonia Nutt.	Berberidaceae	S	Early spring	*Apis, Bombus*	–	1
Malus Mill.	Rosaceae	T	Spring	*Apis, Bombus*	(308)	1

Genus/ species[a]	Family	Plant form[b]	Flowering	Pollinators (HB = hummingbirds)	Host native Lepidoptera family (species)	Sources[c]
Myrica L.	Myricaceae	S	Mid-spring	*Apis, Bombus*	(106)	1,3,4
Nyssa L.	Cornaceae	T	Mid-spring	*Apis, Bombus*	(25)	1,2
Ostrya virginiana (Mill.) K. Koch	Betulaceae	T	Early spring	Wind	(91)	1
Oxydendrum DC.	Ericaceae	S/T	Mid-summer	*Apis, Bombus*	*Saturniidae* (14)	1,4
Parthenocissus Planch.	Vitaceae	V	Mid-summer	*Apis*, native solitary bees	*Geometridae, Sphingidae* (32)	1,7
Physocarpus opulifolius (L.) Maxim., orth. cons.	Rosaceae	S	Mid-summer	*Apis, Bombus, Nymphalidae*	*Geometridae* (146)	1,3,4
Populus L.	Salicaceae	T	Spring	Wind	9 families (358) (*Papilionidae, Nymphalidae*)	1
Prunus L.	Rosaceae	S/T	Spring/summer	*Apis, Bombus*	13 families (>450) (*Papilionidae, Lycaenidae, Limacodidae*)	1–5,7,9
Quercus L.	Fagaceae	T	Spring/summer	Wind	13 families (518)	1–4
Rhododendron L.	Ericaceae	S	Spring/summer	*Apis, Andrena*, HB	*Lycaenidae* (50)	1,2,3,4
Rhus L.	Anacardiaceae	T	Early summer	*Apis*	*Lycaenidae* (54)	1,4
Ribes L.	Grossulariaceae	S	Early summer	*Bombus*, HB	*Lycaenidae* (92)	1–5
Robinia L.	Fabaceae	T	Spring	*Apis, Bombus*	*Hesperiidae* (67)	4
Rosa L.	Rosaceae	S	Early summer	*Apis, Bombus*	7 families (122)	1–4
Rubus L.	Rosaceae	S	Mid-summer	*Apis, Bombus*	9 families (151)	1–4
Salix L.	Salicaceae	S/T	Spring	*Apis, Syrphidae*	11 families (440) (*Papilionidae, Nymphalidae*)	1
Sambucus L.	Caprifoliaceae	S	Early summer	*Apis, Diptera*	(40)	1,2
Sassafras albidum (Nutt.) Nees	Lauraceae	S/T	Spring/summer	*Apis, Bombus*	*Papilionidae, Saturniidae* (36)	1,2,4
Smilax L.	Smilacaceae	V	Spring	*Apis, Coleoptera, Diptera*	(17)	1
Sorbus L.	Rosaceae	S/T	Early summer	*Apis, Bombus*	*Papilionidae* (62)	1,4
Spiraea alba Du Roi	Rosaceae	S	Spring/summer	*Apis*	*Lycaenidae, Saturniidae* (86)	1,2,4,7
Stewartia ovata (Cav.) Weath.	Theaceae	S	Summer	*Apis, Bombus, Nymphalidae*	(1)	1,4
Styrax L.	Styracaceae	S	Spring	*Apis, Bombus*	–	1,4
Symphoricarpos Duham.	Caprifoliaceae	S	Summer	*Apis*	*Nymphalidae* (24)	1,3,4
Tilia L.	Tiliaceae	T	Spring/summer	*Apis*	*Nymphalidae, Sphingidae* (142)	1,4
Ulmus L.	Ulmaceae	T	Early spring	Wind	*Nymphalidae* (206)	1,2,4
Vaccinium L.	Ericaceae	S	Late spring	*Apis, Bombus*	*Lycaenidae* (286)	1–4
Viburnum L.	Caprifoliaceae	S/T	Early summer	*Apis, Nymphalidae*	*Lycaenidae, Nymphalidae, Noctuidae (97)*	1–4,7
Vitis L.	Vitaceae	V	Summer	*Apis*, native solitary bees	*Geometridae, Sphingidae* (72)	1,7
Wisteria L.	Fabaceae	V	Spring/summer	*Apis, Xylocopa*	*Hesperiidae* (18)	1,4,5
Zanthoxylum americanum Mill.	Rutaceae	S/T	Early summer	Native solitary bees	*Papilionidae* (6)	1,3,5

[a] Nomenclature follows USDA NRCS (2016).

[b] S = shrub. T = tree. V = vine.

[c] Sources: 1: Tallamy and Shropshire (2009). 2: Webb (2008). 3: LJWC (2015). 4: Cullina (2002). 5: BAMONA (2015). 6: Schweitzer (1980). 7: Fergusen (1975). 8: Wright and Pavulaan (1999). 9: Lill (2008).

Given the estimates that up to 90 percent of wetland and riparian habitat has been lost in the Midwestern United States alone (EPA 2015), marketing the importance of native Salicaceae for riparian restoration and its associated benefits to water quality, native pollinators, migratory songbirds, and butterflies could stimulate interest in these easy-to-grow species that can be grown from both seeds and cuttings. Willows and cottonwoods are dioecious, so growers will need to produce male and female nursery stock. Seedlings will result in a mixture of sexes; cutting propagation, however, will require that donor trees are identified to gender before cutting collection (Landis et al. 2003).

Rosaceae Species

Many common, native woody Rosaceae shrub genera commercially available in the native nursery trade are crucial for native bees, European honey bees, and bumble bees (Apidae) and host an overwhelming number of rare and common butterfly and moth species (Wagner et al. 2003). Native cherries, such as *Prunus americana* Marshall (American plum), *P. pensylvanica* L. f. (pin cherry), *P. serotina* Ehrh. (black cherry), and *P. virginiana* L. (chokecherry), support exceptionally high lepidopteran richness, serving as hosts for 429 species in the gossamer-winged butterfly family (Lepidoptera: Lycaenidae) (Tallamy and Shropshire 2009) and for swallowtail butterflies (Papilionidae).

Other Rosaceae woody genera, such as *Rubus* L. (wild raspberry), are preferential nectar sources for butterflies and moths (Grundel et al. 2000). *Rubus* and *Rosa* L. (wild rose) host up to 9 lepidopteran families and more than 100 species each (Tallamy and Shropshire 2009), and *Spiraea alba* Du Roi (white spiraea) hosts 86 gossamer-winged butterfly and sphinx moth (Sphingidae) species. *Amelanchier alnifolia* (Nutt.) Nutt. ex. M. Roem (serviceberry) occurs across the Northern and Central United States and hosts at least 6 butterfly and moth families and up to 125 species.

Ericaceae Species

Native Ericaceae shrubs generally flower during spring and provide early important nectar and pollen sources for pollinators. Examples include *Arctostaphylos uva-ursi* (L.) Spreng. (bearberry), *Gaylussacia* Kunth (huckleberry), *Rhododendron* L. (native azalea), *Vaccinium* L. (blueberry and cranberry), including native *Vaccinium* species that are important commercial food crops. These genera are also important larval hosts for butterflies and moths: more than 340 gossamer-winged butterfly species, including copperwings (Lycaeninae), blues (Polyommatinae), and hairstreaks (Theclinae). Eight *Gaylussacia* species and at least 20 native *Rhododendron* and 20 *Vaccinium* species occur in the Eastern United States (Gleason and Cronquist 1991), yet many are not widely available in nurseries, including some that have broad geographic ranges in the Eastern United States. *Gaylussacia baccata* (Wangenh.) K. Koch, *G. frondosa* (L.) Torr. & A. Gray ex Torr., and *G. dumosa* (Andrews) Torr. & A. Gray (black, blue, and dwarf huckleberry, respectively) occur throughout most of the Eastern and Southeastern United States and consequently have larger restoration and homeowner markets, while other species are found in smaller ranges in the Southeastern States and may be available from only a few specialist nurseries.

Rhododendrons are some of the most popular ornamental woody plants in the Eastern United States. Native *Rhododendron* species, in general, are available in a few specialist nurseries. Five species are found throughout the Northeastern and Southeastern United States: *Rhododendron arborescens* (Pursh) Torr. (smooth azalea), *R. calendulaceum* (Michx.) Torr. (flame azalea; figure 3), *R. maximum* L. (great laurel), *R. periclymenoides* (Michx.) Shinners (pink azalea), and *R. prinophyllum* (Small) Millais (early azalea).

These species exhibit a range of flower color, habit, and height and can easily be used for mass flowering shrub plantings in urban landscapes. Other native *Rhododendron* species have more restricted southeastern ranges but are important components of forests, larval hosts, or of conservation concern.

Among the Ericaceae, the Eastern United States is the center of *Vaccinium* diversity and origin of important food crops: *V. angustifolium* Aiton (lowbush blueberry), *V. corymbosum* L. (highbush blueberry), and *V. macrocarpon* Aiton (cranberry). *Viburnum arboreum* Marshall (farkleberry) and *V. stamineum* L. (deerberry) occur across the Eastern United States

Figure 3. Flowers of native rhododendrons, such as *Rhododendron calendulaceum* (flame azalea), provide pollen and nectar to a variety of insects that pollinate plants, including honey and mining bees; serve as host to the larvae of more than 50 species of gossamer-winged butterflies; and offer a stunning visual display in the home garden or natural landscape. (Photo by Joseph G. Strauch, Jr., Strauch Photography, 1995)

but are not widely promoted. Blueberries are very popular as home landscape food crops, and other *Vaccinium* species, with more restricted ranges, can be promoted for similar purposes.

Spring-Flowering Plants

Many spring-flowering native shrubs are critical early nectar and pollen sources for bees and also host numerous butterfly and moth species. For example, *Myrica gale* L. (sweetgale) supports native bees and bumble bees and hosts at least 106 species of butterflies and moths (table 2). Spring-flowering *Viburnum prunifolium* L. (black haw) and summer flowering *Itea virginica* (Virginia sweetspire) are pollinated by bees and brush-footed butterflies (Tallamy and Shropshire 2009). *Itea virginica* also serves as an alternate, later season host to a recently described butterfly (*Celastrina idella* D. Wright and Pavulaan [Lycaenidae]) when flowers of its preferred host, *Ilex* L. (holly), are unavailable (Wright and Pavulaan 1999).

It is interesting that mid-spring flowering *Lindera benzoin* (L.) Blume (spicebush), which can be grown as a 1+0 bareroot crop (Hoss 2006), is pollinated by brush-footed butterflies and hosts nine swallowtail and gossamer-winged butterfly species. Spicebush could be marketed as an alternative to the ornamental *Buddleja davidii* L. (Buddlejaceae) (butterfly bush), which does not host native lepidopteran species.

Spring-flowering *Hydrangea* L. (hydrangea), *Sassafras albidum* (Nutt.) Nees (sassafras), *Styrax* L. (snowbell), *Oxydendrum*, and summer-flowering native plants, including *Campsis radicans* (L.) Seem. Ex Bureau (trumpet creeper; figure 4), *Lonicera* L. (honeysuckle), and *Physocarpus opulifolius* (L.) Maxim. (common ninebark) are important nectar sources. These species also host larvae of multiple moth species, including exceptionally beautiful genera, such as sphinx moths and the luna moth (*Actias luna* L. Saturniidae) and also the smaller moths of the Geometridae. Native plants that produce tubular flowers, such as *Campsis, Diervilla* Mill. (bush honeysuckle), and *Lonicera*, are also nectar sources and are pollinated by migratory ruby-throated hummingbirds (*Archilochus colubris* L. [Trochilidae]). It is important to note that native trees and shrubs that flower or continue flowering during late summer and early fall in the upper Midwest and Northeast, such as *Diervilla lonicera* Mill. (northern bush honeysuckle), *Sambucus* L. (elderberry), *Symphoricarpos* Duham. (snowberry), and *Viburnum* provide

Figure 4. The large, tubular flowers of *Campsis radicans* (trumpet creeper), a native vine, are visited by bumble bees and hummingbirds. Foliage is consumed by the larvae of at least seven species of sphinx moths, sometimes referred to as “hummingbird moths.” (Photo by Joseph G. Strauch, Jr., Strauch Photography, 1995)

late-season nectar sources at a different stratum, or canopy level, than do late-flowering native forbs, and they also provide necessary shelter during the fall migration of monarch butterflies.

Other Species

Native woody vines provide wildlife cover in restoration plantings and provide screening in home landscapes. Woody vines in the Fabaceae family, including *Wisteria frutescens* L. Poir. (American wisteria), exhibit similar desirable characteristics found in widely marketed introduced Asian species, but they are pollinated by native carpenter bees (*Xylocopa* L.) and honey bees (*Apis* L.) and host the larvae of skipper butterflies (Hesperiidae). *Aristolochia macrophylla* Lam. (pipevine) is the larval host for the pipevine swallowtail butterfly (*Battus philenor* L.), a butterfly of unknown conservation status. Formerly popular native vines in the Vitaceae family, such as *Campsis radicans* and *Parthenocissus quinquefolia* (L.) Planch. (Virginia creeper), can, in the current market, be repromoted to support pollinators.

Other lesser known woody taxa, such as *Zanthoxylum americanum* Mill. (common pricklyash), host swallowtail butterflies, such as the eastern tiger swallowtail (*Papilio glaucus* L.) and the largest North American butterfly, the giant swallowtail (*P. cresphontes* Cramer) (figure 5). Larval host specificity to these showy butterflies could also be used as a marketing strategy.

Shrub layers in natural communities contain numerous caterpillars necessary for feeding and rearing broods of migratory songbirds. Native shrubs planted in abundance in urban areas, in turn, can attract and increase nesting success for songbirds that depend on adequate cover, preferential nesting sites, and protein-rich food sources supplied by the larvae of butterflies and moths (Burghardt et al. 2009, Tallamy 2004). Thus, market promotion for pollinators can also include the benefits for assisting migratory songbird populations.

Marketing Woody Species

Although native bees and bumble bees are the most efficient pollinators, butterflies and moths are often less threatening and more visually stunning (figure 5).

Figure 5. Butterflies, such as this giant swallowtail (*Papilio cresphontes*; Lepidoptera: Papilionidae), with its beautiful colors and wing shapes, can add zest to marketing materials, especially when the butterfly can be specifically matched to a particular woody species. In this case, noting that larvae of this butterfly consume leaves of common pricklyash (*Zanthoxylum americanum*) makes this small tree sound better than its common name suggests. (Photo by Tom Clark, www.Flickr.com, 2007)

Therefore, incorporating images of them into brochures, catalogs, and order forms can be a vibrant addition in concert with plant descriptions. State nurseries may be able to find useful images within their departments of natural resources that often contain amateur photographers willing to share their efforts. New online repositories, such as Flickr (https://www.flickr.com), hold an immense number of images uploaded by professionals and amateurs. These images can easily be searched by scientific and/or common names, and the contact information of the photographers is usually available too. Many amateur photographers are more than willing to allow use of their photos. Some photographers allow downloading of their images without obtaining prior permission, but always respect the photographers by asking for permission and giving proper credit when the image is used. Provide photographers with a copy or link so they can see the final product. If you find an image you like, make sure you note the Web address; the search function can sometimes make it difficult to relocate images.

The U.S. Department of Agriculture (USDA) National Agroforestry Center (http://nac.unl.edu) has several excellent publications connecting the role of woody vegetation and pollinator health including fact sheets for niche species, such as *Asimina triloba* (L.) Dunal (pawpaw), *Sambucus*, and woody florals (e.g., *Salix* and *Cornus* L. [dogwood]) that support pollinators and have income potential for landowners (figure 6). Linking potential nursery customers with these resources can also encourage sales of woody plants.

Consider marketing your woody plants by offering "packages" that include several species and provide more benefit as a set than they might provide individually. For example, a package might focus on providing pollen and nectar sources throughout the growing season. The package could include species from genera such as *Salix*, *Prunus*, and *Tilia* L. to provide early spring, spring, and early summer pollen and nectar sources, respectively. Or a plant package could include *Kalmia* (laurel), *Zanthoxylum*, and *Aesculus* L. (buckeye) to provide understory, mid-canopy, and overstory sources or different plant forms, such as vines (*Bignonia* L. [bignonia]), shrubs (*Ribes* L. [currant]), and trees (*Catalpa* Scop. [catalpa]) (figure 7).

Figure 6. Some woody plants, such as this *Sambucus* (elderberry), provide nectar and pollen for pollinators and fruits for human consumption. (Photo by Steve Burt, 2010)

Figure 7. Consider marketing woody plants in packages that provide a suite of characteristics. Ideally, species in these packages would bloom at different seasons or occur at different levels of the forest canopy, and could include shrubs, vines, and trees, such as this *Catalpa*. (Photo by Karen-Louise Taylor, www.Flickr.com, 2012)

Summary

Recovery of declining pollinator populations will require that the woody plant nursery industry promote the use of native tree, shrub, and woody vine species that provide nectar to pollinators and/or serve as hosts for larvae of butterflies and moths. Promoting these plants presents opportunities to showcase woody species currently in production and to bring additional native species into the market. Wetland, forest, and other restoration projects and urban re-greening and home landscapes can encourage and implement the wide-scale use of native pollinator-dependent/pollinator-supportive woody plants.

Native plant nurseries will play a critical role in national pollinator recovery efforts by promoting the pollination ecology of these species to clients and the general public. Multiple environmental and economic benefits to restoration and landscaping markets that result from the wide-scale use of native woody plants can also be used to promote these species. Nurseries can benefit by supplying a large potential market and providing additional native species into the trade, while re-marketing some species that have been longtime standards in the nursery trade.

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Resources for Propagating Eastern Native Woody Species

Baskin, C.C.; Baskin, J.M. 1998. Seeds: ecology, biogeography and evolution in dormancy and germination. San Diego: Academic Press. 666 p.

Cullina, W. 2002. Native trees, shrubs, and vines: a guide to using, growing and propagating North American woody plants. Boston: Houghton Mifflin. 354 p.

Dumroese, R.K.; Landis, T.D.; Luna, T. 2012. Raising native plants in nurseries: basic concepts. Gen. Tech. Rep. RMRS-GTR-274. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 84 p.

Native Plant Propagation Database. 2016. http://npn.rngr.net. (August 2016).

USDA Forest Service. 2008. Woody plant seed manual (online version). http://nsl.fs.fed.us/nsl_wpsm.html. (August 2016).

Examples of Reference Guides for Butterflies and Moths

Brock, J.P.; Kaufman, K. 2006. Field guide to butterflies of North America. Boston: Houghton Mifflin. 392 p.

Covell, C.V., Jr. 1984. A field guide to the moths of eastern North America. Boston: Houghton Mifflin. 624 p.

Glassberg, J. 1999. Butterflies through binoculars: a field guide to the butterflies of eastern North America. New York: Oxford University Press. 400 p.

Opler, P.A. 1994. Peterson first guide to butterflies and moths: a simplified guide to the common butterflies and moths of North America. Boston: Houghton Mifflin. 128 p.

Opler, P.A.; Malilul, V. 1998. A field guide to eastern butterflies. Boston: Houghton Mifflin. 512 p.

Wagner, D.L. 2005. Caterpillars of eastern North America. Princeton, NJ: Princeton University Press. 496 p.

Wright, A.B. 1993. Peterson first guide to caterpillars of North America. Boston: Houghton Mifflin. 128 p.

REFERENCES

Alaux, C.; Brunet, J.L.; Dussaubat, C.; Mondet, F.; Tchamitchan, S.; Cousin, M.; Le Conte, Y. 2010. Interactions between *Nosema* microspores and a neonicotinoid weaken honeybees (*Apis mellifera*). Environmental Microbiology. 12(3): 774–782.

Burghardt, K.T.; Tallamy, D.W.; Philips, C.; Shropshire, K.J. 2010. Non-native plants reduce abundance, richness, and host specialization in lepidopteran communities. Ecosphere 1(5): 1-22.

Burghardt, K.T.; Tallamy, D.W.; Shriver, G.W. 2009. Impact of native plants on bird and butterfly biodiversity in suburban landscapes. Conservation Biology. 23(1): 219–224.

Butterflies and Moths of North America (BAMONA). 2015. http://www.butterfliesandmoths.org/. (June 2015).

Cox-Foster, D.L.; Conlan, S.; Holmes, E.C.; Palacios, G.; Evans, J.D.; Moran, N.A.; Lipkin, W.I. 2007. A metagenomic survey of microbes in honey bee colony collapse disorder. Science. 318(5848): 283–287.

Cullina, W. 2002. Native trees, shrubs, and vines: a guide to using, growing, and propagating North American woody plants. Boston: Houghton Mifflin. 354 p.

Dainat, B.; Evans, J.D.; Chen, Y.P.; Gautheir, L.; Neumann, P. 2012. Predictive markers of honey bee colony collapse. PLoS One 7(2): e32151.

Fergusen, D.C. 1975. Host records for Lepidoptera reared in eastern North America. Tech. Bull. 1521. Washington, DC: U.S. Department of Agriculture, Agricultural Research Service. 49 p. http://naldc.nal.usda.gov/download/CAT76667713/PDF. (June 2015).

Gill, R.J.; Ramos-Rodriguez, O.; Raine, N.E. 2012. Combined pesticide exposure severely affects individual- and colony-level traits in bees. Nature. 491(7422): 105–108.

Gleason, H.; Cronquist, A. 1991. Manual of vascular plants of the Northeastern United States and adjacent Canada. New York: New York Botanical Garden Press. 910 p.

Grundel, R.; Pavlovic, N.B.; Sulzman, C.L. 2000. Nectar plant selection by the Karner blue butterfly (*Lycaeides melissa samuelis*) at the Indiana Dunes National Lakeshore. American Midland Naturalist. 144(1): 1–10.

Harrison, M.E. 2006. Unusual native trees. Native Plants Journal. 7(3): 262–266.

Hoss, G. 2006. Propagation protocol for spicebush (*Lindera benzoin*). Native Plants Journal 7(2): 134–136.

Integrated Taxonomic Information System. 2015. http://www.itis.gov/. (June 2015).

Johnson, R.M.; Ellis, M.D.; Mullin, C.A.; Frazier, M. 2010. Pesticides and honey bee toxicity—USA. Apidologie. 41(3): 312–331.

Johnson, R.M.; Evans, J.D.; Robinson, G.E.; Berenbaum, M.R. 2009. Changes in transcript abundance relating to colony collapse disorder in honey bees (*Apis mellifera*). Proceedings of the National Academy of Sciences. 106(35): 14790–14795.

Ladybird Johnson Wildflower Center (LJWC). 2015. Native plants database. https://www.wildflower.org/plants/. (June 2015).

Landis, T.D.; Dreesen, D.R.; Dumroese, R.K. 2003. Sex and the single *Salix*: considerations for riparian restoration. Native Plants Journal. 4(2): 111–117.

Lill, J.T. 2008. Caterpillar-host plant relationships recorded from Plummers Island, Maryland (Insecta: Lepidoptera). Bulletin of the Biological Society of Washington. 15(1): 75–79.

Meyer, S.E. 2005. Intermountain Native Plant Growers Association: a nonprofit trade organization promoting landscape use of native plants. Native Plants Journal. 6(2): 104–107.

Ostaff, D.P.; Mosseler, A.; Johns, R.C.; Javorek, S.; Klymko, J.; Ascher, J.S. 2015. Willows (*Salix* spp.) as pollen and nectar sources for sustaining fruit and berry pollinating insects. Canadian Journal of Plant Science. 95(3): 505–516.

Schweitzer, D.F. 1980. The identity of the plant referred to as *Andromeda* by WTM Forbes. Journal of the Lepidopteran Society. 34(1): 24.

Tallamy, D.W. 2004. Do alien plants reduce insect biomass? Conservation Biology. 18(6): 1689–1692.

Tallamy, D.W. 2007. Bringing nature home: how you can sustain wildlife with native plants. Portland, OR: Timber Press. 288 p.

Tallamy, D.W.; Shropshire, K.J. 2009. Ranking native lepidopteran use of native versus introduced plants. Conservation Biology. 23(4): 941–947 (plus online supplemental file: COBI_1202_sm_AppendixS3-S5.xls). NOTE: Portions of the supplemental file are available from the authors at http://udel.edu/~dtallamy/host/ (March 2016) and a simplified, popularized version is available at http://www.wildones.org/download/NativeCaterpillarsMothButterflies&HostNativeWoodies.pdf. (March 2016).

U.S. Department of Agriculture, Natural Resources Conservation Service (USDA NRCS). 2016. The PLANTS database. http://plants.usda.gov. (March 2016).

U.S. Environmental Protection Agency (EPA). 2015. Wetlands: status and trends. http://water.epa.gov/type/wetlands/vital_status.cfm. (July 2015).

Wagner, D.L.; Nelson, M.W.; Schweitzer, D.F. 2003. Shrubland Lepidoptera of southern New England and southeastern New York: ecology, conservation and management. Forest Ecology and Management. 185(1-2): 95–112.

Wardhaugh, C.W. 2014. The spatial and temporal distributions of arthropods in forest canopies: uniting disparate patterns with hypotheses for specialisation. Biological Reviews. 89(4): 1021–1041.

Webb, J.K. 2008. Beyond butterflies: gardening for native pollinators. Athens, GA: University of Georgia Cooperative Extension. B1349. 7 p. http://extension.uga.edu/publications/files/pdf/B%201349_1.PDF. (August 2016).

White House. 2015. https://m.whitehouse.gov/blog/2015/05/19/announcing-new-steps-promote-pollinator-health.

Whitehorn, P.R.; O'Connor, S.; Wackers, F.L.; Goulson, D. 2012. Neonicotinoid pesticide reduces bumble bee colony growth and queen production. Science. 336(6079): 351–352.

Winfree, R.; Aguilar, R.; Vázquez, D.P.; Lebuhn, G.; Aizen, M.A. 2009. A meta-analysis of bees' responses to anthropogenic disturbance. Ecology. 90(8): 2068–2076.

Wright, D.M.; Pavulaan, H. 1999. *Celastrina idella* (Lycaenidae: Polyommatinae): a new butterfly species from the Atlantic coastal plain. Taxonomic Report of the International Lepidopteran Society. 1(9): 1–11.

Native Plant Germination and Growth in a Subirrigation System

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Abstract

Native plant and forest nurseries consume high amounts of water when irrigating crops with overhead and hand-watering systems. As water conservation continues to be an issue, subirrigation is being considered as an alternative watering method by growers and nursery owners. We tested the germination and growth of redosier dogwood (*Cornus sericea*) in a subirrigation system. During germination, we compared treatments with and without overhead misting and germination cloth in addition to subirrigation. We also tested two fertilizers—Osmocote® Pro 17-5-11 and Nutri-Rich 8-2-4—applied in two ways—incorporated or top dressed. Results showed that germination was successful using subirrigation only, but germination was highest in treatments that also had germination cloth and received overhead misting twice a day. The treatments with incorporated Osmocote® grew more in the nursery, but the treatments with top-dressed Osmocote® grew taller after outplanting. The Nutri-Rich fertilizer did not work in this experiment because of a pest infestation. The experiment showed that subirrigation can be used to successfully germinate seed and that nursery cultural practices can be manipulated to improve germination rates, to reduce overall water and fertilizer use, and to adjust growth rates in the nursery and the field. This paper was presented at the annual meeting of the Western Forest and Conservation Nursery Association (Eugene, OR, October 26–27, 2015).

Introduction

Forest tree and native plant nurseries grow seedlings for reforestation and restoration projects. Given that the seedlings are typically planted in projects that have environmental objectives, nursery growers want to ensure that the plants are grown in a sustainable manner. Growing seedlings in a nursery requires resources, including water. Developing more water-efficient practices to grow plants can reduce the nursery's water use (Landis 1989).

Subirrigation, or ebb-and-flood irrigation, is one system used in container nurseries to irrigate plants. In a subirrigation system, containers sit in a tray or reservoir, which is then flooded, allowing water to enter into holes in the bottom of the containers. After a period of soaking, any unabsorbed water is drained. The volume of water movement is a balance between medium porosity and bulk density, container configuration, and water requirements of the plants (Ferrarezi et al. 2015). Subirrigation applies water directly to the growing medium, resulting in a higher water-use efficiency compared with overhead irrigation (Gent and McAvoy 2011). Holding tanks can be used to store the unabsorbed water for reuse. Subirrigation systems have been used to grow healthy seedlings while reducing overall water and fertilizer use and decreasing weeds (Bumgarner et al. 2008, Davis et al. 2011, Wilen et al. 1999); in these experiments, the seedlings were either transplanted into the containers or grown with overhead irrigation during the germination phase.

As growers' repertoires expand to include growing a variety species of using subirrigation, it becomes necessary to identify the most effective way to optimize water use. At the same time, growers need to determine best practices and successful protocols to produce healthy seedlings of each species (Schmal et al. 2011). Nurseries that currently use subirrigation to grow seedlings still use overhead irrigation during the germination phase, which requires additional infrastructure (e.g., Dumroese et al. 2011). If subirrigation systems are to be used independent of overhead irrigation infrastructure, subirrigation must meet the water needs of the plant throughout the growing season. Therefore, the irrigation system and the growing media must provide sufficient water to the seed or seedling during each growing stage, particularly the germination phase. To properly grow high-quality seedlings it is likely that nursery cultural treatments, such as irrigation method and fertilizer application, may need to be adjusted.

The objective of our study was to determine whether it is possible to germinate redosier dogwood (*Cornus sericea* L.) seed in a subirrigation system and if fertilizer type and application method affect the growth of this species during its time in the nursery and its first year after planting. We also examined whether different nursery cultural practices affect germination.

Redosier dogwood is an appropriate species for this experiment. The species is often found along margins of streams and wetlands, where the soils are saturated for a portion of the growing season but are dry by late summer (Stevens and Dozier 2000). In addition, redosier dogwood is a popular choice for landscaping in the Pacific Northwest, with many nurseries and growers in the area producing it often and in large quantities. The species develops a broad canopy that deflects water when overhead irrigation is used. Using subirrigation can ensure that each container receives the water it needs (Davis et al. 2008, Landis and Wilkinson 2004).

Material and Methods

The experiment was conducted at Oxbow Native Plant Nursery, located within the Oxbow Farm and Conservation Center in Carnation, WA (~47°41'N., 121°58'W.). Seed for this study was obtained in northern Idaho and was stratified for 136 days at 0 to 1.5 °C (32 to 35 °F) before sowing. Seed viability was tested by placing seed in a closed, clear plastic container under a full-spectrum light and recording germination for 4 weeks. The light was on an automatic timer for 16 hours of daylight and 8 hours of darkness. The seeds were misted three times a day to keep them moist and were kept under ambient temperature, which was tracked with a temperature-humidity sensor (Decagon Devices, Inc., Pullman, WA). A seed was counted as germinated when 5 mm (0.2 in) of the radicle was visible (Baskin and Baskin 2014). Mean germination was 86 percent (n = 4, standard deviation = 3.63, descriptive statistics from R, version 3.1.1).

The greenhouse at the Oxbow Native Plant Nursery is a Cravo greenhouse (Cravo Equipment Ltd., Brandtford, ON, Canada) and regulates temperature automatically by opening and closing roof and side panels; there is no supplemental heating, cooling, or lighting in the greenhouse. For this experiment, Ray-Leach SC10 containers (Stuewe & Sons, Inc., Tangent, OR) were filled with Sunshine Mix #4 Aggregate Plus (Sun Gro® Horticulture, Agawam, MA, Lot S13-153). The medium was made of 65 to 75 percent Canadian Sphagnum peat moss; the remaining proportion was horticultural grade perlite and dolomitic limestone. The Ray-Leach cells were placed in racks that held 98 containers each. A total of 2,800 containers were used in the study, arranged in a split plot design with five replications. On June 11, 2014, three seeds were sown in each container. The seeds were then covered with approximately 0.5 cm (0.20 in) of medium.

Subirrigation

The subirrigation system consisted of cement mixing tubs measuring 0.61 x 0.91 x 0.20 m (24 in x 36 in x 8 in). Before sowing, all tubs were filled with 50 L (13 gal) of water and the trays were soaked for 2 hours. At this point, the containers were saturated, except for the unconsolidated peat at the top of the container. Any remaining water in each tub was drained into a 70-L (18-gal) container (Rubbermaid, Atlanta, GA) between subirrigations. The irrigation water was recycled for each irrigation, with a separate supply maintained for each subirrigation tub. Subsequent irrigations soaked for 1 hour (germination phase) or 15 minutes (growth phase). For each irrigation event, the supply was topped off to 50 L (13 gal) with fresh water from the greenhouse water supply. In the third replication, a temperature and humidity sensor (Decagon Devices, Pullman,WA) was installed in each irrigation treatment.

Fertilizer Treatments

Two nursery fertilizers were used: (1) Osmocote® Pro Control Release 17-5-11 (3-4 month release, Everris, Geldermalsen, Netherlands) and (2) Nutri-Rich 8-2-4 (Stutzman Environmental Products, Inc., Canby, OR). The Osmocote® product is a general purpose fertilizer made of coated prills and is acceptable for use in containerized nurseries. The Nutri-Rich product is an organic-certified, granulized product made primarily of chicken manure. The advertised applications of Nutri-Rich include use on trees and shrubs. Each fertilizer was applied in one of two ways: either (1) incorporated into the growing medium or (2) applied as a top dressing. The rate of fertilization was determined by the medium recommended application rate by Osmocote® (Dumroese et al. 2007). The amount of Nutri-Rich was adjusted to provide the same amount of nitrogen (N) as the Osmocote®. For the incorporated treatment, 96.36 g (3.40 oz) Osmocote® or 394.70 g (13.92 oz) Nutri-Rich were mixed into the medium before filling the containers. For the top-dressed treatment, 0.688 g (0.024 oz) of Osmocote® or 2.82 g (0.099 oz) of Nutri-Rich fertilizer were applied to the top of each container before sowing. In the top-dressed containers, care was taken to keep the seeds from contacting the fertilizer, though the higher top-dressing rate of Nutri-Rich fertilizer made this difficult. One-and-a-half container racks were placed in each of 20 subirrigation tubs (figure 1). From each of the four fertilizer treatments, 35 containers were put in a tub, for a total of 140 containers per tub.

Germination Treatments

Four germination treatments were used during the emergence phase (first 6 weeks after sowing): (1) unmisted and uncovered, (2) unmisted and covered with a germination cloth, (3) overhead misted and uncovered, and (4) overhead misted and covered with a germination cloth. The germination cloth was 0.5 oz Plant and Seed Guard (DeWitt Company, Sikeston, MO), a lightweight, white fabric. The treatments that were overhead misted were misted twice a day, in the morning and evening. All treatments were subirrigated during the emergence phase every other day in the morning. Each germination treatment was applied to five subirrigation tubs (whole plots in a split plot design).

Emergence Phase

Following sowing, redosier dogwood seeds were tracked twice daily for emergence. A seed was considered to have emerged when its cotyledons fully cleared the surface of the medium (figure 2). When a seed emerged, it was marked with a ballpoint pin; a different color was used for the first, second, and third seed to emerge in each container. Redosier dogwood seed is technically classified as

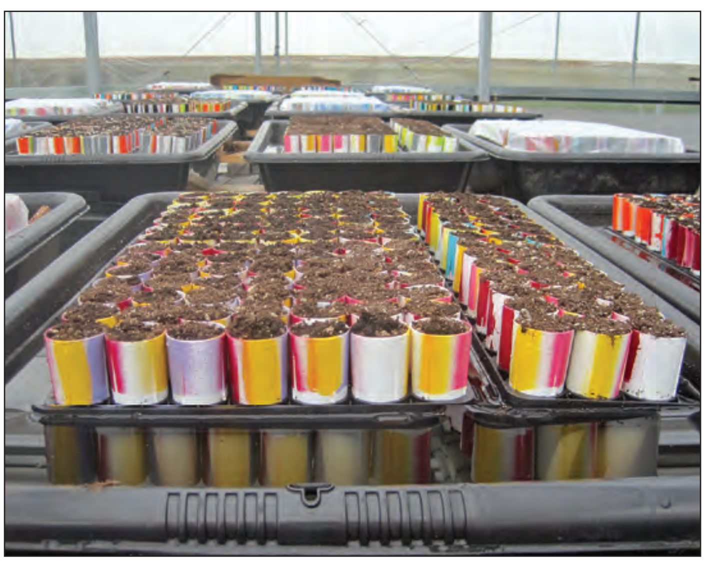

Figure 1. Large cement mixing trays were used to subirrigate seedlings grown in Ray-Leach containers. One-and-a-half racks of Ray-Leach containers fit in the mixing tray. The tray had a plug at the bottom to facilitate draining irrigation water into a storage tub. The containers covered with germination cloth are visible in the background. (Photo by Rebecca Sheridan, 2014)

Figure 2. Newly emerged seedlings were marked with a ballpoint pin when the cotyledons cleared the media surface. At this time, the date of emergence was recorded. (Photo by Rebecca Sheridan, 2014)

a stone containing two embryos. Therefore, each of the seeds planted could potentially produce two seedlings. If two germinants emerged in close proximity or had visibly emerged from the same seed coat, they were classified as seedlings from the same stone. Emergence was scored by container, where at least one seedling had to emerge in a container for it to be counted as having a successful emergence. Emergence was tracked for 5 weeks after the first seedling emerged. If a seedling died during the emergence phase, it was removed, its place was marked with an additional pin, and a possible cause of death was recorded. At the end of the emergence phase, the quality of each remaining seedling was noted.

Growth Phase

After the 6-week emergence phase, each container was thinned to one seedling per cell and the reservoirs of irrigation water were emptied and refilled. The containers, originally organized within the tubs by germination treatment, were reorganized so that the same fertilizer treatments were grouped within the same subirrigation tub. This reorganization meant that seedlings would be exposed to only the assigned fertilizer type if the fertilizer leached into the recycled irrigation water during the experiment. The original plot and subplot identities, however, were tracked through the rest of the experiment.

During the growth phase, the irrigation schedule was based on gravimetric weights, in which the containers were allowed to dry to 80 percent of field capacity during August, then to 70 percent during September and October. The pH and electrical conductivity (EC—a proxy measurement for available fertilizer) of the irrigation water were measured weekly to monitor whether the water stayed within safe ranges for seedlings. The seedlings were not pruned. At the end of August, the seedlings were moved from the Oxbow Native Plant Nursery to the Franklin H. Pitkin Forest Nursery in Moscow, ID (46°43'N., 116°57'W.) and kept outside. Samples were taken from the recycled irrigation water in August before the move and again in October at the end of the growing season and were tested for nutrients. In addition to the scheduled irrigation events, the seedlings received 2.64 cm (1.04 in) of rain during the 2 months they were held outside at the Pitkin Forest Nursery before outplanting.

Outplanting

Seedlings were outplanted in the last week of October 2014 to a relatively flat, tilled agricultural field at the Pitkin Forest Nursery, with coarse loamy soil. No additional experimental treatments or irrigation were applied when the seedlings were planted. During the week after planting, 1.88 cm (0.73 in) of rain fell. Seedling survival was recorded in May 2015. Seedlings were considered dead if they failed to leaf out, if leaves were fully desiccated, or if the seedling was missing entirely. Seedling root collar diameter and height were measured on all outplanted seedlings in November 2014, when the seedlings' leaves had turned red and were beginning to senesce, and again in July 2015, at which time growth was ceasing due to the seasonal summer drought. Field growth was calculated as the difference in height and root collar diameter from the time of outplanting to the final measurements in July.

Statistical Methods

Statistical analyses were done in R, version 3.1.1. The experiment was a split-plot design, in which the whole plot level (germination treatment) was a randomized complete block design. There were five blocks consisting of four irrigation tubs grouped on a table. The subplot level (fertilizer treatments) was also a randomized complete block design. The two phases of this experiment—(1) the emergence phase and (2) the growth and outplanting phase—were analyzed separately. Data collected during the emergence phase were subject to analysis of variance (ANOVA) to test the effects of fertilizer type and germination treatment on emergence. During the growth and outplanting phase, data were analyzed using a multivariate analysis of variance (MANOVA) with a Pillai's trace test to test the effects of fertilizer type and irrigation method on height and root collar growth. MANOVA was used because height and root collar diameter are dependent variables on the same experimental unit, a seedling. Significance was determined at the $\alpha \leq 0.05$ level. The model assumptions of normality and constant variance were evaluated using diagnostic plots, and the assumptions were determined to hold, with no data transformations deemed necessary.

Results

Emergence

In the treatments with Nutri-Rich fertilizer, very few seedlings emerged, which appeared to be due to a fungus gnat infestation, in which the larvae ate germinating seed before seedlings emerged. Therefore, those data were eliminated from the study. Interaction was significant between the Osmocote® fertilizer treatments and germination treatment ($p = 0.04$) (figure 3). Emergence was greater in treatments with overhead misting ($p < 0.001$). The treatments without overhead misting trended toward higher emergence in seedlings with top-dressed fertilizer than those with incorporated fertilizer ($p = 0.06$).

Growth

Measurements of height and root collar diameter in November 2014 accounted for seedling growth through their time in the nursery. A significant interaction occurred between the germination and fertilizer treatments ($p = 0.02$). Seedlings with incorporated Osmocote® fertilizer were taller than seedlings with top-dressed fertilizer (figures 4 and 5). The seedlings with incorporated Osmocote® also had larger root collar diameters (data not shown).

Figure 4. The seedlings were germinated and grown using subirrigation. In this photo, seedlings on the left were grown with top-dressed Osmocote® fertilizer and those on the right were grown with incorporated Osmocote® fertilizer. By November 2014, the seedlings with incorporated fertilizer were significantly taller than the seedlings with top-dressed fertilizer. (Photo by Rebecca Sheridan, 2014)

After planting, some seedlings suffered from herbivory, presumably by rabbits (Riley 2014), and some experienced frost heave; however, most were able to persist and grow in spite of these challenges. Redosier dogwood has the ability to resprout, and this growth pattern was observed in some cases in the field.

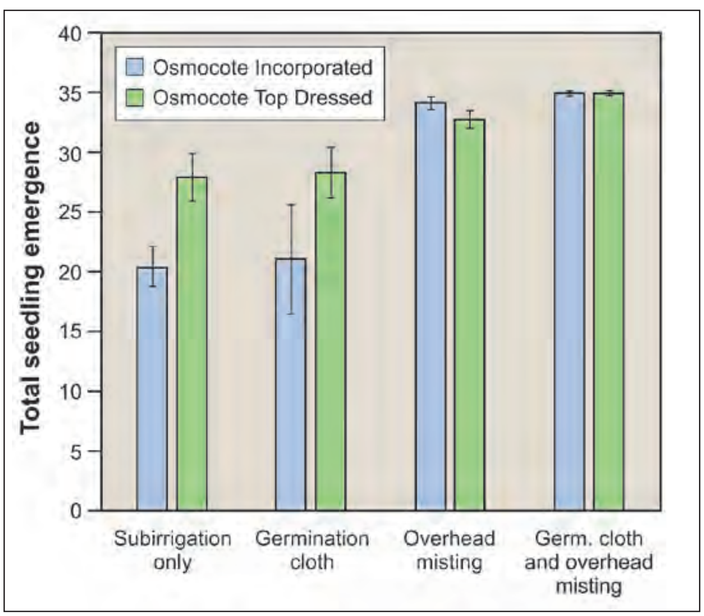

Figure 3. Seedling emergence was tracked by irrigation and fertilization treatment. The highest rates of emergence occurred in treatments that received overhead irrigation in addition to subirrigation. A statistically significant interaction ($p < 0.05$) occurred between the irrigation type and the fertilization method. The bars show standard error for five replications.

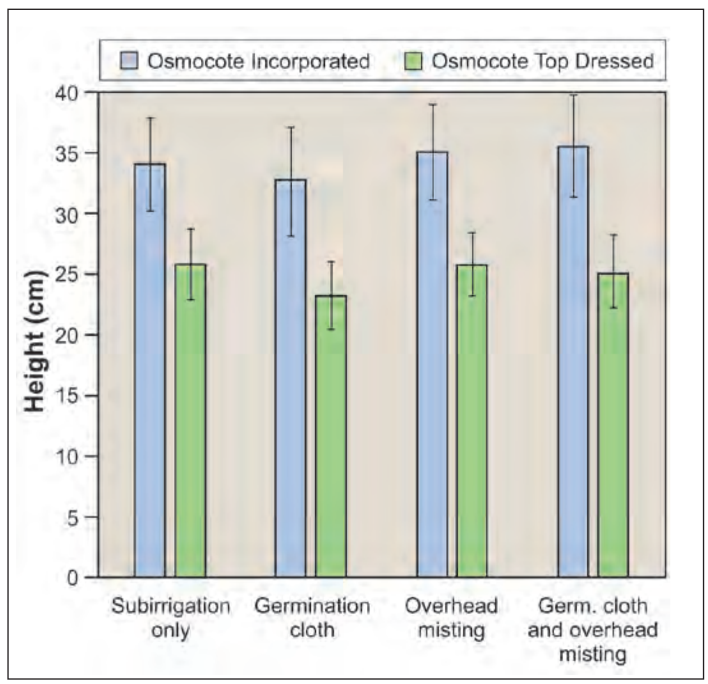

Figure 5. Seedling height after the nursery growing season (measured in November 2014, after the seedlings had dropped their leaves). Seedlings grown with incorporated Osmocote® fertilizer were taller than those with top-dressed fertilizer ($p<0.001$). The bars show standard error for five replications.

Seedling growth after outplanting was significantly affected by fertilizer type ($p < 0.001$) and germination treatment ($p < 0.02$), with no significant interaction between the two treatments. Seedlings with top-dressed fertilizer had greater height and root collar diameter growth than did those with incorporated fertilizer (table 1).

Discussion

The first phase of this experiment showed that it is possible to germinate seed using subirrigation only, but the emergence rates were lower in this treatment compared with those that also received overhead misting. The emergence phase has been identified as a challenge to adoption of subirrigation in nurseries (Dumroese et al. 2007). Even without sufficient water, seed may still germinate, but the seed will be more vulnerable to disease and decay, and germination will be less uniform (Bewley and Black 1994). Nursery growers work to avoid these situations. Alternative nursery cultural techniques, such as a grit layer on the top of containers, could also be used in conjunction with subirrigation to create favorable germination conditions. As nursery growers make decisions about propagation protocols using subirrigation, they will need to consider the natural history of the species with which they are working (Schmal et al. 2011). The redosier dogwood seed used in this experiment is relatively large, and the species is a wetland plant. The size and germination characteristics of other species might affect their suitability for use in a subirrigation system.

The treatments with Nutri-Rich fertilizer did not produce many seedlings. Although fungus gnat larvae were seen in all the treatment types, a greater number of larvae were observed in the containers with Nutri-Rich. It is unknown whether this condition was a direct consequence of the fertilizer, or if it was due to changes in the physical characteristics of the medium resulting from the fertilizer. In another study, Nutri-Rich fertilizer increased the medium's water-holding capacity in a subirrigation system (Dunlap 2015). Fungus gnats were also a problem in a previous subirrigation study, and reducing irrigation frequency helped address the issue (Dumroese et al. 2006).

In subirrigation systems, nitrogen (N) from the controlled-release fertilizer is primarily retained within the medium and plant, and little N is lost in runoff water (Morvant et al. 2001, Pinto et al. 2008). EC is higher at the top of containers that are subirrigated when growing a species that does not have fibrous roots in the upper layer of medium (Davis et al. 2008). By contrast, subirrigated containers that are planted with a species that has shallow, fibrous roots do not show elevated EC in the upper medium (Pinto et al. 2008). In this experiment, the seedlings were not observed to have numerous shallow roots, and the seedlings grown with incorporated fertilizer probably had better access to the fertilizer while growing in the nursery. Fertilizer that is retained within the media is available to the plant for use after outplanting (Dumroese et al. 2006, 2011), which may explain

Table 1. Fertilizer treatment ($p < 0.001$) and germination treatment ($p < 0.02$) had a significant effect on height and root collar diameter growth.

Treatment	Height growth (cm) and (standard error)	Root collar diameter growth (mm) and (standard error)
Osmocote® incorporated		
Subirrigation only	15.9 (4.0)	1.57 (0.51)
Germination cloth	21.5 (5.4)	2.03 (0.31)
Overhead misting	18.2 (4.0)	1.73 (0.40)
Germination cloth and overhead misting	15.1 (3.6)	1.78 (0.38)
Osmocote® top dressed		
Subirrigation only	18.9 (4.2)	1.78 (0.43)
Germination cloth	20.4 (4.0)	2.04 (0.43)
Overhead misting	22.5 (5.0)	1.97 (0.46)
Germination cloth and overhead misting	20.0 (3.8)	1.95 (0.40)

cm = centimeter. mm = millimeter.

Note: The standard errors are for five replications.

why we observed greater growth of the top-dressed seedlings after outplanting. The top-dressed fertilizer, which stays relatively dry in a subirrigation system compared with the incorporated fertilizer, may have broken down more slowly and, therefore, may have been available to the seedling in greater amounts after outplanting. Improving seedling quality or outplanting success with fertilizer has its limits, and extremely high rates of fertilization can negatively impact seedling quality and survival (Bumgarner et al. 2015), especially on dry sites. The germination treatments also had significant effects on growth after outplanting, which demonstrates the importance of following seedlings through outplanting to determine if nursery cultural practices continue to affect seedlings after outplanting (Davis et al. 2011).

This experiment demonstrated that it is possible for seed to germinate using subirrigation. This finding leads to further questions about how to improve germination and what options are best for fertilizing seedlings in subirrigation. Subirrigation will not be the irrigation method of choice for every nursery or every species, but it is an important tool that nursery growers can consider among their propagation options.

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REFERENCES

Baskin, C.C. and Baskin, J.M. 2014. Seeds: ecology, biogeography, and evolution of dormancy and germination. 2nd ed. San Diego: Academic Press.1586 p.

Bewley, J.; Black, M. 1994. Seeds: physiology of development and germination. 2nd ed. New York: Plenum Press. 445 p.

Bumgarner, M.; Salifu, K.; Jacobs, D.F. 2008. Subirrigation of *Quercus rubra* seedlings: nursery stock quality, media chemistry, and early field performance. HortScience. 43(7): 2179–2185.

Bumgarner, M.; Salifu, K.; Mickelbart, M.; Jacobs, D.F. 2015. Effects of fertilization on media chemistry and *Quercus rubra* seedling development under subirrigation. HortScience. 50(3): 454–460.

Davis, A.S.; Aghai, M.M.; Pinto, J.R.; Apostol, K.G. 2011. Growth, gas exchange, foliar nitrogen content, and water use of subirrigated and overhead-irrigated *Populus tremuloides* Michx. seedlings. HortScience. 46(9): 1249–1253.

Davis, A.S.; Jacobs, D.F.; Overton, R.P.; Dumroese, R.K. 2008. Influence of irrigation method and container type on northern red oak seedling growth and media electrical conductivity. Native Plants Journal. 9(1): 5–12.

Dumroese, R.K.; Davis, A.S.; Jacobs, D.F. 2011. Nursery response of *Acacia koa* seedlings to container size, irrigation method, and fertilization rate. Journal of Plant Nutrition. 34(6): 877–887.

Dumroese, R.K.; Jacobs, D.F.; Davis, A.S.; Pinto, J.R.; Landis, T.D. 2007. An introduction to subirrigation in forest and conservation nurseries and some preliminary results of demonstrations. In: Riley, L.E.; Dumroese, R.K.; Landis, T.D., tech. coords. National proceedings, forest and conservation nursery associations—2006. Proceedings RMRS-P-50. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 20–26.

Dumroese, R.K.; Pinto, J.R.; Jacobs, D.F.; Davis, A.S.; Horiuchi, B. 2006. Subirrigation reduces water use, nitrogen loss, and moss growth in a container nursery. Native Plants Journal. 7(3): 253–261.

Dunlap, L.J. 2015. Using subirrigation to grow native plants for restoration. Moscow, ID: University of Idaho. 49 p. Master's thesis.

Ferrarezi, R.S.; Weaver, G.M.; van Iersel, M.W.; Testezlaf, R. 2015. Subirrigation: historical overview, challenges, and future prospects. HortTechnology. 25(3): 262–276.

Gent, M.P.N.; McAvoy, R.J. 2011. Water and nutrient uptake and use efficiency with partial saturation ebb and flow watering. HortScience. 46(5): 791–798.

Landis, T.D. 1989. Irrigation and water management. In: Landis, T.D.; Tinus, R.W.; McDonald, S.E.; Barnett, J.P., eds. The container tree nursery manual. Agricultural Handbook 674. Washington, DC: U.S. Department of Agriculture, Forest Service: 69-118. Chapter 2. Vol. 4.

Landis, T.D.; Wilkinson, K. 2004. Subirrigation: a better option for broad-leaved container nursery crops? Forest Nursery Notes. Summer 2004: 14–17.

Morvant, J.K.; Dole, J.M.; Cole, J.C. 2001. Fertilizer source and irrigation system affect geranium growth and nitrogen retention. HortScience. 36(6): 1022–1026.

Pinto, J.R.; Chandler, R.A.; Dumroese, R.K. 2008. Growth, nitrogen use efficiency, and leachate comparison of subirrigated and overhead irrigated pale purple coneflower seedlings. HortScience. 43(3): 897–901.

Riley, I. 2014. Personal communication. Graduate student, Idaho Cooperative Fish and Wildlife Unit, College of Natural Resources, University of Idaho, Moscow.

Schmal, J.; Dumroese, R.K.; Davis, A.S.; Pinto, J.R.; Jacobs, D.F. 2011. Subirrigation for production of native plants in nurseries: concepts, current knowledge, and implementation. Native Plants Journal. 12(2): 81–93.

Stevens, M.; Dozier, I. 2000. Plant guide: redosier dogwood *Cornus sericea* L. Baton Rouge, LA: U.S. Department of Agriculture, National Resources Conservation Service, National Plant Data Center. 5 p. http://plants.usda.gov. (January 2015).

Wilen, C.; Schuch, U.; Elmore, C. 1999. Mulches and subirrigation control weeds in container production. Journal of Environmental Horticulture. 174(4): 174–180.

Effect of Nursery Photoperiod Manipulation on Coastal Douglas-fir Seedling Development: Early Results

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Abstract

Photoperiod manipulation by artificial short-day treatment (blackout) is increasingly used as a tool to induce dormancy in nursery-grown seedlings. This article summarizes preliminary results from a project to evaluate optimum blackout protocols for Douglas-fir (Pseudotsuga menziesii [Mirb.] Franco) seedlings. We subjected seedlings to three blackout intensities (mild, moderate, and long) and compared morphological and physiological responses at the time of lifting and during the next growing season with seedlings in a control treatment (ambient day length) and a progressive blackout treatment involving a gradual reduction of light during the hardening phase. We additionally characterized morphology, bud break, and root growth in response to varying rhizosphere temperatures. Preliminary results indicate that seedlings subjected to blackout treatments had earlier bud break in both a controlled hydroponic culture and a field plot. Seedlings from the mild, moderate, and long blackout treatments had less root growth in the hydroponic trial but greater early spring shoot and root biomass in the field plot. By the end of the growing season, however, biomass in the field plot did not differ among treatments. Cold hardiness was unaffected by treatments. Additional results from this trial and another trial to examine blackout effects on varying seed sources will be published at a later date. This paper was presented at the annual meeting of the Western Forest and Conservation Nursery Association (Eugene, OR, October 26–27, 2015).

Introduction

Dormancy induction of nursery-grown seedlings in early autumn is important to prevent frost damage, promote better shoot-to-root ratios, and minimize stress during lifting and storage. Dormancy can be induced by reducing fertilization or irrigation or by physical manipulation (Grossnickle and South 2014). It can be difficult, however, to successfully induce dormancy. For example, container-grown Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) seedlings did not move into an endodormant state when exposed to water stress in combination with reduced fertility in early fall (Macdonald and Owens 2006). These techniques also have the potential to reduce plant vigor and thus decrease subsequent survival and performance after outplanting (Villar-Salvador et al. 2015). For example, Douglas-fir seedlings with low internal nitrogen (N) levels were less cold hardy than seedlings with higher N levels (Timmis 1974).

Because of fewer negative effects on plant quality compared with conventional techniques, forest tree nurseries increasingly are using photoperiod manipulation during propagation (i.e., short-day treatments or blackout) to slow growth and induce dormancy in conifer species from northern latitudes (Hawkins et al. 1996). In general, the greater the reduction in photoperiod and the earlier the initiation of light deprivation, the more rapidly dormancy is induced. Intense light deprivation, however, can reduce plant reserves and hence reduce growth in the next year (Hawkins et al. 1996). Research indicates that blackout can be used to induce dormancy in species such as Douglas-fir (Jacobs et al. 2008, Turner and Mitchell 2003). To define the optimum blackout protocol for this species, it is necessary to examine the effects of different blackout treatments on seedling dormancy, morphology, and performance after planting.

Root growth and stress resistance also influence seedling survival and performance after outplanting (Grossnickle and South 2014, Villar-Salvador et al. 2015). Vigorous root development following field planting is necessary to minimize potential for seedling physiological drought and ensure survival (Grossnickle 2005). Soil temperature in most temperate outplantings during winter or early spring is usually relatively cold (i.e., <10 ºC [50 °F]) and can limit root growth and establishment of planted seedlings (Jacobs et al. 2008, Villar-Salvador et al. 2015). Adequate cold hardiness and stress resistance are needed during drought and low-temperature events (Grossnickle and South 2014, Villar-Salvador et al. 2015). Frost resistance is especially important in both fall and early spring for seedling performance and survival. Photoperiod has an important role in frost tolerance, because it affects both bud set and dormancy release. Seedlings additionally must resist stresses of transport to the outplanting site and, following planting, seedlings usually must deal with late spring frosts. Thus, cold resistance in late spring is of particular interest, but it has been little studied in combination with blackout treatments.

This article summarizes preliminary results from an ongoing study to test blackout treatments and rhizosphere temperature effects on Douglas-fir phenology, quality, and vigor, with the objectives of determining optimal blackout protocols and coming to a better understanding of seedling performance after outplanting.

Materials and Methods

Seedlings

Douglas-fir seeds were collected from the Washington State Department of Natural Resources Meridian Seed Orchard (Olympia, WA), representing a composite of collections harvested from 2001 through 2010 from the South Sound (0 to 610 m [0 to 2,000 ft] elevation) breeding block.

Seeds were sown on February 18, 2014, into 170 mL (10 in^3), 77-cell Styroblock™ containers (Beaver Plastics Ltd., Acheson, AL, Canada). Soil media consisted of an 80:20 peat:perlite medium with 60 g seedling^{-1} of Nutricote Total 18-6-8 Type 180 controlled-release fertilizer preincorporated into the medium. All seedlings were grown under equivalent operational practices at the L.T. Mike Webster Forest Nursery near Olympia, WA (46°57’00” N. 122°57’36” W.). Seedlings were grown under greenhouse cover until June 3, 2014, when they were moved outdoors.

Blackout Treatments

We tested five treatments with varying periods of light deprivation. Treatments were initiated on July 14, 2014, as follows:

1. Control—ambient photoperiod.
2. Mild—7 days blackout, 7 days ambient light, 7 days blackout.
3. Moderate—14 days blackout, 7 days ambient light, 7 days blackout.
4. Long—21 days blackout, 7 days ambient light, 7 days blackout.
5. Progressive—continuous (initiated August 1).

It is conventional to apply blackout treatments in a static manner at the same time each day for the treatment period, as in our mild, moderate, and long blackout treatments that received 9 hours of light and 15 hours of darkness during blackout. The conifer phytochrome system, however, which, in part, is responsible for stimulating bud set during shortening photoperiods, likely responds to environmental inputs other than the single mechanism of absolute day length. For example, the phytochrome system may respond to increasing or decreasing day lengths (Greer et al. 1989). Thus, we included the progressive treatment that consisted of a progressive reduction of light based on the natural photoperiod of 1 month ahead and gradually (weekly) decreasing to meet the natural photoperiod at the end of October. We started with 120 min light reduction on August 1 (to simulate light levels on September 1) and finished with 10 min of light reduction on October 30. A total of 616 seedlings were assigned to each treatment.

All treatments received equal amounts of water stress by gradually lowering gravimetric block weights to 55 to 60 percent from late June through late September. Seedlings were lifted from containers on December 3, 2014, and cooler stored at 2±1°C (35±1°F).

Morphology Characterization

Forty-eight seedlings per treatment were destructively sampled after lifting. Shoots were cut at the point of insertion of the cotyledon and separated into shoots and roots. Root plugs were carefully washed to remove growing medium. Then all seedling fractions were gently washed with tap water, rinsed in deionized water, oven dried for 72 h at 60 °C (140° F), weighed, and ground. Shoot-to-root ratio was estimated by dividing shoot mass by root mass.

Cold Hardiness Assessment

Cold hardiness was determined on 48 seedlings per treatment in mid-April 2015. Five subsamples of 100 mg of leaves and five subsamples of 100 mg of roots from each seedling were placed into 20 ml (0.67 oz) vials and filled with 10 ml (0.34 oz) of deionized water. The five subsamples per organ corresponded to five test temperatures: 2 (control), -10, -20, -30 and -40 ºC (35.6, 14, -4, -22, and -40 ºF). The control treatment was placed into a refrigerator (2 ºC [35.6 ºF), and the four remaining vials per organ were placed into a programmable freezer (So-Low Environmental Equipment Co., Inc., Cincinnati, OH). Beginning with an initial temperature of 0 ºC (32 ºF), the temperature was decreased by 0.3 ºC min-1 (0.5 ºF min^{-1}). Each test temperature was maintained for a period of 30 min, after which time the vials designated for that test temperature were removed, and the temperature continued to decrease to the next temperature. Vials were thawed at 2 ºC (35.6 ºF) for approximately 24 h and then moved to ambient conditions to complete thawing. After thawing, electrolyte leakage of leaves and roots was measured with an HI 9813 portable conductivity meter (Hanna Instruments, Inc., Woonsocket, RI). Maximum conductivity was determined by placing vials in an autoclave (Getinge USA, Inc., Rochester, NY) at 120 ºC (248 ºF) for 20 min. Electrolyte leakage liberation (ELL) values were then calculated as a percentage of conductivity at each test temperature compared with that at maximum conductivity, and finally were expressed as the difference of ELL between control temperature and frost temperatures (ELLc).

Root Temperature Treatments

Seedling growth under different rhizosphere temperatures was assessed by growing seedlings in hydroponic tanks. On May 4, 2015, seedlings were removed from cold storage and the root plug was cleaned of substrate. Then, seedlings were transplanted into hydroponic tanks in a greenhouse with root zone temperatures of 5, 10, or 20 ºC (41, 50, or 68 °F), corresponding to low, normal, and optimum soil temperatures in the spring (figure 1). We used three to four tanks per temperature with eight seedlings per treatment in each tank. The number of new roots was recorded after 4 weeks. In addition, budbreak day of each seedling in the different tanks was recorded.

Field Trial

A garden plot was established at the Webster Nursery to evaluate field response following blackout treatments. Approximately 300 seedlings per treatment were planted on February 26, 2015, in a research block at the nursery. The soil is a Cagey loamy sand. In the first year of field growth, we recorded the budbreak date for each seedling. In addition, 40 seedlings per treatment were randomly chosen and excavated on May 11 and again on August 16 of the first year (second-year data will be obtained in 2016). Excavated seedlings were divided into new shoots, old shoots, old roots (plug roots), and new fine roots and were measured for dry mass.

Study Design and Data Analyses

The effect of blackout treatment on shoot and root mass at lifting was analyzed with one-way analysis of variance (ANOVA). For cold hardiness, temperature

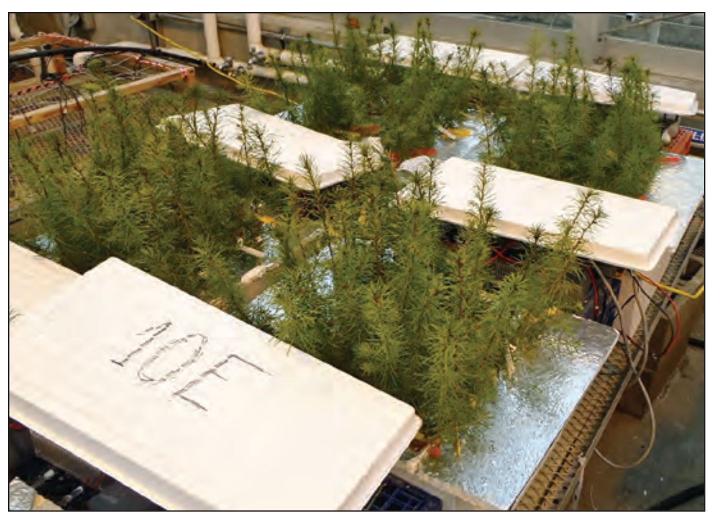

Figure 1. Douglas-fir seedlings from different blackout treatments were grown in a hydroponic system for 28 days under controlled root zone temperatures. (Photo by Mercedes Uscola, 2015)

and blackout treatments were considered as independent variables in a two-way ANOVA for each organ separately. For budbreak date in the field trial and hydroponic culture, we ran an event history analysis. The analysis function used is the Cox mixed-effects proportional-hazards model with days to bud break as the dependent variable and blackout and temperature (in the hydroponic trial) as the independent variable(s). For the number of new roots in the hydroponic culture experiment, tank was considered as the random effect in a generalized linear model, and temperature and blackout treatments were the independent variables. In the field trial, shoot and root mass growth was obtained by subtracting average initial biomass at lifting from biomass of each seedling at the time of harvest. Then, mass growth was analyzed independently for each sampling date by a one-way ANOVA with blackout treatment as the independent variable. When significant factor effects were detected, Tukey's Honestly Significant Difference test was used to identify differences between treatment means at $\alpha = 0.05$. Statistical analyses were conducted with R version 3.1.0 (Spring Dance, release 2014-04-10).

Preliminary Results and Discussion

Blackout Treatment Effects on Morphology

At lifting, the progressive and mild treatments were too mild to stop shoot mass growth compared with the control seedlings ($P = 0.0065$; figures 2 and 3). The other blackout treatments, however, effectively reduced shoot mass growth compared with control seedlings. It is interesting to note that differences in morphology also occurred below ground ($P = 0.017$). The mild treatment produced seedlings with the highest root mass, the control and progressive treatments resulted in the lowest root mass, and the long and moderate treatments had intermediate root mass.

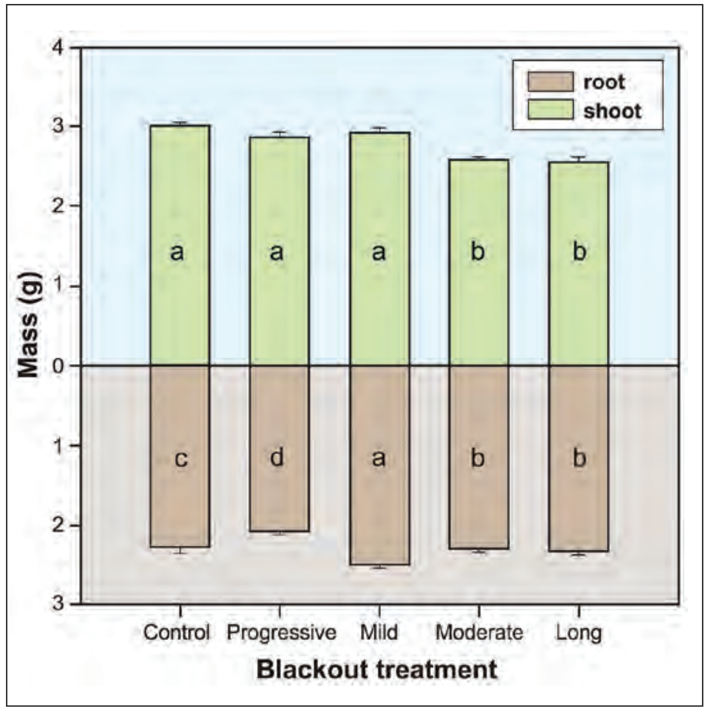

Figure 3. Shoot and root mass of Douglas-fir seedlings subjected to five different blackout treatments to induce bud set. Different letters denote significant differences in root or shoot mass at $\alpha = 0.05$.

These differences in shoot and root mass promoted lower shoot-to-root ratios in blackout-treated seedlings, especially in mild and moderate seedlings (data not shown). A well-balanced shoot-to-root system, with a sturdy stem and a large fibrous root system, provides the best chance for seedling survival, especially in droughty sites (Grossnickle 2012).

Cold Hardiness

Jacobs et al. (2008) found that greater cold hardiness of blackout-treated seedlings compared with seedlings under normal day-length conditions was maintained throughout the spring deacclimation period. They suggest increased fall cold hardiness associated with blackout treatment may be maintained under

Figure 2. Douglas-fir seedlings subjected to five different blackout treatments varied in morphology at the time of lifting. (Photo by Nabil Khadduri, 2014)

freezer-storage conditions through spring dormancy release. In this study, however, we found similar cold resistance in late spring for both blackout-treated seedlings and control seedlings at all temperatures for both leaves and roots (figure 4).

Root Temperature Effects

Rhizosphere temperature ($P < 0.001$) had an effect on bud break, which was independent of blackout treatment (interaction $P = 0.67$). By the end of the experiment (28 days), 90.6 percent of seedlings in the 20 ºC (68 ºF) treatment broke bud, but only 60.3 and 30.5 percent of seedlings exhibited bud break in the 10 and 5 ºC (50 and 41 °F) treatments, respectively. Higher rhizosphere temperature also significantly increased the number of new roots, with maximum growth at 20 ºC (68 ºF), independent of the blackout treatment (figure 5a). Limitations to new growth at low temperatures can be explained, at least in part, because of inhibitions to root hydraulic conductivity and metabolic activity (Bowen 1991).

The number of new root tips was greatest in progressive and control seedlings (figure 5b). By contrast, Jacobs et al. (2008) showed that blackout treatment increased Douglas-fir root growth compared

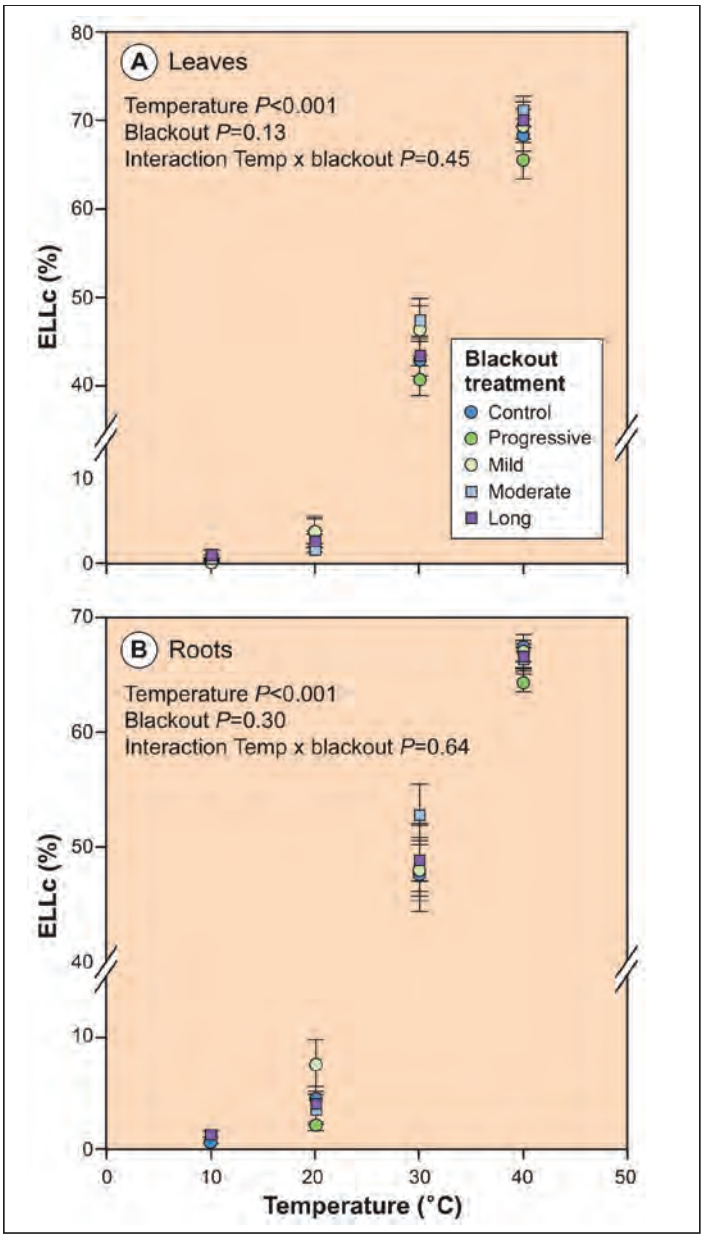

Figure 4. Electrolyte leakage liberation (ELL) following freezing of (a) leaves and (b) roots of Douglas-fir seedlings subjected to five different blackout treatments. Values at each temperature were corrected by subtracting the ELL at control temperature (2°C [35.6 ºF]).

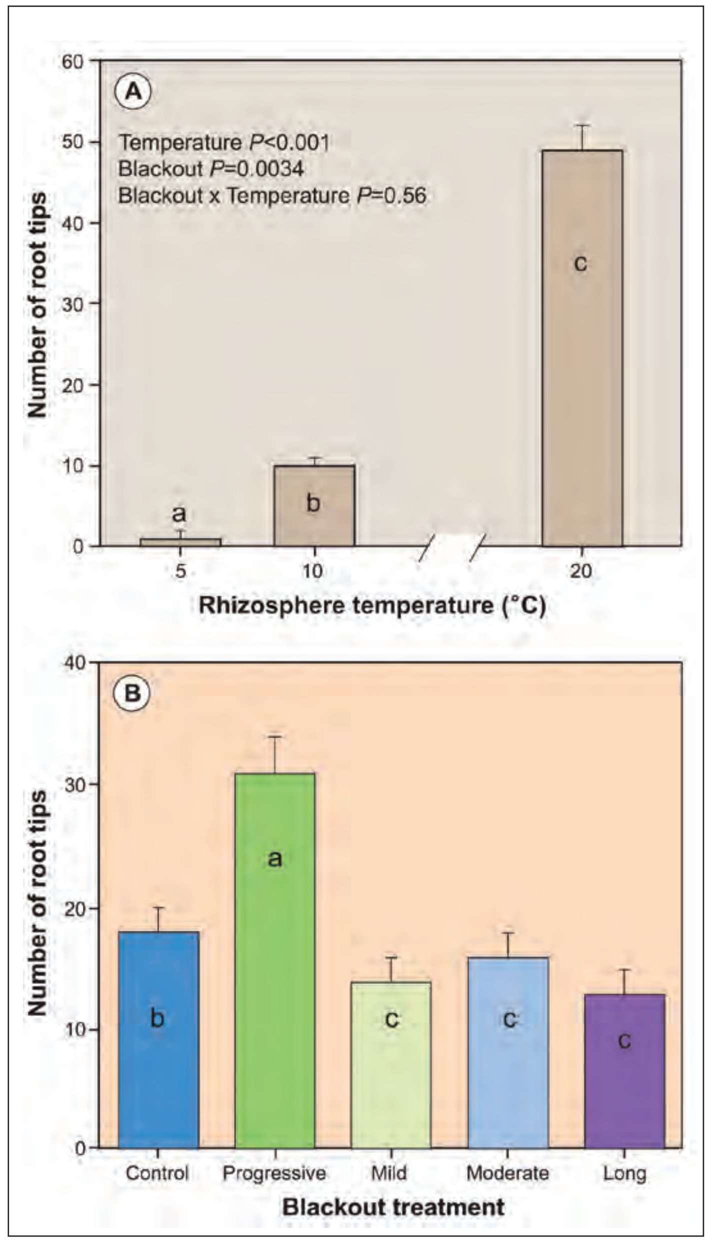

Figure 5. Effect of (a) rhizosphere temperature and (b) blackout treatment on the number of new root tips of Douglas-fir seedlings after 28 days in hydroponic tanks.

with controls at low soil temperatures. In this experiment, root growth of blackout-treated seedlings was less than controls, especially in the most intensely blackout-treated seedlings. This finding could indicate that the most intense blackout treatments reached a limit in which negative effects appeared, perhaps due to reduction of carbohydrates (Carpenter et al. 1983). Blackout treatment ($P < 0.001$) also had an effect on bud break in the hydroponic experiment. By the end of the experiment (28 days), mild-, moderate-, and long-treated seedlings had 62 to 67 percent bud break, whereas the control and progressive-treated seedlings had only 50 percent bud break.

Field Performance and Phenology

The effect of blackout treatment on bud break occurred in a similar manner under field conditions, with the control and progressive-treated seedlings breaking bud later than the other treatments ($P < 0.001$; figure 6). The number of days needed for 50 percent of the seedlings to break bud was less than 20 days in the mild, moderate, and long blackout-treated seedlings, but the control and progressive-treated seedlings needed 27 and 30 days, respectively. Reduction in photoperiod has been shown to decrease days to bud break in several temperate conifer species (Brigas and D´Aoust 1993, Hawkins et al. 1996). In Douglas-fir, photoperiod effect on bud break can be strongly dependent on provenance (Campbell and Sugano 1975). Spring phenology of temperate forest trees is optimized to maximize the length of the growing season while minimizing the risk of freezing damage. Earlier bud break can be advantageous for seedlings to be more competitive with vegetation, but it could also increase the risk of frost damage in early spring. In early spring, shoot and root biomass of excavated seedlings differed significantly among treatments ($P < 0.001$ for both roots and shoots; figure 7a). In general, control and progressive seedlings had lower biomass growth than seedlings from the mild, moderate, and long blackout-treated seedlings. These differences may be explained, in part, by bud-break differences. By the end of the first growing season, however, dry mass of shoots and roots did not differ among treatments ($P = 0.71$ and $P = 0.70$ for roots and

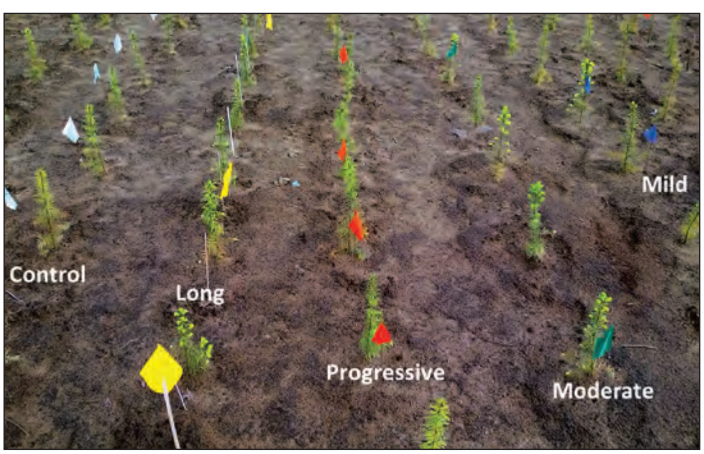

Figure 6. Spring bud break varied among Douglas-fir seedlings subjected to different blackout treatments. Note that the progressive-treated and control seedlings have later bud break. (Photo by Nabil Khadduri, 2015)

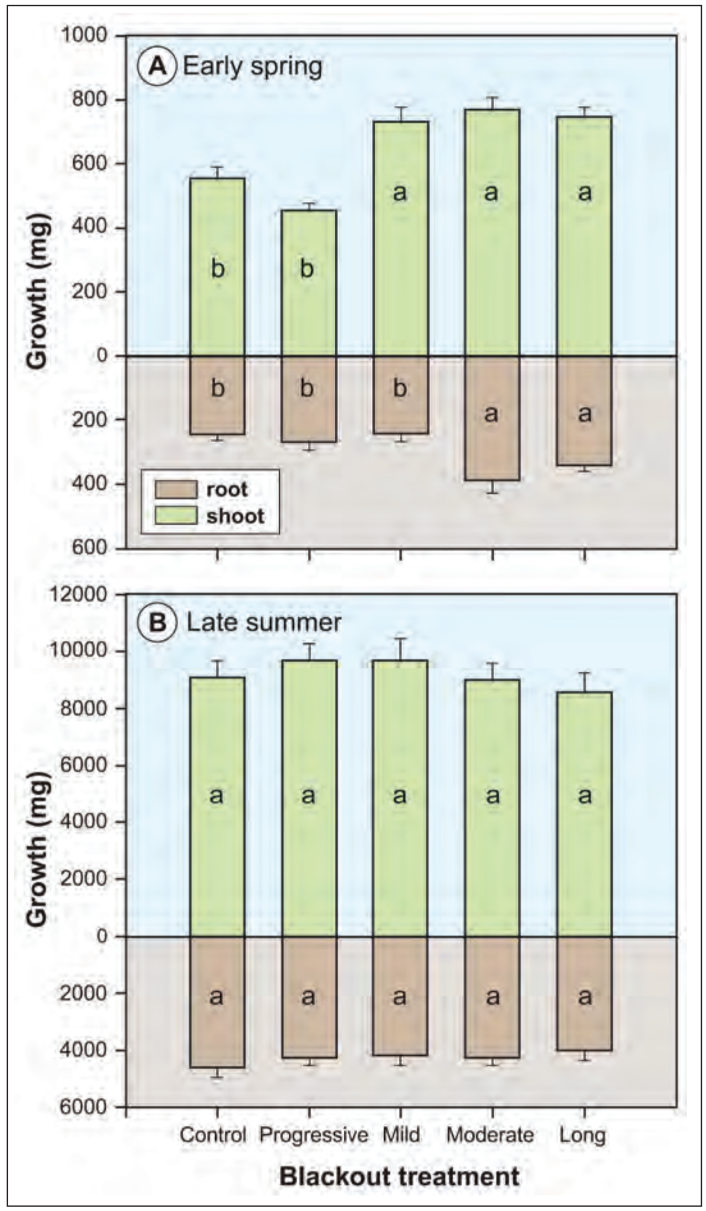

Figure 7. Shoot and root growth (a) in early spring and (b) at the end of the first growing season in the field for Douglas-fir seedlings previously subjected to five different blackout treatments.

shoots, respectively; figure 7b). Nonetheless, due to initial mass differences among treatments, total mass differences persisted after 1 year of growth in the field (data not shown).

Future Directions

Whether the observed effects of blackout will persist under field conditions after a second year is unclear. Thus, we are continuing to evaluate field performance over a second growing season. Interactions between blackout treatments and latitude of seed lot origin may also affect dormancy development and cold hardiness (Coursolle et al. 1997). To address these factors, we are also conducting a new trial looking at the effect of blackout on seed sources from southern Oregon, Washington, and British Columbia. Results will be published in a forestry journal in the next couple of years.

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REFERENCES

Bowen, G.D. 1991. Soil temperature, root growth and plant function. In: Waisel, Y.; Dekker, M., eds. Plant roots: the hidden half. New York: Science: 309–330.

Brigas, F.J.; D´Aoust, A.L. 1993. Influence of photoperiod on shoot and root frost tolerance and bud phenology of white spruce seedlings (*Picea glauca*). Canadian Journal of Forest Research. 23(2): 219–228.

Campbell, R.K.; Sugano, A.I. 1975. Phenology of bud burst in Douglas-fir related to provenance, photoperiod, chilling, and flushing temperature. Botanical Gazette. 136(3): 290–298.

Carpenter, A.S.B.; Immel, M.J.; Smith, N.D. 1983. Effect of photoperiod on the growth and photosynthetic capacity of Paulownia seedlings. Castanea. 48(1): 13–18.

Coursolle, C.; Bigras, F.J.; Margolis, H.A.; Hébert, C. 1997. Dehardening and second-year growth of white spruce provenances in response to duration of long-night treatments. Canadian Journal of Forest Research. 27(8): 1168–1175.

Greer, D.H.; Stanley, C.J.; Warrington, I.J. 1989. Photoperiod control of the initial phase of frost hardiness development in *Pinus radiata*. Plant Cell and Environment. 12(6): 661–668.

Grossnickle, S.C. 2005. Importance of root growth in overcoming planting stress. New Forest. 30(2): 273–294.

Grossnickle, S.C. 2012. Why seedlings survive: influence of plant attributes. New Forest. 43(5): 711–738.

Grossnickle, S.C.; South, D.B. 2014. Fall acclimation and the lift/store pathway: effect on reforestation. The Open Forest Science Journal. 7: 1–20.

Hawkins, C.; Eastham, A.; Story, T.; Eng, R.Y.N.; Draper, D.A. 1996. The effect of nursery blackout application on Sitka spruce seedlings. Canadian Journal of Forest Research. 26(12): 2201–2213.

Jacobs, D.F.; Davis, A.S.; Wilson, B.C.; Dumroese, R.K.; Goodman, R.C.; Salifu, K.F. 2008. Short-day treatment alters Douglas-fir seedling dehardening and transplant root proliferation at varying rhizosphere temperatures. Canadian Journal of Forest Research. 38(6): 1526–1535.

Macdonald, J.E.; Owens, J.N. 2006. Morphology, physiology, survival, and field performance of containerized coastal Douglas fir seedlings given different dormancy-induction regimes. HortScience. 41(6): 1416–1420.

Timmis, R. 1974. Effect of nutrient stress on growth, bud set, and hardiness in Douglas-fir seedlings. In: Tinus, R.W.; Stein, W.I.; Balmer, W.E., eds. Proceedings, North American containerized forest tree seedling symposium. Pub. No. 68. Denver: Great Plains Agricultural Council: 187–193.

Turner, J.; Mitchell, S.J. 2003. The effect of short day treatments on containerized Douglas-fir morphology, physiology and phenology. New Forest. 26(3): 279–295.

Villar-Salvador, P.; Uscola, M.; Jacobs, D.F. 2015. The role of stored carbohydrates and nitrogen in the growth and stress tolerance of planted forest trees. New Forest. 46(5): 813–839.

Phenology of Pacific Northwest Tree Species

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Abstract

Phenology is the study of the timing of recurring biological events. For foresters, the most commonly observed phenological events are budburst, flowering, and leaf fall, but other harder to observe events, such as diameter-growth initiation, are also important. Most events that occur in the spring are influenced by past exposure to cool (chilling) temperatures and also to warm (forcing) temperatures. For trees in the Pacific Northwest, chilling temperatures generally promote earlier growth initiation, but species differ in their sensitivity to chilling and forcing and to whether some minimum amount of chilling is required for certain events, such as budburst, to occur at all. The initiation of diameter growth for the studied species does not require chilling and may begin 6 to 8 weeks before height growth. The timing of height growth may affect the pattern of diameter growth early in the season. The timing of reproductive events for conifers varies by species and can occur well before vegetative growth begins. This paper was presented at the annual meeting of the Western Forest and Conservation Nursery Association (Eugene, OR, October 26–27, 2015).

Introduction

Phenology is the study of the timing of recurring biological events such as growth initiation in plants, insect hatching, or bird migrations. The timing of these events is critically important, because it determines how well periods of activity are matched with periods of suitable environmental conditions. In trees, phenology represents a balancing act; if growth begins too early in the year, tender new tissues can be killed by frost, but, if growth begins late, the length of the growing season is shortened and opportunities are missed to grow under the favorable temperature and moisture conditions of spring and early summer. These missed opportunities may be especially costly in temperate climates with short growing seasons due to cold or drought, or both. Trees in temperate regions rely on winter chilling, photoperiod, and warm temperatures to control phenological events, but species differ in the number of factors which control an event such as budburst (Körner and Basler 2010).

An understanding of tree phenology is important for effective nursery and forest management. Many physiological processes in temperate trees occur seasonally, including spring budburst, the initiation and progression of diameter growth, sap flow, flowering, development and dispersal of seeds, fall budset or growth cessation, the development of leaf color and leaf fall, and the timing of root growth. Understanding what determines when these key processes occur is fundamental to our understanding of tree function, and it helps us predict how changes in the environment will affect forest productivity and health. This may be particularly important for understanding the impacts of predicted changes in future climate (IPCC 2014), including evaluating possible management options. In addition, the effectiveness of management actions, such as fertilizer or pesticide application, depends on the timing of those treatments relative to tree activity and development. An understanding of tree phenology can help optimize treatment effects.

Phenological events in trees are typically triggered by cues from their environment, but the relationship between phenology and the environment can be complex. At mid to high latitudes, temperature is often the primary signal for phenological events, particularly in the spring. Exposure to warm temperatures accumulated over the fall, winter, and spring, referred to as "forcing," typically triggers budburst, flowering, and cambial reactivation; however, exposure to cool temperatures while the tree is dormant, referred to as "chilling," also plays a critical role (Romberger 1963, Sarvas 1974, Vegis 1964). In some cases, a phenological event in the spring cannot occur unless a tree has experienced a sufficient amount of chilling. Also, regardless of whether a tree has a minimum or obligate chilling requirement, the amount of chilling can influence how much forcing is required, with the amount of required forcing generally declining with greater chilling (Carlson 1985, Harrington et al. 2010, Ford et al. 2016). As a consequence, warmer temperatures brought on by climate change can either delay or promote phenological events, depending on the decrease in chilling relative to the increase in forcing, respectively. Other factors, such as photoperiod and plant nutrient status, can also influence phenology, and the relationships between phenology and environmental cues can differ by species and genotype (Gould et al. 2011, Harrington and Gould 2015).

In this article, we summarize some recent information we have learned about the phenology of several of our native trees in the Pacific Northwest. We focus on initiation and seasonal progression of height and diameter growth, including the timing of spring budburst and cambial activation. We also briefly discuss flowering phenology, including seed cone receptivity and pollen shed.

Budburst and the Initiation of Height Growth

In most Pacific Northwest trees, shoot growth begins in the spring with the resumption of cell division and cell elongation from the shoot apical meristem within a bud formed during the previous growing season (cf. Allen and Owens 1972). As spring progresses, the expansion of the needle tissues can no longer be contained inside the bud and the new shoot bursts through the bud scales. In our studies, we determined the initiation of height growth for several species by observing the timing of when the bud scales of the terminal bud had parted sufficiently to enable us to view green leaf tissue. In the case of western redcedar (*Thuja plicata* Donn ex D. Don), which does not form vegetative buds, we determined height growth initiation by measuring shoot length periodically during the spring.

The timing of budburst can vary substantially due to differences in the environment or genetics, or both. For example, results from the Douglas-fir Seed-Source Movement Trial (Gould et al. 2012) show that the range in date of terminal budburst of individual trees from one seed source (represented by the progeny of two mother trees from each of five populations with similar adaptive characteristics and from an area of similar climates) of coast Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco var. *menziesii*) was about 20 days over 6 years at a single low-elevation site in Washington (classified as "medium" in terms of climate; figure 1, table 1). The range in date of budburst for that same seed source was more than 40 days during 1 year across three test sites that differ greatly with respect to temperature. The range in date of budburst across three sites and three different seed sources was over 50 days in 1 year. The coldest site resulted in the latest budburst and the narrowest range in budburst dates (figure 1). These results from the Douglas-fir Seed-Source Movement Trial illustrate that the range of initial dates of budburst and also the range in time to complete budburst can vary substantially among sites and among seedlots at a single site.

Tradeoffs exist between bursting bud late and bursting bud early. Bursting bud late helps a tree avoid spring frosts and foliar pathogens that thrive on new tissues

Table 1. Geographic and climate summaries for the study locations.

Site	Name	Latitude	Longitude	Elevation (m)	MAT (°C)	MWMT (°C)	MCMT (°C)	MAP (mm)
Cold	Doorstop	46.9° N.	122.0° W.	860	7.5	15.2	1.2	1821
Medium	Buckhorn2	46.5° N.	123.0° W.	240	10.3	17.7	3.8	1470
Hot	Stone	42.3° N.	122.9° W.	415	12.2	21.9	4.0	503
Olympia	OFSL	47.0° N.	123.0° W.	58	10.6	18.0	4.2	1266

C = Celsius. m = meter. MAP = mean annual precipitation. MAT = mean annual temperature. MCMT = mean coldest month temperature. mm = millimeter. MWMT = mean warmest month temperature. OFSL = Olympia Forestry Sciences Laboratory.

Note: All climate variables refer to the 1981-to-2010 normals.

Source: All climate variables were taken from ClimateWNA (Wang et al. 2012).

in cool, moist conditions. Bursting bud early allows for trees to capture favorable growing conditions in the earlier parts of the growing season when they begin to experience warm temperatures while still having access to abundant soil moisture. These tradeoffs can lead to differences among populations in date of budburst due to differential natural selection. When grown in a common garden, trees from drier and colder climates tend to burst bud earlier (St. Clair et al. 2005, Gould et al. 2011; see also the "hot" and "cold" seed sources in figure 1, respectively), while those from mild climates burst bud later (the "medium" seed source in figure 1). One possible explanation for this pattern is that the growing season is short in both dry and cold locations. In dry locations, parents that burst bud early and grew quickly during the early part of the growing season before the onset of drought in the summer were able to outcompete those that burst bud late, and, thus, were better able to survive and reproduce and to pass on the inherited characteristics of early budburst to their offspring (St. Clair et al. 2005, White et al. 1979). In cold locations, early bud burst may have resulted from selection for lower chilling requirements or lower flushing requirements, or both (Howe et al. 2003). The later arrival of spring at colder locations resulted in selection of those parents that can start growing more quickly to take advantage of the shorter growing season. At mild sites with a longer growing season and adequate moisture later in summer, trees are under less pressure to start growth earlier in the year and may increase their fitness by delaying budburst to avoid frost and leaf pathogens that can be important stressors in

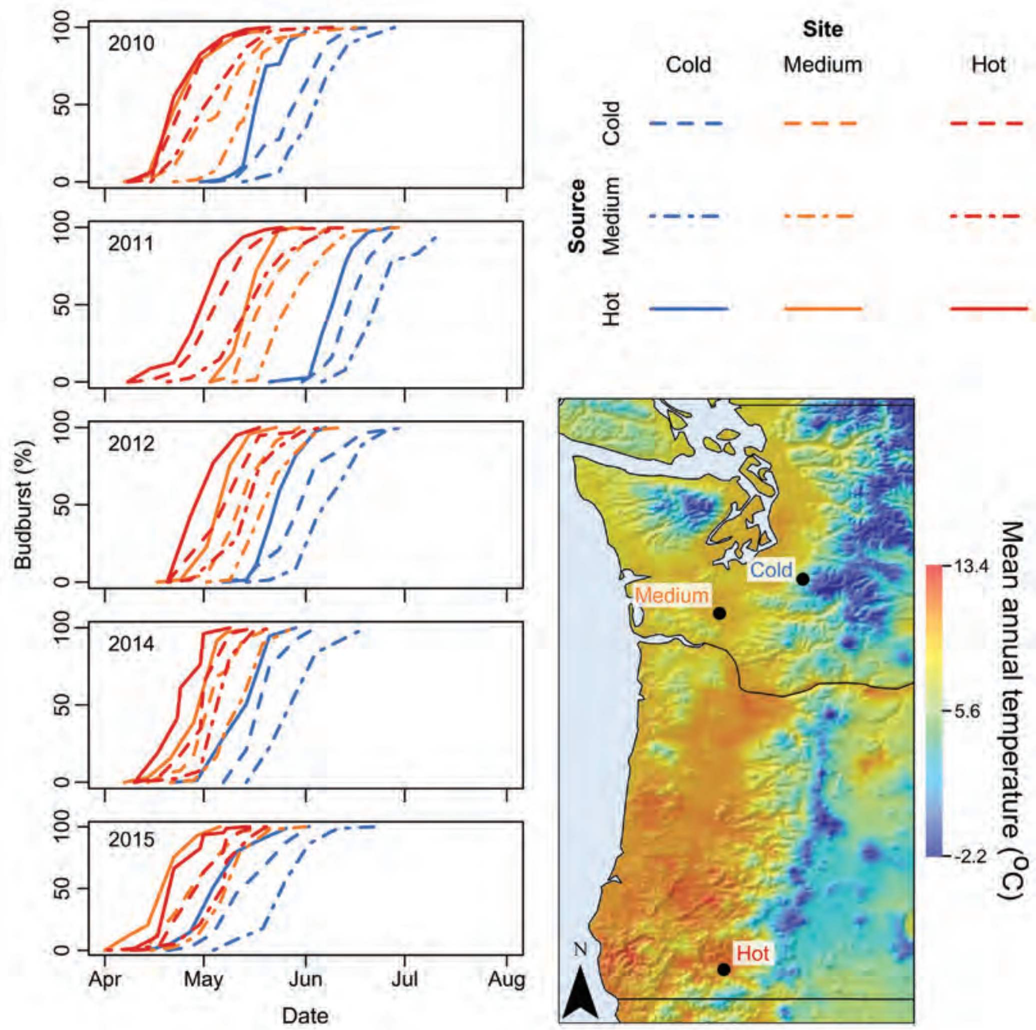

Figure 1. Progression of terminal budburst over 5 years in three seedlots of Douglas-fir grown in three common gardens. The common garden locations were Stone, a hot, dry site near Medford, OR; Buckhorn2, a mild site near Centralia, WA; and Doorstop, a cold, wet site near Mount Rainier National Park, WA. The seedlots shown were chosen to be ones that would be considered local for each location: a low-elevation Oregon Siskiyou Mountains source for Stone, a Washington Coast source for Buckhorn2, and a high-elevation Washington Cascades source for Doorstop. Each seedlot consisted of trees from five populations, with collections of seed from two mother trees per population.

the cool and damp conditions of early spring.

Faster growth rates can sometimes compensate for later budburst, allowing for trees to avoid early-season stresses while still achieving high productivity (Gould et al. 2012). The trees shown in figure 2 are representative of this possibility. Here we can see that budburst occurred much earlier in the Douglas-fir sapling from a southern Oregon Coast seedlot than in the tree from a Washington Coast seedlot, but, by the end of this particular year, the two trees both had grown the same amount. In this example, the tree from the Oregon Coast seedlot also stopped growing in height briefly, set bud, and then reflushed. The tree from the Washington Coast seedlot burst bud much later than the Oregon Coast seedlot, then grew faster during the early summer; it grew more continuously and, thus, avoided the brief period of summer budset evidenced by the other source. Different growth strategies have benefits and risks related to frost, drought, and second flushing and no one strategy will be best for all conditions.

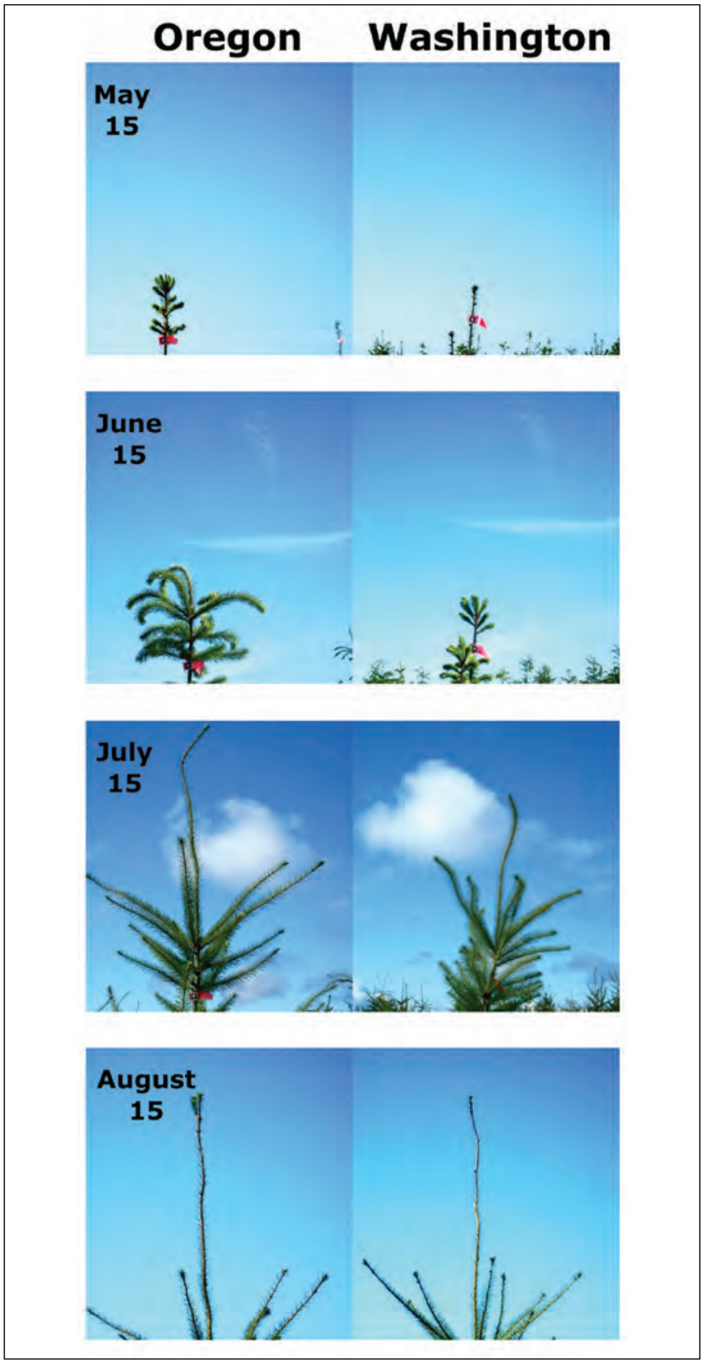

Figure 2. Time-lapse cameras can be used to follow budburst, the seasonal progression of height growth, and development of multiple flushing or other traits. In this example, we followed trees from two seed sources (southern Oregon Coast and Washington Coast) planted in the Buckhorn2 common garden near Centralia, WA. Cameras were located to the south of each tree being followed. The trees were in their fourth growing season after planting. A video clip of the full season of time-lapse images is available at https://youtu.be/KipZfWnjkB4.

Understanding the timing of budburst for different tree species and how the risks and opportunities trees face change over the year can inform decisions, such as selecting seed sources or planting windows or scheduling herbicide or pesticide applications. In addition, understanding the presence of alternative growth patterns within a species may provide tree breeders with additional traits to consider.

The relationship between temperature and terminal budburst also differs greatly among species. Some species must experience some minimum amount of chilling after budset before budburst can occur and are said to have an obligate or absolute chilling requirement. In the Pacific Northwest, these species include Douglas-fir, true firs (*Abies* spp.), western larch (*Larix occidentalis* Nutt.), and western hemlock (*Tsuga heterophylla* [Raf.] Sarg.) (Harrington and Gould 2015, Nelson and Lavender 1979, Wommack 1960). Pacific madrone (*Arbutus menziesii* Pursh), on the other hand, can burst terminal bud in the spring without chilling (Harrington and Gould 2015). Western redcedar does not have vegetative buds and also resumes height growth without chilling (Harrington and Gould 2015). In addition, species differ in their relationships between the amount of chilling received and the amount of forcing required for budburst to occur. For all Northwest tree species we studied, increased chilling reduces the amount of forcing needed to initiate height growth in the spring, regardless of whether the species has an obligate chilling requirement or not.

Ponderosa pine (*Pinus ponderosa* Lawson & C. Lawson) is complicated in its response to chilling, with some seed sources exhibiting an obligate chilling requirement (Omi et al. 1991, Sloan 1991) and others not (Burr et al. 1989, Wenny et al. 2002). In our seedling trials, we observed that the amount of winter chilling influenced the initiation of budburst in eight seedlots of ponderosa pine, the length of time the budburst lasted, the rank order of sources to begin or complete budburst, and the completeness of budburst in the population (figure 3). For example, under the highest chilling level (a lath house in Olympia, WA), the beginning of budburst differed by 20 days among seedlots, and all lots burst bud completely and quickly. With slightly warmer conditions (4 days per week in a greenhouse), all seedlots were still adequately chilled and they all achieved 100 percent budburst. Under warmer winter environments, budburst took much longer for all trees in a population, and the seedlots diverged into groups with complete budburst and groups with substantial percentages of seedlings not bursting their terminal bud. In the warmest environment (plants in a heated greenhouse all winter) only one high-elevation lot from southwest Oregon had 100 percent of seedlings bursting bud, and only 40 percent or fewer of the seedlings from two of the three Washington sources burst bud at all.

Understanding the relationships between temperature and budburst enables us to predict the timing of budburst under different climatic conditions (e.g., Harrington et al. 2010) and, thus, enables us to predict when budburst occurred in the past and also predict when budburst will likely occur in the future based on climate projections (Harrington and Gould 2015). Although budburst can vary substantially from year to year (by 30 days or more at a location), the trend for Douglas-fir over the past half century or more has been for earlier budburst (figure 4). For Salem, OR, we predicted that the date of 50 percent of individuals reaching terminal budburst for Douglas-fir ranged from April 12 to May 11 and that the date advanced an average of approximately 2 days per decade from 1949 to 2015: this is similar to the 2.5 days per decade observed for budburst and flowering of plant species in nine European countries from 1971 to 2000 (Menzel et al. 2006) . The predicted date of terminal budburst for Douglas-fir in Olympia, WA ranged from April 23 to May 23, and budburst also advanced over time. This response of advancing budburst with

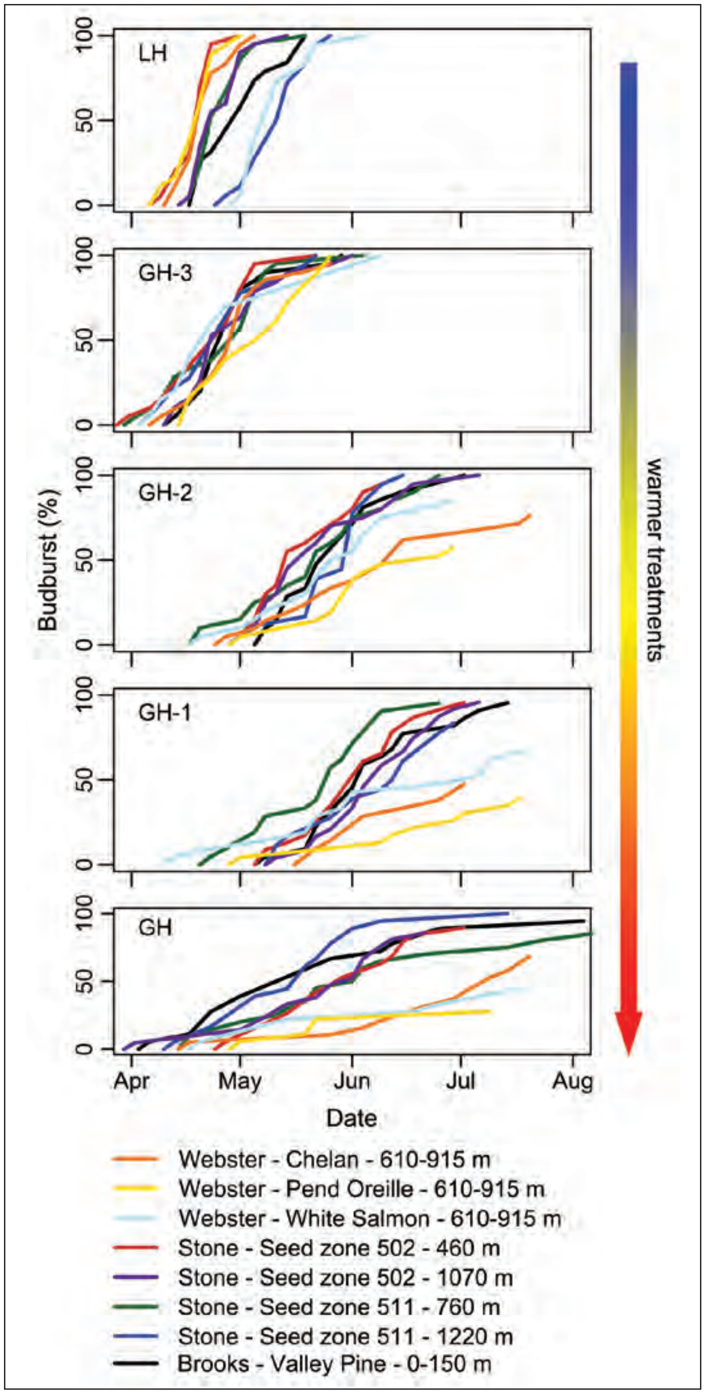

Figure 3. Patterns of the progression of terminal bud burst in eight ponderosa pine seedlots grown under five different temperature environments. These data came from a trial conducted during fall and winter 2014 and spring and summer 2015 at the Olympia Forestry Sciences Laboratory near Olympia, WA. Potted seedlings were kept under outside ambient conditions (LH = lath house), in a greenhouse where air temperature did not drop below 15 ˚C (GH), or moved back and forth weekly between the two environments (e.g., GH-3 means plants were moved outside the greenhouse 3 days per week).

warmer temperatures is typical of sites with substantial chilling. Studies of responses to recent warming found that growth initiation is occurring earlier in the year, on average, likely due to increased forcing in locations that have continued to experience sufficient

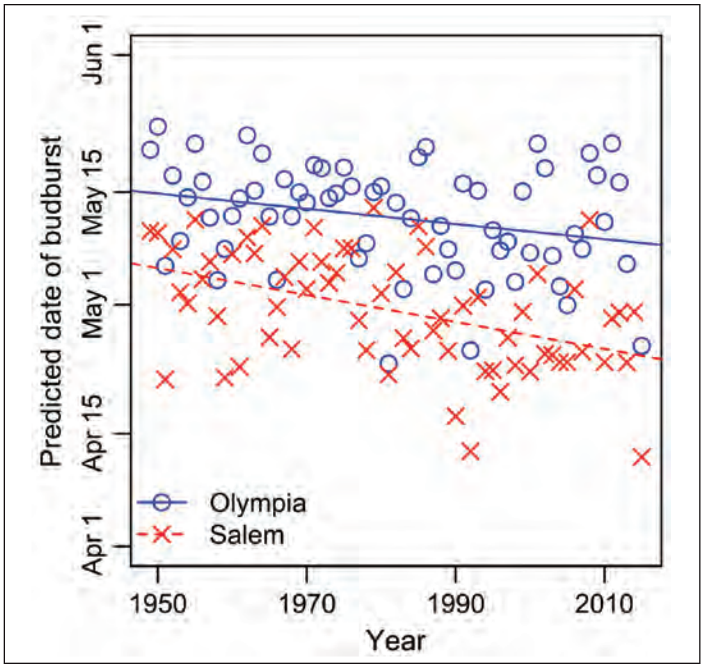

Figure 4. The date of terminal budburst for Douglas-fir was predicted from daily records of hourly temperature from Salem, OR, and Olympia, WA. Mean date of budburst was always predicted to be earlier in Salem than in Olympia and was quite variable from year to year. The slope of the line between year and predicted date of budburst was negative, indicating, on average, the date of budburst has advanced by 2 days per decade during this time period.

chilling (Wolfe et al. 2005). Many examples exist, however, of species that are not responding to warming temperatures or are even initiating growth later, a result often attributed to reductions in chilling (Cook et al. 2012, Parmesan 2007). In addition, trees are more likely to respond to loss of chilling with delays in budburst in environments where chilling is already low (Harrington et al. 2010). Therefore, locations with already warm winters may be the most likely to experience delays in budburst in response to climate change, and this response may become more prevalent as warming progresses. Thus, uniform advances in budburst in response to climate change are unlikely. Instead, budburst responses will likely vary by species, within the ranges of individual species, and over time with increasing warming.

Diameter Growth

The initiation of diameter growth follows reactivation of the vascular cambium, reactivation of the bark cambium, and rehydration of stem and bark cells. We determined the initiation, progression, and cessation of diameter growth for Douglas-fir, western redcedar, and Sitka spruce (*Picea sitchensis* [Bong.] Carrière) by observing changes in the diameters of these trees over the growing season using electronic dendrometers, sensitive instruments that can detect very small changes in stem diameter.

The timing of diameter growth initiation and progression is strongly affected by seasonal weather and other environmental conditions. Based on data from dendrometers at several sites, diameter growth for Douglas-fir seedlings generally begins in March or early April at low-elevation sites in western Washington and Oregon (figure 5) but may be delayed until May at higher elevations (figure 6). Differences in the timing of diameter-growth initiation and progression between seed sources at a location tend to be smaller than differences in the timing of budburst, but they are still present (figure 5a) and statistically significant (Gould et al. 2012). Like budburst, the timing of diameter-growth

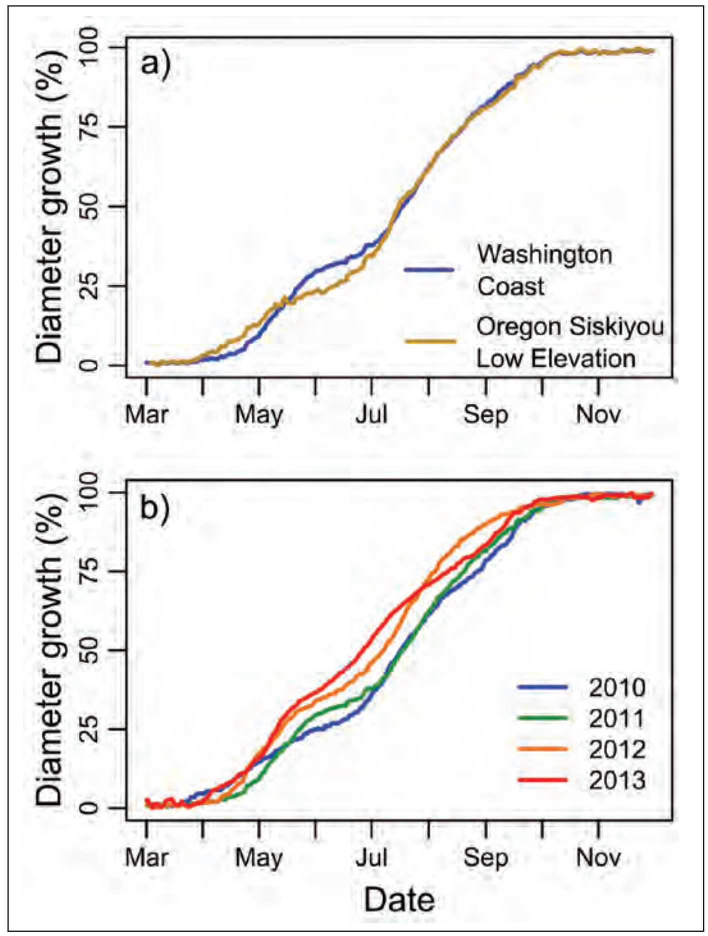

Figure 5. Electronic dendrometers measured (a) diameter growth patterns in 2011 for two seedlots (Washington Coast and low-elevation Oregon Siskiyou Mountains) of Douglas-fir planted at the Buckhorn2 common garden site near Centralia, WA. Diameter growth initiation began sooner for the low-elevation Oregon Siskiyou Mountains seedlot and had an earlier slowdown in growth than for the Washington Coast seedlot. Relative growth rates later in the season were very similar for the two sources. In addition, (b) diameter growth patterns for one seedlot (Washington Coast) of Douglas-fir in multiple years were measured at the same site. Patterns differed from year to year, with variation in temperature and precipitation.

initiation is influenced by both chilling and forcing, though there does not appear to be a minimum chilling requirement (Ford et al. 2016). Differences in patterns among years can be much larger than differences between sources (cf. figure 5a versus 5b); for example, the date when 30 percent of seasonal diameter growth had occurred varied by about 45 days in one seed source at one site across 4 years (figure 5b). Differences among years are associated with patterns of temperature and precipitation and their influence on the date of diameter growth initiation and diameter growth rates; in a similar way, diameter growth phenology for a seed source differs across locations with different climates (figure 6a). Diameter growth in seedlings is often sharply curtailed around the time of budburst and the early stages of height growth, suggesting that seedlings could be preferentially allocating photosynthate or other resources to cell division to support expansion of needle primordia and shoot growth, and not diameter growth, at this time (figure 7). The seasonal progression of diameter growth for western redcedar and Sitka spruce, in general, is similar to that of Douglas-fir (figure 8). Western redcedar has indeterminant growth, however, and tends to exhibit a more linear progression of growth during the season (if environmental conditions are favorable) than do either Sitka spruce or Douglas-fir. This growth pattern means that more of the seasonal growth occurs earlier and later in the season for western redcedar than for the other two species.

Understanding the phenology of diameter growth can inform decisions about the timing of repeated measurements, especially for short time intervals. For example, it could be important to ensure that the timing of repeated measurements for a 1- or 2-year measurement interval happens when the trees are not growing in diameter, but care in the timing of a 5- or 10-year measurement interval would be less important.

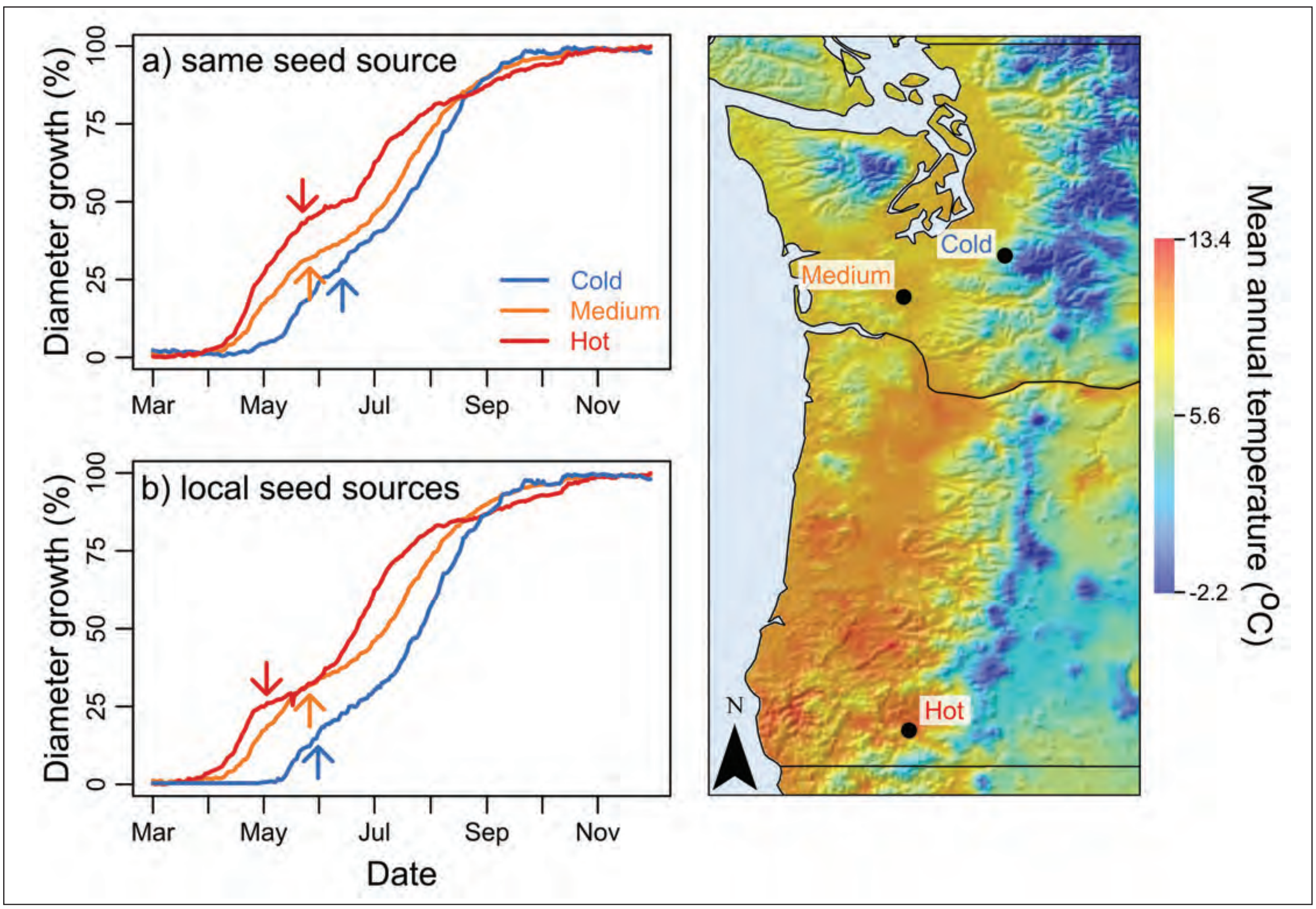

Figure 6. Diameter growth patterns for Douglas-fir in 2012 varied by both seed source and outplanting location (site). (a) The same seed source was planted (source = Washington Coast) at all three sites. The date of budburst is marked by arrows for the three sites. (b) Diameter growth for the local seed sources was monitored at three sites with a range in mean annual temperature. The date of budburst for the local seed source is marked on each dendrometer trace.

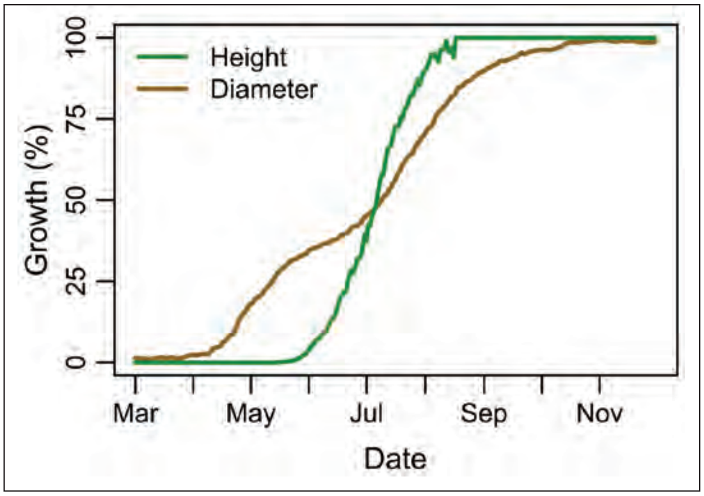

Figure 7. Relative patterns of height and diameter growth for Douglas-fir in 2012, based on eight trees from a Washington Coast seedlot planted at the Buckhorn2 site located near Centralia, WA (site labeled as "Medium" in figure 1). Note that significant diameter growth occurred before the beginning of height growth.

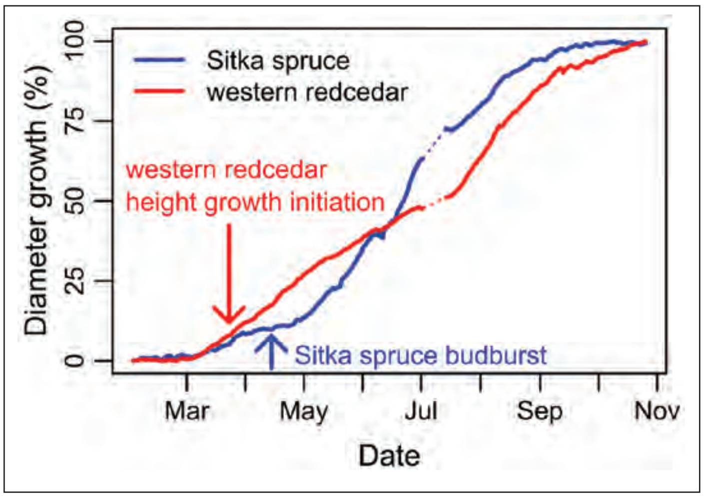

Figure 8. Within-season patterns of diameter growth for Sitka spruce and western redcedar in 2015 in a lath house at the Olympia Forestry Sciences Laboratory near Olympia, WA. Bareroot seedlings were obtained from the Washington Department of Natural Resources, L.T. Mike Webster Nursery (spruce seedlot = Twin Harbors, 0–2745 m; western redcedar seedlot = Skagit, 610–1220 m) in 2014 and transplanted into pots. Each line is the mean of six trees. The dotted portion of the lines indicates when the dendrometers were removed from the seedlings to move them to larger pots.

Reproductive Phenology

Reproductive phenology is key to successful seed production. As with vegetative phenology, early flowering runs the risk of frost damage and late flowering reduces the time period for cone development and seed filling. In addition, the synchrony of pollen release and female flower receptivity is key to the production of viable seeds for trees with separate male and female flowers, which is the case for dioecious species (male and female organs on separate plants; e.g., *Fraxinus*, *Populus*, and *Salix* species) and monecious species (male and female reproductive organs in different structures but on the same tree; e.g., most conifers and many angiosperms such as Alnus and Acer species). Local managers of seed orchards are well aware of variation within their orchards from year to year, and general ranges in characteristics such as flowering, cone ripening, and seed dispersal have been documented for most woody species in the United States and elsewhere (cf. Bonner and Karrfalt 2008).

As with the initiation of vegetative growth, the timing of reproductive stages in Douglas-fir and western redcedar can vary substantially from year to year (figure 9; El-Kassaby 1999) and is presumably responding to climate cues and past conditions. Our observations of pollen release and female flower receptivity for these two monecious species suggest that these events are well-synchronized under the current climate. It is unknown if these phenological processes could

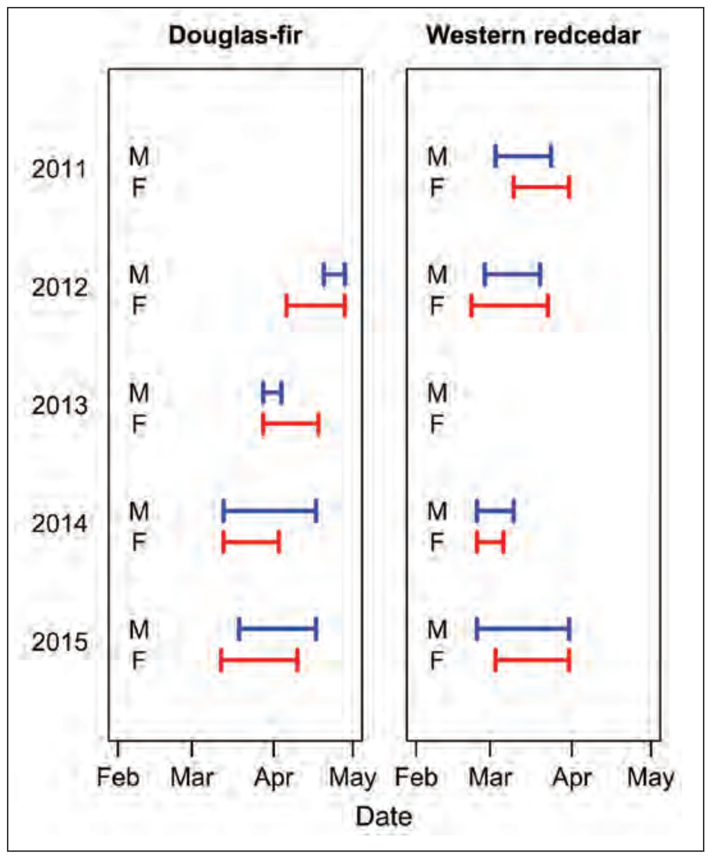

Figure 9. Reproductive status was monitored for Douglas-fir saplings in the Stone common garden near Medford, OR, and for clones of western redcedar at the Washington State Department of Natural Resources, Meridian Seed Orchard near Olympia, WA. The Douglas-fir saplings, planted in the fall of 2008, were from seed sources that would be considered local for that location (low-elevation Oregon Siskiyou Mountains). The western redcedar plants were established from rooted cuttings of eight clones planted in 2001 or 2005 (locations of parent trees ranged from 60 to 600 m in western Washington). Shown is the date range for female receptivity and pollen shed.

respond differently to warming and become decoupled in the future, leading to phenological mismatches due to climate change. Changes in climate disrupting the synchrony of male and female flower phenology could lead to a small percentage of individuals providing pollen in a seed orchard at the time when female flowers are receptive (e.g., Alizoti et al. 2010), which could potentially reduce genetic diversity or, in a worst case scenario, result in little or no pollen being available at the time it is needed, reducing the production of viable seed. We hope to continue to expand our work on phenology to understand the factors controlling reproduction so we can better predict which processes, species, and sites might be at risk under future climates, and so we can learn if there are ways to reduce these risks.

Conclusions

Most foresters are well aware that the timing of biological events can vary substantially across years, locations, species, or genotypes, and they appreciate that these observations can have practical significance. We understand that phenological responses to climate change will differ, depending on the species and genotype and the position on the landscape (in terms of current and predicted changes in climate). Furthermore, some phenological traits may be more sensitive to climate change than others; for example, the timing of budburst varies more among populations than the initiation of diameter growth. Most information on phenology of tree species has focused on budburst and flowering. Predicting how trees respond to their current and future environments will require much more information on plant functions such as growth, form, and reproduction as well as interactions with other species. For example, some species or locations may gain a competitive advantage in terms of a longer effective growing season; trees in some areas may become less or more valuable due to changes in stem taper or wood characteristics, while others may see changes in interactions with insect or fungal pests as a result of phenological mismatches. We hope that future work on phenology will (1) document phenological changes over time for many species and locations, including the phenology of organisms that interact with trees, and (2) collect detailed observations of phenological events along with monitoring of environmental conditions to develop models that can be used to predict how phenology of trees in the Pacific Northwest will change in the future. Phenological studies should help foresters in their day-to-day activities, including developing recommendations for adapted seed sources or for the timing of activities such as planting, sowing, or vegetation control. In addition, such studies should increase our understanding of range limitations for individual species and competitive interactions in stands with mixtures of tree species.

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REFERENCES

Alizoti, P.G.; Kilimis, K.; Gallios, P. 2010. Temporal and spatial variation of flowering among Pinus nigra Arn. clones under changing climatic conditions. Forest Ecology and Management. 259(4): 786–797.

Allen, G.S.; Owens, J.N. 1972. The life history of Douglas-fir. Ottawa, QC, Canada: Information Canada. 139 p.

Bonner, F.T.; Karrfalt, R.P., eds. 2008. The woody plant seed manual. Agric. Handb. 828. Washington, DC: U.S. Department of Agriculture, Forest Service. 1223 p.

Burr, K.E.; Tinus, R.W.; Wallner, S.J.; King, R.M. 1989. Relationships among cold hardiness, root growth potential and bud dormancy in three conifers. Tree Physiology. 5(3): 291–306.

Carlson, W.C. 1985. Effects of natural chilling and cold storage on budbreak and root growth potential of loblolly pine (Pinus taeda L.). Canadian Journal of Forestry Research. 15(4): 651–656.

Cook, B.I.; Wolkovich, E.M.; Parmesan, C. 2012. Divergent responses to spring and winter warming drive community level flowering trends. Proceedings of the National Academy of Sciences of the United States of America. 109(23): 9000–9005.

El-Kassaby, Y. 1999. Phenotypic plasticity in western redcedar. Forest Genetics. 6(4): 235–240.

Fitter, A.H.; Fitter, R.S.R. 2002. Rapid changes in flowering time in British plants. Science. 296(5573): 1689–1691.

Ford, K.R.; Harrington, C.A.; Bansal, S; Gould, P.J.; St. Clair, J.B. 2016. Will changes in phenology track climate change? A study of growth initiation timing in coast Douglas-fir. In press: Global Change Biology. doi: 10.1111/gcb.13328

Gould, P.J.; Harrington, C.A.; St. Clair, J.B. 2011. Incorporating genetic variation into a model of budburst phenology of coast Douglas-fir (*Pseudotsuga menziesii* var. *menziesii)*. Canadian Journal of Forest Research. 41(1): 139–150.

Gould, P.J.; Harrington, C.A.; St. Clair, J.B. 2012. Growth phenology of coast Douglas-fir seed sources planted in diverse environments. Tree Physiology. 32(12): 1482–1496.

Harrington, C.A.; Gould, P.J. 2015. Tradeoffs between chilling and forcing in satisfying dormancy requirements for Pacific Northwest tree species. Frontiers in Plant Science. doi:10.3389/fpls.2015.00120.

Harrington, C.A.; Gould, P.J.; St. Clair, J.B. 2010. Modeling the effects of winter environment on dormancy release of Douglas-fir. Forest Ecology and Management. 259(4): 798–808.

Howe, G.T.; Aitken, S.N.; Neale, D.B.; Jermstad, K.D.; Wheeler, N.C.; Chen, T.H.H. 2003. From genotype to phenotype: unraveling the complexities of cold adaptation in forest trees. Canadian Journal of Botany. 81(12): 1247–1266.

Intergovernmental Panel on Climate Change (IPCC). 2014. Climate change 2014: impacts, adaptation, and vulnerability. Part A: global and sectoral aspects. In: Field, C.B.; Barros, V.R.; Dokken, D.J.; Mach, K.J.; Mastrandrea, M.D.; Bilir, T.E.; Chatterjee, M.; Ebi, K.L.; Estrada, Y.O.; Genova, R.C.; Girma, B.; Kissel, E.S.; Levy, A.N.; MacCracken, S.; Mastrandrea, P.R.; White, L.L., eds. Fifth assessment report of the Intergovernmental Panel on Climate Change. Cambridge, United Kingdom; New York: Cambridge University Press. 1,132 p.

Körner, C.; Basler, D. 2010. Phenology under global warming. Science. 327(5972): 1461–1462.

Menzel, A; Sparks, T.H.; Estrella, N.; Koch, E,; Aasas, A,; Ahas, R.; Alm-Kübler, K.; Bissolli, P.; Braslavská, O.; Briede, A.; Chmielewski; Crepinsek, Z.; Curnel, Y., Dahl, Å; Defila, C.; Donnelly, A.; Filella, Y., Jatczak, K.; Måge, F.; Mestre, A.; Nordli, Ø.; Peñuelas, J.; Pirinen, P.; Remišová, V.; Scheifinger, H.; Striz, M.; Susnik, A.; Van Vliet, A.; Wielgolaski, F.; Zach, S.; Zust, A. 2006. European phenological response to climate change matches the warming pattern. Global Change Biology 12 (10): 1969-1976.

Nelson, E.A.; Lavender, D.P. 1979. The chilling requirement of western hemlock seedlings. Forest Science. 25(3): 485–490.

Omi, S.K.; Rose, R.; Sabin, T.E. 1991. Effectiveness of freezer storage in fulfilling the chilling requirement of fall-lifted ponderosa pine seedlings. New Forests. 5(4): 307–326.

Parmesan, C. 2007. Influences of species, latitudes and methodologies on estimates of phenological response to global warming. Global Change Biology. 13(9): 1860–1872.

Romberger, J.A. 1963. Meristems, growth and development in woody plants: an analytical review of anatomical, physiological, and morphogenic aspects. USDA For. Serv. Tech. Bull. 1293. Washington, DC: U.S. Government Printing Office. 214 p.

Sarvas, R. 1974. Investigations on the annual cycle of development on forest trees active period. II. Autumn dormancy and winter dormancy. Helsinki, Finland: Communicationes Instituti Forestalis Fenniae. 84 p.

Sloan, J.P. 1991. Ponderosa and lodgepole pine seedling bud burst varies with lift date and cultural practices in an Idaho nursery. USDA For. Serv. Res. Note INT–397. Ogden, UT: Intermountain Research Station. 9 p.

St. Clair, J.B.; Mandel, N.L.; Vance-Borland, K.W. 2005. Genecology of Douglas-fir in western Oregon and Washington. Annals of Botany. 96(7): 1199–1214.

Vegis, A. 1964. Dormancy in higher plants. Annual Review of Plant Physiology. 15: 185–224.

Wang, T.; Hamann, A.; Spittlehouse, D.L.; Murdock, T.Q. 2012. ClimateWNA: high-resolution spatial climate data for western North America. Journal of Applied Meteorology and Climatology. 51: 16–29.

Wenny, D.L.; Swanson, D.J.; Dumroese, R.K. 2002. The chilling optimum of Idaho and Arizona ponderosa pine buds. Western Journal of Applied Forestry. 17(3): 117–121.

White, T.L.; Ching, K.K.; Walters, J. 1979. Effects of provenance, years, and planting location on bud burst of Douglas-fir. Forest Science. 25(1): 161–167.

Wolfe, D.W.; Schwartz, M.D.; Lakso, A.N.; Otsuki, Y.; Pool, R.M.; Shaulis, N.J. 2005. Climate change and shifts in spring phenology of three horticultural woody perennials in Northeastern USA. International Journal of Biometeorology. 49(5): 303–309.

Wommack, D.E. 1960. Effect of winter chilling and photoperiod on growth resumption in Douglas-fir, *Pseudotsuga menziesii* (Mirb.) Franco. Corvallis, OR: Oregon State College. 82 p. M.S. thesis.

Useful Mobile Applications for Nursery and Field Personnel

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Abstract

The dramatic increase in use of mobile devices has resulted in an accompanying increase in mobile applications (apps). These downloadable software programs are available for numerous personal and professional purposes. Mobile devices and apps are being used to increase productivity, access information, and improve efficiency within many professions. This article describes several mobile apps, along with some Web-based tools, that have potential benefit to nursery production, reforestation, restoration, and conservation operations. This paper was presented at a joint meeting of the Northeast Forest and Conservation Nursery Association and Southern Forest Nursery Association (Kent Island, MD, July 20–23, 2015) and the annual meeting of the Western Forest and Conservation Nursery Association (Eugene, OR, October 26–27, 2015).

Introduction

Mobile technology has increased dramatically in the past few years. The average person interacts with his or her mobile device approximately 150 times per day to retrieve text, voice, and e-mail messages; get the time; take photos; check social media; access information; and use many other functions (Meeker and Wu 2013). Mobile applications (apps)—software programs that can be downloaded and accessed via a smartphone or other mobile device—are available for many purposes. Cloud technology has also influenced app development, enabling users to securely store and access information and to synchronize and integrate with other users and devices (Taylor 2015). Businesses are creating increasingly more mobile enterprise apps and equipping their employees with mobile devices to increase productivity, collaboration, and efficiency (Panepinto 2014, Stanley 2015, Taylor 2015). People are also using mobile apps for marketing (Chaffey 2016), for education and research (Drill 2012, 2013), and for agriculture (Ciampitti 2014, Hopkins 2015).

The ever-expanding array of available apps and the portability of mobile devices make this technology ideal for many field uses, including forestry, restoration, and nursery operations. This article highlights mobile apps and Web-based tools that have potential to accomplish or simplify a variety of tasks in those natural resource fields.

Mobile Apps

As of July 2015, 1.6 million apps were available to Google Android users and 1.5 million apps were available to Apple iOS users, reflecting a 400-percent increase in available apps in just 5 years (Statista 2015). Apps exist for nearly every imaginable use: communication, shopping, finances, hobbies, games, fitness, information, music, travel, and so much more. In addition to apps created for personal use, many science-based apps can serve as decision-support tools by analyzing and storing data and by providing information, calculations, and guidelines. Recordkeeping features in many apps automatically attach time and location information to data. Most apps are either available for free or for a nominal fee. Before paying for an app, it is always wise to check reviews or consult others who are familiar with that app to determine its potential benefits.

For purposes of this article, we researched available apps with potential application to nursery production and outplanting of trees and shrubs for reforestation, restoration, and conservation. Table 1 lists these apps

Table 1. Currently available apps with potential benefit to nursery production, reforestation, restoration, and conservation operations. Most apps are available in both Apple iOS and Google Android platforms. Check your device's app store to determine availability and to see details about each app's developer and functions. Some developers also have a Web site to further describe their apps and how to use them; it can be very useful to do an Internet search for each app by name to check for additional information.

App Name	Cost	Description
Integrated Pest Management		
IPM Toolkit	Free	Allows the user to read news articles, view videos, download publications, and access pictures to aid in adapting IPM practices to any agricultural operation. There are built-in news feeds from the University of Wisconsin IPM blogs, Twitter, and YouTube channels. The app, however, can be customized to use feeds from any region. The IPM pest picture search uses a national database of more than 200,000 images from all areas of the country.
SSCA Tank Mix	Free	Estimates the amount of water and product required for a spray application after the user enters the application volume, pesticide and adjuvant rates, and tank capacity. The user can also enter the amount remaining in the tank at fill-up to calculate the net amount of pesticide and water to put in tank.
Mix Tank	Free + in-app purchases	Assists with the proper tank mixing sequence of crop protection products. Also captures product use rates and application information and maintains spray logs for record keeping. Included is a database of over 1,300 crop protection products from more than 17 manufacturers. The available weather Integration feature ($5.99) helps prevent spray drift risk by displaying weather information.
Greenhouse Scout	$9.99	Provides a summary of information on biocontrol of common greenhouse insect pests, as well as an interactive interface for collecting, organizing, and presenting scouting data and recording product applications. Users must create an account and define locations on the Web site. Includes photos and information on a variety of insect pests and beneficials.
Purdue Tree Doctor	$1.99	Helps to identify and manage tree problems in the Midwestern and Eastern United States caused by a variety of factors including insects and diseases.
Forest Insect Pests in North America	Free	Helps users to recognize common pest insects and to understand their life cycles and how they damage trees. Photos are searchable by both common and scientific names.
Plant Diagnostic Sample Submission	Free	Allows users to submit digital photo samples to a university lab (located in the Midwest and Northeast) for diagnosis or identification. Some labs may charge a fee.
Biobest Side Effects	Free	Gives guidelines for the integrated use of biocontrol agents and pollinators in combination with crop protection products. Allows users to find pesticides compatible with specific biologicals.
Mapping		
SSCA Flag This	Free	Allows users to flag a GPS location that requires action (scouting for plant symptoms, draining standing water, etc.). After taking a picture or making a voice recording of instructions, the entry can be shared via email. The recipient receives directions to the specific location via Google Maps, along with the image and the recording.
Acre & Area & Acreage	$1.99	Calculates acreage and square feet/yards/inches/meters/kilometers based on values entered (e.g. length and width).
MyMeasure	$2.99	Allows users to measure length, perimeter, and area by using an interactive cross hair to trace the outline of any feature on a map.
Avenza PDF Maps	Free	Allows users to load their own maps and find, purchase, and download maps for a variety of purposes with a connected iTunes-like map store. Downloaded maps are stored on the user's device and are always available even when not connected to the Internet.
MotionX GPS	$1.99	Tracks routes and is useful for tracking site perimeters, inventory/treatment routes, setting waypoints, and much more. App can be upgraded ($6.99) to use multilayers.

App Name	Cost	Description
Plant Nutrition		
TankMix	Free	Calculates the amount of product and water needed to treat a specific field area, the amount of product needed for a specific tank size, and the amount of product needed for a desired volume to volume ratio.
Fertilizer Blend Calculator	$4.99	Designed for farmers, calculates details for custom dry or liquid fertilizer blends (products and proportions defined by the user). The output includes net elements in blend per acre, weight per load, volume, costs, etc.
SSCA Fertilizer Blend	Free	Assists in calculating liquid or dry fertilizer blends to meet fertility goals. The user enters the desired N-P-K-S fertility for a field and selects from available fertilizer products. The app calculates the blend requirements, the application rate, the resulting N-P-K-S fertility, and the cost. The user can enter soil test information and target recommendations to obtain the necessary fertilizer additions.
N Price Calculator	Free	Allows the user to compare the price of various forms of nitrogen fertilizer products in terms of their price per pound of nitrogen.
Plant Tool	$2.99	Serves as a reference tool to help identify nutrient deficiencies and to provide information and guidelines about nutrients, soil pH, and fertilizer applications.
Crop Nutrients in Irrigation Water Calculator	Free	After users input laboratory results of their irrigation water, estmiates the amount of nutrients delieverd. Users can adjust feritlizer management strategies based on the results.
Plant Identification		
Leafsnap	Free	Uses visual recognition software to identify tree species from photographs of their leaves. Contains high-resolution images of leaves, flowers, fruit, petiole, seeds, and bark. Includes the trees of the Northeast (but will soon include the trees of the entire continental United States).
vTree	Free	Contains factsheets for woody plants from all over North America, including descriptions, range maps, and images. Filter the species list for any location using GPS or an address, by answering tree attribute questions, or by using search terms. Tree questions or photos can be sent to "Dr. Dendro," a tree expert at Virginia Tech, to help with identification.
TreeBook	Free	Allows users to identify trees using images, search terms, synonyms for trees, layman terms, or detailed terminology. Supports a tree leaf key and provides a botanical glossary of the most common tree identifiers. Includes hand-drawn images, photos, and range maps of each tree.
Invasive Plants in Southern Forests	Free	Provides a field guide for identification of 56 nonative invasive plants in forests in the 13 Southern States, including trees, shrubs, vines, grasses, ferns, and forbs. Includes basic management strategies. User can report new sightings by submiting photos and reports.
ID Weeds	Free	Allows users to search for weeds by common or scientific name or to identify weeds based upon different characteristics. Photos and details about each weed are included. App is specific to the South Central United States.
Other (Growing tools, soil, weather)		
Greenhouse Growers Toolbox Lite	Free + in-app purchases	For the free Lite version, includes three calculators (greenhouse volume and area, dripper timings and volumes, and acid or product dosing). The full version ($32.99) includes five more calculators (boiler fuel cost, hydronic boiler size estimator, irrigation pump capacity, irrigation rate targets, and radaiton and light unit conversions).
PGR Mix Master	Free	Allows users to calculate dilutions for plant growth regulators. The user can specify the product, the final dilution volume, and the dilution concentration.
Trial Tracker	Free	Assists with tracking greenhouse plant trials. Online and mobile portals enable tracking and sharing of plant measurements, crop data points, plant treatments, etc.

App Name	Cost	Description
NOAA Radar Plus	$1.99	Provides accurate and timely weather data using NOAA's weather sources. It is a high-resolution, predictive radar app with forecasts, etc., useful for weather-dependent scheduling of field and nursery culturing.
Growing Degree Days	Free	Estimates the maturity of a crop based on current and past growing degree days data for a specific location.
SoilWeb	Free	GPS-based, real-time access to USDA-NRCS soil survey data around the United States. This application retrieves graphical summaries of soil types associated with the user's current geographic location. Sketches of soil profiles are linked to official soil series page within the California Soil Resource Lab's online soil survey.

IPM = Integrated Pest Management; GPS = Global Positioning System; SSCA = Saskatchewan Soil Conservation Association; PGR = plant growth regulator; NOAA = National Oceanic and Atmospheric Administration; USDA = U.S. Department of Agriculture; NRCS = Natural Resources Conservation Service.

and their descriptions. This list is by no means exhaustive, but it represents several apps that may be the most useful in various nursery and field operations.

Web-Based Tools

In addition to the availability of mobile apps, several useful tools can be accessed on Web sites via a mobile device or a desktop computer. Table 2 presents a list of especially useful grower tools available online.

Looking to the Future

The use of mobile devices to access the Internet has now surpassed the use of desktop computers (Chaffey 2016), and the number of available mobile apps has skyrocketed over the past few years. This trend is likely to continue. Furthermore, younger professionals who have grown up with modern technology, will expect to use mobile technology as a primary tool for obtaining information, performing calculations, recordkeeping, marketing, etc. While it is still of utmost importance to

Table 2. Web-based tools available to growers, with calculations and guidelines to assist with nursery activities.

Application	Description
FertCalc	FERTCALC is an online spreadsheet capable of calculating fertilizer formulations for water soluble fertilizer. FERTCALC calculates values for up to four injectors. http://extension.unh.edu/Agric/AGGHFL/fert_calc.cfm
DLICalc	DLICALC calculates daily light integral (DLI) for supplemental lighting in a greenhouse. http://extension.unh.edu/Agric/AGGHFL/dlicalc/index.cfm
AlkCalc	This calculator provides recommendations for the amount of acid to add to irrigation water in order to modify the pH and alkalinity levels. In addition, the calculator provides the amount of added phosphorus, nitrogen, and sulfur that the corresponding acids will provide, plus an economic comparison of each acid. http://extension.unh.edu/Agric/AGGHFL/alk_calc.cfm
PGRCalc	PGRCALC is a web based calculator capable of calculating plant growth regulator mixing rates. PGRCALC can calculate mixing amounts for sprays, and if appropriate, drenches (ppm and mg a.i.) and dips. PGRCALC will also calculate your final solution costs, after you provide the chemical cost. http://extension.unh.edu/Agric/AGGHFL/Pg_calc.cfm
 Back Pocket Grower	Back Pocket Grower™ provides training and crop management tools to greenhouse and nursery growers. The site includes interactive tools to calculate solutions, understand economics, and determine water quality. http://www.backpocketgrower.com

understand the concepts and processes associated with a mobile app's function to assist with job responsibilities, using these apps can improve efficiency, accuracy, knowledge, and productivity.

The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

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REFERENCES

Chaffey, D. 2016. Statistics on consumer mobile usage and adoption to inform your mobile marketing strategy mobile site design and app development. Leeds, United Kingdom: Smart Insights. http://www.smartinsights.com/mobile-marketing/mobile-marketing-analytics/mobile-marketing-statistics/. (May 2016).

Ciampitti, I. 2014. Top mobile apps for agriculture. AgPro. December 29, 2014. http://www.agprofessional.com/news/top-mobile-apps-agriculture. (May 2016).

Drill, S.L. 2012. Mobile applications for extension. Journal of Extension. 50(5): 5TOT1. http://www.joe.org/joe/2012october/tt1.php. (May 2016)

Drill, S.L. 2013. Mobile applications for participatory science. Journal of Extension. 51(1): 1TOT1. http://www.joe.org/joe/2013february/tt1.php. (May 2016)

Hopkins, M. 2015. 10 must-have agriculture apps that will make you more efficient in 2016. CropLife. December 15, 2015. http://www.croplife.com/editorial/matt-hopkins/10-must-have-agriculture-apps-that-will-make-you-more-efficient-in-2016/. (May 2016).

Meeker, M.; Wu, L. 2013. Internet trends: D11 conference. [San Francisco, CA]: Kleiner, Perkins, Caufield and Byers (KPCB). 117 p. http://www.kpcb.com/file/kpcb-internet-trends-2013. (May 2016).

Panepinto, J. 2014. The productivity payoff of mobile apps at work. Harvard Business Review. November 13, 2014. https://hbr.org/2014/11/the-productivity-payoff-of-mobile-apps-at-work. (May 2016).

Stanley, R. 2015. Mobile apps in the workforce: overcoming challenges to reap the benefits of a fully mobile workforce. Burlington, MA: ClickSoftware. http://blogs.clicksoftware.com/index/mobile-apps-in-the-workforce-overcoming-challenges-to-reap-the-benefits-of-a-fully-mobile-workforce/. (May 2016).

Statista. 2015. Number of apps in leading app stores as of July 2015. Hamburg, Germany: Statista, Inc. http://www.statista.com/statistics/276623/number-of-apps-available-in-leading-app-stores/. (May 2016).

Taylor, M. 2015. Growing in the cloud: modern nursery data management systems. Tree Planters' Notes. 53(2): 63–67.

Whitebark Pine Germination: Is It Really That Difficult?

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Abstract

The U.S. Department of Agriculture, Forest Service, Dorena Genetic Resource Center (DGRC) has been producing whitebark pine (*Pinus albicaulis* Engelm.) seedlings for outplanting and for testing for resistance to white pine blister rust (caused by the exotic pathogenic fungus *Cronartium ribicola*) since 2000. During the past 15 years, DGRC has designed and implemented numerous studies to improve seed use efficiency and germination percentages. In 2015, three new stratification protocols were tested against operational protocols on eight seedlots from three national forests to examine differences in speed of germination and total germination. The stratification treatments included (1) 140-day stratification in sand, (2) presoak in 1,000 parts per million gibberellic acid and 140-day stratification, (3) 140-day stratification in peat moss, and (4) control (operational method). No significant difference in speed of germination among treatments was observed, but the seeds stratified for 140 days in sand had significantly higher total germination than all other treatments. This paper was presented at the annual meeting of the Western Forest and Conservation Nursery Association (Eugene, OR, October 26–27, 2015).

Introduction

Why Do We Still Care?

Whitebark pine (*Pinus albicaulis* Engelm.) is an important ecosystem component and is considered a "keystone" species in certain high-elevation northwestern forests (Tomback et al. 2001). The seeds are a major food source for a variety of mammals, ranging from the red and Douglas squirrels (*Tamiasciurus hudsonicus* and *T. douglasii*) to black and grizzly bears (*Ursus americanus* and *U. arctos*). The Clark's nutcracker (*Nucifraga columbiana*) also depends on whitebark pine seeds and is one of the main sources of whitebark pine seed dissemination (Mattson et al. 2001). Whitebark pine can be one of the first tree species to colonize an area following catastrophic disturbances, including fire and landslides, and to play a vital role in soil stabilization and cover for regeneration of other tree species. As one of the few tree species found in many alpine areas, mature whitebark pine trees can be an important contributor to high-country aesthetics.

Whitebark pine populations, however, are declining due to a number of factors, including mountain pine beetle (*Dendroctonus ponderosae*), fire, and global climate change. In addition, white pine blister rust, caused by the exotic pathogenic fungus *Cronartium ribicola*, is a significant threat to the survival of the species in the Pacific Northwest and western Canada (Aubrey et al. 2008). In July 2011, the U.S. Fish and Wildlife Service issued notice that listing of whitebark pine as threatened or endangered is warranted but currently precluded by higher priority actions. Whitebark pine currently resides on the candidate species list (USFWS 2011). In addition, the Canadian Government listed whitebark pine as Schedule 1 Endangered under its Species at Risk Act (Government of Canada 2016).

Why Are Seedlings So Expensive?

Very few commercial nurseries have produced whitebark pine seedlings during the past 20 years. Because whitebark pine is a high-elevation species, seeds are often difficult to obtain. Late-spring snow and cold can disrupt or delay flower pollination, resulting in either minimal seed crops or seeds that are immature when cone harvesting occurs in the fall. Cone collection is also expensive. To prevent competition for seeds from nutcrackers and squirrels, cone-bearing trees, often located in remote sites, must first be climbed in the spring and early summer to cage conelets (figure 1). Trees must again be climbed in the fall to collect cones.

Figure 1. Caging whitebark pine conelets to prevent competition from nutcrackers and squirrels for seed crops. (Photo by Haley Smith, USDA Forest Service, 2016)

Whitebark pine seeds are difficult to extract from the cones, often requiring special extraction equipment or hand labor. In addition, due to a high lipid content, seed viability may be significantly reduced in long-term storage compared with other pines.

Whitebark pine seedlings are also expensive and challenging to produce (Overton et al. 2016). Seeds can be difficult to germinate, requiring special stratification, scarification, and handling during germination. Even with special handling, germination is erratic, depending on seed maturity. Seedlings are often slow growing and may require extended photoperiods during the growing season. Depending on the outplanting situation, seedlings from some seed sources may require three growing seasons before reaching the target size.

Previous Trials and Tribulations of Growing Whitebark Pine Seedlings at Dorena Genetic Resource Center

The U.S. Department of Agriculture (USDA), Forest Service, Dorena Genetic Resource Center (DGRC) is primarily a disease-resistance testing center and tree-improvement seed extractory in Cottage Grove, OR. The oldest program focuses on testing for resistance of five-needle pines to blister rust. Although western white pine (*Pinus monticola* Douglas ex D. Don) and sugar pine (*P. lambertiana* Douglas) historically have been the main focus, DGRC has begun working with all five-needle pine species native to North America and also with many European species.

DGRC began growing whitebark pine seedlings for blister rust resistance-testing and outplanting trials in 2000. In early small trials, the seeds were stratified and handled in a similar manner to the traditional pine species, using extended cold-stratification and direct-sowing methods. Germination in these trials was poor to nonexistent, and the few seedlings that were produced were often damaged or lost to birds and mice.

Trials to improve germination and culturing methods were initiated in 2002, based on work done by Burr et al. (2001). During the past 14 years, studies have included work on stratification length, scarification methods, fresh versus stored seeds, long-term storage seed viability, and seed viability based on embryo size (table 1).

Operational seed-handling and germination protocols evolved at DGRC based on the results of these previous studies, eventually leading to operational protocols in use by 2014. Only seeds that had been stored for at least 1 year were sown for rust testing and outplanting. Seeds were placed in mesh bags (figure 2) and soaked for 24 hours in hydrogen peroxide (H_2O_2), rinsed, and soaked an additional 24 hours in water (H_2O). Mesh bags were placed in plastic tubs, placed in warm stratification at

Figure 2. Mesh bags used for stratifying individual seedlots in tubs. (Photo by Richard Sniezko, USDA Forest Service, 2009)

Table 1. Whitebark pine germination studies designed and implemented at Dorena Genetic Resource Center, 2002 to 2014.

Year	Objective	Treatments	Results
2002	Prestratification seed soak	24 hr H_2O_2 24 hr H_2O 48 hr running H_2O	No difference.
2002	Stratification length	30-d warm, 30-d cold, 30-d warm 60-d cold, 30-d warm, 90-d cold	Highest and most consistent germination with 30-d warm, 90-d cold.
2002	Germination temperature	17 °C day, 15 °C night 20 °C day, 18 °C night	Highest germination with higher temperature, but more moldy seeds.
2004	Seed scarification	Nicking Sanding	No difference; sanding much more consistent and safer.
2004	Photoperiod length	No extended photoperiod 18-hr photoperiod 24-hr photoperiod	No significant difference between 18- and 24-hr photoperiod; both better than no extended photoperiod.
2006	Embryo length	< 25% cavity fill 25 to 50% cavity fill 50 to 75% cavity fill	Seeds with embryos filling 50% of the cavity or greater are considered viable.
2006	Long-term storage seed viability	1-yr freezer storage 5-yr freezer storage 10-yr freezer storage	Better germination with storage lengths less than 5 years, but 10 years still exhibited good viability.
2010	Long-term storage seed viability	Repeat of 2006 trial with same seedlots	Seedlots stored for 14 years starting to lose viability.
2010	Fresh vs. stored seeds	Seeds from current year 1-yr freezer storage 5-yr freezer storage	Better germination with seeds freezer-stored for 1 to 5 years.
2013	Stratification length	Operational (30-d warm, 90-d cold) Extended (30-d warm, 110-d cold)	Better germination with extended stratification.
2014	Stratification length	Operational (30-d warm, 90-d cold) Interrupted (30-d warm, 90-d cold; 21-d warm, 30-d cold)	Slightly better germination with interrupted stratification, but very moldy seeds.

C = Celsius. d = day. H_2O = water. H_2O_2 = hydrogen peroxide. hr = hour. yr = year.

10 °C (50 °F) for 30 days, and moved to cold stratification at 1 to 2 °C (34 to 36 °F) for 110 days.

Upon completion of the stratification period, seeds were individually hand-scarified using sanding machines that were designed and built at DGRC (figure 3). Scarified seeds were placed on blotter paper in 10-x-10-x-2.5-cm (4-x-4-x-1-in) germination containers that were placed in a germinator at 19 °C day/17 °C night (66 °F day/63 °F night) with a 12-hour photoperiod (figure 4). As seeds germinated, they were sown into individually labeled containers (figure 5).

By 2014, germination of whitebark pine seeds under DGRC operational protocols ranged from 5 to 95 percent germination, depending on seed maturity, with an average germination of 71 percent. Although germination in most species depends on seed quality, maximum germination for even minimally viable whitebark pine seeds is important due to the high value of the seeds.

Figure 3. Sanding machine designed and constructed at DGRC for scarifying whitebark pine seeds before germination. (Photo by Judith Danielson, USDA Forest Service, 2009)

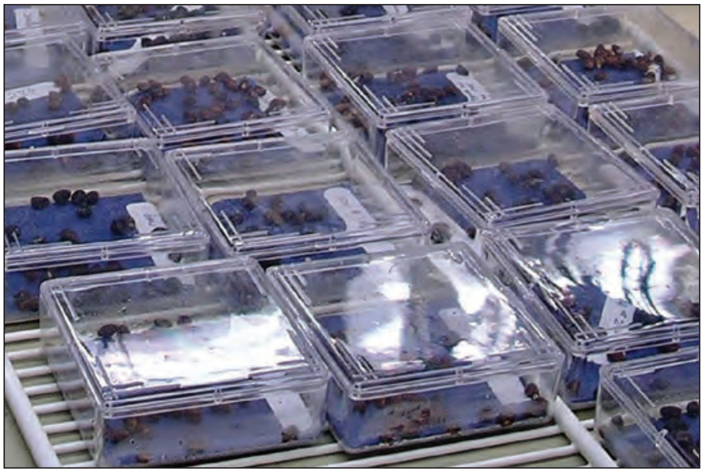

Figure 4. Whitebark pine seeds placed on blotter paper in 10-x-10-x-2.5-cm (4-x-4-x-1-in) germination containers to germinate before sowing. (Photo by Richard Sniezko, USDA Forest Service, 2010)

Table 2. Eight whitebark pine seedlots from three national forests spanning 3 collection years were included in the germination study.

Collection year	Seed origin (National Forest)	Seedlot ID	Percent filled
2009	Fremont-Winema	005030	90
2009	Fremont-Winema	005043	80
2009	Deschutes	011116	80
2010	Deschutes	011182	93
2010	Gifford Pinchot	350718	96
2010	Gifford Pinchott	350714	81
2011	Deschutes	011221	72
2011	Fremont-Winema	005164	80

Figure 5. As whitebark pine seeds germinate, they are sown into individually labeled containers for emergence. (Photo by Judith Danielson, USDA Forest Service, 2009)

2015 Germination Study—Materials and Methods

In 2015, a small trial was designed and implemented to determine if three different seed pretreatment and stratification methods would result in improved germination over the standard DGRC protocols. Six hundred seeds from each of eight whitebark pine seedlots (table 2) were divided into three treatments plus a control, with three replications included in each treatment.

Treatment 1 was a combination of DGRC protocols and protocols developed by the Alberta Tree Improvement and Seed Centre (Smoky Lake, AB, Canada) (Robb 2015). Seeds were placed in mesh bags and soaked for 48 hours in aerated water using an aquarium aerator. Bags were then layered in tubs of fine sand, and the tubs were placed in warm stratification at 10 °C (50 °F) for 30 days followed by cold stratification at 1 to 2 °C (34 to 36 °F) for 110 days. Seeds were not scarified at the end of the stratification period.

Treatment 2 was based on protocols DGRC has used to overcome internal dormancy in some native shrub species seeds. Seeds were placed in mesh bags and soaked for 24 hours in 1,000 parts per million (ppm) gibberellic acid (GA_3), rinsed, and soaked an additional 24 hours in H_2O. Bags were then placed in warm stratification (in plastic tubs) at 10 °C (50 °F) for 30 days followed by cold stratification at 1 to 2 °C (34 to 36 °F) for 110 days. At the end of the stratification period, seeds were scarified using the DGRC sander.

Treatment 3 was based on protocols that DGRC has used to soften hard seedcoats in some native shrub species seeds. Seeds were placed in mesh bags and soaked for 24 hours in H_2O_2, rinsed, and soaked an additional 24 hours in H_2O. Mesh bags were layered in plastic tubs containing peat moss and placed in cold stratification at 1 to 2 °C (34 to 36 °F) for 140 days. Seeds were not scarified at the end of the stratification period.

Treatment 4 was the standard DGRC protocol and was considered the control. Seeds were placed in mesh bags and soaked for 24 hours in H_2O_2, rinsed, and soaked an additional 24 hours in H_2O. Mesh bags were placed in plastic tubs, placed in warm stratification at 10 °C (50 °F) for 30 days followed by cold stratification at 1 to 2 °C (34 to 36 °F) for 110 days. At the end of the stratification period, seeds were scarified using the DGRC sander.

After seed pretreatments, seeds from all treatments were subjected to standard germination testing. Seeds were placed on blotter paper in 10-x-10-x-2.5-cm (4-x-4-x-1-in) germination containers in a germinator at 19 °C day/17 °C night (66 °F day/63 °F night) with a 12-hour photoperiod. Germination on all treatments was tracked every day for 3 weeks beginning 4 days following placement of seeds into the germinator. Seeds were considered germinated when the radical protruded at least 1 mm (0.04 in) and was curved.

2015 Germination Study—Results

No significant difference was found among treatments in speed of germination; however, significant differences were found among treatments in total germination (figure 6). Seeds that were stratified in peat without scarification (treatment 3) had significantly lower germination than all other treatments. Seeds that were soaked in GA_3 before stratification and scarified before germination (treatment 2) were significantly lower than the standard DGRC method (treatment 4) or the Alberta protocol (treatment 1). Seeds from treatment 2, however, were far less moldy than all other treatments, and the GA_3 had turned the seedcoats in all lots black. Seeds that were soaked in aerated water, stratified in sand, and not scarified (treatment 1) had significantly higher germination than those receiving the standard treatment used at DGRC (treatment 4). Seeds in treatment 1 also developed much less mold throughout the germination period than those from the control treatment.

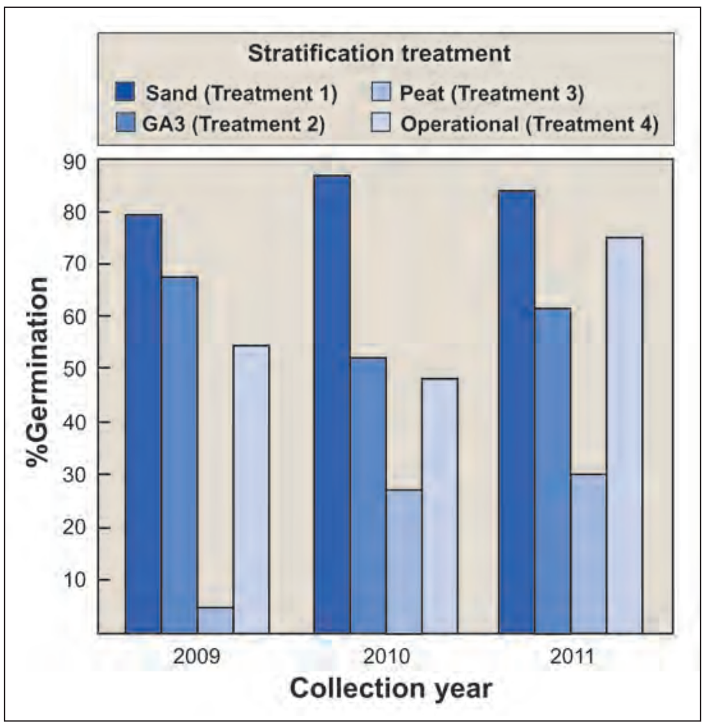

Figure 6. Significant differences were found among four stratification treatments for eight lots of whitebark pine from 3 collection years. Stratification in sand was significantly better than stratification in peat, presoak in GA_3, or the operational method used at Dorena Genetic Resource Center.

Discussion and Conclusions

Three pretreatment and stratification methods for whitebark pine seeds were tested against standard protocols used at DGRC in an attempt to increase germination and reduce labor costs. These methods were based on protocols used to overcome both internal and external dormancy in conifers and other native species.

Presoaking of seeds in GA_3 is a common method used to overcome internal seed dormancy in a variety of native and commercial species. Depending on the species, GA_3 concentrations for presoak can range from 250 to 2,000 ppm. Several studies have found, however, that higher concentrations of GA_3 can actually inhibit germination (Machado de Mello et al. 2009; Rojas-Arechiga et al. 2011). The presoak for whitebark pine seeds used in this study was based on that used with other native species at DGRC. It is possible the concentration used in this study was higher than needed for this species and could have inhibited germination.

Layering seeds in peat has been used as a substitute for the warm stratification period sometimes required to soften seedcoats in several conifers and native species; for example, western white pine, rose species (*Rosa* spp.), and dogwood species (*Cornus* spp.). Seeds stratified in this medium, however, are often moldy at the end of the cold-stratification period, and germination may be affected by this surface mold. The whitebark pine seeds in peat in this study were quite moldy at the end of the 140-day stratification period, and germination may have been reduced as a result.

Stratifying seeds in sand without scarification may be one method to streamline the germination process. In similar studies, Robb (2015) found that seeds layered in sand are subject to less changes in moisture content than seeds stratified in bags in tubs. Therefore, seeds remain fully imbibed throughout the stratification period, and seedcoats are softened without scarification. Seed scarification by hand can be very erratic, can injure the seed, and depends on the experience of personnel. Stratification in sand removes those variables.

Although only eight lots from three national forests were used in this study, the resulting germination percentages were encouraging. Further testing is needed before any decisions can be made to switch standard protocols.

In the fall of 2015, all the whitebark pine seedlots for both operational blister rust resistance testing and outplanting (222 seedlots from Washington, Oregon, and British Columbia) were equally divided into the standard DGRC protocols and the protocols used for stratifying in sand without scarification. Germination tracking will take place in the spring of 2016. If the new protocols prove effective for seeds across this large geographic range, further testing with these methods will include direct seeding versus pregermination, reducing stratification length, and testing this method on other hard-to-germinate species.

As demand for whitebark pine seedlings for outplanting increases, the number of nurseries interested in growing this high-value species will also increase. Unless germination and growing protocols become more efficient and less labor intensive, however, it may not be cost effective for production nurseries.

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REFERENCES

Aubrey, C.; Goheen, G.; Shoal, R.; Ohlson, T.; Lorenz, T.; Bower, A.; Mehmel, C.; Sniezko, R. 2008. Whitebark pine restoration strategy for the Pacific Northwest Region 2009–2013. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. 212 p.

Burr, K.E.; Eramian, A.; Eggleston, K. 2001. Growing whitebark pine seedlings for restoration. In: Tomback, D.F.; Arno, S.F.; Keane, R.E., eds. Whitebark pine communities. Washington, DC: Island Press: 325–345.

Government of Canada. 2016. Species at risk: whitebark pine. Gatineau, QC, Canada: Environment Canada. http://www.registrelep-sararegistry.gc.ca/species/speciesDetails_e.cfm?sid=1086#docs. (March 2016).

Machado de Mello, A.; Streck, N.A.; Blankenship, E.E. 2009. Gibberellic acid promotes seed germination in *Penstemon digitalis* cv. Husker Red. HortScience. 44(3): 870–873.

Mattson, D.J.; Kendall, K.C.; Reinhart, D.P. 2001. Whitebark pine, grizzly bears, and red squirrels. In: Tomback, D.F.; Arno, S.F.; Keane, R.E., eds. Whitebark pine communities. Washington, DC: Island Press: 121–136.

Overton, E.C.; Park, J.; Robertson, N.; Eramian, A. 2016. Current practices for growing whitebark pine seedlings at the U.S. Department of Agriculture, Forest Service, Coeur d'Alene Nursery. Tree Planters' Notes. 59(1): 64–68.

Robb, L. 2015. Personal communication. Provincial Seed Specialist. Smoky Lake, AB, Canada: Alberta Tree Improvement and Seed Centre.

Rojas-Arechiga, M.; Aguilar, K.M.; Golubov, J.; Mandujano, M.C. 2011. Effect of gibberellic acid on germination of seeds of five species of cacti from the Chihuahuan Desert, northern Mexico. The Southwestern Naturalist. 56(3): 393–435.

Tomback, D.F.; Arno, S.F.; Keane, R.E. 2001. The compelling case for management intervention. In: Tomback, D.F.; Arno, S.F.; Keane, R.E., eds. Whitebark pine communities. Washington, DC: Island Press: 3–25.

U.S. Fish and Wildlife Service (USFWS). 2011. Endangered and threatened wildlife and plants; 12-month finding on a petition to list *Pinus albicaulis* as endangered or threatened with critical habitat. Federal Register 76 (138): 42631-42654. http://www.fws.gov/mountain-prairie/species/plants/whitebarkpine/76FR42631.pdf. (March 2016).