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

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Abstract

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

Introduction

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

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

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

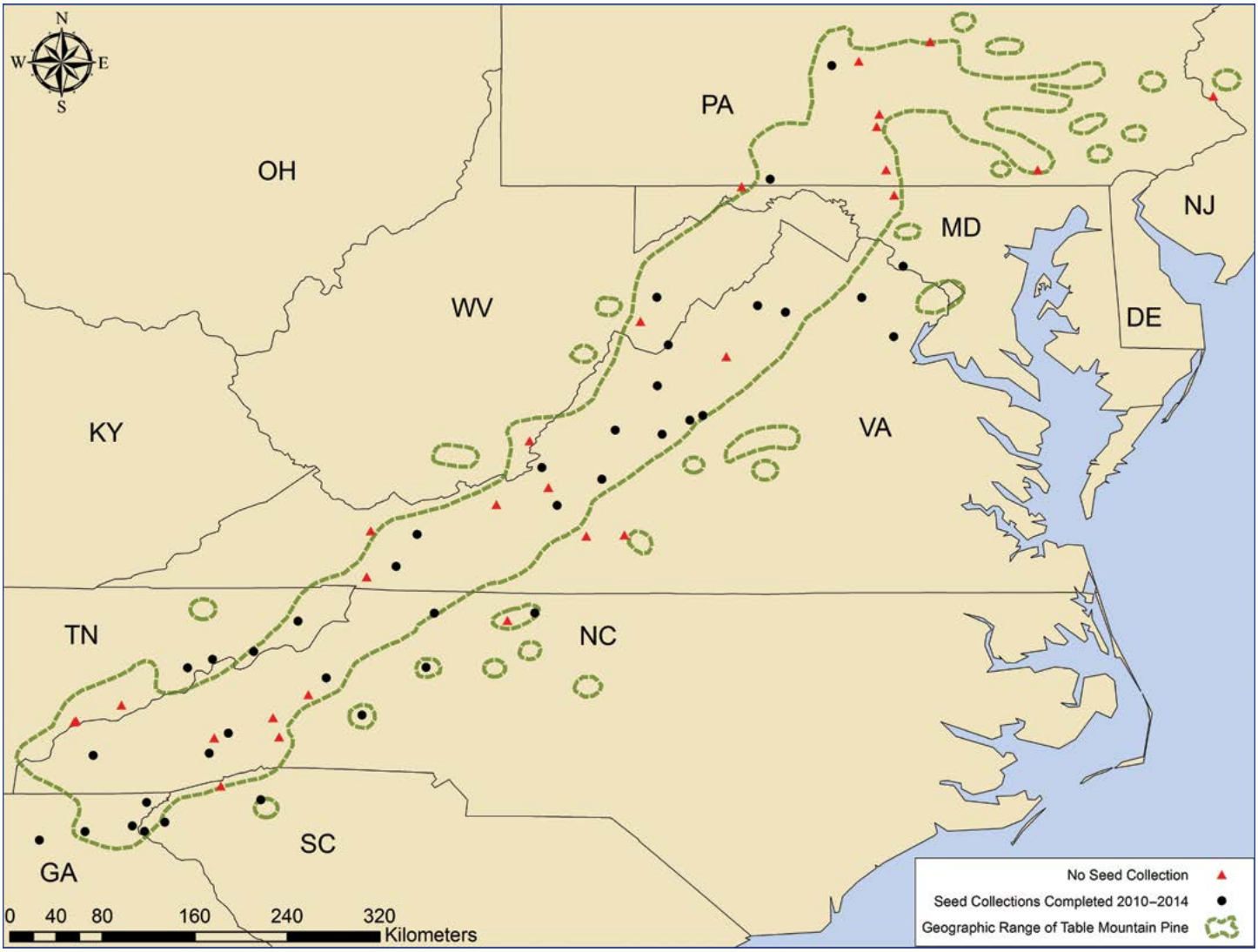

Figure 1. The geographic distribution of Table Mountain pine in the central and southern Appalachian Mountains and the locations of 65 known population occurrences identified by Camcore. Seed collections were completed in those indicated by black circles. No seed collections were attempted in those indicated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

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

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

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

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

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

Seed Collection Strategy and Protocols

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

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

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

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

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

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

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

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

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

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

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

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

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

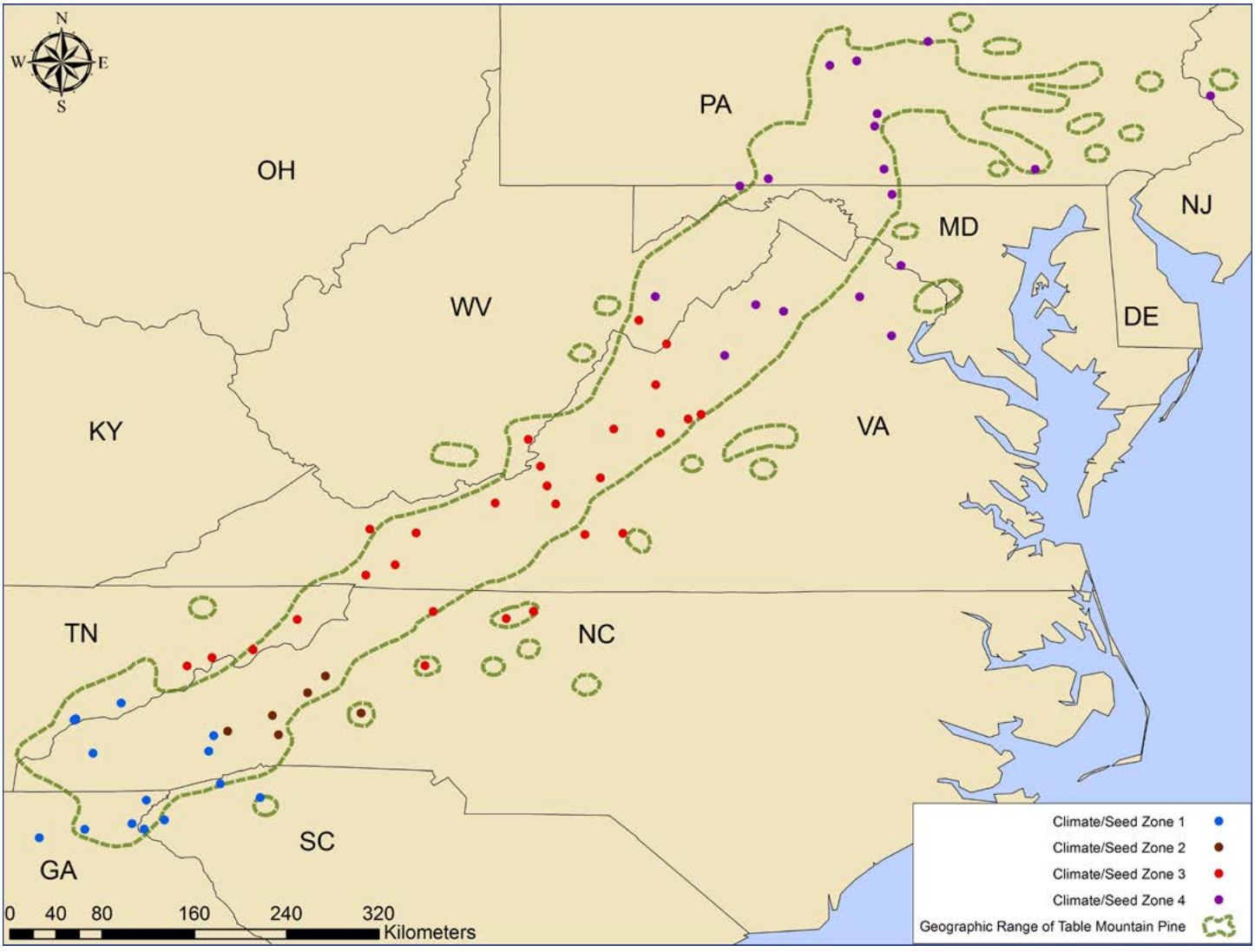

Figure 4. The four climate/seed zones identified for Table Mountain pine following the climate similarity cluster analysis.

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

Provenance Seed Collections and Seed Distribution

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

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

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

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

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

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

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

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

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

DBH = diameter at breast height.

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

Conclusions

The cooperative program between Camcore and USDA Forest Service on the conservation of Table Mountain pine has been successful. The program acquired 390,530 seeds for gene conservation and reforestation purposes and amassed the largest genetic base for the species that exists outside of natural stands. Although additional seed collections are needed to sample the underrepresented northern extreme of the TMP range and unsampled ecological subregions and plant hardiness zones, the genetic resources that have been acquired thus far represent a genetically diverse and broadly adaptable seed resource that can be used effectively to aid reforestation efforts with the species. The USDA Forest Service plans to use a portion of the seed to establish a seed orchard to support planned reforestation efforts, and has already sown seeds to produce seedlings for stand restoration following tornado damage on the Nantahala National Forest in North Carolina. Ongoing research includes a genetic diversity study using microsatellite molecular markers to compare the levels of genetic diversity

captured in the seed sample to that of the natural stands where the seed originated. This study will also consider how 20 years of additional stand management and decline have affected the fine-scale genetic structure and integrity of natural TMP stands since the last thorough genetic assessment of the species by Gibson and Hamrick (1991).

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