Conservation Gap Analysis of Native U.S. Pines

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Pinus albicaulis Engelm. (Whitebark pine)
Pinus aristata Engelm. (Colorado bristlecone pine)
Pinus arizonica Engelm. (Arizona pine)
Pinus attenuata Lemmon (Knobcone pine)
Pinus balfouriana Balf. (Foxtail pine)
Pinus banksiana Lamb. (Jack pine)
Pinus clausa (Chapm. ex Engelm.) Vasey ex Sarg. (Sand pine)
Pinus contorta Douglas ex Loudon (Lodgepole pine)
Pinus coulteri D. Don (Coulter pine)
Pinus echinata Mill. (Shortleaf pine)
Pinus edulis Engelm. (Pinyon)
Pinus elliottii Engelm. (Slash pine)
Pinus engelmannii Carrière (Apache pine)
Pinus flexilis James (Limber pine)
Pinus glabra Walter (Spruce pine)
Pinus jeffreyi Balf. (Jeffrey pine)
Pinus lambertiana Douglas (Sugar pine)
Pinus leiophylla Schiede & Deppe (Chihuahuan pine)
Pinus longaeva D.K. Bailey (Intermountain bristlecone pine)
Pinus monophylla Torr. & Frém. (Singleleaf pine)
Pinus monticola Douglas ex D. Don (Western white pine)
Pinus muricata D. Don (Bishop pine)
Pinus palustris Mill. (Longleaf pine)
Pinus ponderosa Lawson & C. Lawson (Ponderosa pine)
Pinus pungens Lamb. (Table mountain pine)
Pinus quadrifolia Parl. ex Sudw. (Parry pinyon)
Pinus radiata D. Don (Monterey pine)
Pinus remota (Little) D.K. Bailey & Hawksw. (Texas pinyon)
Pinus resinosa Aiton (Red pine)
Pinus rigida Mill. (Pitch pine)
Pinus sabiniana Douglas ex Douglas (Digger pine)
Pinus serotina Michx. (Pond pine)
Pinus strobiformis Engelm. (Southwestern white pine)
Pinus strobus L. (Eastern white pine)
Pinus taeda L. (Loblolly pine)
Pinus torreyana Parry ex Carrière (Torrey pine)
Pinus virginiana Mill. (Virginia pine)

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ACKNOWLEDGEMENTS

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INTRODUCTION

Trees are facing increasing threats globally, including habitat loss, natural systems modification, land use change, climate change, and pests and diseases. With more than 800 native tree species in the continental United States and more than 60,000 tree species globally, prioritizing species and conservation activities is vital for effectively utilizing limited resources. To facilitate this conservation planning, we developed a gap analysis methodology that examines both the accomplishments and most urgent needs for *in situ* (on-site) and *ex situ* (off-site) conservation of priority, at-risk tree groups in the U.S. This methodology was first implemented in our flagship report, *Conservation Gap Analysis of Native U.S. Oaks* (Beckman et al., 2019).

This report is one of seven that present the results of a second phase of gap analyses, which focuses on native U.S. trees within a group of priority genera that were selected due to particular economic importance, potential challenges with conventional *ex situ* conservation, and/or threats from emerging pests and diseases: *Carya, Fagus, Gymnocladus, Juglans, Pinus, Taxus,* and selected Lauraceae (*Lindera, Persea, Sassafras*). In each report, we provide a summary of ecology, distribution, and threats, and present results based on new data from a global survey of *ex situ* collections and a conservation action questionnaire that was distributed in 2019 to a wide range of conservation practitioners in the U.S. and botanical gardens globally. The aim of this report is to help prioritize conservation actions and coordinate activities between stakeholders to efficiently and effectively conserve these keystone trees in the U.S.

ECOLOGY & DISTRIBUTION

There are approximately 40 species of pine (*Pinus*) native to the United States. Here we follow the treatment in The Gymnosperm Database (2020) — with the exception of *Pinus cembroides*, which is not included here due to remaining taxonomic uncertainty and small distribution in the U.S. — totalling 37 species of *Pinus*. All are cone-bearing evergreens, often distinguished by resinous wood, bundled needle-like leaves, and a single straight trunk. *Pinus* species are distributed across the U.S., occupy a wide range of habitats, and take varying forms from windswept shrubs to monolithic trees (Figure 1; Table 1). They are often keystone species within their habitat. Many pine species are well-documented, but a significant number are lesser known, narrow endemics. Distinction among species can be difficult and disagreements still remain regarding the status of various infrataxa as true species, and vice versa. Native U.S. *Pinus* species provided the foundation for the birth of the U.S. lumber industry, and are still a vital resource today. Native American communities used pine bark, resin, and gum for a wide variety of medicinal and structural applications (Arbor Day Foundation, 2020).

Pinus remota (AlissJP)

Pinus engelmannii (Chris M)

Table 1. Summary of the ecology, distribution, and conservation status of 37 native U.S. *Pinus* species. * = species not in Flora of North America (1993), therefore ecology and distribution information are from The Gymnosperm Database (2020).

Species	**Ecology and Distribution** (from Flora of North America, 1993)				**Conservation Status** (IUCN, 2020)	
	Common name	Distribution	Habit	Habitat	IUCN Red List Category	Current population trend
Pinus albicaulis	Whitebark pine	CA, ID, MT, NV, OR, WA, WY; Canada	Trees to 21m; trunk to 1.5m diameter	Thin, rocky, cold soils at or near timberline, montane forests; 1300–3700m	Endangered	Decreasing
Pinus aristata	Colorado bristlecone pine	AZ, CO, NM	Trees to 15m; trunk to 1m diameter	Subalpine and alpine; 2500–3400m	Least Concern	Stable
*Pinus arizonica**	Arizona pine	AZ, NM, TX; Mexico	Trees to 35m; trunk to 1.2m diameter	Mountains; 1800–2800m	Least Concern	Unknown
Pinus attenuata	Knobcone pine	CA, OR; Mexico	Shrubs or trees to 24m; trunk to 0.8m diameter	Fire successional on dry slopes and foothills of Sierra Nevada and the Cascade and Coast ranges; 300–1200m	Least Concern	Stable
Pinus balfouriana	Foxtail pine	CA	Trees to 22m; trunk to 2.6m diameter	Timberline and alpine meadows; 1500–3500m	Near Threatened	Stable
Pinus banksiana	Jack pine	IL, IN, ME, MI, MN, NH, NY, PA, VT, WI; Canada	Trees to 27m; trunk to 0.6m diameter	Fire successional in boreal forests, tundra transition, dry flats, and hills, sandy soils; 0–800m	Least Concern	Stable
Pinus clausa	Sand pine	AL, FL	Trees to 21m; trunk to 0.5m diameter	Fire successional in sand dunes and white sandhills; 0–60m	Least Concern	Stable
Pinus contorta	Lodgepole pine	AK, CA, CO, ID, MT, NV, OR, SD, UT, WA, WY; Canada; Mexico	Shrubs or trees to 50m; trunk to 0.9m diameter	Maritime fog forests, bogs, and dry foothills...low to high montane forests, often to timberline; 0–3500m	Least Concern	Stable
Pinus coulteri	Coulter pine	CA; Mexico	Trees to 24m; trunk to 1m diameter	Dry rocky slopes, flats, ridges, and chaparral, transitional to oak-pine woodland; 300–2100m	Near Threatened	Decreasing
Pinus echinata	Shortleaf pine	AL, AR, DE, FL, GA, IL, KY, LA, MD, MS, MO, NY, NC, OH, OK, PA, SC, TN, TX, VA, WV	Trees to 40m; trunk to 1.2m diameter	Uplands, dry forests; 200–610m	Least Concern	Increasing
Pinus edulis	Pinyon	AZ, CA, CO, NM, OK, TX, UT, WY; Mexico	Shrubs or trees to 21m; trunk to 0.6m diameter	Dry mountain slopes, mesas, plateaus, and pinyon-juniper woodland; 1500–2100m	Least Concern	Stable
Pinus elliottii	Slash pine	AL, FL, GA, LA, MS, SC	Trees to 30m; trunk to 0.8m diameter	Flatwoods, mostly over limestone... lowland to upland forests, old fields, and fine white sands, mostly long-hydroperiod soils; 0–150m	Least Concern	Increasing
Pinus engelmannii	Apache pine	AZ, NM; Mexico	Trees to 35m; trunk to 0.6m diameter	High and dry mountain ranges, valleys, and plateaus; 1500–2500m	Least Concern	Stable
Pinus flexilis	Limber pine	AZ, CA, CO, ID, MT, NE, NV, NM, ND, OR, SD, UT, WY; Canada	Trees to 26m; trunk to 2m diameter	High montane forests, often at timberline Elevation: (1000–)1500–3600m	Least Concern	Decreasing
Pinus glabra	Spruce pine	AL, FL, GA, LA, MS, SC	Trees to 30m; trunk to 1m diameter	Sandy alluvium and mesic woodland; 0–150m	Least Concern	Stable
Pinus jeffreyi	Jeffrey pine	CA, NV, OR; Mexico	Trees to 61m; trunk to 2.5m diameter	High, dry montane forests mostly above the Pinus ponderosa zone; 2000–2500m	Least Concern	Stable
Pinus lambertiana	Sugar pine	CA, NV, OR; Mexico	Trees to 75m; trunk to 3.3m diameter	Montane dry to moist forests; 330–3200m	Least Concern	Stable
Pinus leiophylla	Chihuahua pine	AZ, NM; Mexico	Trees to 25m; trunk to 0.9m diameter	Dry slopes and plateaus; 1500–2500m	Least Concern	Stable
Pinus longaeva	Intermountain bristlecone pine	CA, NV, UT	Trees to 16m; trunk to 2m diameter	Subalpine and alpine; 1700–3400m	Least Concern	Stable
Pinus monophylla	Singleleaf pinyon	AZ, CA, ID, NV, UT; Mexico	Trees to 14m; trunk to 0.5m diameter	Dry low-montane or foothill pinyon-juniper woodland; 1000–2300m	Least Concern	Stable
Pinus monticola	Western white pine	CA, ID, MT, NV, OR, WA; Canada	Trees to 70m; trunk to 2.5m diameter	Montane moist forests, lowland fog forests; 0–3000m	Near Threatened	Decreasing
Pinus muricata	Bishop pine	CA; Mexico	Trees to 24m; trunk to 0.9m diameter	Dry ridges to coastal, windshorn forests, often in or around bogs; 0–300m	Vulnerable	Unknown
Pinus palustris	Longleaf pine	AL, FL, GA, LA, MS, NC, SC, TX, VA	Trees to 47m; trunk to 1.2m diameter	Dry sandy uplands, sandhills, and flatwoods; 0–700m	Endangered	Decreasing

Species	Ecology and Distribution (from Flora of North America, 1993)				Conservation Status (IUCN, 2020)	
	Common name	Distribution	Habit	Habitat	IUCN Red List Category	Current population trend
Pinus ponderosa	Ponderosa pine	AZ, CA, CO, ID, MT, ND, NM, NE, NV, OK, OR, SD, TX, UT, WA, WY; Canada; Mexico	Trees to 72m; trunk to 2.5m diameter	Slopes, canyons and rims, and tablelands...montane, dry, open forests...tablelands, canyon slopes and rims, and foothills, western Great Plains, Rocky Mountains; 0–3000m	Least Concern	Stable
Pinus pungens	Table mountain pine	DE, GA, MD, NJ, NC, PA, SC, TN, VA, WV	Trees to 12m; trunk to 0.6m diameter	Dry, mostly sandy or shaly uplands, Appalachians and associated Piedmont; 500–1350m	Least Concern	Stable
Pinus quadrifolia	Parry pinyon	CA; Mexico	Trees to 10m; trunk to 0.5m diameter	Dry rocky sites; 1200–1800m	Least Concern	Stable
Pinus radiata	Monterey pine	CA; Mexico	Trees to 30m; trunk to 0.9m diameter	Coastal fog belt; 30–400m	Endangered	Decreasing
*Pinus remota**	Texas pinyon	TX; Mexico	Shrubs or small trees to 9m; trunk to 0.4m diameter	Edwards Plateau, isolated mountain ranges, cold Chihuahuan desert; 450–1850m	Least Concern	Stable
Pinus resinosa	Red pine	CT, IL, ME, MA, MI, MN, NH, NJ, NY, PA, VT, WV, WI; Canada	Trees to 37m; trunk to 1.5m diameter	Sandy soils, eastern boreal forests; 200–800m	Least Concern	Increasing
Pinus rigida	Pitch pine	CT, DE, GA, KY, ME, MD, MA, NH, NJ, NY, NC, OH, PA, RI, SC, TN, VT, VA, WV; Canada	Trees to 31m; trunk to 0.9m diameter	Upland or lowland, sterile, dry to boggy soils; 0–1400m	Least Concern	Increasing
Pinus sabiniana	Digger pine	CA	Trees to 25m; trunk to 1.2m diameter	Dry foothills on the west slope of the Sierra Nevada, and in the coast ranges, nearly ringing the Central Valley of California; 30–1900m	Least Concern	Stable
Pinus serotina	Pond pine	AL, DE, FL, GA, MD, NJ, NC, SC, VA	Trees to 21m; trunk to 0.6m diameter	Flatwoods, flatwoods bogs, savannas, and barrens; 0–200m	Least Concern	Stable
Pinus strobiformis	Southwestern white pine	AZ, NM, TX; Mexico	Trees to 30m; trunk to 0.9m diameter	Arid to moist summit elevations, montane forests; 1900–3000m	Least Concern	Stable
Pinus strobus	Eastern white pine	CT, DE., GA, IL, IN, IA, KY, ME, MD, MA, MI, MN, NH, NJ, NY, NC, PA, OH, RI, SC, TN, VT, VA, WV, WI; Canada; Guatemala; Mexico	Trees to 67m; trunk to 1.8m diameter	Mesic to dry sites; 0–1500m	Least Concern	Increasing
Pinus taeda	Loblolly pine	AL, AR, DE, FL, GA, KY, LA, MD, MS, NJ, NC, OK, SC, TN, TX, VA	Trees to 46m; trunk to 1.6m diameter	Mesic lowlands and swamp borders to dry uplands; 0–700m	Least Concern	Increasing
Pinus torreyana	Torrey pine	CA	Trees to 15m; trunk to 1m diameter	Two small areas of southern California: near Del Mar (San Diego County) and on the northeastern shore of Santa Rosa Island (Santa Barbara County)	Critically Endangered	Decreasing
Pinus virginiana	Virginia pine	AL, DE, GA, IN, KY, MD, MS, NJ, NY, NC, OH, PA, SC, TN, VA, WV	Trees to 18m; trunk to 0.5m diameter	Dry uplands, sterile sandy or shaly barrens, old fields, and lower mountains; 0–900m	Least Concern	Increasing

Pinus aristata (Ed Hedborn, The Morton Arboretum)

Pinus longaevae (E. Hahn, The Morton Arboretum)

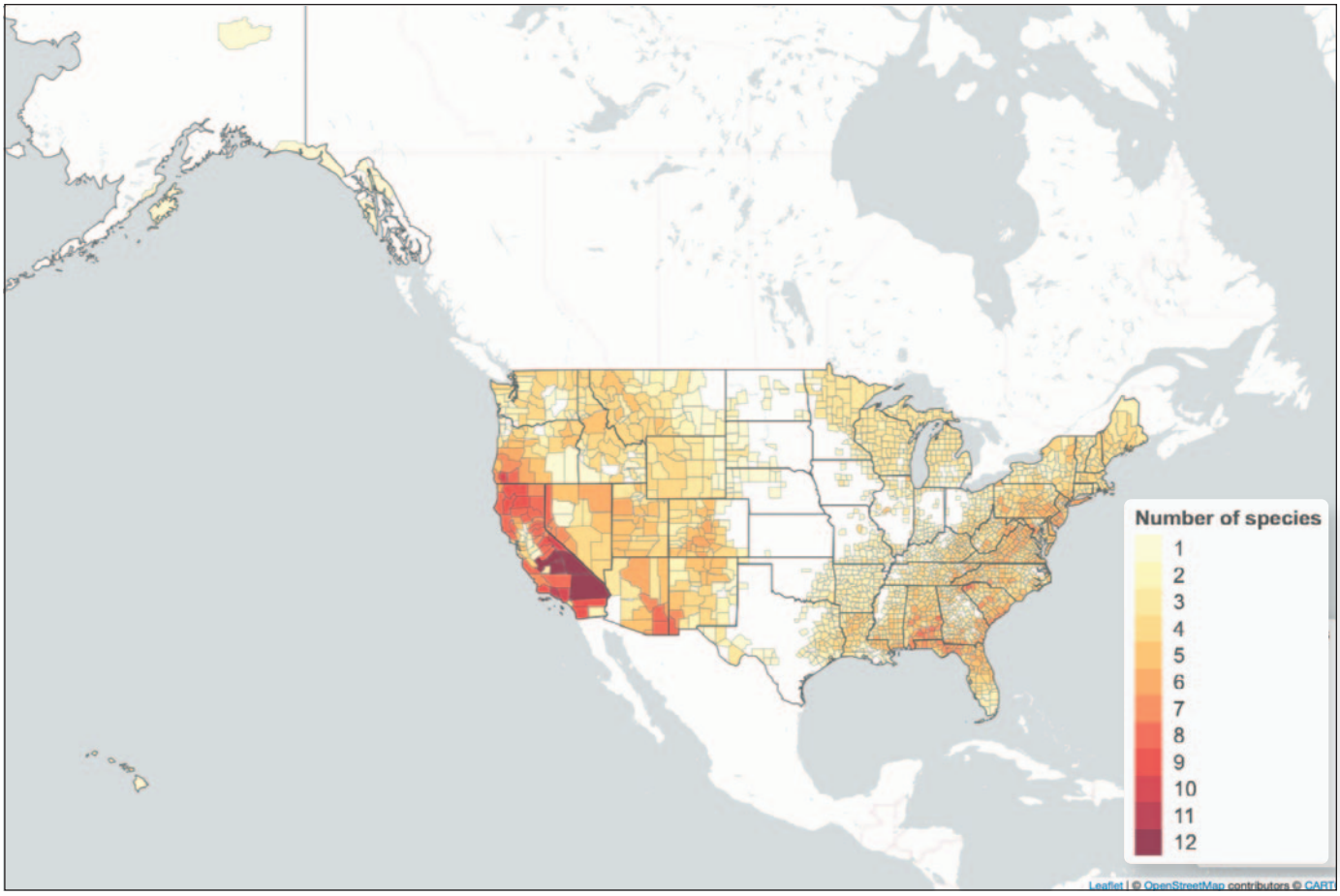


Figure 1. Species richness of 37 native U.S. *Pinus* species by U.S. county. County level distribution data from USDA PLANTS and Biota of North America Program (BONAP) have been combined to estimate species presence (Kartesz, 2018; USDA NRCS, 2018).

PESTS & DISEASES

Native U.S. *Pinus* species face a variety of pests and diseases. Some are widely devastating as single agents — such as mountain pine beetle and white pine blister rust — and others contribute to a suite of pressures that inhibit reproduction, cause decline, and sometimes lead to mortality. Results from the USDA Forest Service study (Potter et al., 2019a) are provided in Table 2, to give an overview of the major pests and diseases affecting native U.S. *Pinus* species. That study performed a thorough literature review, including more than 200 sources, and consulted dozens of expert entomologists and pathologists to identify up to five of the most serious insect, disease, and parasitic plant threats facing each of 419 native U.S. tree species; priority was given to pests and diseases causing mortality of mature trees, rather than agents primarily affecting reproductive structures or seedlings. A second USDA Forest Service study, *Prioritizing the conservation needs of United States tree species: Evaluating vulnerability to forest insect and disease threats* (Potter et al., 2019b), combined results from Potter et al. (2019a) with species trait and vulnerability data to further categorize overall pest and disease vulnerability of the 419 target native U.S. tree species. Results from this study are provided in Table 3.


Pinus engelmannii (Kretyen)

Table 2. The most serious insect, disease, and parasitic plant agents affecting native U.S. *Pinus* species, from the results of Potter et al. (2019a), which analyzed 419 native U.S. tree species. Numbers represent the severity of the agent's impact on the host species. * = nonnative invasive agent. Table adapted, with permission, from Potter et al. (2019a).

Host species	Insect, Disease, or Parasitic Plant Agent												
	Armillaria root disease (*Armillaria* spp.)	California fivespined ips (*Ips paraconfusus*)	Jack pine budworm (*Choristoneura pinus*)	Jeffrey pine beetle (*Dendroctonus jeffreyi*)	Mountain pine beetle (*Dendroctonus ponderosae*)	Phytophthora root rot (*Phytophthora cinnamomi*)*	Pine engraver beetles (*Ips* spp.)	Pinyon ips (*Ips confusus*)	Pitch canker (*Fusarium circinatum*)*	Roundheaded pine beetle (*Dendroctonus adjunctus*)	Southern pine beetle (*Dendroctonus frontalis*)	Western pine beetle (*Dendroctonus brevicomis*)	White pine blister rust (*Cronartium ribicola*)*
Pinus albicaulis	3				8								8
Pinus aristata					8		3						5
Pinus arizonica	3												
Pinus attenuata							5		3				
Pinus balfouriana					8								8
Pinus banksiana			5										
Pinus clausa	1						1				3		
Pinus contorta	3				8		3						
Pinus coulteri							5		1			8	
Pinus echinata						5	1		1		5		
Pinus edulis								8					
Pinus elliottii							1		1		1		
Pinus engelmannii											3		
Pinus flexilis					8		3						8
Pinus glabra							1				3		
Pinus jeffreyi				5			5						
Pinus lambertiana					8								8
Pinus leiophylla	3										3		
Pinus longaeva					1								8
Pinus monophylla								8					
Pinus monticola	3				8								8
Pinus muricata									5				
Pinus palustris							1		1		1		
Pinus ponderosa	5				8		8						
Pinus pungens							1				3		
Pinus quadrifolia								3					
Pinus radiata							5		5				
Pinus remota													
Pinus resinosa													
Pinus rigida											3		
Pinus sabiniana									1				
Pinus serotina							1				3		
Pinus strobiformis	3						5			5			8
Pinus strobus													5
Pinus taeda							3				5		
Pinus torreyana		5							3				
Pinus virginiana									3		3		

Severity of agent's impact

10 = near complete mortality of all mature host trees (>95%)
8 = significant mortality of mature host trees (25% to 95%)
5 = moderate mortality of mature host trees (10% to 25%)
3 = moderate mortality in association with other threats, such as drought stress (1% to 10%)
1 = minor mortality, generally to host trees that are already stressed (<1%)

Pinus banksiana (Deb Brown, The Morton Arboretum)

Pinus torreyana (Richard O. Barry)

The following maps (Figures 2-17) show the distribution and impact of pests and pathogens listed in Table 2. Three sources were consulted for data: 1) National Forest Damage Agent Range Maps, created by the USDA Forest Service, Forest Health Assessment and Applied Sciences Team. Data are "an integration of various sources, reviewed by regional authorities…intended to display the biological extent of major damage agents, or the range over which they have been a managerial concern" (USDA Forest Service, 2019); 2) National Insect and Disease Risk Maps, created by the USDA Forest Service, Forest Health Technology Enterprise Team. These maps show areas with the greatest predicted hazard of basal area loss by 2027. Green areas are predicted to have little to no loss, light red areas are predicted to be some loss, and dark red areas are predicted to have the most loss. Methodology information can be found in the full USDA publication (Krist et al., 2014); 3) EDDMapS, managed by University of Georgia's Center for Invasive Species and Ecosystem Health. These maps are created through a web-based mapping system for documenting invasive species distribution and facilitating Early Detection and Rapid Response programs (EDRR; EDDMapS, 2020).

Armillaria root disease *(Armillaria* spp.*)*

Current county-level distribution

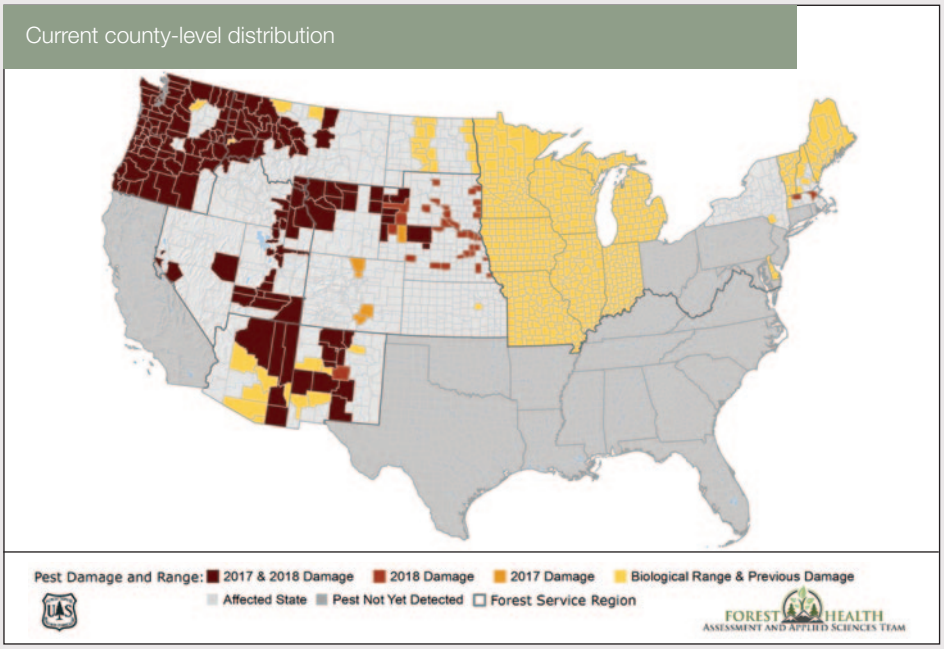


Figure 2. National Forest Damage Agent Range Map for armillaria root disease (*Armillaria* spp.); created by the USDA Forest Service, Forest Health Assessment and Applied Sciences Team (USDA Forest Service, 2019).

Jack pine budworm *(Choristoneura pinus)*

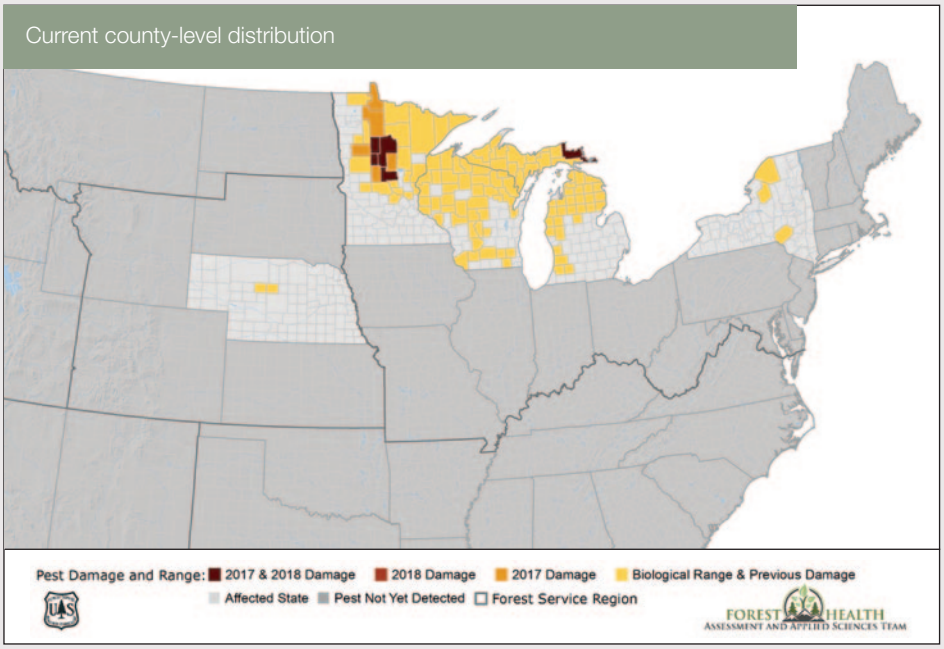


Figure 3. National Forest Damage Agent Range Map for jack pine budworm (*Choristoneura pinus*); created by the USDA Forest Service, Forest Health Assessment and Applied Sciences Team (USDA Forest Service, 2019).

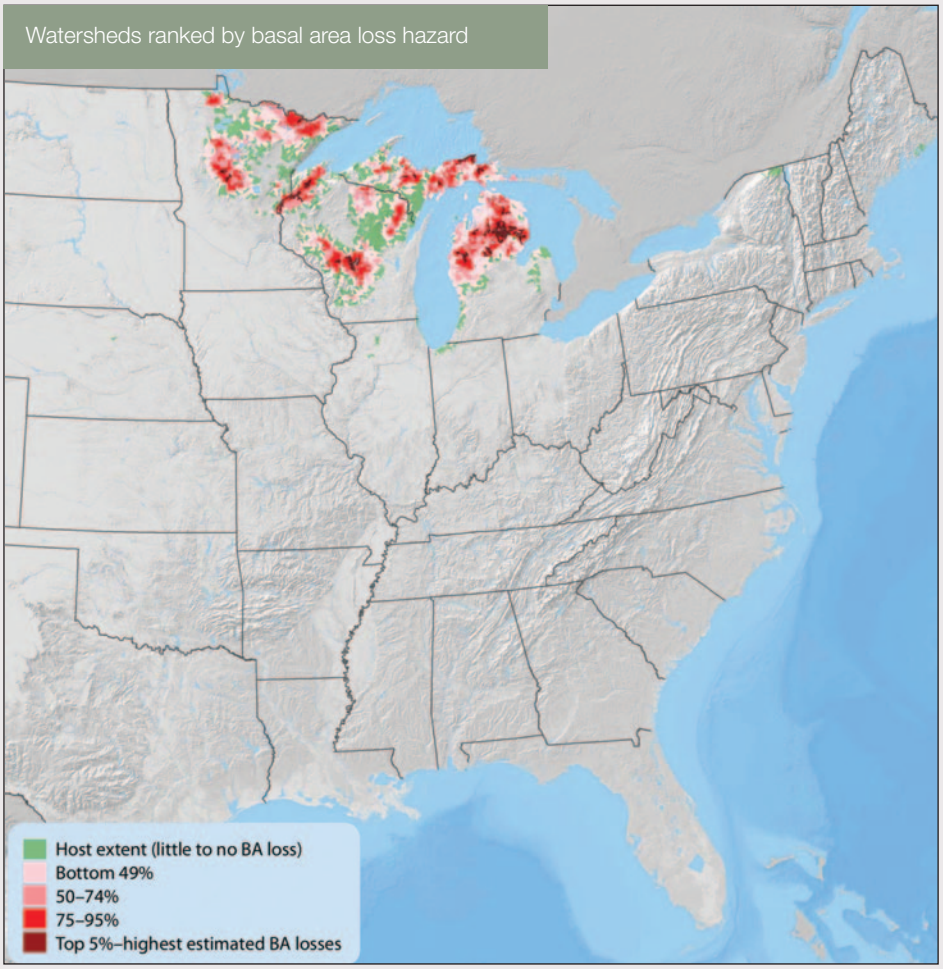


Figure 4. National Insect and Disease Risk Map quantifying the predicted impact of jack pine budworm (*Choristoneura pinus*) on *Pinus banksiana* by 2027; created by the USDA Forest Service, Forest Health Technology Enterprise Team (Krist et al., 2014).

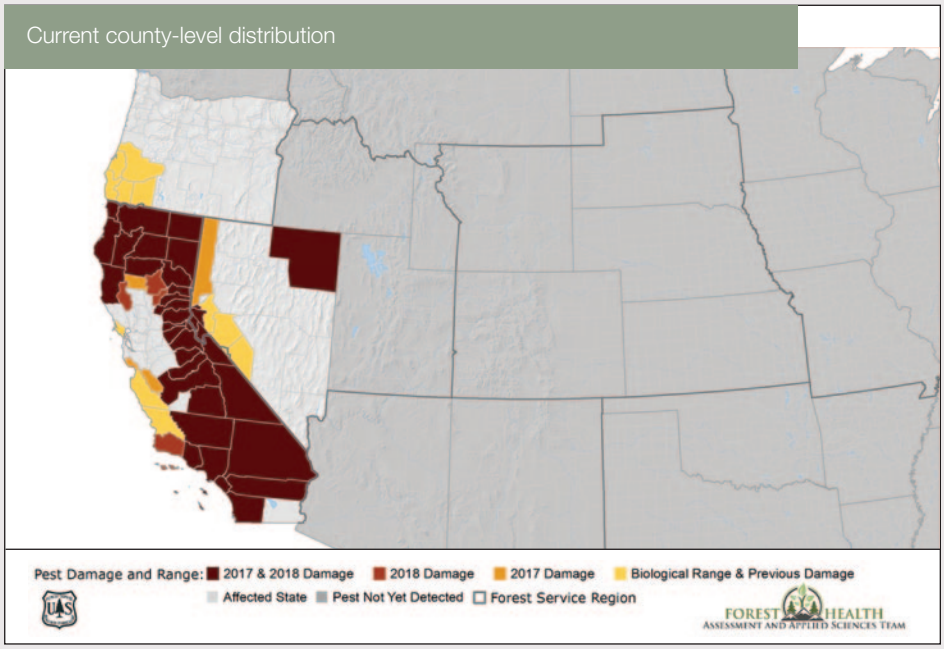


Figure 5. National Forest Damage Agent Range Map for jeffrey pine beetle (*Dendroctonus jeffreyi*); created by the USDA Forest Service, Forest Health Assessment and Applied Sciences Team (USDA Forest Service, 2019).

Figure 6. National Insect and Disease Risk Map quantifying the predicted impact of jeffrey pine beetle (*Dendroctonus jeffreyi*) on *Pinus jeffreyi* by 2027; created by the USDA Forest Service, Forest Health Technology Enterprise Team (Krist et al., 2014).

Mountain pine beetle *(Dendroctonus ponderosae)*

Current county-level distribution

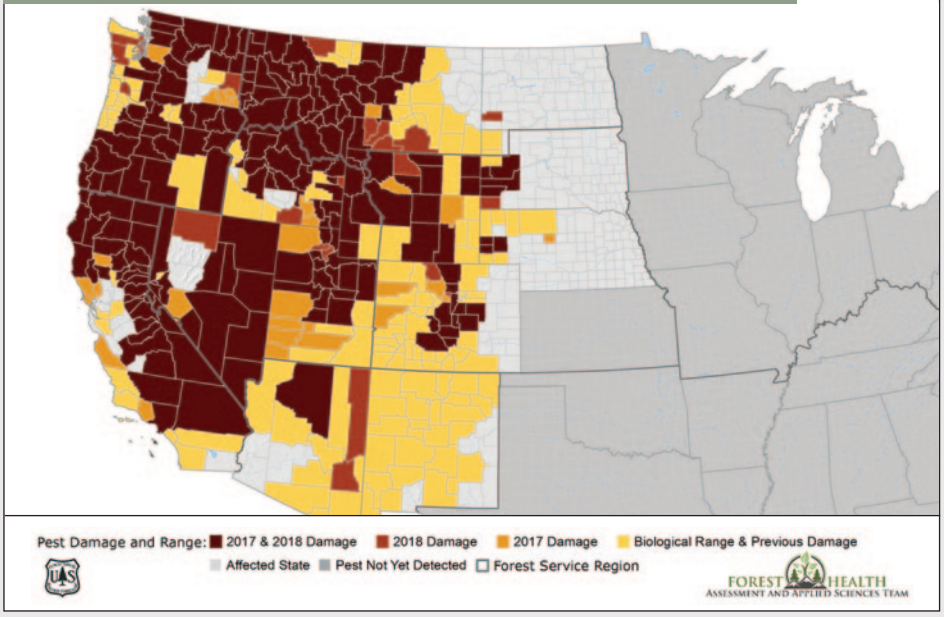


Figure 7. National Forest Damage Agent Range Map for mountain pine beetle (*Dendroctonus ponderosae*); created by the USDA Forest Service, Forest Health Assessment and Applied Sciences Team (USDA Forest Service, 2019).

Watersheds ranked by basal area loss hazard

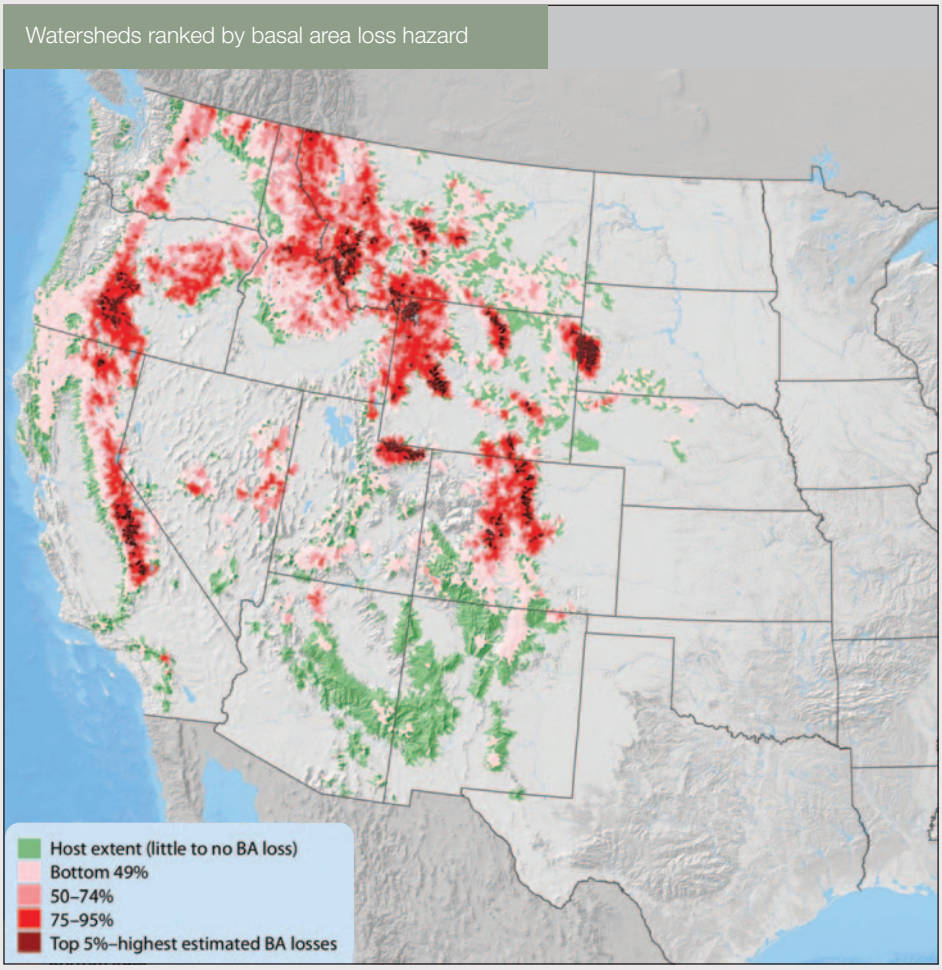


Figure 8. National Insect and Disease Risk Map quantifying the predicted impact of mountain pine beetle (*Dendroctonus ponderosae*) on *Pinus albicaulis, P. contorta, P. flexilis, P. lambertiana, P. monticola, P. ponderosa*, and *P. strobiformis* by 2027; created by the USDA Forest Service, Forest Health Technology Enterprise Team (Krist et al., 2014).

Phytophthora root rot *(Phytophthora cinnamomi)*

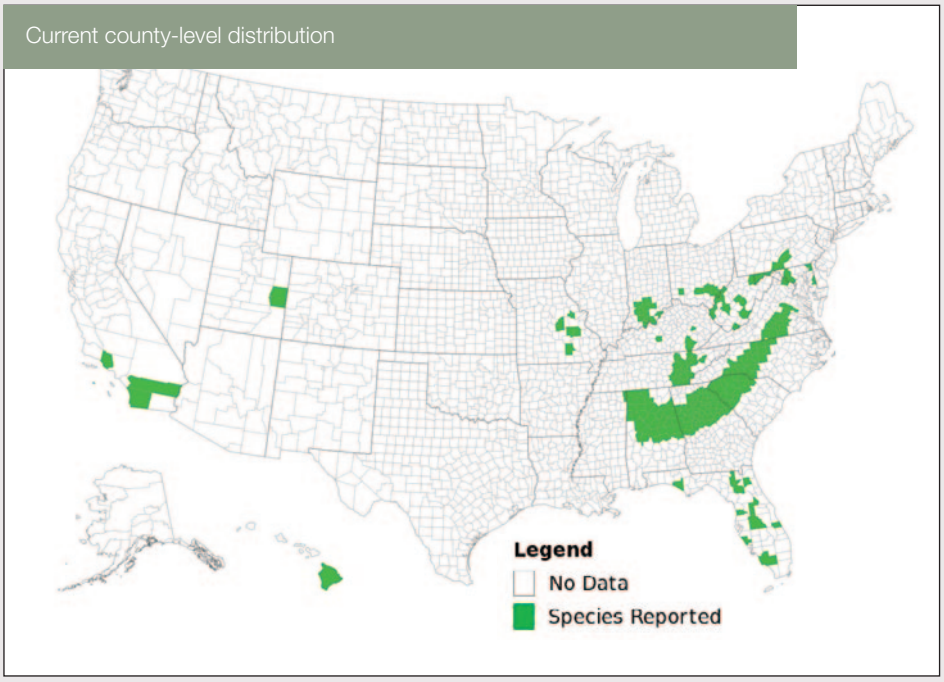


Figure 9. Distribution of phytophthora root rot (*Phytophthora cinnamomi*), created by EDDMapS (2020).

Engraver beetles *(Ips* spp.*)*

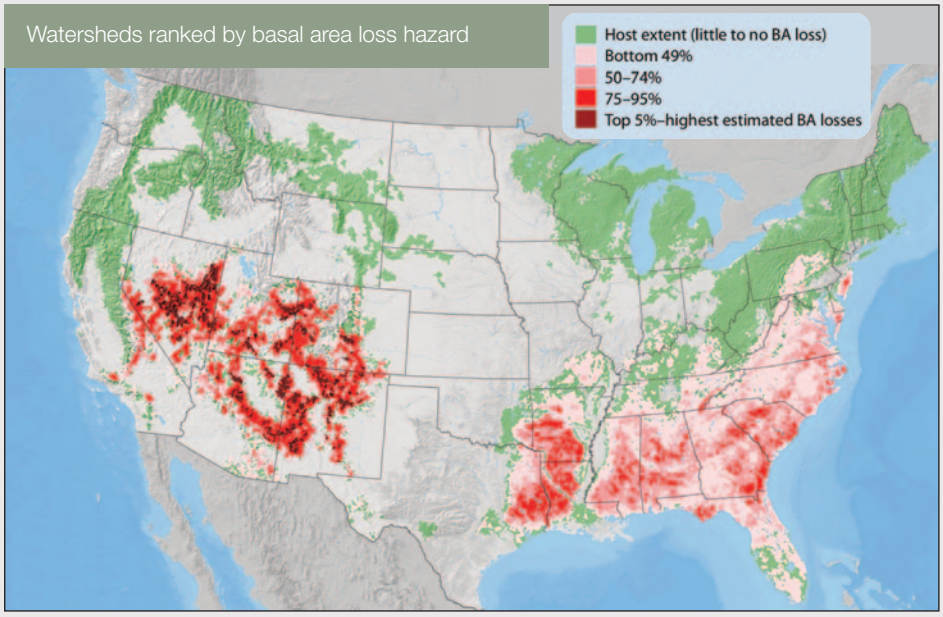


Figure 10. National Insect and Disease Risk Map quantifying the predicted impact of engraver beetles (*Ips spp.*) on *Pinus echinata, P. edulis, P. elliottii, P. palustris, P. ponderosa, P. rigida, P. serotina, P. strobus, P. taeda*, and *P. virginiana* by 2027; created by the USDA Forest Service, Forest Health Technology Enterprise Team (Krist et al., 2014).

Roundheaded pine beetle *(Dendroctonus adjunctus)*

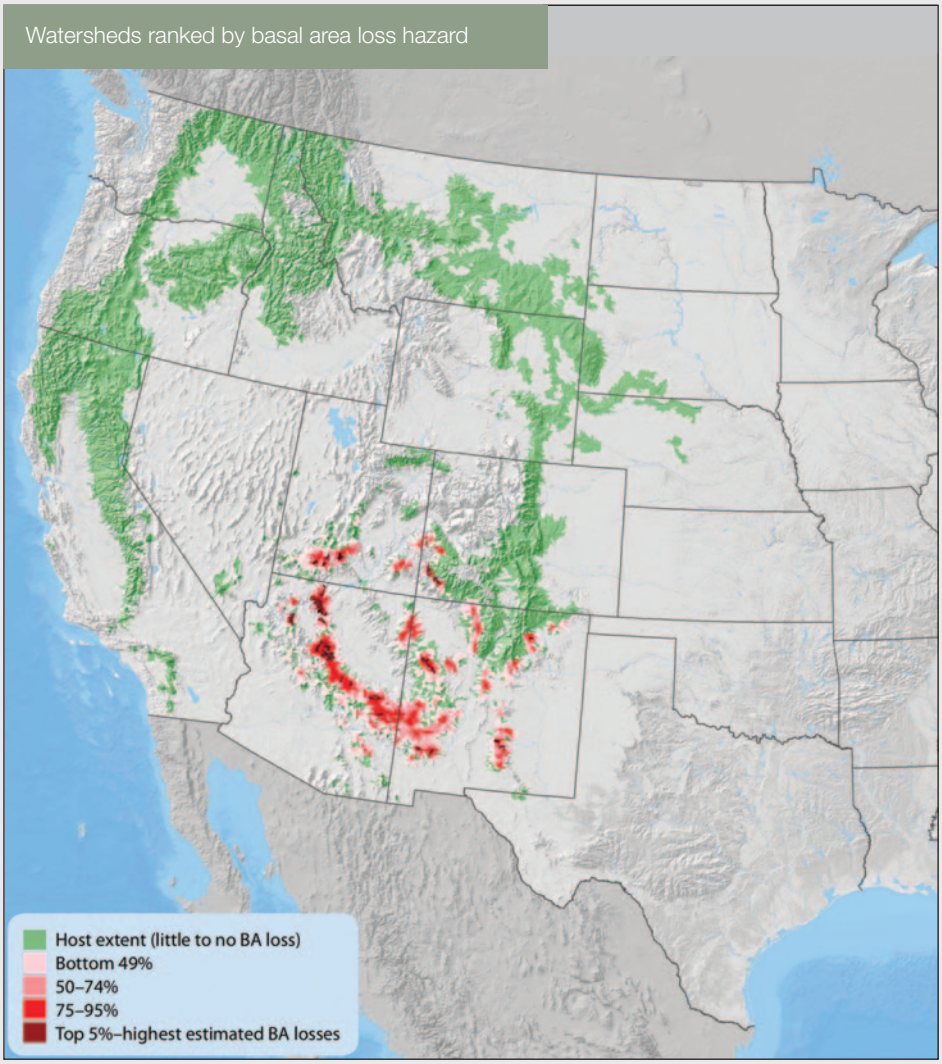


Figure 11. National Insect and Disease Risk Map quantifying the predicted impact of roundheaded pine beetle (*Dendroctonus adjunctus*) on *Pinus ponderosa* by 2027; created by the USDA Forest Service, Forest Health Technology Enterprise Team (Krist et al., 2014).

Pinus glabra (Susan McDougall)

Pinus serotina (Matt Lobdell, The Morton Arboretum)

Southern pine beetle *(Dendroctonus frontalis)*

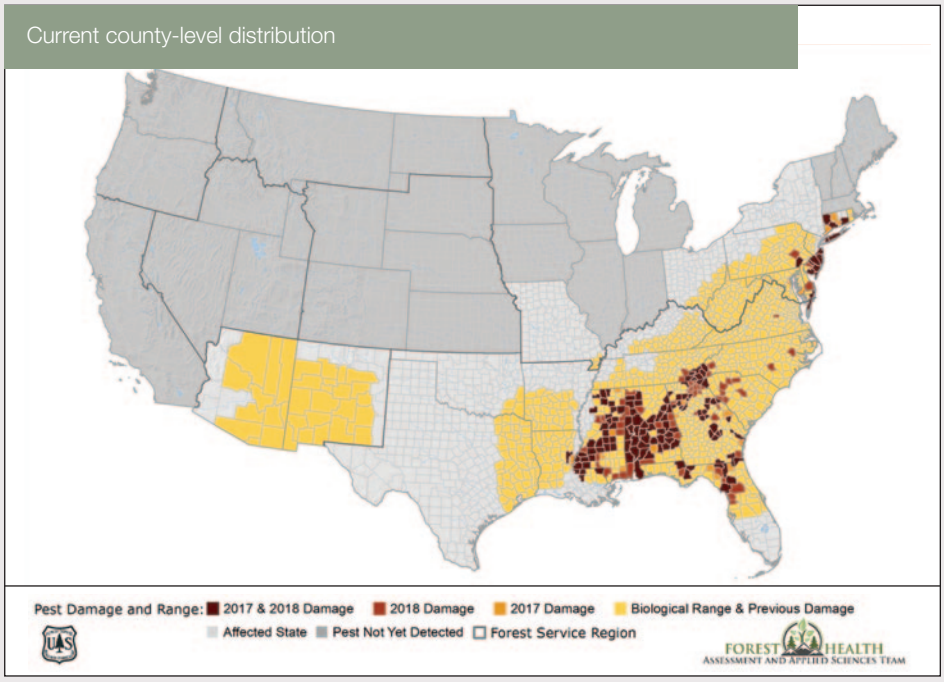


Figure 12. National Forest Damage Agent Range Map for southern pine beetle (*Dendroctonus frontalis*); created by the USDA Forest Service, Forest Health Assessment and Applied Sciences Team (USDA Forest Service, 2019).

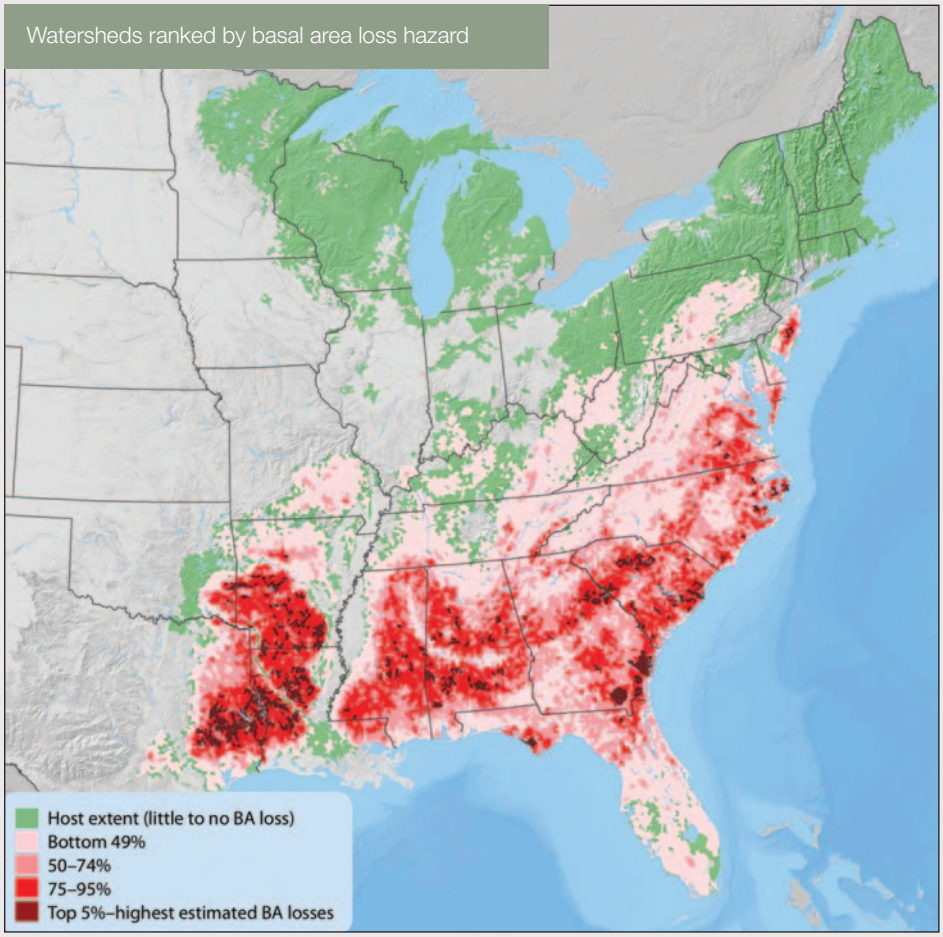


Figure 13. National Insect and Disease Risk Map quantifying the predicted impact of southern pine beetle (*Dendroctonus frontalis*) on *Pinus echinata, P. elliottii, P. palustris, P. rigida, P. serotina, P. strobus, P. taeda*, and *P. virginiana* by 2027; created by the USDA Forest Service, Forest Health Technology Enterprise Team (Krist et al., 2014).

Western pine beetle *(Dendroctonus brevicomis)*

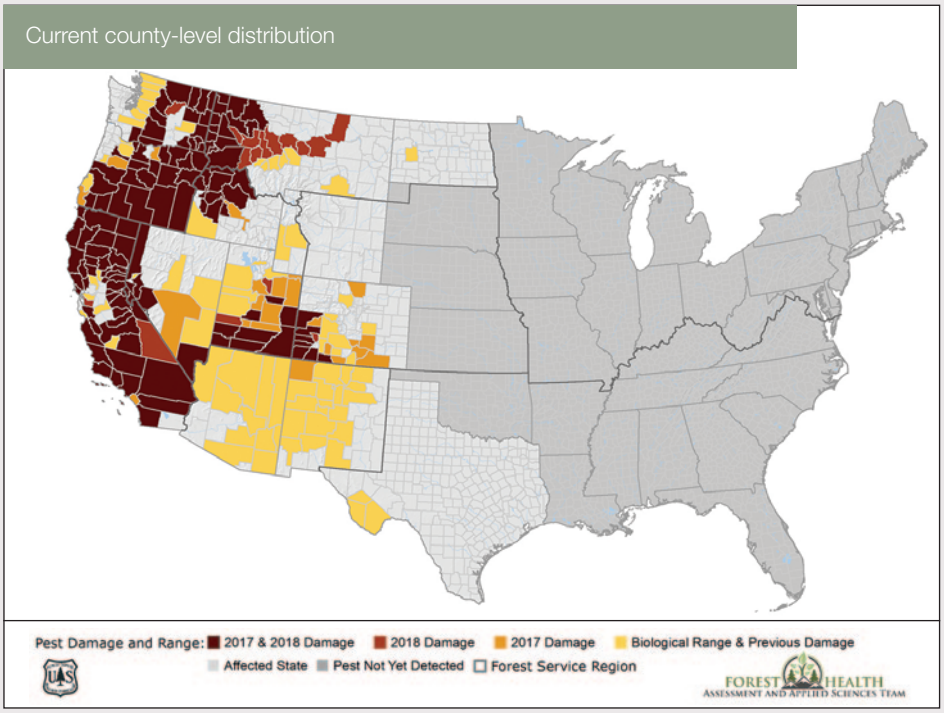


Figure 14. National Forest Damage Agent Range Map for western pine beetle (*Dendroctonus brevicomis*); created by the USDA Forest Service, Forest Health Assessment and Applied Sciences Team (USDA Forest Service, 2019).

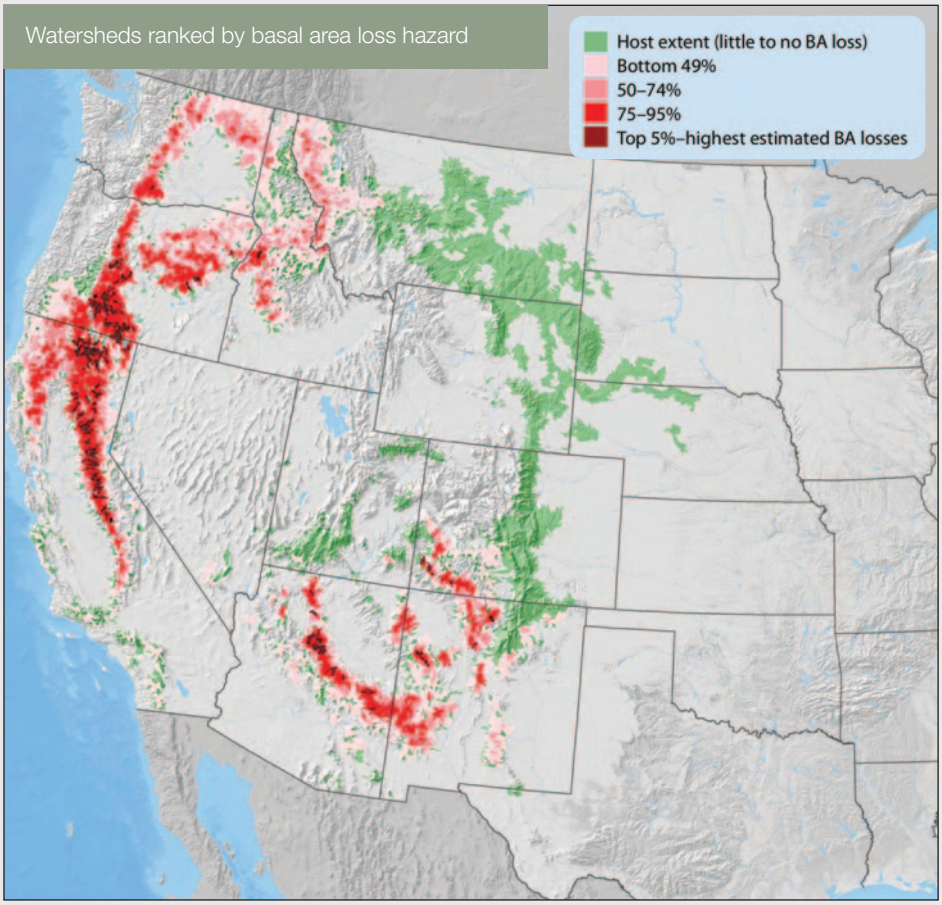


Figure 15. National Insect and Disease Risk Map quantifying the predicted impact of western pine beetle (*Dendroctonus brevicomis*) on *Pinus coulteri* and *P. ponderosa* by 2027; created by the USDA Forest Service, Forest Health Technology Enterprise Team (Krist et al., 2014).

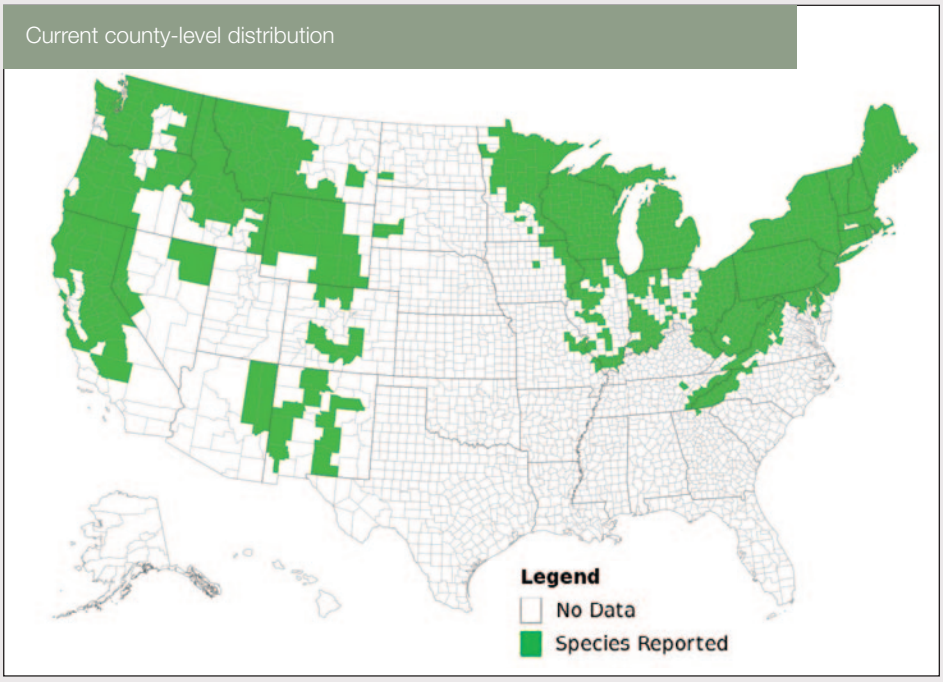


Figure 16. Distribution of white pine blister rust (*Cronartium ribicola*), created by EDDMapS (2020).

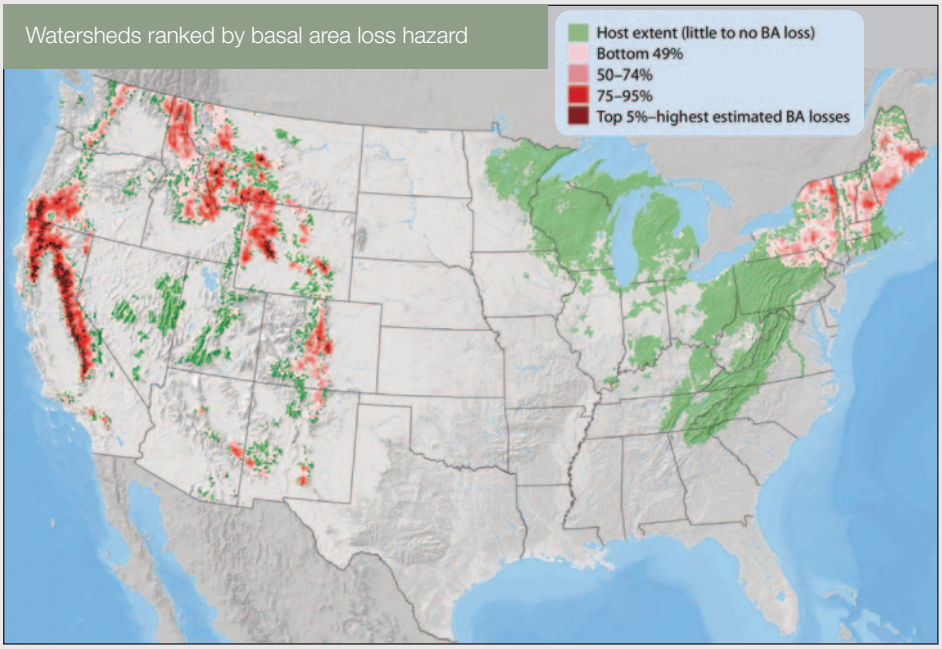


Figure 17. National Insect and Disease Risk Map quantifying the predicted impact of white pine blister rust (*Cronartium ribicola*) and its effect on *Pinus albicaulis, P. aristata, P. flexilis, P. lambertiana, P. monticola, P. strobiformis*, and *P. strobus* by 2027; created by the USDA Forest Service, Forest Health Technology Enterprise Team (Krist et al., 2014).

Table 3. Pest and disease vulnerability of native U.S. *Pinus* species, from the results of a USDA Forest Service study that analyzed 419 native U.S. tree species. Species are ordered by overall rank, from most vulnerable to least vulnerable. Figure is adapted, with permission, from Potter et al. (2019b).

Pinus lambertiana (Susan McDougall)

Pinus flexilis (Ed Hedborn, The Morton Arboretum)

Species	Vulnerability Class*	Overall Rank (of 419)
Pinus torreyana	B	18
Pinus balfouriana	A2	50
Pinus washoensis (*P. ponderosa subsp. ponderosa*)	B	64
Pinus aristata	A2	80
Pinus longaeva	A2	102
Pinus lambertiana	A2	104
Pinus flexilis	A2	107
Pinus pungens	C	131
Pinus coulteri	A2	139
Pinus monophylla	A2	168
Pinus sabiniana	C	182
Pinus monticola	A2	197
Pinus radiata	B	202
Pinus remota	D	204
Pinus quadrifolia	B	205
Pinus attenuata	C	210
Pinus clausa	C	215
Pinus engelmannii	B	235
Pinus muricata	B	247
Pinus glabra	C	248
Pinus edulis	D	250
Pinus jeffreyi	B	273
Pinus arizonica	B	277
Pinus ponderosa	A4	289
Pinus palustris	E	299
Pinus rigida	E	300
Pinus echinata	E	304
Pinus serotina	E	333
Pinus albicaulis	A4	339
Pinus strobiformis	A4	345
Pinus taeda	E	361
Pinus leiophylla	D	362
Pinus virginiana	E	370
Pinus elliottii	E	380
Pinus strobus	E	386
Pinus contorta	A4	400
Pinus banksiana	E	405
Pinus resinosa	E	416

*Vulnerability Classes

A) High current severity
   1) High vulnerability
   2) Potential adaptation
   3) Potential persistence
   4) Potential persistence and adaptation

B) Potential high vulnerability to future threats

C) Potential high sensitivity to future threats

D) Potential low adaptation to future threats

E) Low current and potential vulnerability

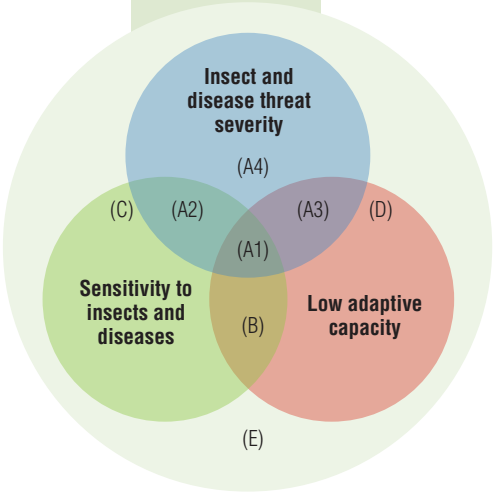


Table 4. Climate change vulnerability of native U.S. *Pinus* species, from the results of a USDA Forest Service study that analyzed 339 native U.S. tree species. Species are ordered by overall rank, from most vulnerable to least vulnerable. Figure is adapted, with permission, from Potter et al. (2017).

Species	Vulnerability Class*	Overall Rank (of 419)
Pinus radiata	B	24
Pinus pungens	C	56
Pinus quadrifolia	D	86
Pinus torreyana	B	89
Pinus glabra	B	93
Pinus coulteri	B	96
Pinus strobiformis	B	115
Pinus remota	D	116
Pinus longaeva	C	127
Pinus balfouriana	D	135
Pinus engelmannii	D	140
Pinus arizonica	B	141
Pinus clausa	D	142
Pinus rigida	C	145
Pinus banksiana	C	159
Pinus leiophylla	D	161
Pinus washoensis (*P. ponderosa subsp. ponderosa*)	D	178
Pinus muricata	D	179
Pinus resinosa	C	201
Pinus serotina	E4	220
Pinus aristata	D	225
Pinus strobus	E4	231
Pinus flexilis	E4	232
Pinus monophylla	E4	257
Pinus attenuata	E4	268
Pinus virginiana	E1	281
Pinus sabiniana	E4	286
Pinus elliottii	E4	290
Pinus monticola	E2	293
Pinus jeffreyi	E4	296
Pinus echinata	E4	298
Pinus palustris	E4	299
Pinus taeda	E4	304
Pinus albicaulis	E4	305
Pinus lambertiana	E2	316
Pinus edulis	E4	320
Pinus contorta	E2	323
Pinus ponderosa	E4	337

*Vulnerability Classes

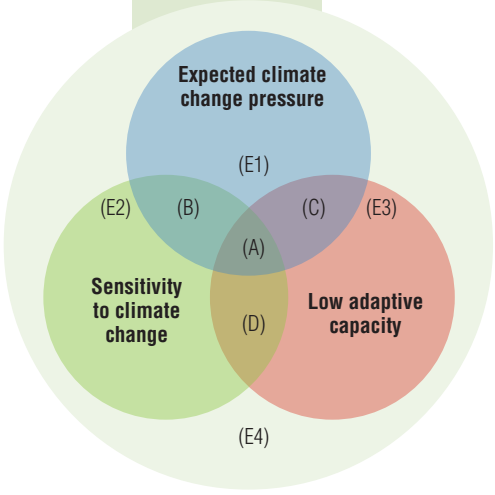
A) High vulnerability, little adaptation or persistence potential

B) High vulnerability, potential adaptation

C) High vulnerability, potential persistence

D) Potential high future vulnerability

E) Low current vulnerability



CLIMATE CHANGE VULNERABILITY

Native U.S. *Pinus* species face varying impacts from climate change, but they do not seem to be highly vulnerable compared to other native U.S. tree genera. Using a similar methodology to Potter et al. (2019b), which focuses on species-specific traits in addition to vulnerability data, Potter et al. (2017) analyzed species vulnerability to climate change in the study, *A United States national prioritization framework for tree species vulnerability to climate change*. A selection of 339 native U.S. tree species were assessed through comprehensive literature review, in addition to input from 25 USDA Forest Service resource managers and scientists from across the country and varying departments within the agency. Results from that study are provided in Table 4.

Pinus strobus (Ed Hedborn, The Morton Arboretum)

EX SITU SURVEY RESULTS

Most *Pinus* species are considered non-exceptional, meaning their seeds can be stored for relatively long periods of time (20+ years) in conventional seed bank conditions of low temperature and moisture. Some *Pinus* species retain viability for shorter periods of time when stored in a conventional seed bank, but still store relatively well (Bonner, 2008). For example, *P. palustris* is considered the most difficult southern pine to store, though careful processing can lead to high viability for at least ten years (Barnett, 2005).

In 2018, we conducted a global accessions-level *ex situ* survey of priority native U.S. tree species within nine target genera: *Carya, Fagus, Gymnocladus, Juglans, Lindera, Persea, Pinus, Sassafras*, and *Taxus*. The request for data was emailed directly to target *ex situ* collections, including arboreta, botanical gardens, private collections, and USDA Forest Service seed orchards. We started with institutions that had reported collections of these genera to BGCI's PlantSearch database, and whose contact information was available in BGCI's GardenSearch database. The data request was also distributed via newsletters and social media through ArbNet, the American Public Gardens Association, Botanic Gardens Conservation International, the Center for Plant Conservation, the Plant Conservation Alliance, The Morton Arboretum, and the USDA Forest Service. A total of 143 collections from 25 countries provided accessions data for our target genera, including 117 collections from 20 countries reporting native U.S. *Pinus* species (Figures 18a and 18b). See Appendix A for a list of participating institutions. When providing *ex situ* collections data, institutions were asked to include the number of individuals in each accession. When such data were unavailable, we assumed the accession consisted of one individual; therefore our results represent a conservative estimate. Also, because *Pinus* species are orthodox and can be seed banked, the *ex situ* survey results presented here include both seed bank and living collections.

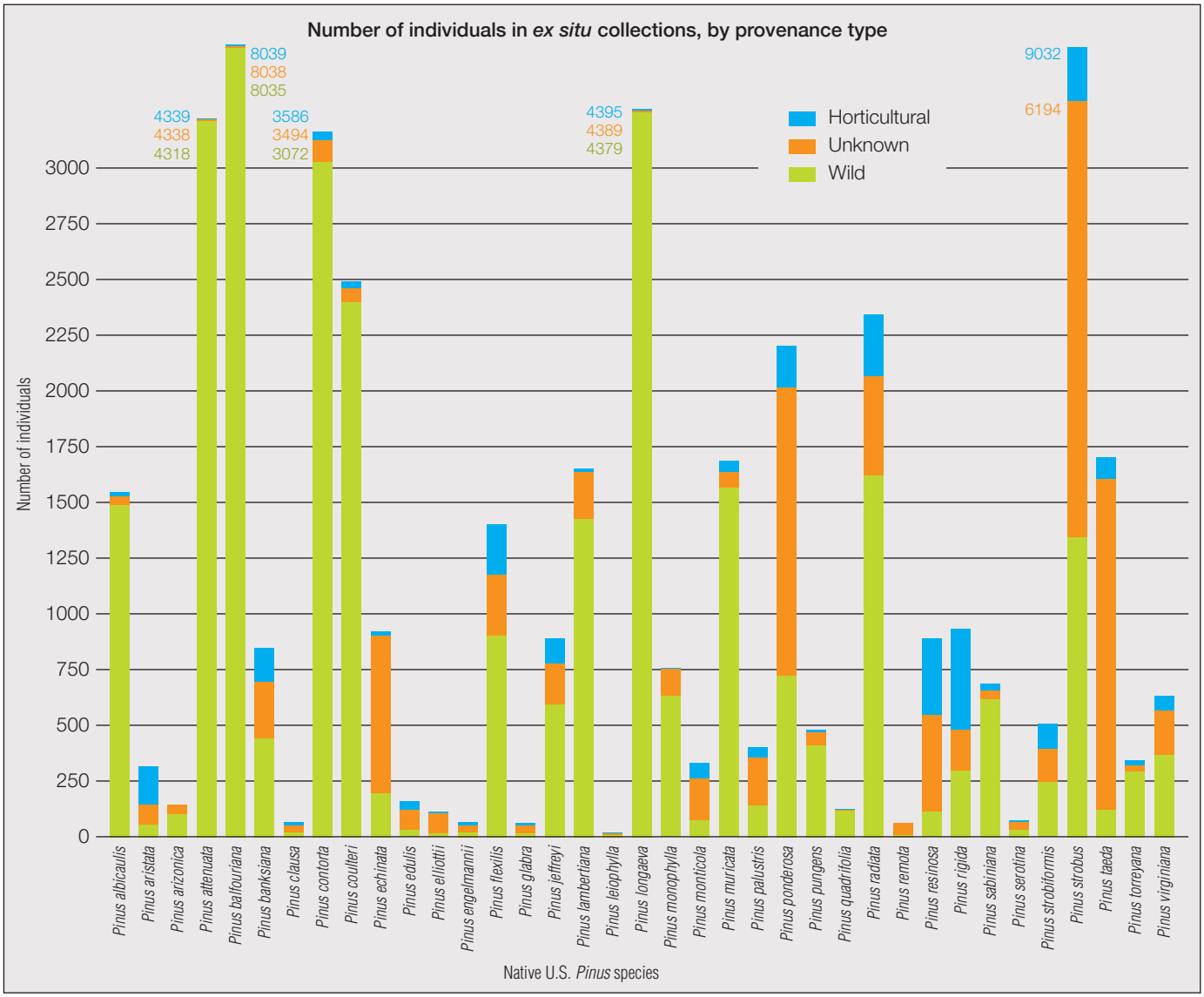


Figure 18a. Results from a 2018 global accessions-level *ex situ* survey for native U.S. *Pinus* species. Colored numbers above a bar indicate the value exceeds the limits of the chart.

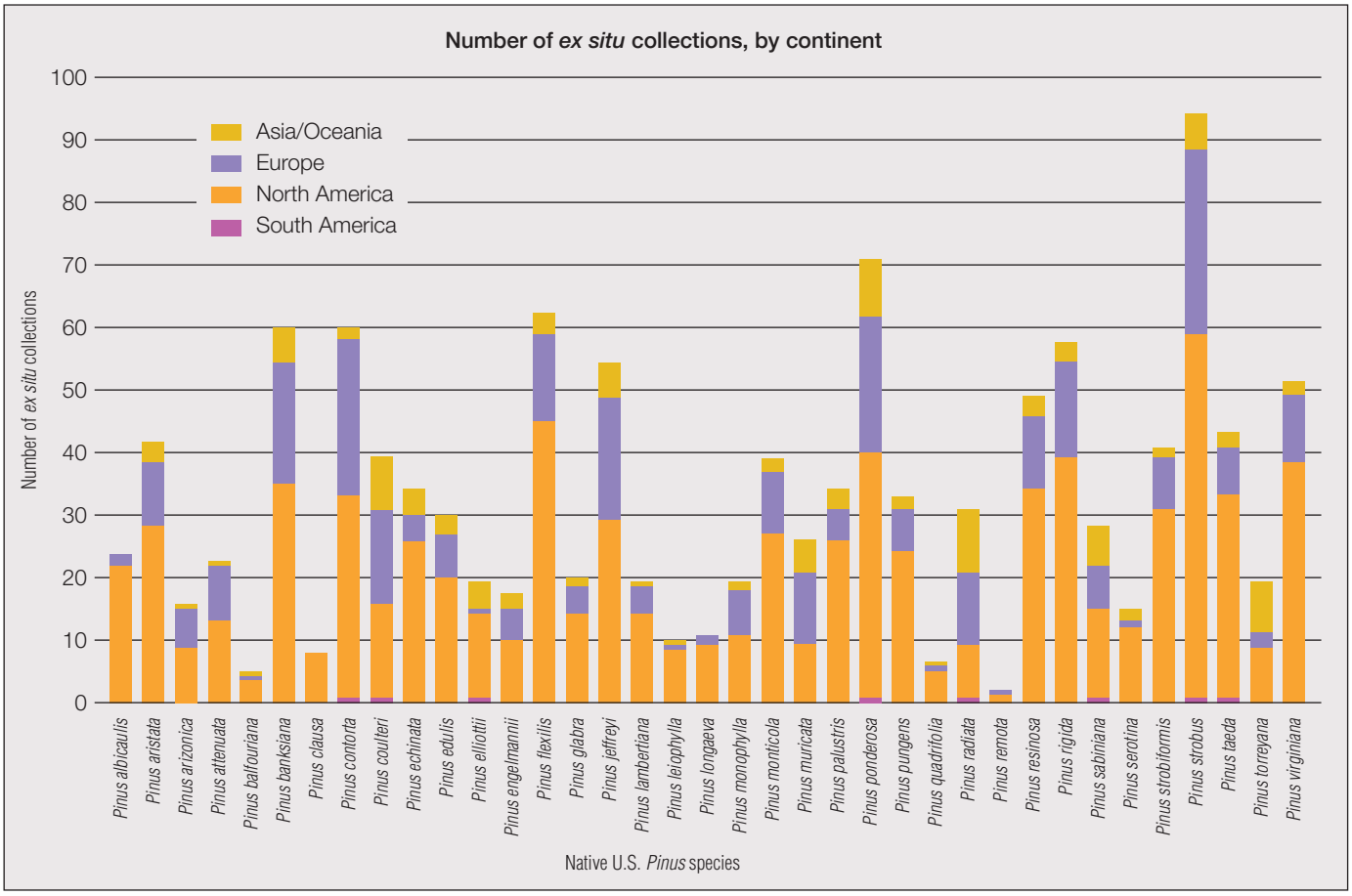


Figure 18b. Results from a 2018 global accessions-level *ex situ* survey for native U.S. *Pinus* species.

Pinus ponderosa (Ed Hedborn, The Morton Arboretum)

SPATIAL ANALYSIS OF *EX SITU* COLLECTIONS

Ex situ collections conserve the most genetic diversity when they represent a large percent of the target species' geographic and ecological range. Therefore, identifying under-represented populations and ecoregions is vital to improving the conservation value of *ex situ* collections. To prioritize regions and species for future *ex situ* collecting, we mapped and analyzed the estimated native distribution of each target species versus the wild provenance localities of germplasm in *ex situ* collections. Based on threat rankings, including IUCN Red List Category and NatureServe Global Status, climate change vulnerability, impact from pests and diseases, and representation in *ex situ* collections, 12 priority native U.S. *Pinus* species were identified as targets for these further spatial analyses.

We used two proxies for estimating *ex situ* genetic diversity representation: geographic and ecological coverage. These proxies are based on the assumption that sampling across a species' full native distribution and all ecological zones it inhabits is the best way to ensure that the full spectrum of its genetic diversity is captured in *ex situ* collections (CPC, 2018; Hanson et al., 2017; Khoury et al., 2015). Using methods introduced by Khoury et al. (2019) and Beckman et al. (2019), we calculated geographic and ecological coverage by comparing two sets of geographic points: 1) known *in situ* occurrences, and 2) *ex situ* collection source localities (i.e., wild occurrences where seed was collected for *ex situ* preservation). To approximate potential suitable habitat, nearby populations, and/or gene flow, we placed a circular buffer around each *in situ* occurrence point and each *ex situ* collection source locality. When buffers around *ex situ* collection source localities overlap with buffers around *in situ* occurrence points, that area is considered 'conserved' by *ex situ* collections (Figures 19-31; Table 5). Because our calculations of geographic and ecological coverage are based on a rough estimation of the distribution of a species, the values reported here should be viewed as estimates that can be used to compare among species for prioritization rather than values reflecting the actual capture of genetic diversity (e.g., alleles or DNA sequence differences) in *ex situ* collections.

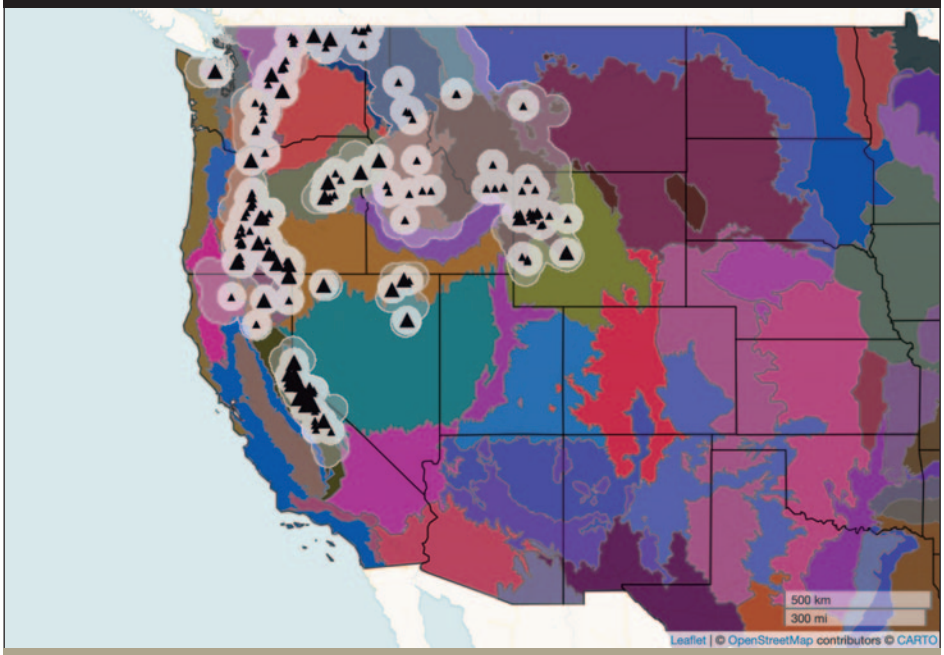
Pinus echinata (Susan McDougall)

Pinus sabiniana (Susan McDougall)

In situ occurrence points for each target species were downloaded from a variety of publicly available data sources, including Biodiversity Information Serving Our Nation (BISON; USGS, 2019), Botanical Information and Ecology Network (BIEN; bien.nceas.ucsb.edu, 2020; Maitner, 2020), Forest Inventory and Analysis (FIA) Program of the USDA Forest Service (Forest Inventory and Analysis Database, 2019), Global Biodiversity Information Facility (GBIF.org, 2020; Chamberlain & Boettiger, 2017), Integrated Digitized Biocollections (iDigBio; idigbio.org, 2020; Michonneau & Collins, 2017), and U.S. herbarium consortia (e.g., SERNEC; Data Portal, 2020). To increase their reliability, these raw data points were automatically vetted using a set of common filters for biodiversity data (Zizka et al., 2019). Points were removed if they fell within 500 meters of a state centroid or 100 meters of a biodiversity institution, or if they were not within a county of native occurrence for the target species based on county-level data from Biota of North America (BONAP; Kartesz, 2018). Points were also removed if they were recorded before 1950, were missing a record year, were recorded as a living or fossil specimen, or were recorded as introduced, managed, or invasive. For species of conservation concern (assessed as Near Threatened, Vulnerable, Endangered, or Critically Endangered on the IUCN Red List) the *in situ* distribution points were also vetted manually based on literature review.

Ex situ data were gathered during the 2018 survey described in the previous section, and records for target species with a wild source locality description were manually geolocated when latitude and longitude were missing. For the twelve target native U.S. *Pinus* species, about 11% of records with wild or unknown provenance were manually geolocated, while 65% had latitude and longitude provided by the institution and 24% contained too little locality information to geolocate to county-level or finer. To map wild provenance localities of *ex situ* individuals, accessions collected from wild localities near each other were grouped together based on latitude and longitude rounded to one digit after the decimal. All data processing and mapping were performed in R (R Core Team, 2020; Graul, 2016).

Pinus albicaulis



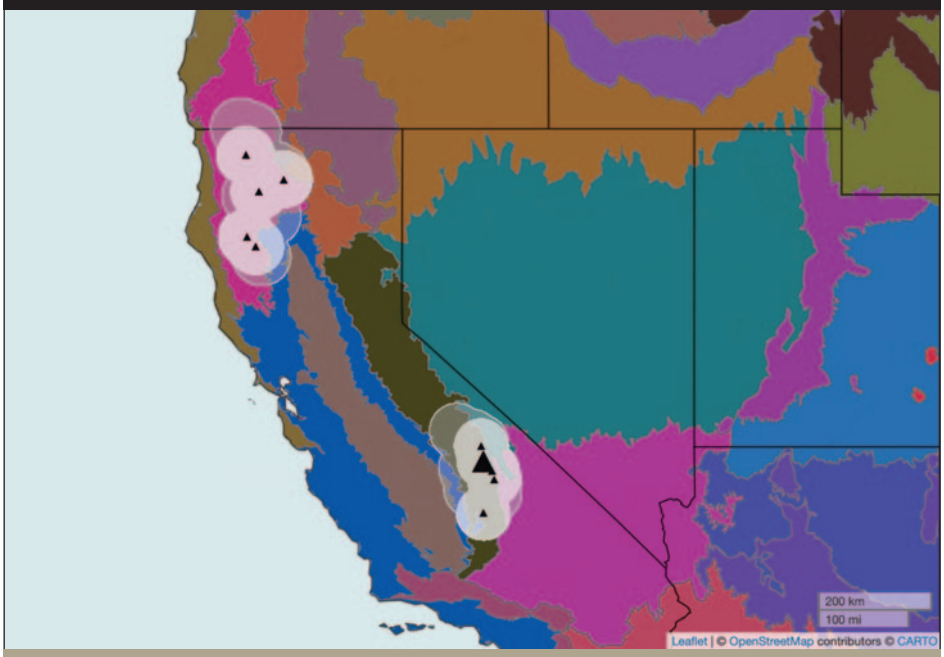
Source locality and number of wild provenance individuals present in *ex situ* collections ▲ 1-10 ▲ 11-29 ▲ 30+

Species' estimated native distribution (50 km buffer around *in situ* occurrence points)

Estimated capture of *ex situ* collections (50 km buffer around wild provenance localities)

Figure 19. Native distribution and wild provenance localities of *ex situ* individuals for *Pinus albicaulis*, based on 50 km buffers around *in situ* occurrence points and *ex situ* source localities. Background colors show EPA Level III Ecoregions (U.S. EPA Office of Research & Development, 2013a).

Pinus balfouriana



Source locality and number of wild provenance individuals present in *ex situ* collections ▲ 1-10 ▲ 11-29 ▲ 30+

Species' estimated native distribution (50 km buffer around *in situ* occurrence points)

Estimated capture of *ex situ* collections (50 km buffer around wild provenance localities)

Figure 20. Native distribution and wild provenance localities of *ex situ* individuals for *Pinus balfouriana*, based on 50 km buffers around *in situ* occurrence points and *ex situ* source localities. Background colors show EPA Level III Ecoregions (U.S. EPA Office of Research & Development, 2013a).

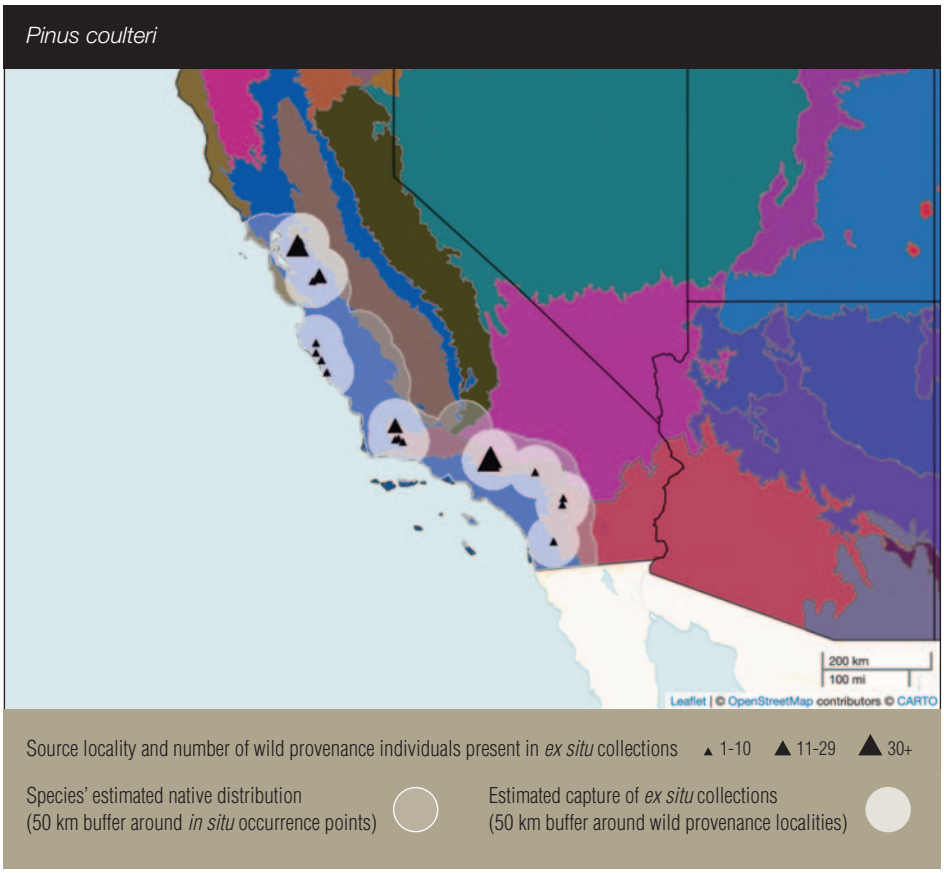


Figure 21. Native distribution and wild provenance localities of *ex situ* individuals for *Pinus coulteri*, based on 50 km buffers around *in situ* occurrence points and *ex situ* source localities. Background colors show EPA Level III Ecoregions (U.S. EPA Office of Research & Development, 2013a). In addition to standard *in situ* occurrence point filters applied to all target species, *P. coulteri* occurrence points were further refined by removing records more than 100 km outside the Elbert L. Little (1971) range map for the species.

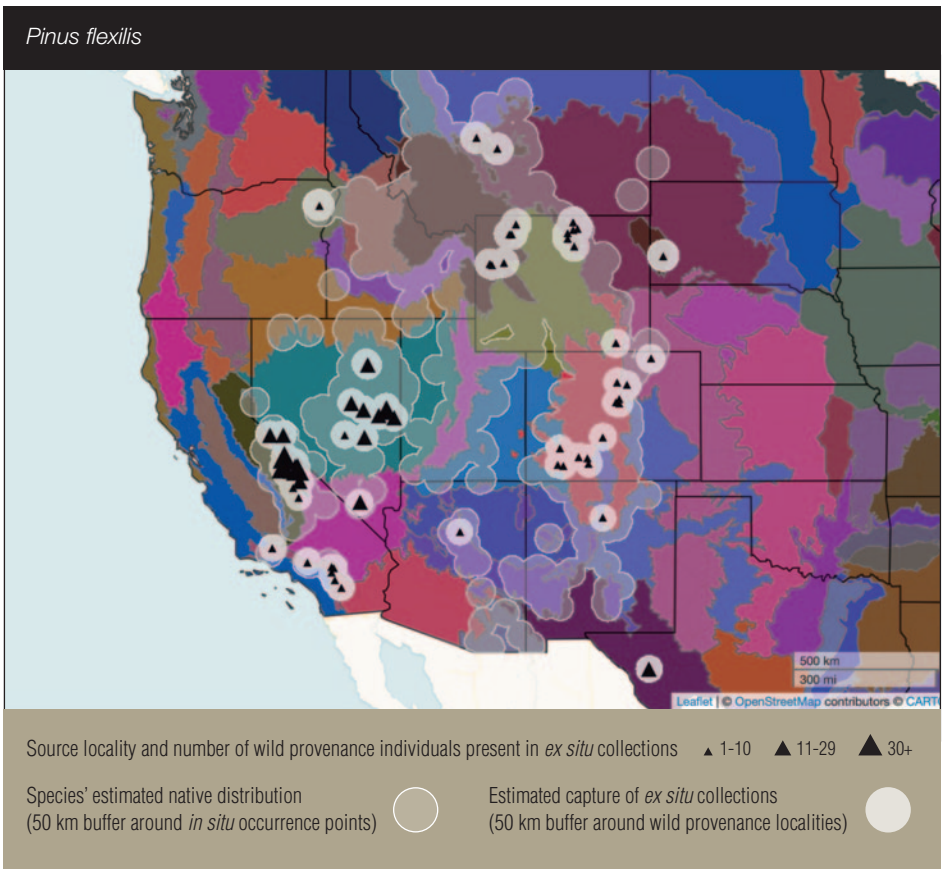


Figure 22. Native distribution and wild provenance localities of *ex situ* individuals for *Pinus flexilis*, based on 50 km buffers around *in situ* occurrence points and *ex situ* source localities. Background colors show EPA Level III Ecoregions (U.S. EPA Office of Research & Development, 2013a).

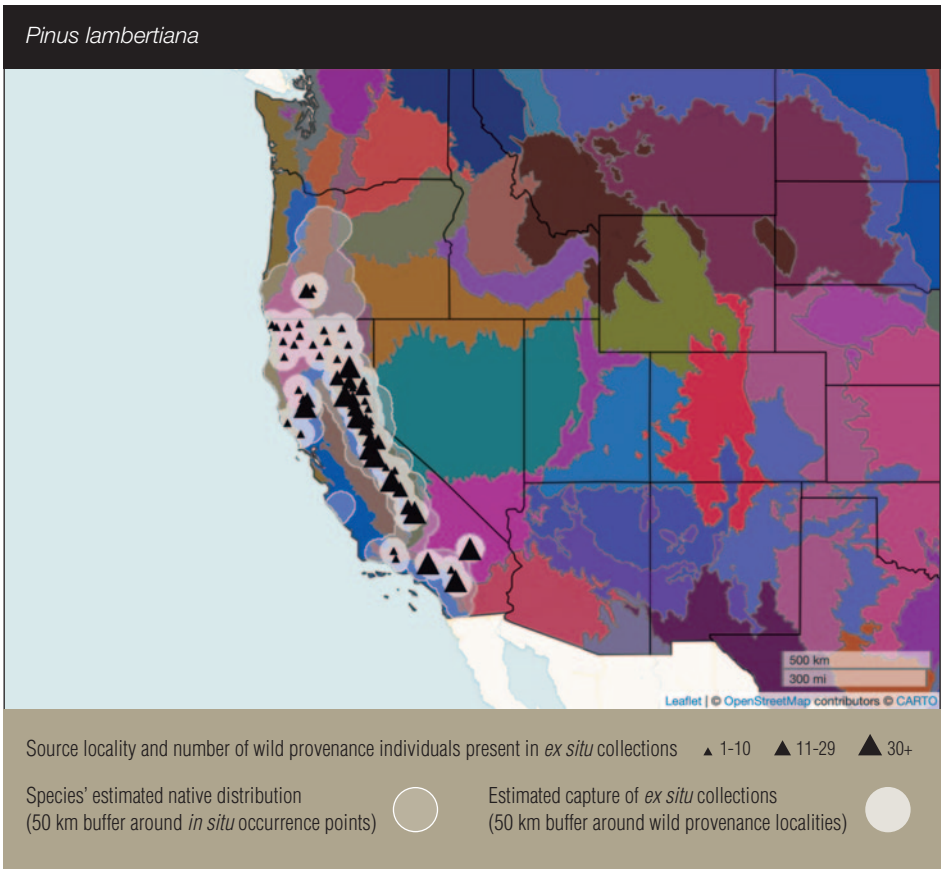


Figure 23. Native distribution and wild provenance localities of *ex situ* individuals for *Pinus lambertiana*, based on 50 km buffers around *in situ* occurrence points and *ex situ* source localities. Background colors show EPA Level III Ecoregions (U.S. EPA Office of Research & Development, 2013a).

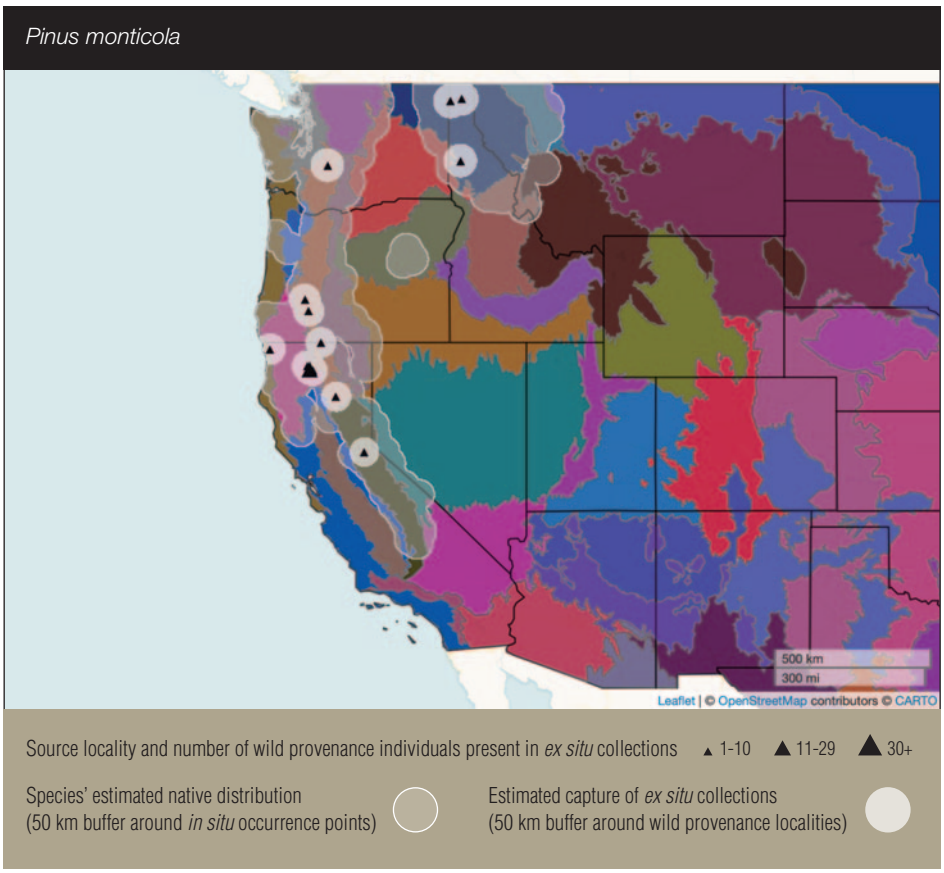


Figure 24. Native distribution and wild provenance localities of *ex situ* individuals for *Pinus monticola*, based on 50 km buffers around *in situ* occurrence points and *ex situ* source localities. Background colors show EPA Level III Ecoregions (U.S. EPA Office of Research & Development, 2013a). In addition to standard *in situ* occurrence point filters applied to all target species, *P. monticola* occurrence points were further refined by removing records more than 100 km outside the Elbert L. Little (1971) range map for the species.

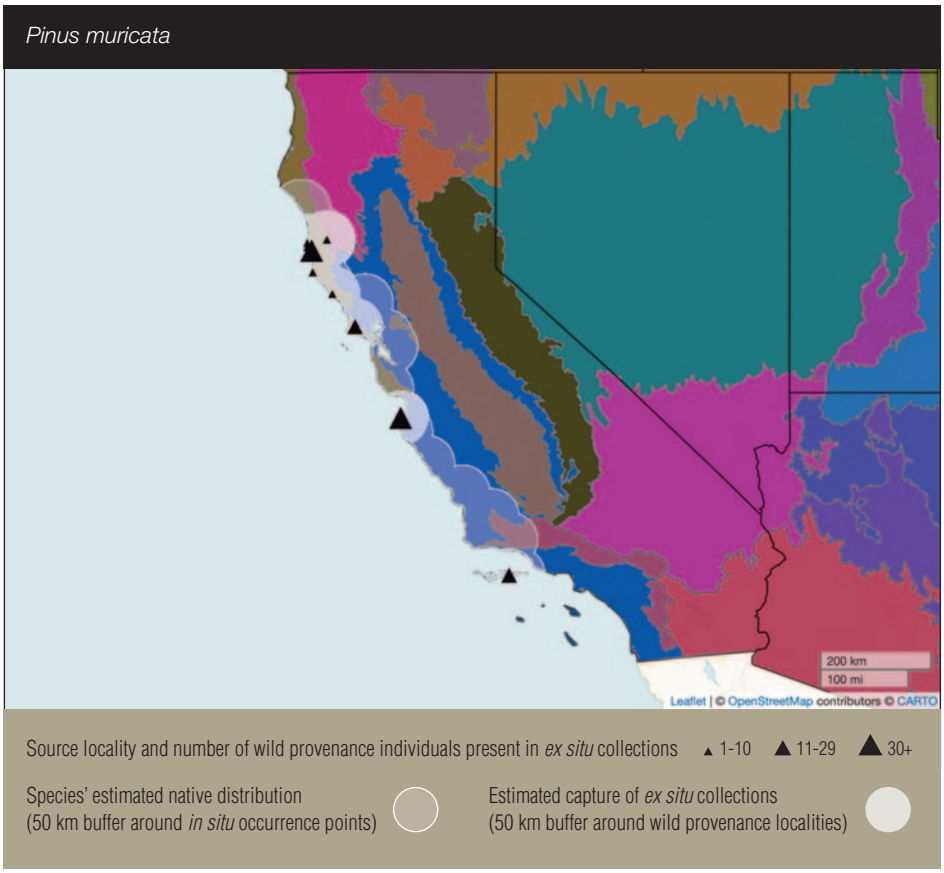


Figure 25. Native distribution and wild provenance localities of *ex situ* individuals for *Pinus muricata*, based on 50 km buffers around *in situ* occurrence points and *ex situ* source localities. Background colors show EPA Level III Ecoregions (U.S. EPA Office of Research & Development, 2013a). In addition to standard *in situ* occurrence point filters applied to all target species, *P. muricata* occurrence points were further refined by removing records more than 100 km outside the Elbert L. Little (1971) range map for the species.

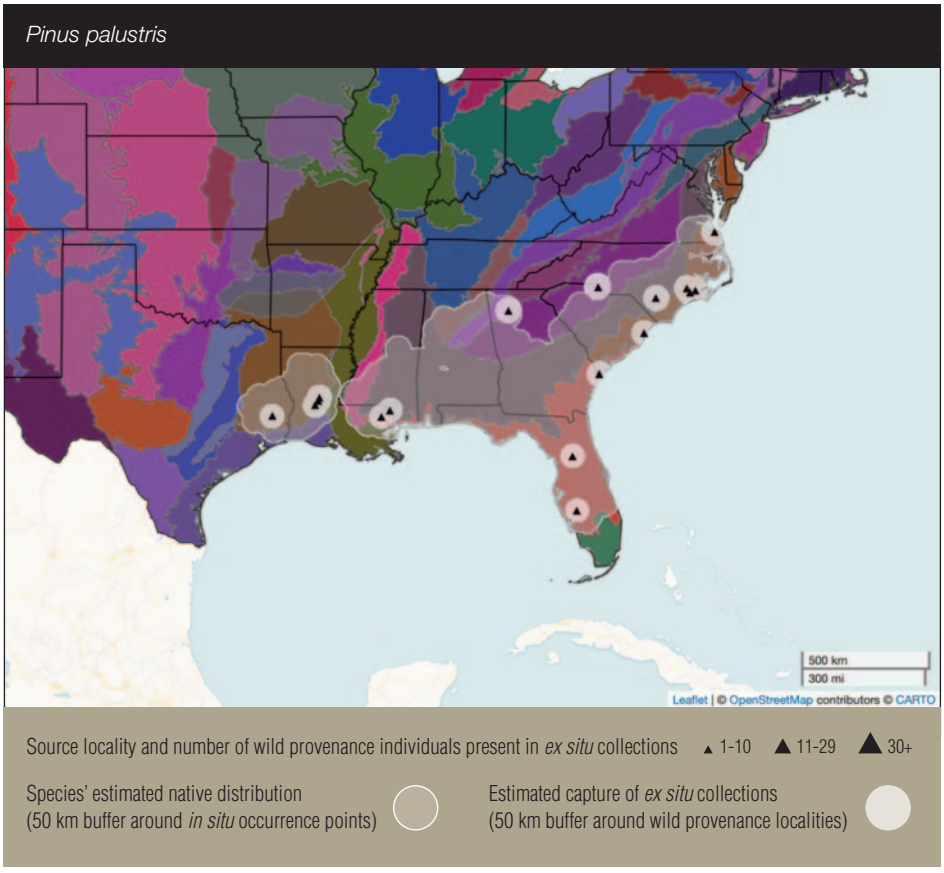
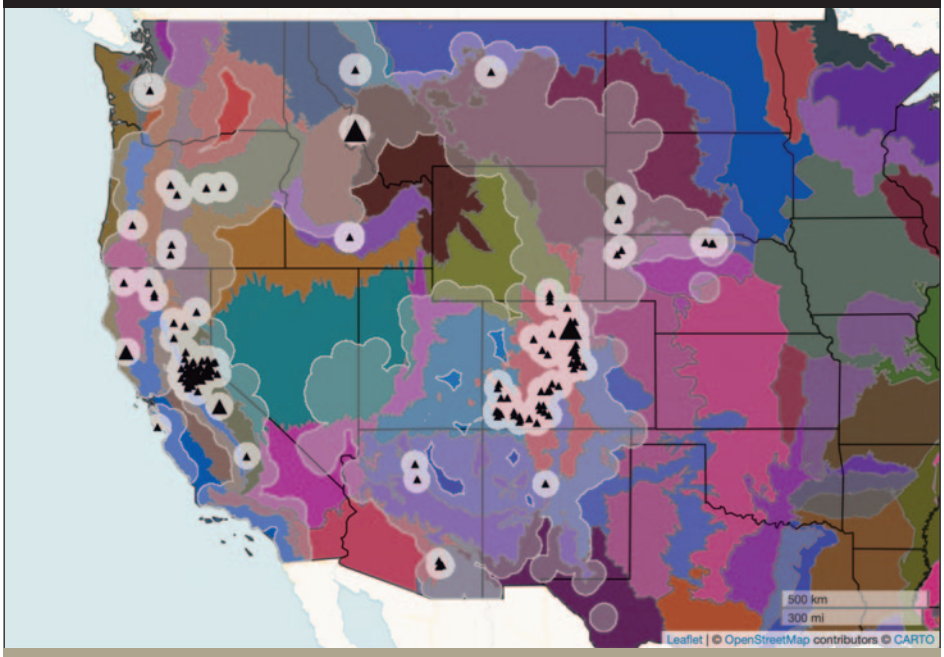


Figure 26. Native distribution and wild provenance localities of *ex situ* individuals for *Pinus palustris*, based on 50 km buffers around in situ occurrence points and *ex situ* source localities. Background colors show EPA Level III Ecoregions (U.S. EPA Office of Research & Development, 2013a). In addition to standard *in situ* occurrence point filters applied to all target species, *P. palustris* occurrence points were further refined by removing records more than 100 km outside the Elbert L. Little (1971) range map for the species.

Pinus ponderosa



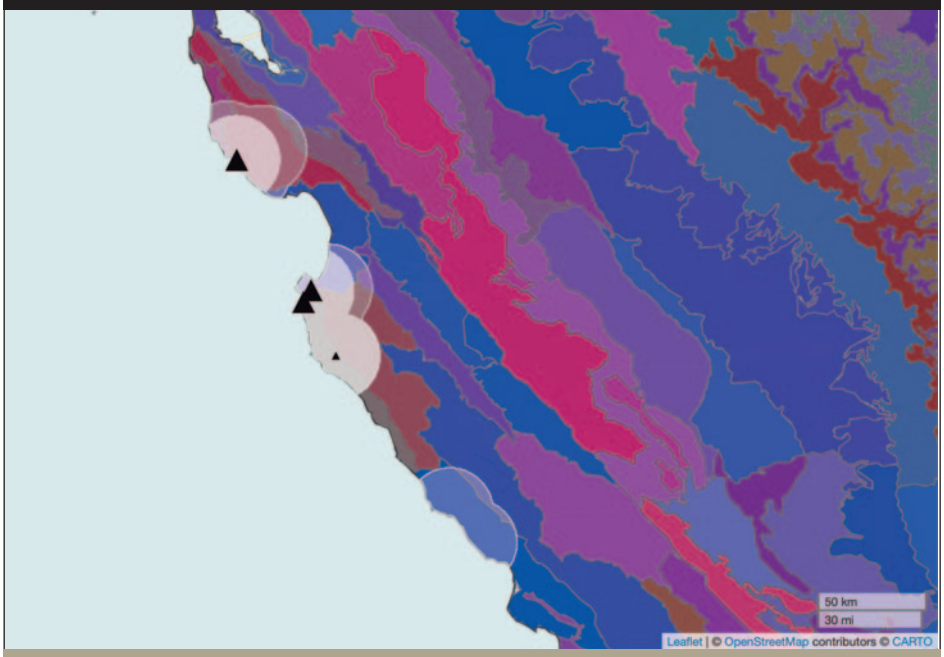
Source locality and number of wild provenance individuals present in *ex situ* collections ▲ 1-10 ▲ 11-29 ▲ 30+

Species' estimated native distribution (50 km buffer around *in situ* occurrence points)

Estimated capture of *ex situ* collections (50 km buffer around wild provenance localities)

Figure 27. Native distribution and wild provenance localities of *ex situ* individuals for *Pinus ponderosa*, based on 50 km buffers around *in situ* occurrence points and *ex situ* source localities. Background colors show EPA Level III Ecoregions (U.S. EPA Office of Research & Development, 2013a). In addition to standard *in situ* occurrence point filters applied to all target species, eastern outliers were removed based on the Elbert L. Little (1971) range map for the species.

Pinus radiata



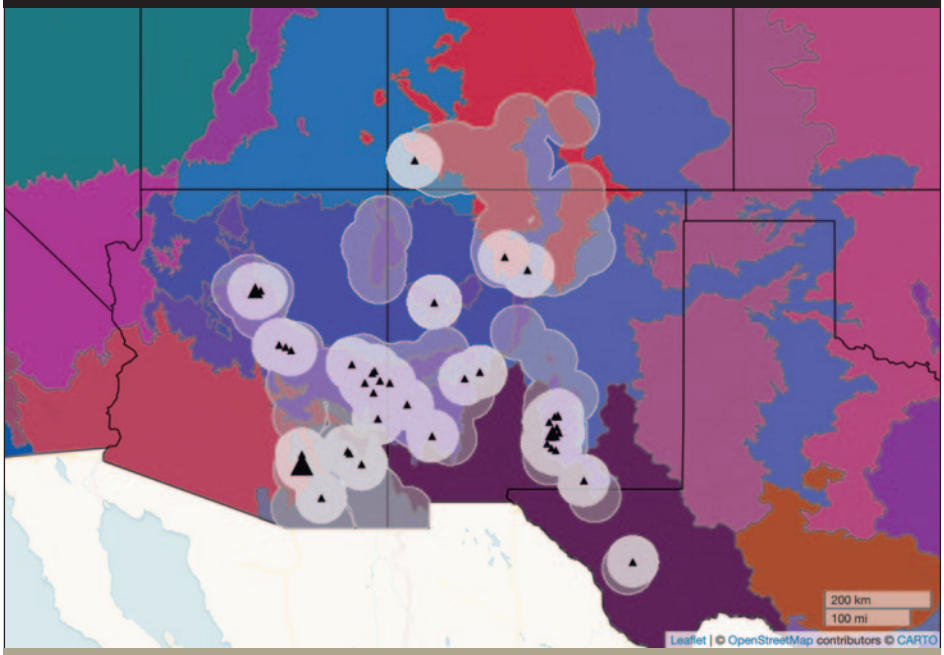
Source locality and number of wild provenance individuals present in *ex situ* collections ▲ 1-10 ▲ 11-29 ▲ 30+

Species' estimated native distribution (50 km buffer around *in situ* occurrence points)

Estimated capture of *ex situ* collections (50 km buffer around wild provenance localities)

Figure 28. Native distribution and wild provenance localities of *ex situ* individuals for *Pinus radiata*, based on 20 km buffers around *in situ* occurrence points and *ex situ* source localities. Due to the species' limited distribution that closely follows the coastline, 20 km buffers have been used here instead of 50 km buffers. The smaller buffer size provides a more accurate estimate of the distribution and representation of *P. radiata* in *ex situ* collections. In addition to standard *in situ* occurrence point filters applied to all target species, points falling outside the native range were removed based on the Elbert L. Little (1971) range map for the species. Background colors show EPA Level IV Ecoregions (U.S. EPA Office of Research & Development, 2013b).

Pinus strobiformis



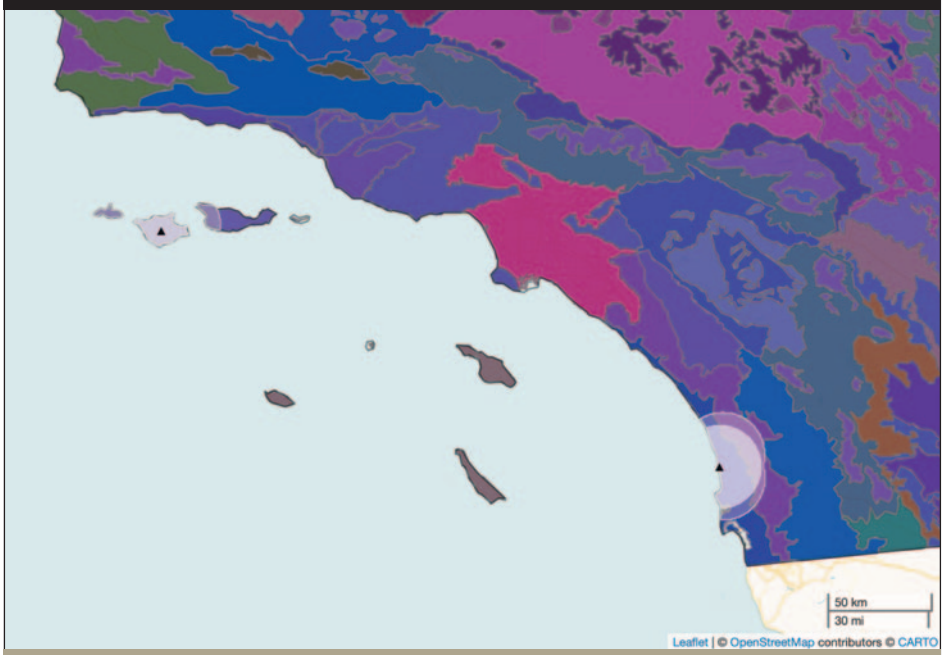
Source locality and number of wild provenance individuals present in *ex situ* collections ▲ 1-10 ▲ 11-29 ▲ 30+

Species' estimated native distribution (50 km buffer around *in situ* occurrence points)

Estimated capture of *ex situ* collections (50 km buffer around wild provenance localities)

Figure 29. Native distribution and wild provenance localities of *ex situ* individuals for *Pinus strobiformis*, based on 50 km buffers around *in situ* occurrence points and *ex situ* source localities. Background colors show EPA Level III Ecoregions (U.S. EPA Office of Research & Development, 2013a).

Pinus torreyana



Source locality and number of wild provenance individuals present in *ex situ* collections ▲ 1-10 ▲ 11-29 ▲ 30+

Species' estimated native distribution (50 km buffer around *in situ* occurrence points)

Estimated capture of *ex situ* collections (50 km buffer around wild provenance localities)

Figure 30. Native distribution and wild provenance localities of *ex situ* individuals for *Pinus torreyana*, based on 20 km buffers around *in situ* occurrence points and *ex situ* source localities. Due to the species' extreme rarity, in addition to the availability of detailed data regarding its distribution (Calscape, 2020), 20 km buffers have been used here instead of 50 km buffers. The smaller buffer size provides a more accurate estimate of the distribution and representation of *P. torreyana* in *ex situ* collections. In addition to standard *in situ* occurrence point filters applied to all target species, points falling outside the native range were removed based on the Elbert L. Little (1971) range map and Calscape (2020) description of the species. Background colors show EPA Level IV Ecoregions (U.S. EPA Office of Research & Development, 2013b).

Table 5. Estimated geographic and ecological coverage of *ex situ* collections of priority native U.S. *Pinus* species. Geographic coverage = area covered by buffers around *ex situ* wild provenance localities / area covered by buffers around *in situ* occurrence points (values are given in km^2). Ecological coverage = number of ecoregions under buffers around *ex situ* wild provenance localities / number of ecoregions under buffers around *in situ* occurrence points. U.S. EPA Level IV Ecoregions (2013b) were used for calculating ecological coverage. Buffer area falling outside the contiguous U.S. was removed for all calculations. Three different-sized buffers (radius of 20 km, 50 km, and 100 km) were used to show the variation in estimated *ex situ* genetic representation depending on assumptions regarding population size and gene flow. *Pinus radiata* and *P. torreyana* are the exception: due to their limited distributions, the larger buffer sizes do not provide meaningful estimates of distribution or representation in *ex situ* collections. Therefore, only the 20 km buffers have been used to calculate coverage for these two species.

Species	20 km buffers		50 km buffers		100 km buffers		Average of all three buffer sizes	
	Geographic coverage	Ecological coverage	Geographic coverage	Ecological coverage	Geographic coverage	Ecological coverage	Geographic coverage	Ecological coverage
Pinus albicaulis	120,872 / 419,003 **(29%)**	147 / 213 **(69%)**	429,944 / 750,514 **(57%)**	205 / 261 **(79%)**	972,435 / 1,181,277 **(82%)**	276 / 302 **(91%)**	**56%**	**80%**
Pinus balfouriana	10,911 / 24,581 **(44%)**	31 / 40 **(78%)**	47,802 / 67,656 **(71%)**	46 / 55 **(84%)**	125,819 / 153,788 **(82%)**	83 / 91 **(91%)**	**66%**	**84%**
Pinus coulteri	15,083 / 56,106 **(27%)**	35 / 66 **(53%)**	64,549 / 110,881 **(58%)**	70 / 87 **(80%)**	141,515 / 169,348 **(84%)**	97 / 105 **(92%)**	**56%**	**75%**
Pinus flexilis	65,217 / 712,127 **(9%)**	106 / 258 **(41%)**	287,586 / 1,414,591 **(20%)**	164 / 308 **(53%)**	800,265 / 2,175,938 **(37%)**	238 / 355 **(67%)**	**22%**	**54%**
Pinus lambertiana	66,297 / 210,631 **(31%)**	87 / 133 **(65%)**	206,311 / 352,011 **(59%)**	135 / 175 **(77%)**	382,642 / 517,597 **(74%)**	171 / 204 **(84%)**	**55%**	**75%**
Pinus monticola	14,612 / 313,467 **(5%)**	36 / 176 **(20%)**	77,067 / 532,493 **(14%)**	67 / 218 **(31%)**	233,412 / 774,166 **(30%)**	123 / 252 **(49%)**	**16%**	**33%**
Pinus muricata	4,945 / 19,280 **(26%)**	12 / 37 **(32%)**	17,879 / 52,518 **(34%)**	31 / 56 **(55%)**	59,176 / 102,640 **(58%)**	61 / 86 **(71%)**	**39%**	**53%**
Pinus palustris	17,865 / 544,484 **(3%)**	29 / 71 **(41%)**	94,545 / 713,948 **(13%)**	43 / 83 **(52%)**	320,036 / 891,300 **(36%)**	69 / 102 **(68%)**	**17%**	**53%**
Pinus ponderosa	97,188 / 1,481,045 **(7%)**	141 / 437 **(32%)**	366,986 / 2,285,561 **(16%)**	227 / 484 **(47%)**	945,408 / 3,193,362 **(30%)**	341 / 521 **(65%)**	**17%**	**48%**
Pinus radiata	2,014 / 3,903 **(52%)**	5 / 10 **(50%)**					**52%**	**50%**
Pinus strobiformis	34,412 / 121,637 **(28%)**	36 / 54 **(67%)**	149,686 / 322,028 **(46%)**	56 / 71 **(79%)**	380,067 / 557,125 **(68%)**	66 / 82 **(80%)**	**48%**	**75%**
Pinus torreyana	916 / 1,366 **(67%)**	3 / 4 **(75%)**					**67%**	**75%**


Pinus virginiana (Deb Brown, The Morton Arboretum)


Pinus clausa (Susan McDougall)

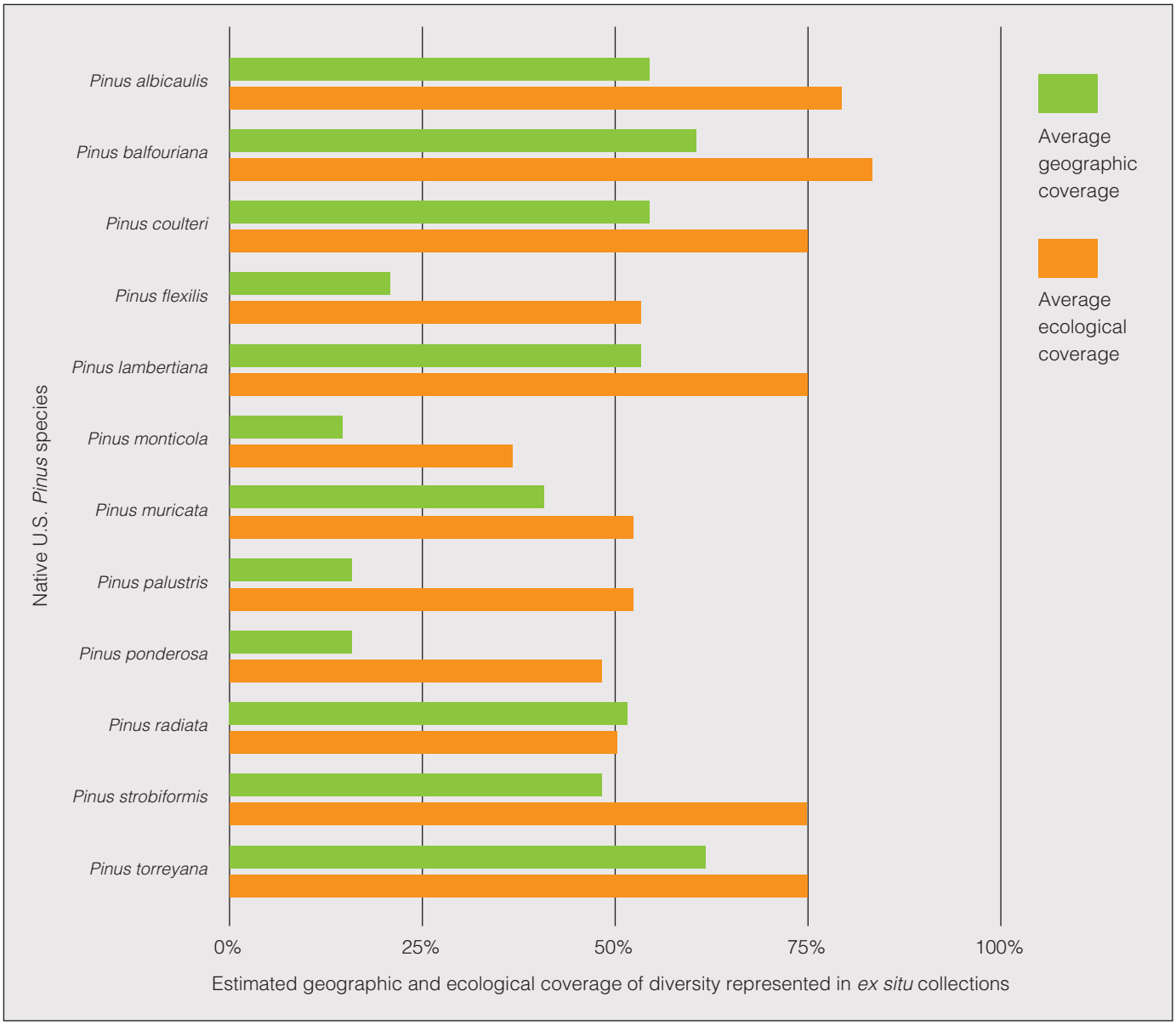


Figure 31. Average geographic and ecological coverage of *ex situ* collections for priority native U.S. *Pinus* species (See Table 5 for details).

Pinus monophylla (Susan McDougall)

Pinus quadrifolia (Susan McDougall)

TREE CONSERVATION QUESTIONNAIRE RESULTS

In 2019, we conducted a Tree Conservation Action Questionnaire for priority native U.S. tree species within nine target genera: *Carya, Fagus, Gymnocladus, Juglans, Lindera, Persea, Pinus, Sassafras*, and *Taxus*. The questionnaire was designed primarily to gather information regarding current or future planned conservation activities, but also to provide a platform to ask experts their opinion regarding most urgent conservation actions and most significant threats for each target species (Figure 32). A subset of target species were chosen to be included in the questionnaire based on threat rankings (IUCN Red List Category and NatureServe Global Status), climate change vulnerability, impact from pests and diseases, and representation in *ex situ* collections.

The questionnaire was emailed directly to targeted *ex situ* collections, content experts, attendees of the 2016 "Gene Conservation of Forest Trees: Banking on the Future" workshop, native plant societies and The Nature Conservancy contacts (from states with 20 or more target species), NatureServe and Natural Heritage Program contacts (from states with ten or more target species), BLM field offices, the USDA Forest Service RNGR National Nursery and Seed Directory, and USFS geneticists, botanists, and pest/disease specialists. The questionnaire was also distributed via newsletters and social media through ArbNet, the American Public Gardens Association, Botanic Gardens Conservation International, the Center for Plant Conservation, the Plant Conservation Alliance, The Morton Arboretum, and the USDA Forest Service.

More than 200 institutions completed the questionnaire, including 69 institutions that provided input on conservation activities for priority native U.S. *Pinus* species. Respondents were given the opportunity to fill in other native U.S. *Pinus* species that they considered of conservation concern; *P. longaeva, P. rigida*, and *P. strobus* were listed by four respondents each; *P. echinata* was listed by three respondents; *P. elliottii, P. ponderosa, P. pugens*, and *P. strobiformis* were listed by two respondents each; *P. contorta, P. edulis, P. quadrifolia, P. resinosa, P. serotina*, and *P. virginiana* were listed by one respondent each. Therefore, of the 37 native U.S. *Pinus* species, 31 were considered of conservation concern by at least one expert. See Appendix A for a list of participants and Appendix B for a full summary of questionnaire responses, which can be used to identify potential collaborators, coordinate conservation efforts, and recognize possible gaps in current activities.

Pinus resinosa (Deb Brown, The Morton Arboretum)

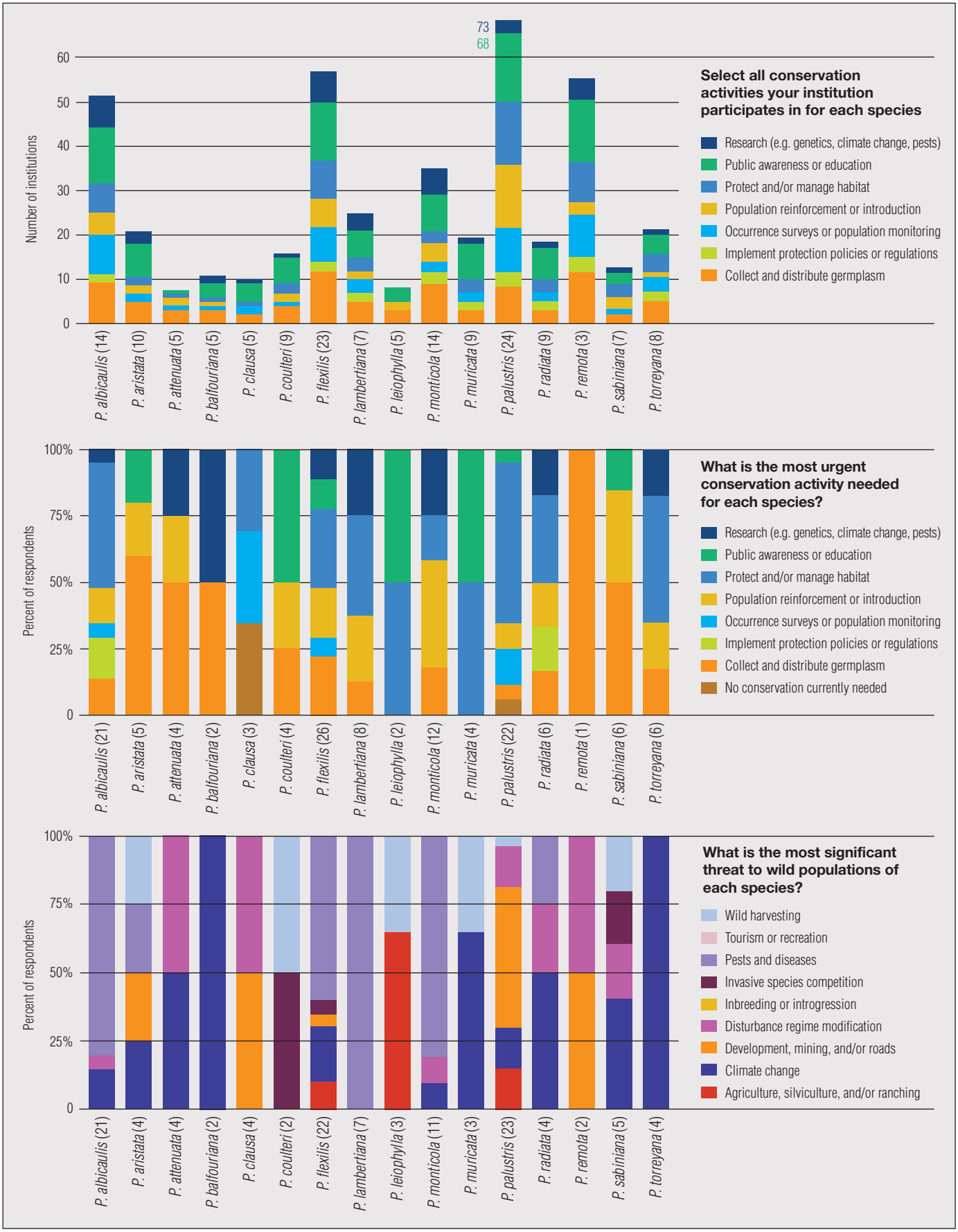


Figure 32. Results from the Tree Conservation Action Questionnaire for priority native U.S. *Pinus* species. The number of institutions or respondents participating in each question is listed in parentheses after the species' name. See Appendix B for details regarding which institutions reported each conservation activity. Colored numbers above a bar indicate the value exceeds the limits of the chart.

CONCLUSIONS & RECOMMENDATIONS

Species' distributions and threats: There are 37 *Pinus* species native to the United States, with high species diversity in both the East and the West but highest diversity in California (Figure 1; Table 1). The majority of priority species are distributed in the western U.S. and most are of conservation concern due to high mortality from one or more pests and diseases, especially bark beetles (Figures 2-17; Tables 2-3). No native U.S. *Pinus* species is predicted to have extremely high vulnerability to climate change; about half are predicted to have high to moderate vulnerability but persistence or adaptation and the other half are predicted to have low vulnerability (Table 4). For more detailed information regarding taxonomy, distribution, and threats to native U.S. *Pinus* species, the USDA Forest Service "Treesearch" platform (https://www.fs.usda.gov/treesearch/search) is an excellent resource.

Conservation quality of *ex situ* collections: Based on data from 117 *ex situ* collections that submitted accessions data for native U.S. *Pinus* species, *P. strobus* and *P. balfouriana* are represented by the most *ex situ* individuals (9,028 and 8,040, respectively). The majority (nearly 85%) for *P. strobus* are of unknown or horticultural origin, likely due to its availability in the nursery trade and adaptability across climates, but nearly 100% of the *P. balfouriana* individuals are of wild origin. The *P. balfouriana* individuals are mostly held as seed at California Botanic Garden (formerly the Rancho Santa Ana Botanic Garden), while the *P. strobus* accessions are distributed among many gardens, both as living specimens and seed. The native U.S. *Pinus* species least represented in *ex situ* include *P. leiophylla* (17 individuals), *P. clausa* (40), and *P. remota* (42), likely due to their relatively limited U.S. distribution. Of the 12 species of conservation concern that were analyzed for geographic and ecological coverage of *ex situ* collections, *P. monticola, P. torreyana*, and *P. palustris* are represented by the fewest individuals (301, 302, and 399, respectively); although of these three species, only *P. torreyana* is represented by a majority of wild origin individuals. Looking at geographic and ecological coverage of wild origin individuals *ex situ*, *P. flexilis, P. monticola, P. palustris*, and *P. ponderosa* have the lowest coverage (geographic coverage <30% and/or ecological coverage <50%), while *P. albicaulis* and *P. balfouriana* have the highest coverage (>55% geographic and >80% ecological). Of the species with the lowest geographic and ecological coverage, *P. ponderosa* is a high priority due to the high current severity of pest/disease impact (Table 3). Although P. torreyana has substantial *ex situ* representation, it has a very small population size, warranting further efforts to ensure as many genotypes as possible are conserved in *ex situ* collections (Figures 18-31; Table 5).

Pinus muricata (Art Poskanzer)

Conservation actions: For the Tree Conservation Action Questionnaire, more than 200 institutions provided information on conservation activities and threats. Conservation activities were reported most frequently for *P. palustris* (24 institutions), *P. flexilis* (23), *P. albicaulis* (14), and *P. monticola* (14), and reported least frequently for *P. remota* (3), *P. attenuata* (5), *P. balfouriana* (5), *P. clausa* (5), and *P. leiophylla* (5). Across all 16 native U.S. *Pinus* species included in the questionnaire, public awareness or education was often the most common activity reported, followed by collect and distribute germplasm. The conservation activities most frequently identified as most urgent varied significantly by species, but protecting and/or managing habitat and collecting and distributing germplasm often emerged as important. Pests and diseases, climate change, and development, mining, and/or roads were most frequently identified as the most significant threats to target *Pinus* species (Figure 32). The USDA Forest Service National Forest Genetics Laboratory (NFGEL) has focused significant effort on native U.S. pine genetics research projects, which are used to inform restoration, conservation, and silviculture activities. A list of these projects and corresponding annual reports can be found at https://www.fs.fed.us/NFGEL/ProjectReports.shtml.

Overall summary and recommendations: The majority of native U.S *Pinus* species are well documented and monitored overall, though high impacts from pests and diseases require more frequent updates to distribution maps and conservation assessments. *Pinus balfouriana*, *P. muricata*, and *P. radiata* may especially benefit from refined mapping due to their relatively small range size, while *P. aristata, P. longaea, P. lambertiana*, and *P. flexilis* should also be special priorities due to high current severity of pest and disease impacts. The variety of highly impactful pests and pathogens affecting native U.S. *Pinus* species should continue to undergo research, and action plans should be updated as new information surfaces. *Ex situ* representation is also a vital consideration for the conservation of native U.S. *Pinus* species, especially in light of threats from pests and pathogens and the disjunct nature of many species' distributions; underrepresented geographic regions and ecoregions should be prioritized for further *ex situ* collecting activities. Also, because most *Pinus* species are orthodox and can therefore be stored efficiently in seed banks, storing high numbers of genetically-distinct individuals is more attainable than for large, recalcitrant species that must be maintained *ex situ* as living specimens or by using alternative technologies such as cryopreservation. Native U.S. *Pinus* species are under serious threat, but their economic, ecological, and cultural importance make them obvious targets for continued conservation priority.

REFERENCES

Arbor Day Foundation. (2020). Pine. Retrieved from https://www.arborday.org/programs/nationaltree/pine.cfm

Barnett, J. P. (2005). Long-term Storage of Longleaf Pine Seeds. Southern Forest Experiment Station, USDA Forest Service. Retrieved from https://npn.rngr.net/publications/tpn/20-2/pdf.2005-06-06.1305016072/at_download/file

Beckman, E., Meyer, A., Denvir, A., Gill, D., Man, G., Pivorunas, D., Shaw, K., & Westwood, M. (2019). *Conservation Gap Analysis of Native U.S. Oaks*. Lisle, IL: The Morton Arboretum. Retrieved from https://www.mortonarb.org/files/conservation-gap-analysis-of-native-US-oaks.pdf

Bonner, F. T. (2008). Storage of Seeds. In F. T. Bonner & R. P. Karrfalt (Authors), *The Woody Plant Seed Manual* (pp. 85-96). Washington, D.C.: U.S. Dept. of Agriculture, Forest Service. Retrieved from https://www.fs.usda.gov/nsl/Wpsm%202008/~a`Chapter%204.pdf

Calscape. (2020). Torrey Pine, *Pinus torreyana*. California Native Plant Society. Retrieved from https://calscape.org/Pinus-torreyana-(Torrey-Pine)?srchcr=sc588b40f44a644

Chamberlain, S. & Boettiger C. (2017). R Python, and Ruby clients for GBIF species occurrence data. *PeerJ PrePrints*. Retrieved from https://doi.org/10.7287/peerj.preprints.3304v1.

CPC (Center for Plant Conservation). (2018). *Best plant conservation practices to support species survival in the wild.* The Center for Plant Conservation.

Data Portal. (2020). Retrieved from http//:sernecportal.org/index.php.

EDDMapS. (2020). Early Detection & Distribution Mapping System. The University of Georgia - Center for Invasive Species and Ecosystem Health. Retrieved from http://www.eddmaps.org/

Flora of North America Editorial Committee (Eds). (1993). *Flora of North America north of Mexico* (Vol. 2). New York and Oxford.

Forest Inventory and Analysis Database (2019). St. Paul, MN: U.S. Department of Agriculture, Forest Service, Northern Research Station. Retrieved from https://apps.fs.usda.gov/fia/datamart/datamart.html

GBIF.org (23 September 2020). GBIF Occurrence Download. https://doi.org/10.15468/dl.hdjwfz

Graul, C. (2016). leafletR: Interactive Web-Maps Based on the Leaflet JavaScript Library. R package version 0.4-0. Retrieved from http://cran.r-project.org/package=leafletR.

Hanson, J. O., Rhodes, J. R., Riginos, C., & Fuller, R. A. (2017). Environmental and geographic variables are effective surrogates for genetic variation in conservation planning. *Proceedings of the National Academy of Sciences*,*114*(48), 12755-12760. doi:10.1073/pnas.1711009114

IUCN. (2020). The IUCN Red List of Threatened Species. Version 2020-2. Retrieved July, 2020 from https://www.iucnredlist.org.

Kartesz, J. T. (2018). The Biota of North America Program (BONAP). Taxonomic Data Center, Floristic Synthesis of North America, Version 1.0. Chapel Hill, NC. Retrieved from http://www.bonap.net/tdc

Krist Jr., F.J., Ellenwood, J.R., Woods, M.E., McMahan, A.J., Cowardin, J.P., Ryerson, D.E., Sapio, F.J., Zweifler, M.O., Romero, S.A. (2014). 2013 – 2027 National Insect and Disease Forest Risk Assessment. USDA Forest Service, Forest Health Protection, Forest Health Technology Enterprise Team. Retrieved from https://www.fs.fed.us/foresthealth/technology/pdfs/2012_RiskMap_Report_web.pdf

Khoury, C. K., Carver, D., Barchenger, D. W., Barboza, G. E., Van Zonneveld, M., Jarret, R., . . . Greene, S. L. (2019). Modelled distributions and conservation status of the wild relatives of chile peppers (Capsicum L.). *Diversity and Distributions, 26*(2). doi:https://doi.org/10.1111/ddi.13008

Khoury, C. K., Heider, B., Castañeda-Alvarez, N. P., Achicanoy, H. A., Sosa, C. C., Miller, R. E., . . . Struik, P. C. (2015). Distributions, *ex situ* conservation priorities, and genetic resource potential of crop wild relatives of sweetpotato [Ipomoea batatas (L.) Lam., I. series Batatas]. *Frontiers in Plant Science, 6*. doi:10.3389/fpls.2015.00251

Little, E. L., Jr. (1971). *Atlas of United States trees*. Volume 1. Conifers and important hardwoods. Misc. Publ. 1146. Washington, DC: U.S. Department of Agriculture, Forest Service.

Maitner, B. (2020). BIEN: Tools for Accessing the Botanical Information and Ecology Network Database. R package version 1.2.4. https://CRAN.R-project.org/package=BIEN.

Michonneau, F. & Collins, M. (2017). ridigbio: Interface to the iDigBio Data API. R package version 0.3.5. Retrieved from https://CRAN.R-project.org/package=ridigbio.

Potter, K. M., Crane, B. S., & Hargrove, W. W. (2017). A United States national prioritization framework for tree species vulnerability to climate change. *New Forests, 48*(2), 275–300. doi: 10.1007/s11056-017-9569-5

Potter, K. M., Escanferla, M. E., Jetton, R. M., & Man, G. (2019a). Important Insect and Disease Threats to United States Tree Species and Geographic Patterns of Their Potential Impacts. *Forests, 10*(4), 304. doi: 10.3390/f10040304

Potter, K. M., Escanferla, M. E., Jetton, R. M., Man, G., & Crane, B. S. (2019b). Prioritizing the conservation needs of United States tree species: Evaluating vulnerability to forest insect and disease threats. *Global Ecology and Conservation, 18.* doi: 10.1016/j.gecco.2019.e00622

R Core Team (2020). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. Retrieved from https://www.R-project.org/.

The Gymnosperm Database. (2020). Conifers of Western North America. Retrieved from https://www.conifers.org/topics/W_NA_trees.php

U.S. EPA Office of Research & Development. (2013a). Level III Ecoregions of the conterminous United States. National Health and Environmental Effects Research Laboratory (NHEERL). Retrieved from ftp://ftp.epa.gov/wed/ecoregions/us/us_eco_l3.zip

U.S. EPA Office of Research & Development. (2013b). Level IV Ecoregions of the conterminous United States. National Health and Environmental Effects Research Laboratory (NHEERL). Retrieved from ftp://ftp.epa.gov/wed/ecoregions/us/us_eco_l4.zip

USDA Forest Service. (2019). Mapping & Reporting: National Forest Damage Agent Range Maps. Retrieved from https://www.fs.fed.us/foresthealth/applied-sciences/mapping-reporting/damage-agent-range-maps.shtml

USDA, NRCS. (2018). The PLANTS Database. National Plant Data Team. Greensboro, NC. Retrieved from http://plants.usda.gov

USGS. (May 2019). Biodiversity Information Serving Our Nation (BISON) -- Species occurrence data for the Nation. U.S. Geological Survey General Information Product 160, version 1.1., U.S. Geological Survey, 2015. Retrieved from https://doi.org/10.3133/gip160.

Zizka, A., Silvestro, D., Andermann, T., Azevedo, J., Duarte Ritter, C., Edler, D., . . . Antonelli, A. (2019). CoordinateCleaner: Standardized cleaning of occurrence records from biological collection databases. *Methods in Ecology and Evolution, 10*(5), 744-751. doi:https://doi.org/10.1111/2041-210X.13152

APPENDIX A. LIST OF PARTICIPANTS

Institutional participants in the 2018 *ex situ* collections survey:

Agro-Botanical Garden of USAMV Cluj-Napoca • Antony Woodland Garden • Arboretum Bramy Morawskiej w Raciborzu • Arboretum Bukovina • Arboretum Kirchberg, Musée national d'histoire naturelle • Arboretum National des Barres • Arboretum w Przelewicach • Arboretum Wespelaar, Foundation • Arboretum Wojslawice, University of Wroclaw • Arizona-Sonora Desert Museum • Arnold Arboretum of Harvard University, The • Atlanta Botanical Garden • Auckland Botanic Gardens • Bamboo Brook Outdoor Education Center • Bartlett Tree Research Laboratories Arboretum • Bayard Cutting Arboretum • Beal Botanical Gardens, W. J. • Bedgebury National Pinetum and Forest • Belmonte Arboretum • Bergius Botanic Garden, Stockholm University • Bessey Nursery, Nebraska National Forests and Grasslands • Boerner Botanical Gardens • Bok Tower Gardens • Botanic Garden Meise • Botanic garden of Le Havre, Ville du Havre • Botanic Garden of Smith College, The • Botanic Gardens of South Australia • Botanischer Garten der Philipps-Universität Marburg • Brenton Arboretum, The • Brookgreen Gardens • Brooklyn Botanic Garden • Bureau of Land Management, Prineville District • Cheryl Kearns, private garden • Chicago Botanic Garden • Cornell Botanic Gardens • Cox Arboretum • Darts Hill Garden Park • Davis Arboretum of Auburn University • Dawes Arboretum, The • Denver Botanic Gardens • Dunedin Botanic Garden • Eastwoodhill Arboretum • Eddy Arboretum, Pacific Southwest Research Station Placerville, The Institute of Forest Genetics (IFG) • Eden Project • Estancia San Miguel • Fairchild Tropical Botanic Garden • Finnish Museum of Natural History LUOMUS • Frelinghuysen Arboretum • Ghent University Botanical Garden • Green Bay Botanical Garden • Green Spring Gardens • GRIN Database, National Plant Germplasm System (NPGS) • Hackfalls Arboretum • Holden Forests & Gardens (Cleveland Botanical Garden and The Holden Arboretum) • Hollard Gardens • Honolulu Botanical Gardens System • Hørsholm Arboretum • Hoyt Arboretum • Huntington, The • Ioulia & Alexandros Diomidis Botanical Garden • Jardin Botanique de l'Université de Strasbourg • Jardin botanique de Montréal • JC Raulston Arboretum • Keith Arboretum, The Charles R. • Key West Tropical Forest and Botanical Garden • Linnaean Gardens of Uppsala, The • Longwood Gardens • Lovett Pinetum • Lyon Arboretum & Botanical Garden of the University of Hawaii • Marie Selby Botanical Gardens • Mercer Botanic Gardens • Millennium Seed Bank Partnership, Royal Botanic Gardens Kew • Missouri Botanical Garden • Montgomery Botanical Center • Morris Arboretum of the University of Pennsylvania, The • Morton Arboretum, The • Moscow State University Botanical Garden Arboretum • Mount Auburn Cemetery • Mt. Cuba Center, Inc. • Muséum national d'Histoire naturelle, Paris • Naples Botanic Garden • National Tropical Botanical Garden • NDSU Dale E. Herman Research Arboretum, Woody Plant Improvement Program • New York Botanical Garden • Norfolk Botanical Garden • North Carolina Arboretum, The • Orto Botanico dell'Università degli studi di Siena • Orto Botanico dell'Universita della Calabria • Peckerwood Garden • Pinetum Blijdenstein • Polly Hill Arboretum, The • Powell Gardens • Pukeiti • Pukekura Park • Rancho Santa Ana Botanic Garden • Real Jardín Botánico Juan Carlos I • Red Butte Garden, The University of Utah • Reiman Gardens, Iowa State University • Rogów Arboretum of Warsaw University of Life Sciences • Royal Botanic Garden Edinburgh • Royal Botanic Gardens Kew, Wakehurst Place • Royal Botanic Gardens Ontario • Royal Botanic Gardens Victoria • Royal Horticultural Society Garden, Wisley • Smale Riverfront Park • Starhill Forest Arboretum • State Botanical Garden of Georgia, University of Georgia • State Botanical Garden of Kentucky, The Arboretum • Stavanger Botanic Garden • Tasmanian Arboretum Inc., The • Timaru Botanic Garden • Tucson Botanical Gardens • Tyler Arboretum • U.S. National Arboretum • UBC Botanical Garden, The University of British Columbia • UC Davis Arboretum and Public Garden • University of California Botanical Garden at Berkeley • University of Connecticut Arboretum • University of Delaware Botanic Gardens • University of Florida/IFAS, North Florida Research and Education Center, Gardens of the Big Bend • University of Guelph Arboretum • University of Washington Botanic Gardens • USFS Brownwood Provenance Orchard • USFS western white pine, sugar pine, and whitebark pine seed orchards in OR and WA • Utrecht University Botanic Garden • Vallarta Botanical Gardens A. C. • VanDusen Botanical Garden • Village of Riverside, Illinois • Waimea Valley Botanical Garden • Wellington Botanical Gardens • Westonbirt, The National Arboretum • Willowwood Arboretum • Winona State University, The Landscape Arboretum at • Xishuangbanna Tropical Botanical Garden (XTBG) of Chinese Academy of Sciences (CAS) • Zoo and BG Plzen

Pinus balfouriana (USDA Forest Service Dorena Genetic Resource Center)

Pinus monticola

Institutional participants in the 2019 Tree Conservation Action Questionnaire:

Adkins Arboretum • Agnes Scott College • Aldrich Berry Farm & Nursery, Inc • Alpha Nurseries, Inc • American Chestnut Foundation, The • American University • Arboretum des Grands Murcins • Arboretum Kalmthout • Arboretum San Miguel • Arboretum Wespelaar • Arkansas Natural Heritage Commission • Atlanta Botanical Garden • Auckland Botanic Gardens • Baker Arboretum • Bartlett Tree Research Lab & Arboretum • Bayard Cutting Arboretum • Bergius Botanic Garden • Bernheim Arboretum and Research Forest • Better Forest Tree Seeds • Blue Mountains Botanic Garden, The • Boehm's Garden Center • Boerner Botanical Gardens • Bok Tower Gardens • Borderlands Restoration Network • Botanic Garden of Smith College • Botanic Garden TU Delft • Botanical Garden of the University of Turku • Bowman's Hill Wildflower Preserve • Brenton Arboretum, The • Brookgreen Gardens • Brooklyn Botanic Garden • California Department of Fish and Wildlife • California Native Plant Society • Catawba Lands Conservancy • Chatham University Arboretum • Chicago Botanic Garden • Cincinnati Zoo & Botanical Garden • City of Columbia Stephens Lake Park Arboretum • City of Hamilton • City of Kansas City, Missouri • Colonial Williamsburg Foundation • Connecticut College Arboretum • Cowichan Lake Research Station • Cox Arboretum and Gardens • David Listerman & Associates, Inc • Dawes Arboretum, The • Delaware Division of Fish and Wildlife • Denver Botanic Gardens • Donald E. Davis Arboretum at Auburn University • Downtown Lincoln Association • Draves Arboretum • Dunedin Botanic Garden • Dunn School • Earth Tones Natives • Ed Leuck Louisiana Academic Arboretum, The • Eden Project • Elmhurst College • Evergreen Burial Park and Arboretum • Excelsior Wellness Center • Fairchild Tropical Botanic Garden • Farmingdale State College • Florida Fish and Wildlife Conservation Commission • Florida Forest Service • Florida Natural Areas Inventory • Folmer Botanical Gardens • Frostburg State University • Georgia Department of Natural Resources • Green Bay Botanical Garden • Growild, Inc • Hackfalls Arboretum • Hastings College • Hazel Crest Open Lands • Holden Forests and Gardens • Huntington, The • Illinois Department of Natural Resources Mason State Nursery • Indiana Native Plant Society • Jane E. Lytle Memorial Arboretum • Jardin Botanique de Paris, Arboretum de Paris • John F. Kennedy Arboretum • Johnson's Nursery, Inc. • Keefer Ecological Services Ltd. • L.E. Cooke Co • Lauritzen Gardens • Le Jardin du Lautaret de la Station alpine Joseph Fourier • Longfellow Arboretum • Longwood Gardens • Louisiana Department of Wildlife and Fisheries • Lovell Quinta Arboretum, The • Maryland Department of Natural Resources • McKeithen Growers, Inc. • Meadow Beauty Nursery • Michigan Natural Features Inventory • Mill Creek MetroParks, Fellows Riverside Gardens • Minnesota Department of Natural Resources • Minnesota Natural Resources Commission • Missouri Arboretum • Missouri Native Plant Society • Missouri State University • Montgomery Botanical Center • Morris Arboretum • Moscow State University Botanical Garden • Mt. Cuba Center • Mt. Desert Land & Garden Preserve • Muscatine Arboretum • Naples Botanical Garden • National Botanical Garden of Georgia • Native Plant Society of Oregon • Native Plant Trust • Natural Resources Canada • Nature Conservancy, The • New College of Florida • New Jersey Audubon • New York Botanical Garden, The • New York City Department of Parks & Recreation • New York Natural Heritage Program • Norfolk Botanical Garden • North Carolina Natural Heritage Program • North Dakota State University • Parque Botânico da Tapada da Ajuda • Peaceful Heritage Nursery • Peckerwood Garden • Pennsylvania Department of Conservation & Natural Resources • Pennsylvania Natural Heritage Program • Pizzo Group • Polly Hill Arboretum, The • Powell Gardens • Pronatura Veracruz • R.L. McGregor Herbarium • Rancho Santa Ana Botanic Garden • Reeseville Ridge Nursery • Regional Parks Botanic Garden • Reveg Edge, The • Rogów Arboretum of Warsaw University of Life Sciences • Royal Botanic Garden Edinburgh • Royal Botanic Gardens Victoria • San Diego Botanic Garden • Santa Barbara Botanic Garden • Sidmouth Civic Arboretum • Sister Mary Grace Burns Arboretum at Georgian Court University • Smith Gilbert • Smithsonian • Springfield-Greene County Parks • Starhill Forest Arboretum • State Botanical Garden of Kentucky, The Arboretum • Strasbourg University Botanic Garden • Tasmanian Arboretum, The • Tennessee Division of Natural Areas • Texas A&M Forest Service • Tower Grove Park • Town of Winthrop • Tree Musketeers • Tucson Botanical Gardens • Twin Peaks Native Plant Nursery • UC Davis Arboretum and Public Garden • United States Botanic Garden • United States Fish and Wildlife Service • United States National Arboretum • University of California • University of California Botanical Garden at Berkeley • University of Florida North Florida Research and Education Center • University of Guelph Arboretum • University of Leicester Botanic Garden • University of Maribor Botanic Garden • University of Minnesota • University of Notre Dame • University of Oklahoma • University of Washington Botanic Gardens • USDA Agricultural Research Service • USDA Forest Service • USDI Bureau of Land Management • VanDusen Botanical Garden • Vietnam National University of Forestry • Village of Bensenville • Village of Riverside • West Virginia Native Plant Society • West Virginia Wesleyan College • Westonbirt, The National Arboretum • Wilson Seed Farms, Inc • Woodland Park Zoo • WRD Environmental, Inc. • Wright Nursery Alberta • Yellowstone Arboretum

Pinus pungens (Ed Hedborn,The Morton Arboretum)

Pinus coulteri (Susan McDougall)

APPENDIX B. RESULTS FROM THE 2019 TREE CONSERVATION ACTION QUESTIONNAIRE

To receive contact information for a specific respondent and target species, please email treeconservation@mortonarb.org.

Species	Institution reporting conservation activities	Country (U.S. state)	Collect and distribute germplasm	Implement protection policies or regulations	Occurrence surveys or population monitoring	Population reinforcement or introduction	Protect and/or manage habitat	Public awareness or education	Research (e.g., genetics, climate change, pests)
Pinus albicaulis	California Native Plant Society[5]	United States (CA)		x	x		x	x	
	Cowichan Lake Research Station[2]	Canada	x					x	x
	Denver Botanic Gardens[1]	United States (CO)	x						
	Keefer Ecological Services Ltd.[8]	Canada	x		x	x	x	x	x
	Native Plant Society of Oregon[5]	United States (OR)			x		x	x	
	Royal Botanic Garden Edinburgh[1]	United Kingdom	x					x	
	Twin Peaks Native Plant Nursery[8]	United States (ID)				x			
	USDA Forest Service[3]	United States (CA)	x	x	x	x	x	x	x
	USDA Forest Service[3]	United States (CO)	x	x	x	x	x	x	x
	USDA Forest Service[3]	United States (ID)	x	x	x	x	x	x	x
	USDA Forest Service[3]	United States (OR)	x	x	x	x	x	x	x
	USDA Forest Service[3]	United States (WA)	x	x	x	x	x	x	
	USDI Bureau of Land Management[3]	United States (ID)	x		x	x	x	x	x
	USDI Bureau of Land Management[3]	United States (MT)	x	x	x	x	x	x	x
	USDI Bureau of Land Management[3]	United States (WY)	x	x	x	x	x		
	Westonbirt, The National Arboretum[1]	United Kingdom						x	x
	Wright Nursery Alberta[8]	Canada	x					x	
	Name not shared[3]	United States (MT)		x	x	x	x	x	
	Name not shared[3]	United States (OR)	x	x	x	x	x	x	x
Pinus aristata	Aldrich Berry Farm & Nursery, Inc[8]	United States (WA)	x						
	Denver Botanic Gardens[1]	United States (CO)	x						
	Draves Arboretum[1]	United States (NY)				x		x	
	Lovell Quinta Arboretum, The[1]	England				x		x	
	Royal Botanic Garden Edinburgh[1]	United Kingdom	x					x	
	University of Leicester Botanic Garden[9]	United Kingdom						x	
	USDA Forest Service[3]	United States (ID)	x		x		x		x
	USDA Forest Service, Rocky Mountain Research Station[3]	United States (CO)	x		x		x	x	x
	VanDusen Botanical Garden[1]	Canada						x	
	Westonbirt, The National Arboretum[1]	United Kingdom						x	x
Pinus attenuata	Bayard Cutting Arboretum[1]	United States (NY)				x	x		
	Royal Botanic Garden Edinburgh[1]	United Kingdom	x					x	
	Santa Barbara Botanic Garden[1]	United States (CA)	x						
	University of Washington Botanic Gardens[1]	United States (WA)				x			
	USDA Forest Service[3]	United States (CA)	x		x				
Pinus balfouriana	Denver Botanic Gardens[1]	United States (CO)	x						
	Royal Botanic Garden Edinburgh[1]	United Kingdom	x					x	
	USDA Forest Service[3]	United States (CA)	x		x	x	x		
	USDA Forest Service, Dorena Genetic Resource Center[3]	United States (OR)						x	x
	Westonbirt, The National Arboretum[1]	United Kingdom						x	x

Species	Institution reporting conservation activities	Country (U.S. state)	Collect and distribute germplasm	Implement protection policies or regulations	Occurrence surveys or population monitoring	Population reinforcement or introduction	Protect and/or manage habitat	Public awareness or education	Research (e.g., genetics, climate change, pests)
Pinus clausa	Bok Tower Gardens[1]	United States (FL)					X		
	Donald E. Davis Arboretum at Auburn University[1]	United States (AL)	X					X	
	Nature Conservancy, The[4]	United States (FL)			X				
	Peckerwood Garden[1]	United States (TX)	X		X			X	
	Westonbirt, The National Arboretum[1]	United Kingdom						X	X
Pinus coulteri	Arboretum des Grands Murcins[1]	France						X	
	Arboretum San Miguel[1]	Argentina					X	X	
	Blue Mountains Botanic Garden, The[1]	Australia	X						
	Lovell Quinta Arboretum, The[1]	England				X		X	
	Royal Botanic Garden Edinburgh[1]	United Kingdom	X					X	
	Santa Barbara Botanic Garden[1]	United States (CA)	X						
	Strasbourg University Botanic Garden[1]	France						X	
	USDA Forest Service[3]	United States (CA)	X		X	X	X		
	Westonbirt, The National Arboretum[1]	United KIngdom						X	X
Pinus flexilis	Bayard Cutting Arboretum[1]	United States (NY)				X	X		
	Bergius Botanic Garden[1]	Sweden		X					
	Bernheim Arboretum and Research Forest[1]	United States (KY)	X						
	Cowichan Lake Research Station[2]	Canada	X					X	
	Denver Botanic Gardens[1]	United States (CO)	X						
	Draves Arboretum[1]	United States (NY)				X		X	
	Elmhurst College[9]	United States (IL)					X	X	
	Keefer Ecological Services Ltd.[8]	Canada	X		X	X	X	X	X
	Lauritzen Gardens[1]	United States (NE)			X				
	Missouri Arboretum[1]	United States (MO)			X			X	
	Moscow State University Botanical Garden[1]	Russian Federation	X						
	Native Plant Society of Oregon[5]	United States (OR)			X		X	X	
	Royal Botanic Garden Edinburgh[1]	United Kingdom	X					X	
	USDA Forest Service[3]	United States (CA)	X		X				
	USDA Forest Service[3]	United States (CO)	X				X		
	USDA Forest Service[3]	United States (ID)	X		X		X		X
	USDA Forest Service[3]	United States (WA)	X		X				
	USDA Forest Service, Dorena Genetic Resource Center[3]	United States (OR)							X
	USDA Forest Service, Rocky Mountain Research Station[3]	United States (CO)	X		X		X	X	X
	USDA Forest Service, Southwest Region[3]	United States (NM)	X			X	X		X
	USDI Bureau of Land Management[3]	United States (ID)			X	X	X	X	X
	USDI Bureau of Land Management[3]	United States (MT)	X	X	X	X	X	X	X
	USDI Bureau of Land Management[3]	United States (UT)			X		X		X
	VanDusen Botanical Garden[1]	Canada						X	
	Westonbirt, The National Arboretum[1]	United Kingdom						X	X
	Wright Nursery Alberta[8]	Canada	X		X			X	
	Yellowstone Arboretum[1]	United States (MT)				X	X		
	Name not shared[1]	Ireland	X					X	
	Name not shared[3]	United States (MT)		X	X	X	X	X	

Species	Institution reporting conservation activities	Country (U.S. state)	Collect and distribute germplasm	Implement protection policies or regulations	Occurrence surveys or population monitoring	Population reinforcement or introduction	Protect and/or manage habitat	Public awareness or education	Research (e.g., genetics, climate change, pests)
Pinus lambertiana	Native Plant Society of Oregon[5]	United States (OR)			x		x	x	
	Royal Botanic Garden Edinburgh[1]	United Kingdom	x					x	
	USDA Forest Service[3]	United States (CA)	x	x	x	x	x	x	x
	USDA Forest Service[3]	United States (OR)	x			x	x	x	x
	USDA Forest Service, Dorena Genetic Resource Center[3]	United States (OR)	x					x	x
	Westonbirt, The National Arboretum[1]	United Kingdom						x	x
	Name not shared[1]	Ireland	x					x	
	Name not shared[3]	United States (OR)	x	x	x	x	x		x
Pinus leiophylla	Cox Arboretum and Gardens[1]	United States (GA)				x			
	Lovell Quinta Arboretum, The[1]	England				x		x	
	Pronatura Veracruz [7]	Mexico	x						
	Royal Botanic Garden Edinburgh[1]	United Kingdom	x					x	
	Name not shared[1]	Ireland	x					x	
Pinus monticola	Arboretum des Grands Murcins[1]	France						x	
	Bayard Cutting Arboretum[1]	United States (NY)				x	x		
	Bergius Botanic Garden[1]	Sweden		x					
	City of Columbia Stephens Lake Park Arboretum[2]	United States (MO)	x					x	
	Cowichan Lake Research Station[2]	Canada	x					x	x
	Denver Botanic Gardens[1]	United States (CO)	x						
	Draves Arboretum[1]	United States (NY)				x		x	
	Rogów Arboretum of Warsaw University of Life Sciences[1]	Poland	x						
	USDA Forest Service[3]	United States (CA)	x		x	x	x		
	USDA Forest Service[3]	United States (ID)	x	x	x	x	x	x	x
	USDA Forest Service[3]	United States (OR)	x		x	x	x	x	x
	USDA Forest Service[3]	United States (WA)	x						
	USDA Forest Service, Dorena Genetic Resource Center[3]	United States (OR)	x					x	x
	USDA Forest Service, Forest Health Protection[3]	United States (OR)	x		x				x
	Westonbirt, The National Arboretum[1]	United Kingdom						x	x
	Name not shared[1]	Ireland	x					x	
	Name not shared[3]	United States (OR)	x	x		x	x		x

Pinus albicaulis (Ed Hedborn, The Morton Arboretum)

Pinus aristata (Ed Hedborn, The Morton Arboretum)

Species	Institution reporting conservation activities	Country (U.S. state)	Collect and distribute germplasm	Implement protection policies or regulations	Occurrence surveys or population monitoring	Population reinforcement or introduction	Protect and/or manage habitat	Public awareness or education	Research (e.g., genetics, climate change, pests)
Pinus muricata	Blue Mountains Botanic Garden, The[1]	Australia	X						
	Dunn School[8]	United States (CA)						X	
	Lovell Quinta Arboretum, The[1]	England				X		X	
	Royal Botanic Garden Edinburgh[1]	United Kingdom	X					X	
	Santa Barbara Botanic Garden[1]	United States (CA)	X						
	USDA Forest Service[3]	United States (WA)	X						
	VanDusen Botanical Garden[1]	Canada						X	
	Westonbirt, The National Arboretum[1]	United Kingdom						X	X
	Name not shared[1]	Ireland	X					X	
Pinus palustris	Bayard Cutting Arboretum[1]	United States (NY)				X	X		
	Blue Mountains Botanic Garden, The[1]	Australia	X						
	Bok Tower Gardens[1]	United States (FL)			X	X	X	X	
	Brookgreen Gardens[1]	United States (SC)		X	X	X	X	X	
	City of Columbia Stephens Lake Park Arboretum[2]	United States (MO)	X					X	
	Cox Arboretum and Gardens[1]	United States (GA)					X	X	
	Denver Botanic Gardens[1]	United States (CO)	X						
	Donald E. Davis Arboretum at Auburn University[1]	United States (AL)	X	X	X	X	X	X	X
	Florida Fish and Wildlife Conservation Commission[2]	United States (FL)				X	X	X	
	Florida Forest Service[2]	United States (FL)			X	X	X	X	
	Florida Natural Areas Inventory[6]	United States (FL)			X				
	Georgia Department of Natural Resources[6]	United States (GA)				X	X	X	
	Louisiana Department of Wildlife and Fisheries[6]	United States (LA)					X		
	Lovell Quinta Arboretum, The[1]	England				X		X	
	Nature Conservancy, The[4]	United States (FL)		X	X	X	X	X	X
	Nature Conservancy, The[4]	United States (MD)				X	X	X	
	New College of Florida[9]	United States (FL)			X	X			
	Norfolk Botanical Garden[1]	United States (VA)				X	X	X	
	North Carolina Natural Heritage Program[6]	United States (NC)			X	X	X	X	
	Royal Botanic Garden Edinburgh[1]	United Kingdom	X					X	
	Sister Mary Grace Burns Arboretum at Georgian Court University[1]	United States (NJ)						X	
	Texas A&M Forest Service[2]	United States (TX)	X	X	X	X	X	X	X
	USDA Forest Service, National Forest System[3]	United States (GA)	X		X	X	X	X	X
	Westonbirt, The National Arboretum[1]	United Kingdom						X	X
	Name not shared[1]	Ireland	X					X	
Pinus radiata	Arboretum San Miguel[1]	Argentina					X	X	
	California Department of Fish and Wildlife[6]	United States (CA)		X	X		X		
	California Native Plant Society[5]	United States (CA)		X	X		X	X	
	Parque Botânico da Tapada da Ajuda, Instituto Superior de Agonomia[9]	Portugal						X	
	Royal Botanic Garden Edinburgh[1]	United Kingdom	X					X	
	Santa Barbara Botanic Garden[1]	United States (CA)	X						
	VanDusen Botanical Garden[1]	Canada						X	
	Westonbirt, The National Arboretum[1]	United Kingdom						X	X
	Name not shared[1]	Ireland	X					X	

Species	Institution reporting conservation activities	Country (U.S. state)	Collect and distribute germplasm	Implement protection policies or regulations	Occurrence surveys or population monitoring	Population reinforcement or introduction	Protect and/or manage habitat	Public awareness or education	Research (e.g., genetics, climate change, pests)
Pinus remota	Cox Arboretum and Gardens[1]	United States (GA)	X			X			X
	Peckerwood Garden[1]	United States (TX)	X		X			X	
	Santa Barbara Botanic Garden[1]	United States (CA)	X						
Pinus sabiniana	Arboretum San Miguel[1]	Argentina					X	X	
	Bayard Cutting Arboretum[1]	United States (NY)				X	X		
	Denver Botanic Gardens[1]	United States (CO)	X						
	University of Washington Botanic Gardens[1]	United States (WA)				X			
	USDA Forest Service[3]	United States (CA)	X		X	X	X		
	VanDusen Botanical Garden[1]	Canada						X	
	Westonbirt, The National Arboretum[1]	United Kingdom						X	X
Pinus torreyana	Bayard Cutting Arboretum[1]	United States (NY)				X	X		
	California Department of Fish and Wildlife[6]	United States (CA)		X	X		X		
	California Native Plant Society[5]	United States (CA)		X	X		X	X	
	North Dakota State University[9]	United States (ND)	X		X			X	X
	Royal Botanic Garden Edinburgh[1]	United Kingdom	X					X	
	Santa Barbara Botanic Garden[1]	United States (CA)	X						
	USDA Forest Service[3]	United States (CA)	X		X		X		
	Name not shared[1]	Ireland	X					X	

Institution types

[1] Arboretum/botanical garden [2] Government (local) [3] Government (national) [4] Land conservancy [5] Native plant society [6] Natural heritage program [7] Other non-governmental organization [8] Private sector [9] University

List of state abbreviations used in Appendix B

U.S. State	Abbreviation	U.S. State	Abbreviation	U.S. State	Abbreviation
Alabama	AL	Kentucky	KY	New Mexico	NM
Arkansas	AR	Louisiana	LA	New York	NY
Arizona	AZ	Massachusetts	MA	Ohio	OH
California	CA	Maryland	MD	Oklahoma	OK
Colorado	CO	Michigan	MI	Oregon	OR
Florida	FL	Minnesota	MN	Pennsylvania	PA
Georgia	GA	Missouri	MO	South Carolina	SC
Iowa	IA	Mississippi	MS	Tennessee	TN
Illinois	IL	North Carolina	NC	Texas	TX
Indiana	IN	North Dakota	ND	Utah	UT
Kansas	KS	New Jersey	NJ	Washington	WA

Pinus palustris (Matt Lobdell, The Morton Arboretum)

Conservation Gap Analysis of Native

U.S. Pines

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Front cover images:
Pinus arizonica (Karen and Brad Emerson)
Pinus strobiformis (iNaturalist, pinidae)
Pinus elliottii (Susan McDougall)
Pinus jeffreyi (Susan McDougall)
Pinus edulis (Ed Hedborn, The Morton Arboretum)
Pinus rigida (Ed Hedborn, The Morton Arboretum)
Pinus muricata (Paul Hami)
Pinus palustris (Susan McDougall)
Pinus attenuata (Susan McDougall)
Pinus coulteri (Susan McDougall)
Pinus ponderosa (Ed Hedborn, The Morton Arboretum)
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