Conservation Gap Analysis of Native U.S. Yews

August 2021

Emily Beckman¹, Abby Meyer², David Pivorunas³, Sean Hoban¹ and Murphy Westwood¹,⁴

¹The Morton Arboretum  ²Botanic Gardens Conservation International, U.S.  
³USDA Forest Service  ⁴Botanic Gardens Conservation International

Taxus brevifolia Nutt. (Pacific yew)
Taxus canadensis Marshall (Canada yew)
Taxus floridana Nutt. ex Chapm. (Florida yew)
ACKNOWLEDGEMENTS

First and foremost, many thanks to the hundreds of institutions who shared their ex situ accessions data and/or reported conservation activities. The original analyses presented in this report are made possible through their support and participation, and we hope this synthesis is a valuable resource for advancing tree conservation goals. A special thanks to the Biota of North America Program (BONAP) and USDA PLANTS for providing valuable in situ occurrence data, Shannon Still for aiding in the development of methods for spatial analyses, and Christina Carrero for coordinating IUCN Red List assessments for priority species. We also thank Botanic Gardens Conservation International U.S. as well as the Science & Conservation Department and leadership team of The Morton Arboretum for their organizational support, and the Institute of Museum and Library Services (award #MA-30-18-0273-18) for aiding in the funding of spatial analysis methodologies presented here. Finally, this publication was made possible by a grant to The Morton Arboretum under a cooperative agreement with the USDA Forest Service (Cooperative Agreement 16-CA-11132546-045).

The Morton Arboretum, 4100 Illinois Route 53, Lisle, IL 60532, USA.

© 2021 The Morton Arboretum

Reproduction of any part of the publication for education, conservation, and other non-profit purposes is authorized without prior permission from the copyright holder, provided that the source is fully acknowledged. Reproduction for resale or other commercial purposes is prohibited without prior written permission from the copyright holder.

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 three species of yew (Taxus) native to the United States. They are notoriously difficult to differentiate visually, but their native distributions do not overlap and therefore they are easily distinguished geographically (Flora of North America, 1993; Figure 1). Native U.S. yews are evergreen trees or shrubs with thin, red or purple-brown, smooth bark, which grows scaly with age. With the exception of *T. brevifolia*, Taxus species are toxic due to the presence of taxine, which is found in the foliage, bark, and seeds. Taxus species have important uses in both past and present culture, including spiritual significance to native peoples and use as a source for the compound paclitaxel used in modern treatment for some types of cancer. Yews also have strong resistance to air pollution and great ornamental value, resulting in hundreds of yew cultivars (Earle, 2020). All three native U.S. yews have decreasing population trends due to a variety of human impacts (IUCN, 2020).

*Taxus brevifolia* (Pacific yew or Western yew) is distributed in the northwestern U.S., including California, Oregon, Washington, Idaho, Montana, and Alaska, and southwestern Canada. It is an evergreen shrub or small tree reaching 15 to 25 meters in height, and is found between sea level and 2,200 meters elevation. *Taxus brevifolia* can grow in “open to dense forests, along streams, moist flats, slopes, deep ravines, and coves” (Flora of North America, 1993). In most of its range, *T. brevifolia* “grows as a tree beneath a closed forest canopy in late-successional forests dominated by large conifers such as *Pseudotsuga menziesii* and *Tsuga heterophylla*, but in drier open forests such as in the Siskiyous and the eastern Cascade Range it adopts a shrub habit...forming broad mats” (Earle, 2020). Due to its durable yet easily-worked wood, *T. brevifolia* is often used locally for novelty items and has been selectively harvested extensively in some areas (Flora of North America, 1993). On the IUCN Red List of Threatened Species, *T. brevifolia* is assessed as Near Threatened due to a nearly 30% decline in the last century (Thomas, 2013). This decline is attributed to fire and logging, as well as past exploitation for its cancer-treating compounds that are now produced using alternate means. An updated assessment should be carried out in the near future, to confirm the species’ status.
**Taxus canadensis** (Canada yew, American yew, or Ground-hemlock) has a broad distribution in the northeastern U.S., upper Midwest, and eastern Canada, though its southern extent has decreased in the last century (Thomas, 2013). It is usually an evergreen shrub, no more than two meters tall, that is low and spreading and is found in “rich forests (deciduous, mixed, or coniferous), bogs, swamps, gorges, ravine slopes, and rocky banks” from zero to 1,500 meters above sea level (Flora of North America, 1993). Long-distance dispersal of *T. canadensis* is usually facilitated by birds, though clonal reproduction is more common and leads to layered populations (Earle, 2020). A variety of impacts have caused declines in *T. canadensis*, including “browsing by native ungulates, fire, intensive forest management, and clearing of land for agriculture and other development.” Impacts from deer browsing have been recorded as particularly intense in some populations, causing a significant decline in seed production and therefore regeneration (Allison, 1990). The population size of *T. canadensis* is still large enough to place it within the Least Concern category on the IUCN Red List, but reassessment should be prioritized (Thomas, 2013).

**Taxus floridana** (Florida yew) is a rare yew, endemic to the Florida panhandle. It is a shrub or small tree, six to ten meters in height, with stout, spreading branches. *Taxus floridana* habitat is “moist, shaded ravines in hardwood forests,” at elevations between 15 and 30 meters (Flora of North America, 1993). It is ranked as Critically Endangered on the IUCN Red List, due to its very small range: “a 24 km section of ravines and bluffs along the Apalachicola River in Liberty and Gladsden counties.” In addition to its limited distribution, *T. floridana* faces threats from low regeneration and increased deer grazing, causing the population to continue to decline. The root cause of insufficient regeneration is not yet understood. *Taxus floridana* is protected in several natural areas, including the Nature Conservancy’s Apalachicola Bluffs and Ravines Preserve and the Torreya State Park (Spector et al., 2011).
Figure 1. Species richness of native U.S. Taxus species by U.S. county, including *T. brevifolia*, *T. canadensis*, and *T. floridana*. 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. Taxus species face few pests and diseases, and all are minor. Results from the USDA Forest Service study *Important Insect and Disease Threats to United States Tree Species and Geographic Patterns of Their Potential Impacts* (Potter et al., 2019a) are provided in Table 1, to give an overview of the major pests and diseases affecting native U.S. Taxus 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 2.

**Table 1.** The most serious insect, disease, and parasitic plant agents affecting native U.S. Taxus species, from the results of Potter et al. (2019a), which analyzed 419 native U.S. tree species. *Taxus canadensis* was not included in the study. 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).

<table>
<thead>
<tr>
<th>Host species</th>
<th>Insect, Disease, or Parasitic Plant Agent</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Black vine weevil <em>(Otiorhynchus sulcatus)</em></td>
</tr>
<tr>
<td></td>
<td>Heterobasidion root disease <em>(Heterobasidion spp.)</em></td>
</tr>
<tr>
<td></td>
<td>Port-Orford-cedar root disease <em>(Phytophthora lateralis)</em></td>
</tr>
<tr>
<td>Taxus brevifolia</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Taxus floridana</td>
<td>1</td>
</tr>
</tbody>
</table>

**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%)
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 2. Pest and disease vulnerability of native U.S. Taxus species, from the results of a USDA Forest Service study that analyzed 419 native U.S. tree species. Taxus canadensis was not included in the study. Species are ordered by overall rank, from most vulnerable to least vulnerable. Figure is adapted, with permission, from Potter et al. (2019b).

<table>
<thead>
<tr>
<th>Species</th>
<th>Vulnerability Class</th>
<th>Overall Rank (of 419)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Taxus floridana</td>
<td>B</td>
<td>31</td>
</tr>
<tr>
<td>Taxus brevifolia</td>
<td>E</td>
<td>390</td>
</tr>
</tbody>
</table>

Table 3. Climate change vulnerability of native U.S. Taxus species, from the results of a USDA Forest Service study that analyzed 339 native U.S. tree species. Taxus canadensis and T. floridana were not included in the study. Species are ordered by overall rank, from most vulnerable to least vulnerable. Figure is adapted, with permission, from Potter et al. (2017).

<table>
<thead>
<tr>
<th>Species</th>
<th>Vulnerability Class</th>
<th>Overall Rank (of 339)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Taxus brevifolia</td>
<td>E2</td>
<td>319</td>
</tr>
</tbody>
</table>

Native U.S. Taxus species face varying impacts from climate change, though data is lacking for T. floridana. It is possible that T. canadensis will face declines if reduced snow cover leads to increased browsing pressure (Thomas, 2013). 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 3.
EX SITU SURVEY RESULTS

Taxus species are considered orthodox, meaning their seeds can be dried to levels necessary for storage in a conventional seed bank, without losing significant viability. Once frozen, the seeds can be stored for years with little deterioration (Forest Research, 2020), though more research may be necessary to determine maximum storage length. Stored Taxus seeds can also take years to break dormancy (Thomas & Polwart, 2003), so living collections may provide opportunities for more accessible germplasm for activities such as research, restoration, or reintroduction.

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 54 collections from 13 countries reporting native U.S. Taxus species (Figure 2). 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 Taxus species are orthodox and can be seed banked, the ex situ survey results presented here include both seed bank and living collections.

Figure 2. Results from a 2018 global accessions-level ex situ survey for native U.S. Taxus species.
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.

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 (e.g., 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 3-6; Table 4). Because our calculations of geographic and ecological coverage are based on a rough estimation of the distribution of a species and only address the portion of a species distribution within the contiguous U.S., 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.

*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 target native U.S. *Taxus* species, about 27% of records with wild or unknown provenance were manually geolocated, while 11% had latitude and longitude provided by the institution and 62% 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).
Figure 3. Native distribution and wild provenance localities of ex situ individuals for Taxus brevifolia in the contiguous U.S., 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, T. brevifolia occurrence points were further refined by removing records more than 100 km outside native counties provided in the USDA PLANTS database (USDA NRCS, 2018).

Figure 4. Native distribution and wild provenance localities of ex situ individuals for Taxus canadensis in the U.S., 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 5. Native distribution and wild provenance localities of ex situ individuals for *Taxus floridana*, 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 (Spector et al., 2011), 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 *T. floridana* in ex situ collections. Background colors show EPA Level IV Ecoregions (U.S. EPA Office of Research & Development, 2013b).

*Taxus floridana* (Richard Carter, Valdosta State University, Bugwood.org)
Table 4. Estimated geographic and ecological coverage of ex situ collections of native U.S. Taxus 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 km²). 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. Taxus floridana is the exception: due to its extreme rarity and the availability of detailed distribution data, 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 T. floridana.

<table>
<thead>
<tr>
<th>Species</th>
<th>20 km buffers</th>
<th>50 km buffers</th>
<th>100 km buffers</th>
<th>Average of all three buffer sizes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Geographic coverage</td>
<td>Ecological coverage</td>
<td>Geographic coverage</td>
<td>Ecological coverage</td>
</tr>
<tr>
<td>Taxus brevifolia</td>
<td>19,793 / 304,644 (6%)</td>
<td>53 / 161 (33%)</td>
<td>102,646 / 502,180 (20%)</td>
<td>92 / 205 (45%)</td>
</tr>
<tr>
<td>Taxus canadensis</td>
<td>14,494 / 398,449 (4%)</td>
<td>39 / 184 (21%)</td>
<td>82,824 / 922,275 (9%)</td>
<td>68 / 210 (32%)</td>
</tr>
<tr>
<td>Taxus floridana</td>
<td>1,701 / 2,311 (88%)</td>
<td>6 / 6 (100%)</td>
<td>6 / 6 (100%)</td>
<td>6 / 6 (100%)</td>
</tr>
</tbody>
</table>

Figure 6. Average geographic and ecological coverage of ex situ collections for native U.S. Taxus species (See Table 4 for details).
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 7). 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 15 institutions that provided input on conservation activities for priority native U.S. Taxus species. Institutions reporting that they could “provide information regarding current conservation activities, most urgent conservation needs, and/or primary threats to wild populations” included 17 for T. brevifolia and 12 for T. floridana. Respondents were given the opportunity to fill in other native U.S. Taxus species that they considered of conservation concern; T. canadensis was listed by five respondents. 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.

**Figure 7.** Results from the Tree Conservation Action Questionnaire for priority native U.S. Taxus 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.
CONCLUSIONS & RECOMMENDATIONS

Species’ distributions and threats: There are three Taxus species native to the United States (Figure 1). Taxus brevifolia is distributed in the Northwest, Taxus canadensis ranges from Minnesota to Maine and south to Tennessee, and Taxus floridana has a very limited distribution in northwest Florida. There are no severe pests or diseases facing native U.S. Taxus species and vulnerability to climate change is generally predicted to be low, other than potential impacts to Taxus canadensis from decreased snowfall and increased deer activity (Tables 1-3). Past population decreases from extraction for both wood and cancer-treating compounds caused initial threats to native U.S. Taxus species, but these pressures have mostly ceased. Native populations are now most affected by changing land use and natural systems modification.

Conservation quality of ex situ collections: Based on data from 54 ex situ collections that submitted accessions data for native U.S. Taxus species, all are represented globally by fairly substantial collections. Taxus canadensis is represented by the most ex situ individuals (595), with about half of wild origin. About 80% of these individuals had the spatial data necessary for mapping their wild ex situ source locality, and the resulting average geographic (12%) and ecological (32%) coverage are the lowest of any native U.S. Taxus species. Taxus brevifolia is also represented by many individuals in ex situ collections (295) and a higher proportion of wild origin individuals (73%), though approximately 50% had enough information to map their wild provenance; geographic and ecological coverage were 23% and 47%, respectively. Populations in Alaska were not included in calculations of geographic and ecological coverage because the ecoregions layer is only available for the contiguous U.S. There is no known representation of the Alaska populations of Taxus brevifolia in ex situ collections, therefore geographic and ecological coverage are lower than reported here. Taxus floridana has the fewest individuals in ex situ collections (140), though still a fairly high number compared to other rare species. Encouragingly, 80% are of wild origin and 80% of these individuals were able to be mapped to their wild collection locality, resulting in an estimated geographic coverage of 86% and ecological coverage of 100%. Although, because Taxus floridana is so rare, further efforts are necessary to ensure as many genotypes as possible are conserved in ex situ collections (Figures 2-6; Table 4).

Conservation actions: For the Tree Conservation Action Questionnaire, conservation activities were reported by ten institutions for Taxus brevifolia and seven institutions for Taxus floridana, out of more than 200 participating institutions total. For both Taxus species included in the questionnaire, collect and distribute germplasm was the most common activity reported, followed by public awareness or education. Occurrence surveys or population monitoring was also reported frequently for Taxus floridana. Protecting and/or managing habitat was the conservation activity most frequently identified as most urgent. Agriculture, silviculture, and/or ranching, climate change, and disturbance regime modification were frequently identified as the most significant threats to target Taxus species. It is encouraging to see collection and distribution of germplasm, public education, and occurrence surveys/poulation monitoring as the most-pursued activities, considering the predicted continuing decline of native U.S. Taxus species. Continuation, and expansion in some instances, of these activities will be vital for conservation success, in addition to collaboration and coordination among stakeholders, especially for Taxus floridana. Further research regarding impacts from climate change and natural systems modification would also aid in developing targeted conservation planning (Figure 7).

Overall summary and recommendations: Other than Taxus floridana, with its very limited distribution and limited regeneration, native U.S. Taxus species do not face significant threats currently. But, due to past declines and predicted population decline moving forward, U.S. native Taxus species should be a priority for continued monitoring, research, and conservation. Updated surveying and distribution modelling efforts would be helpful in tracking the conservation status of these species. Ex situ representation of native U.S. Taxus species is fairly robust, but further collecting efforts should be focused especially on Taxus floridana, to secure germplasm from all individuals, and the southern range of Taxus canadensis, in the event that climate change pushes the species further north. Native U.S. Taxus species are both a beautiful and important part of natural areas, in addition to their role in cultivated landscapes, and deserve continued conservation attention.
REFERENCES


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 Wojlaslawicz, 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 • Besseis Nursery, Nebraska National Forests and Grasslands • Boerner Botanical Gardens • Bok Tower Gardens • Botanic Garden Meise • Botanic garden of Le Havre, Ville du Havre • Botanic Gardens of Smith College, Tho • Botanic Gardens of South Australia • Botanischer Garten der Philipps-Universität Marburg • Brenton Arboretum, The • Brockgreen 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 • Felsinghuyzen Arboretum • Ghent University Botanical Garden • Green Bay Botanical Garden • Green Spring Gardens • GRIN Database, National Plant Germplasm System (NPGS) • Hackfalls Arboretum • Hidden Forests & Gardens (Cleveland Botanical Garden and The Holden Arboretum) • Hollard Gardens • Honolulu Botanical Gardens System • Horseshall 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. • Museum 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’Università della Calabria • Peckerwood Garden • Pinetum Blijdenstein • Polyt 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 • Vallaia Botanical Gardens A. C. • VanDusen Botanical Garden • Village of Riverside, Illinois • Waimea Valley Botanical Garden • Wellington Botanical Gardens • Westonbirt, The National Arboretum • Willowood Arboretum • Winona State University, The Landscape Arboretum at • Xishuangbanna Tropical Botanical Garden (XTBG) of Chinese Academy of Sciences (CAS) • Zoo and Bg Plzen
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 Murecins • Arboretum Kalmthout • Arboretum San Miguel • Arboretum Wespekoar • 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 • Emirhurst 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 • Hasilings 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. • Keefle Ecological Services Ltd. • L.E. Cooke Co • Launzi 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 • McKethen 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 • Muscataline 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, Tho • 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 • Pizzogrillo • Polly Hill Arboretum, The • Powell Gardens • Pronatura Veracruz • R.L. McGregor Herbarium • Rancho Santa Ana Botanic Garden • Reesleville Ridge Nursery • Regional Parks Botanic Garden • Revege Edge, The • Rogow 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 • Stark Hill 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 Gueph Arboretum • University of Leicester Botanic Garden • University of Maribor Botanic Garden • University of Minnesota • University of Notre Dame • University of Oklahoma • University of Washington Botanical Gardens • USDA Agricultural Research Service • USDA Forest Service • USDI Bureau of Land Management • Van Deusen 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 • WIRD Environmental, Inc. • Wright Nursery Alberta • Yellowstone Arboretum
## 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.

### List of state abbreviations used in Appendix B

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

### Taxus brevifolia

<table>
<thead>
<tr>
<th>Institution reporting conservation activities</th>
<th>Country (U.S. state)</th>
<th>Collect and distribute germplasm</th>
<th>Implement protection policies or regulations</th>
<th>Occurrence surveys or population monitoring</th>
<th>Population enforcement or introduction</th>
<th>Protect and/or manage habitat</th>
<th>Public awareness or education</th>
<th>Research (e.g., genetics, climate change, pests)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bayard Cutting Arboretum¹</td>
<td>United States (NY)</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cowichan Lake Research Station²</td>
<td>Canada</td>
<td></td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Keefer Ecological Services Ltd.²</td>
<td>Canada</td>
<td></td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rogów Arboretum of Warsaw University of Life Sciences¹</td>
<td>Poland</td>
<td></td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Royal Botanic Garden Edinburgh³</td>
<td>United Kingdom</td>
<td></td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Santa Barbara Botanic Garden³</td>
<td>United States (CA)</td>
<td></td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>University of California Botanical Garden at Berkeley⁸</td>
<td>United States (CA)</td>
<td></td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VanDusen Botanical Garden³</td>
<td>Canada</td>
<td></td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Westonbirt, The National Arboretum³</td>
<td>United Kingdom</td>
<td></td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Name not shared⁹</td>
<td>Ireland</td>
<td></td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>x</td>
</tr>
</tbody>
</table>

### Taxus floridana

<table>
<thead>
<tr>
<th>Institution reporting conservation activities</th>
<th>Country (U.S. state)</th>
<th>Collect and distribute germplasm</th>
<th>Implement protection policies or regulations</th>
<th>Occurrence surveys or population monitoring</th>
<th>Population enforcement or introduction</th>
<th>Protect and/or manage habitat</th>
<th>Public awareness or education</th>
<th>Research (e.g., genetics, climate change, pests)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atlanta Botanical Garden¹</td>
<td>United States (GA)</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bayard Cutting Arboretum¹</td>
<td>United States (NY)</td>
<td></td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Donald E. Davis Arboretum at Auburn University¹</td>
<td>United States (AL)</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Florida Natural Areas Inventory⁴</td>
<td>United States (FL)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nature Conservancy, The ; Florida⁴</td>
<td>United States (FL)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peckerwood Garden¹</td>
<td>United States (TX)</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Name not shared⁹</td>
<td>Ireland</td>
<td></td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### 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
Conservation Gap Analysis of Native

U.S. Yews

For further information please contact:

The Morton Arboretum
4100 Illinois Route 53
Lisle, IL 60532
Tel: 630-968-0074
Fax: + 44 (0) 1223 461481
Email: treeconservation@mortonarb.org
Web: www.mortonarb.org

BGCI
Descanso House
199 Kew Road, Richmond
Surrey, TW9 3BW
United Kingdom
Tel: +44 (0)20 8332 5953
Fax: +44 (0)20 8332 5956
E-mail: info@bgci.org
Web: www.bgci.org

Front cover images:
Taxus brevifolia (Jason Hollinger)
Taxus canadensis (Ed Hedborn, The Morton Arboretum)
Taxus floridana (Tom Cox)

Back cover image:
Taxus brevifolia (Wsiegmund)

Design:
John Morgan. www.seascape design.co.uk