Conservation Gap Analysis of

Kentucky Coffeetree

May 2021

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Gymnocladus dioicus (L.) K. Koch (Kentucky coffeetree)

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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

Gymnocladus dioicus, or Kentucky coffeetree, is distributed throughout temperate forests in the eastern and central United States and southeastern Canada, though its range is fragmented and it is uncommon within its habitat. Its native range stretches from New York, west to Minnesota, south to Oklahoma, and east to Kentucky and Tennessee. The tree can also be found in the Dakotas, Texas, Georgia, and the Carolinas, and is naturalized in Alabama, West Virginia, Virginia, and Delaware. It is the only native member of the genus *Gymnocladus* in North America. *Gymnocladus dioicus* grows alongside other hardwood trees, and prefers moist, humus-rich, limestone soils in bottom-land woods or rocky, wooded hillsides, though it enjoys full sun and can tolerate a wide variety of soil types (Row & Geyer, 2007; Schmitz & Carstens, 2018). The species' local rarity is not well understood, but no obvious or direct threat presents itself. It is suspected that "indirect, often overlooked, ecological changes" are the source of rarity, for example the absence of an effective seed dispersal agent, the species' intolerance to shade, and the requirement of scarification of seeds for successful germination (Carstens & Schmitz, 2017). Zaya and Howe (2009) assert that, "the Kentucky coffeetree...is an ecological paradox," with its large pods that resemble fruits consumed and dispersed by elephants and rhinoceros, but which are toxic to cattle and sheep and dispersed only by water. They predict that *G. dioicus* was once dispersed by large-mammal herbivory, and with the loss of that relationship it has been driven to rarity. Little is known about the specific uses of Kentucky coffeetree by Native Americans of the Great Lakes region, but comparison to similar species points to likely uses for "food, medicine, and in their recreational and ceremonial practices." It is also likely that these cultural uses were an important factor in shaping the native distribution of Kentucky coffeetree (VanNatta, 2009). *Gymnocladus dioicus* is assessed as Vulnerable on the IUCN Red List, due its fragmentation, rarity on the landscape, and population decline (Carrero, 2020).

Gymnocladus dioicus (Deb Brown, The Morton Arboretum)

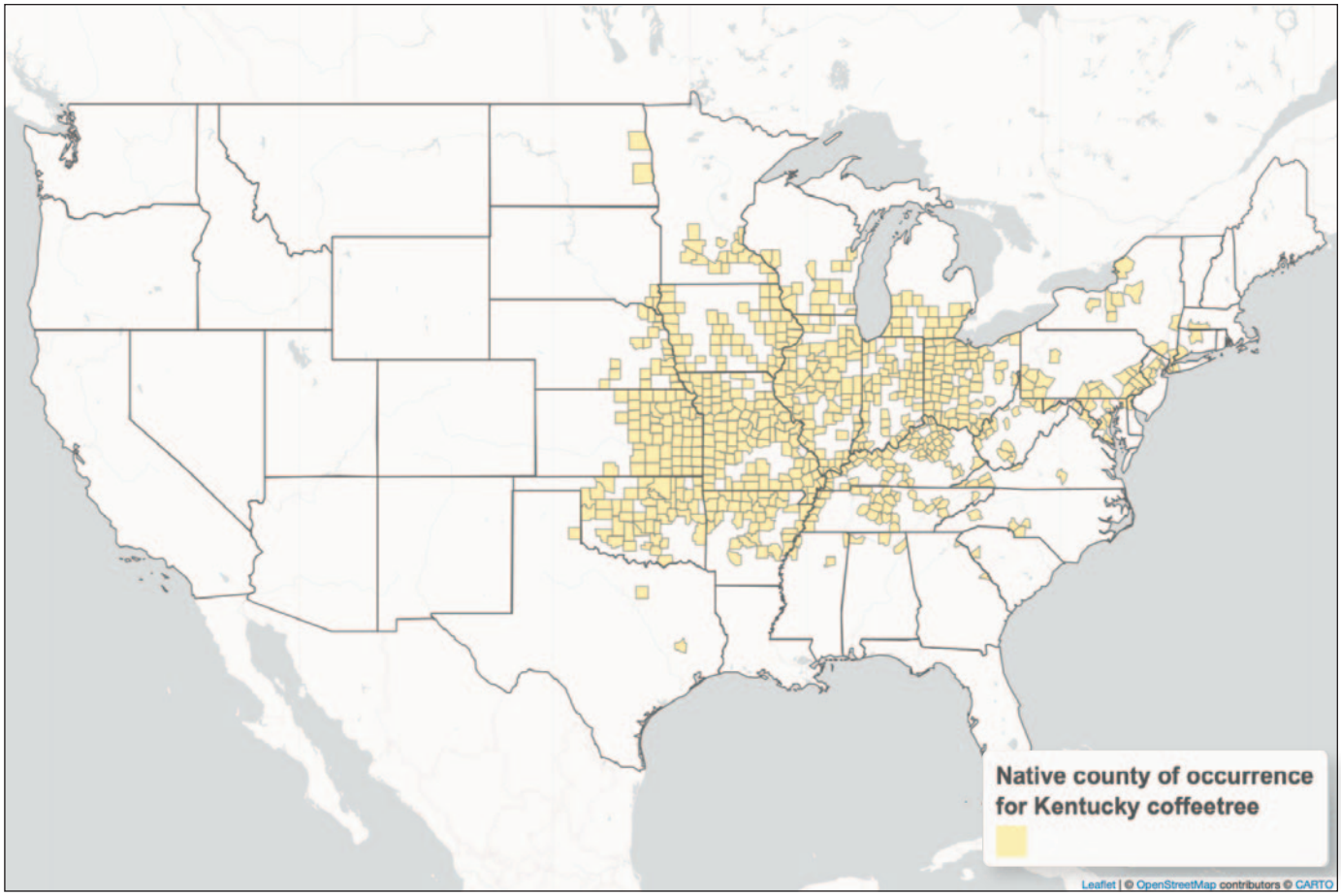

Figure 1. County level native distribution of *Gymnocladus dioicus* in the United States. County level distribution data from USDA PLANTS and Biota of North America Program (BONAP) have been combined to estimate species presence (Kartesz, 2018; USDA NRCS, 2018).

PESTS & DISEASES

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., 2019) are provided in Table 1, to give an overview of the pests and diseases affecting *Gymnocladus dioicus*, though all are minor. 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.

Table 1. The most serious insect, disease, and parasitic plant agents affecting *Gymnocladus dioicus*, from the results of Potter et al. (2019), which analyzed 419 native U.S. tree species. Numbers represent the severity of the agent's impact on the host species. Table adapted, with permission, from Potter et al. (2019).

Host species	Insect, Disease, or Parasitic Plant Agent	
	Verticillium wilt (*Verticillium* spp.)	White mottled rot (*Ganoderma* spp.)
Gymnocladus dioicus	1	1

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%)

CLIMATE CHANGE VULNERABILITY

A recent analysis of U.S. tree vulnerability to climate change, which used species-specific intrinsic traits to assess trees species' risk of negative effects from climate change, found Kentucky coffeetree to have high vulnerability, though potential adaptation to climate change (Potter et al., 2017). Fahey et al. (2013) examined the growth and resilience of four important urban street-tree species across four land use categories in Illinois. They found Kentucky coffeetree to be the most resistant to drought, even averaging higher growth after a significant drought. However, wild populations are often found in floodplains with extremely well-drained soils that could be significantly impacted by small increases in the frequency or duration of floods (Schmitz & Carstens, 2018). Therefore the impact of climate change on *G. dioicus* may depend on the type of hydrological changes created.

WILD HARVESTING & LAND USE CHANGE

Gymnocladus dioicus has strong, heavy wood, which is used as timber in a variety of applications. This has caused wild populations to decline rapidly due to overharvesting. This trend has been exacerbated because Kentucky coffeetree's seeds are only spread by waterways and often have difficulty germinating in the wild (Row & Greyer, 2007). According to Canada's Species at Risk report for *G. dioicus*, habitat loss within the species range in Ontario has been extensive in the last 200 years due to agriculture and urban land uses. It is considered threatened within Canada where six of its 33 known populations have been extirpated (Environment Canada, 2014). Habitat loss is also a concern in the U.S. portion of Kentucky coffeetree's range, in addition to competition with a variety of invasive species (Schmitz & Carstens, 2018).

Gymnocladus dioicus (Ed Hedborn, The Morton Arboretum)

MAJOR CONSERVATION INITIATIVES

In 2009, The Brenton Arboretum and the North Central Regional Plant Introduction Station (NCRPIS) initiated a collaboration aiming to create comprehensive *ex situ* germplasm collections of Kentucky coffeetree from across the species' native distribution. This tree was selected due to its adaptation to poor soils and drought, lack of serious threat from pests or pathogens, and attractive compound leaves and yellow fall color – making it a valuable species to conserve and invest in as an urban street-tree replacement for other decimated tree groups such as ash. These efforts have resulted in very extensive *G. dioicus* collections, which will conserve the genetic diversity of this tree as populations continue to disappear, and be used for research towards its use in urban settings (Carstens & Schmitz, 2017). After nearly ten years of collecting, a total of 88 seed accessions have been deposited in the National Plant Germplasm System and 130 accessions from different wild provenances planted at the Brenton Arboretum. In addition, a replicated block of 750 trees (representing 50 wild populations) was planted at the Plant Introduction Station in Ames, Iowa. This planting will one day help inform our knowledge of pollinators, growth rates, and hardiness of *G. dioicus*. The Brenton Arboretum and NCRPIS are planning to continue their collaboration by retrieving seed from unrepresented ecoregions, outlying populations, and unique habitats (Schmitz & Carstens, 2018).

University extensions and other non-profit groups are also promoting Kentucky coffeetree to be used as a landscape tree. In its profile of the tree, Iowa State University Extension and Outreach states, "Kentucky coffeetree should be used more in the landscape. It will grow on a wide range of soils from limestone, clay, and soils which may be droughty. It is relatively free of insect and disease pests" (Iowa State University, 2018). Although these initiatives will not save the wild populations of *G. dioicus*, they may create awareness and therefore contribute to its *in situ* conservation.

Gymnocladus dioicus has also been the subject of genetic analyses to determine patterns of genetic diversity and levels of sexual versus clonal reproduction (Lumb, 2018). Samples were collected from populations in the core of the species' distribution in the U.S. and four regions of southwestern Ontario. Results "indicated that *G. dioicus* has remarkably high genetic similarity across its range," due to low levels of sexual reproduction; the lack of sexual reproduction is thought to be most impacted by habitat degradation and insufficient seed scarification necessary for germination. Lumb (2018) asserts that "*G. dioicus* is effectively incapable of establishing new populations or re-establishing historical populations…[and] increasing the number of mixed-sex populations (either by transplanting or cultivar reintroduction efforts) will likely have a negligible impact on potential adaptive variation," because sexual reproduction and seed germination are so rare. Best practices for *in situ* conservation of *G. dioicus* must be carefully considered moving forward.

EX SITU SURVEY RESULTS

Gymnocladus dioicus is considered orthodox, meaning its seeds can be stored long-term in conventional seed bank conditions of low temperature and moisture (Royal Botanic Gardens Kew, 2020). Therefore, living collections are not as important to the conservation of Kentucky coffeetree, but serve as a resource for both research and public education.

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 90 collections from 18 countries reporting *Gymnocladus dioicus* (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. Because *Gymnocladus dioicus* is orthodox and can be seed banked, the *ex situ* survey results presented here include both seed bank and living collections.

Gymnocladus dioicus (Ed Hedborn, The Morton Arboretum)

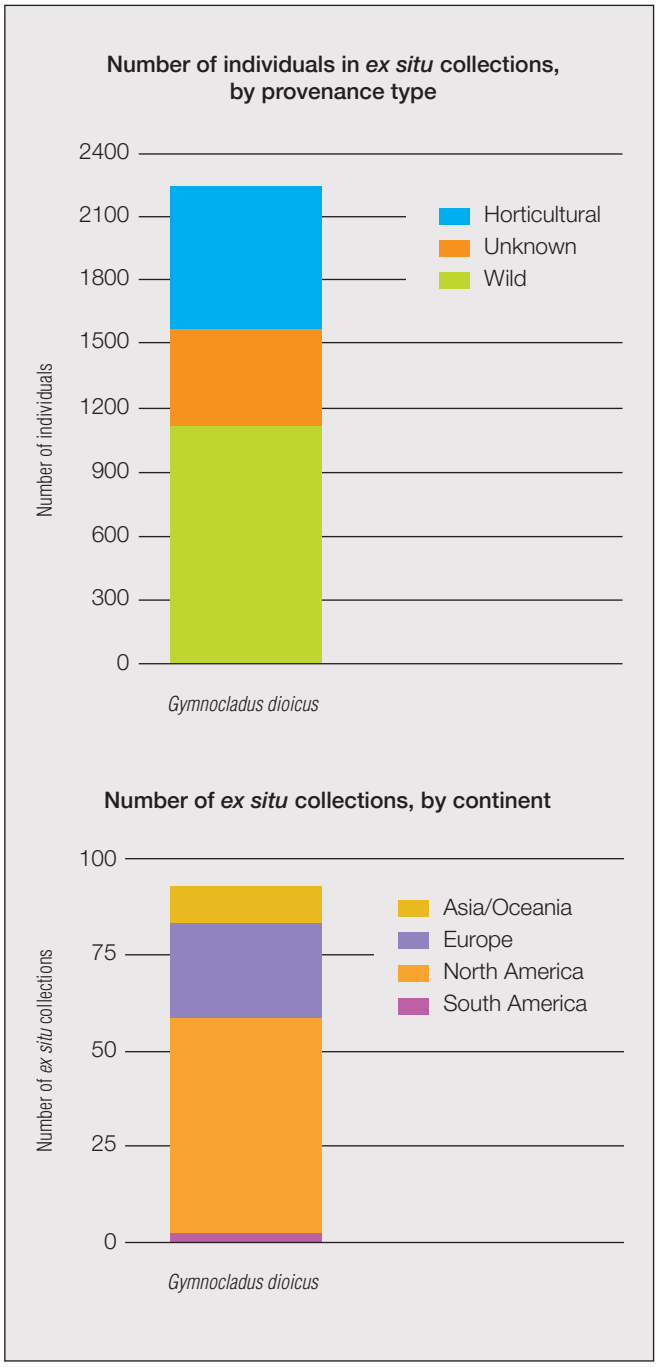

Figure 2. Results from a 2018 global accessions-level *ex situ* survey *Gymnocladus dioicus*.

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 *G. dioicus* 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 (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 3-4; Table 2). 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 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.

Gymnocladus dioicus (Ed Hedborn, The Morton Arboretum)

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In situ occurrence points for *G. dioicus* 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 *G. dioicus* 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.

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 *Gymnocladus dioicus*, about 9% of records with wild or unknown provenance were manually geolocated, while 58% had latitude and longitude provided by the institution and 34% 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).

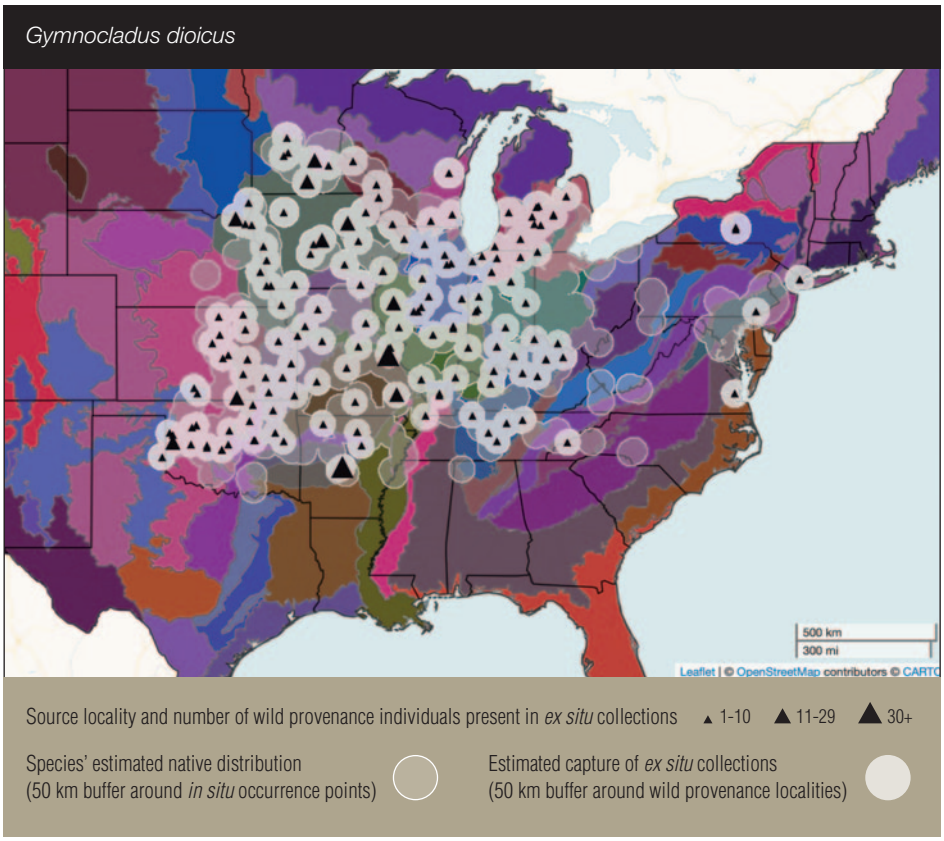

Figure 3. Native distribution and wild provenance localities of *ex situ* individuals for *Gymnocladus dioicus* in the U.S., based on 50 km buffers around *in situ* occurrence points and *ex situ* source localities. Background colors show EPA Level III Ecoregions (U.S. EPA Office of Research & Development, 2013a). Some records, especially smaller outliers in the eastern part of its distribution, may represent naturalized or remnant plantings.

Table 2. Estimated geographic and ecological coverage of *ex situ* collections of *Gymnocladus dioicus*. 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.

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
Gymnocladus dioicus	178,107 / 569,968 **(31%)**	137 / 203 **(67%)**	862,612 / 1,434,088 **(60%)**	191 / 254 **(75%)**	1,588,028 / 2,098,490 **(76%)**	271 / 320 **(85%)**	**56%**	**76%**

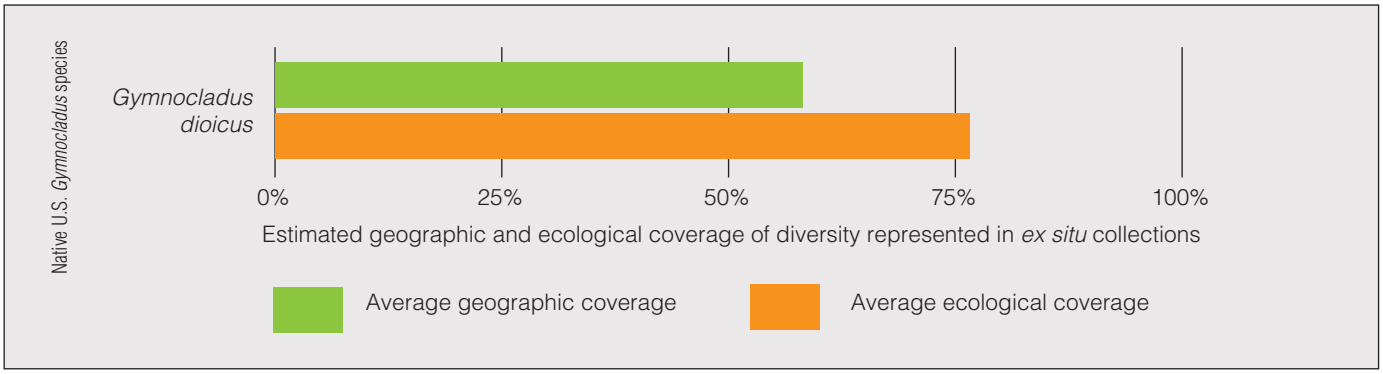

Figure 4. Average geographic and ecological coverage of *ex situ* collections for *Gymnocladus dioicus* (See Table 2 for details).

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 5). 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 44 institutions that provided input on conservation activities for *Gymnocladus dioicus*. 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.

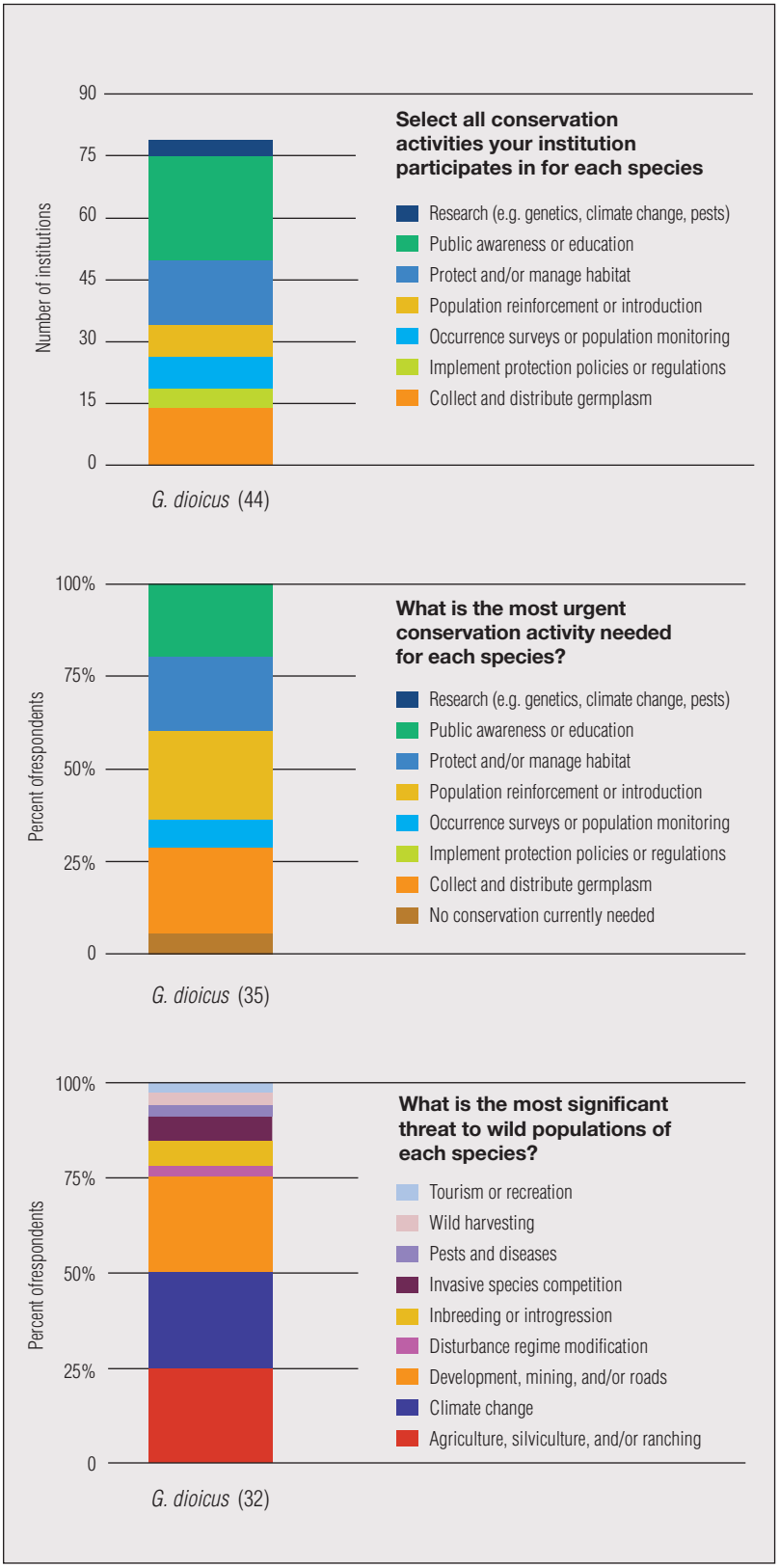

Figure 5. Results from the Tree Conservation Action Questionnaire for *Gymnocladus dioicus.* The number of institutions or respondents participating in each question is listed in parentheses after the species' name. See Appendix B for details regarding which institutions reported each conservation activity.

CONCLUSIONS & RECOMMENDATIONS

Species' distributions and threats: *Gymnocladus dioicus*, or Kentucky coffeetree, is distributed throughout temperate forests in the eastern and central United States and southeastern Canada, though its range is fragmented and it is uncommon within its habitat (Figure 1). Though it prefers moist, humus-rich, high-drainage soils in bottom-land woods or rocky, wooded hillsides, Kentucky coffeetree tolerates a variety of soil types and habitats. It is also recognized as a valuable urban street-tree (Row & Geyer, 2007; Schmitz & Carstens, 2018). A recent analysis of U.S. tree vulnerability to climate change found *G. dioicus* to have high vulnerability, though potential adaptation to climate change (Potter et al., 2017). *Gymnocladus dioicus* has also been shown to have high drought tolerance as well as likely sensitivity to frequent flooding (Fahey et al., 2013, Schmitz & Carstens, 2018). Due to its strong, heavy wood with many timber uses, overharvesting has caused wild populations to decline rapidly; land use change and habitat degradation have also contributed to its decline, especially in its Canadaian distribution (Environment Canada, 2014; Lumb, 2018). These trends have been exacerbated by Kentucky coffeetree's difficulty in spreading and germinating in the wild (Row & Geyer, 2007). The species currently faces no serious threat from pests or pathogens (Table 1).

Conservation quality of *ex situ* collections: Based on data from 64 *ex situ* collections that submitted accessions data for Kentucky coffeetree, the species is represented by 2,254 individuals in *ex situ* collections globally, nearly half of which are of wild origin. Of the wild origin individuals, 80% had enough wild locality information to be mapped (Figure 2-3). These individuals provide an estimated 56% geographic coverage and 76% ecological coverage of the species' total native distribution (Figure 4; Table 2). Due to the extensive collecting efforts of The Brenton Arboretum and the North Central Regional Plant Introduction Station, *ex situ* representation of *G. dioicus* is very substantial. It is evident that concerted collecting efforts can greatly impact the conservation quality of *ex situ* collections.

Gymnocladus dioicus (Ed Hedborn, The Morton Arboretum)

Gymnocladus dioicus (Ed Hedborn, The Morton Arboretum)

Conservation actions: For the Tree Conservation Action Questionnaire, 44 of the more than 200 participating institutions reported conservation activities for Kentucky coffeetree. Public awareness or education (27 institutions) was the most common activity reported, followed by collect and distribute germplasm (14) and protect and/or manage habitat (14). The conservation activities most frequently identified as most urgent were collect and distribute germplasm and population reinforcement or introduction. Agriculture, silviculture, and/or ranching, climate change, and development, mining, and/or roads were identified as the most significant threats to *G. dioicus* (Figure 5). The most extensive conservation effort known to be directed specifically toward *G. dioicus*, and one of the most significant *ex situ* collecting efforts for a native U.S. tree species, is the wild seed collecting collaboration between The Brenton Arboretum and the North Central Regional Plant Introduction Station (NCRPIS). This initiative created *ex situ* collections of Kentucky coffeetree that conserve the species' genetic diversity and provide material for research towards its use in urban settings (Schmitz & Carstens, 2018).

Overall summary and recommendations: Current conservation activities for Kentucky coffeetree, including *ex situ* collection and distribution of germplasm, habitat protection, and public awareness, should be continued and expanded upon. Other *in situ* conservation efforts such as population reinforcement or introduction will likely be necessary to preserve this species moving forward, but should be considered carefully. Because *G. dioicus* rarely reproduces sexually in the wild, population reinforcement or introduction may not have the desired long-term effects (Lumb, 2018). Further research may be necessary, including cross-sector efforts to test possible solutions on a smaller scale before moving to larger introduction or reintroduction initiatives. Continued field surveys, which can be carried out in conjunction with *ex situ* collecting efforts, should be implemented to monitor the species decline, and perhaps provide more information regarding impacts to the species and most effective future mitigation. Community-specific education or legislation may be necessary if populations of the species are continuing to experience harvesting. With its unique ecology, engaging history, resilience in urban landscapes, and continued role in the wild despite declines, Kentucky coffeetree should remain a priority for a variety of stakeholders engaged in U.S. tree conservation and research.

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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

Gymnocladus dioicus (Susan McDougall)

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

Gymnocladus dioicus (Susan McDougall)

Gymnocladus dioicus (Kitty Kohout, The Morton 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.

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)
Gymnocladus dioicus	Alpha Nurseries, Inc[8]	United States (MI)	X						
	Arboretum des Grands Murcins[1]	France						X	
	Arboretum San Miguel[1]	Argentina					X	X	
	Arkansas Natural Heritage Commission[6]	United States (AR)					X	X	
	Bayard Cutting Arboretum[1]	United States (NY)				X	X		
	Bergius Botanic Garden[1]	Sweden		X					
	Blue Mountains Botanic Garden, The[1]	Australia	X						
	Boehm's Garden Center[8]	United States (IL)	X					X	
	City of Columbia Stephens Lake Park Arboretum[2]	United States (MO)	X					X	
	City of Hamilton[2]	United States (OH)			X		X	X	
	City of Kansas City, Missouri[2]	United States (MO)				X			
	Cox Arboretum and Gardens[1]	United States (GA)					X		
	Denver Botanic Gardens[1]	United States (CO)	X						
	Downtown Lincoln Association[1]	United States (NE)	X						
	Draves Arboretum[1]	United States (NY)				X		X	
	Elmhurst College[9]	United States (IL)					X	X	
	Folmer Botanical Gardens[1]	Canada				X			
	Hastings College[9]	United States (NE)		X			X	X	
	Holden Forests and Gardens[1]	United States (OH)						X	
	Illinois Department of Natural Resources Mason State Nursery[2]	United States (IL)	X			X			
	Indiana Native Plant Society, Southwest Chapter[5]	United States (IN)						X	
	Johnson's Nursery, Inc.[8]	United States (WI)	X						
	Lauritzen Gardens[1]	United States (NE)					X		
	Longwood Gardens[1]	United States (PA)	X					X	
	Minnesota Department of Natural Resources[2]	United States (MN)		X	X		X	X	
	Missouri Arboretum[1]	United States (MO)						X	
	Morris Arboretum[1]	United States (PA)					X		
	Moscow State University Botanical Garden[1]	Russian Federation	X						
	New York Natural Heritage Program[6]	United States (NY)			X			X	
	Pennsylvania Natural Heritage Program, Western Pennsylvania Conservancy[6]	United States (PA)				X		X	
	R.L. McGregor Herbarium[9]	United States (KS)			X				
	Rogów Arboretum of Warsaw University of Life Sciences[1]	Poland	X						
	Sister Mary Grace Burns Arboretum at Georgian Court University[1]	United States (NJ)						X	
	State Botanical Garden of Kentucky, The Arboretum[1]	United States (KY)	X					X	
	Strasbourg University Botanic Garden[1]	France						X	
	United States Fish and Wildlife Service, Clarks River National Wildlife Refuge[3]	United States (KY)					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)
Gymnocladus dioicus	United States Fish and Wildlife Service[3]	United States (MO)	X			X	X	X	X
	University of Guelph Arboretum[1]	Canada	X		X			X	
	University of Leicester Botanic Garden[9]	United Kingdom						X	
	University of Oklahoma[9]	United States (OK)			X				
	VanDusen Botanical Garden[1]	Canada						X	
	Village of Bensenville[2]	United States (IL)		X	X	X	X	X	
	Westonbirt, The National Arboretum[1]	United Kingdom						X	X
	WRD Environmental, Inc.[8]	United States (IL)					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

Gymnocladus dioicus (Ed Hedborn, The Morton Arboretum)

Conservation Gap Analysis of

Kentucky Coffeetree

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Front cover images:
Gymnocladus dioicus (Ed Hedborn, The Morton Arboretum)

Back cover image:
Gymnocladus dioicus (Ed Hedborn, The Morton Arboretum)

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