

Article

Tree Advisor: A Novel Woody Plant Selection Tool to Support Multifunctional Objectives

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Abstract: Purposefully planted trees and shrubs can provide multiple benefits when appropriately planned and designed. Tools to help select species that will function more effectively than other species for ecosystem services, production, and aesthetic purposes are generally lacking. To address this challenge, we developed an interactive plant selection tool entitled Tree Advisor that rates woody species for a wide range of different purposes based on plant attributes. In this prototype decision support tool, 90 species of trees and shrubs are rated for 14 different purposes in the northern and central Great Plains region of the United States. A rating algorithm was developed based on the scientific literature regarding plant functions and related attributes that determine relative performance of a species for each purpose. User input and best practices for developing effective decision support tools informed the tool development process. Based on user feedback, the tool supports multifunctional planning and enables a user to quickly develop a short list of the better species to use which can then be refined by the user based on suitability under local site conditions, commercial availability, and availability of locally adapted cultivars and hybrids. This tool development approach can serve as a model for producing multifunctional woody plant selection tools for other ecoregions.



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1. Introduction

Nature-based solutions are defined by the International Union for Conservation of Nature (IUCN) as “actions to protect, sustainably manage, and restore natural or modified ecosystems, that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits” [1]. These actions can involve deliberately planted vegetation [2] and are being proposed and implemented through a number of international planting programs including Trillion Trees [3], Nature Conservancy’s Plant a Billion Trees campaign [4], and the agroforestry-based Grow Ahead program [5]. In the United States, some of these nature-based efforts include the Chesapeake Bay Program, which rely on riparian forest buffers to aid in the mitigation of water quality problems [6] and the Great Lakes Restoration Initiative, a diverse effort that has included vegetative plantings for stormwater infiltration and habitat restoration [7]. In addition to large-scale programs, vegetation-based solutions are being implemented through numerous state and locally led efforts from municipal green infrastructure projects [8] to conservation practices in agricultural landscapes [9].

To maximize the benefits of these plantings, while minimizing potential unintended consequences, landowners, natural resource professionals, and other decision makers need useful and actionable information to guide plant selection. Plant species are diverse in form, function, and environmental response, which provides opportunities for designing vegetative interventions that can produce a suite of desired outcomes. Research indicates that landowners and natural resource professionals want more information and practical

tools regarding plant materials and plant material selection [10,11]. In particular, decision makers have specified that they would like user-friendly resources that can facilitate species selection to accomplish multiple functions [10,12]. Historically, resources and tools on plant selection tend to focus on species characteristics and environmental tolerances with few resources providing information on specific functions and purposes [13–15]. More recently, some resources are connecting species with functions and purposes; however, it is not always transparent on why a species is considered appropriate for a specific function or purpose [16,17].

Trait-based ecology has been suggested as an evidence-based approach to identifying species that can perform better than other species for a particular function based on plant attributes [18–20]. Plant attributes determine functional capabilities that, in turn, determine relative performance for a purpose, and multiple functions may be required to achieve a purpose [19]. This approach is being applied in a variety of plant selection frameworks including ecosystem restoration [21,22], erosion control [23], stormwater pollutant removal [24] and agroforestry [25,26]. Decision support tools (DSTs) incorporating plant attribute data are now being developed, and some examples include plant selection DSTs for urban heat island mitigation [27] and stormwater biofilters [28]. Currently, the available plant selection DSTs are focused on a single purpose and do not facilitate multifunctional design. In addition, these tools do not provide a ranking between species to aid decision makers in determining which species might be relatively better than others for performing a particular purpose.

The effectiveness and adoption of a DST can be influenced by the interface design and functionality of the tool. Research had shown that complex DSTs can end up being difficult for a target audience to use as well as difficult to support and maintain over the long term, often resulting in DSTs that are eventually discarded [29–31]. Based on DST evaluation literature, users expect a tool that is simple to use, entails minimal or no training, requires limited data input, and provides desired information in an efficient manner [30,32–34]. For maximum adoption, a DST should be intuitive to pick up and not require relearning how to use the tool when there are lapses in use [32,35]. Users also expect DSTs to be delivered in an online format that does not require them to download a DST nor have a particular software program in order to run the DST [34,35]. Best practices for developing human-centered computer-based DSTs are available to guide interface design and functionality [33,36]. Some of the principles include an interface with minimal choices, Fitt’s law and visual hierarchy, maintaining negative or white space, Gestalt design laws, and a grid-based layout.

The goal of our study was to develop and evaluate an evidence-based plant selection tool that can support multifunctional planning and design. This study aimed to identify plant attributes that are beneficial for a variety of common purposes across rural to urban landscapes and create an online decision support tool that rates species based on their relative performance potential. We concentrated our effort on trees and shrubs because these species typically take longer to become established and mature to a point to provide the desired outcomes. Woody species require a greater investment in time and management, and hence it is critical to make an informed decision [37]. Our study focused on developing a regional-based tool with the aim that this prototype application could serve as a model for other regions. Specific objectives for the DST include:

1. Include multiple purposes and allow users to select those purposes;
2. Develop a transparent, scientific-based rating process for the plant species;
3. Use best practices to develop a user-friendly tool and interface;
4. Design the tool to allow for easy updating and revisions;
5. Incorporate end-user feedback through the development process.

2. Materials and Methods

An overview of the process used to develop the decision support tool called Tree Advisor (www.fs.usda.gov/nac-plant-guide/ accessed on 6 February 2022) is shown in

Figure 1. The study area selected for the development of the DST was the Northern and Central Great Plains ecoregion as approximately defined by the U.S. Environmental Protection Agency Level 1 Ecoregions [38]. This ecoregion was selected because of its history of tree planting to address environmental and economic issues [39]. In response to the 1930s Dust Bowl, the Prairie States Forestry Project planted over 220 million seedlings, creating 30,000 km of shelterbelts from North Texas to North Dakota to address severe soil erosion and loss of agricultural production [40]. The area also has a relatively lower number of woody species that can grow in the ecoregion compared to many other U.S. ecoregions, offering a more manageable number of species for developing and evaluating a prototype [14]. Another selection consideration is woody plant encroachment into native grasslands, which is an important land management concern in the region needing actionable information [41,42].

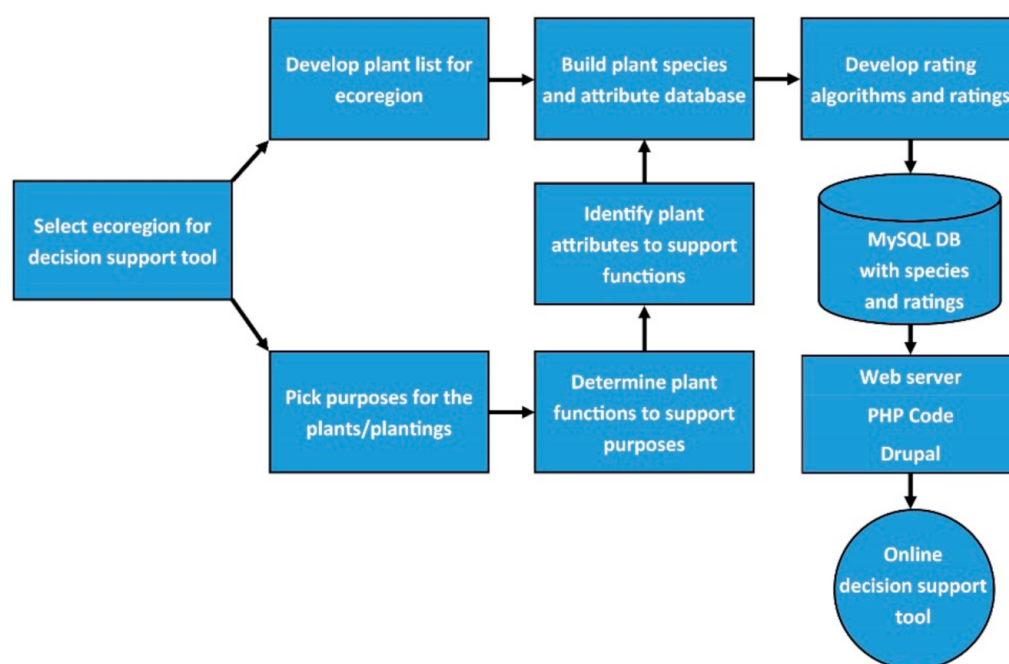


Figure 1. Framework used to develop the decision support tool called Tree Advisor.

The 2012 USDA Plant Hardiness Zone Map was used as the spatial framework for organizing Tree Advisor. While it is focused primarily on one variable (mean annual extreme minimum temperature), the USDA Plant Hardiness Zone Map is a commonly used standard for determining which plants are most likely to thrive at a location [43]. The study region was divided into 12 sub-regions bounded by USDA Plant Hardiness Zones 3, 4, 5, and 6 divided into western (W), central (C), and eastern (E) zones based on annual average precipitation (Figure 2). The annual average precipitation was obtained from the PRISM 30 yr Normal Annual Precipitation: Period 1981–2010 [44]. The boundaries of the 12 sub-regions correlated roughly with the significant changes in the list of tree and shrub species that would grow well in each region.

The regionwide species list for Tree Advisor was developed through a comprehensive review of regional and national literature and databases on the distribution and use of trees and shrubs in the study region [13–16,45–84]. While the list focuses on native species, introduced species that have a history of use in the region were also included. Growing conditions in this region can be challenging for woody species, and introduced, non-invasive plants can provide important functions in appropriate locations [14,16]. Regional plant experts provided feedback on a preliminary species list and the final resulting list of species includes 90 trees and shrubs Appendix A (Table A1). Species were allocated to the 12 sub-regions based on the native range and use within the region.

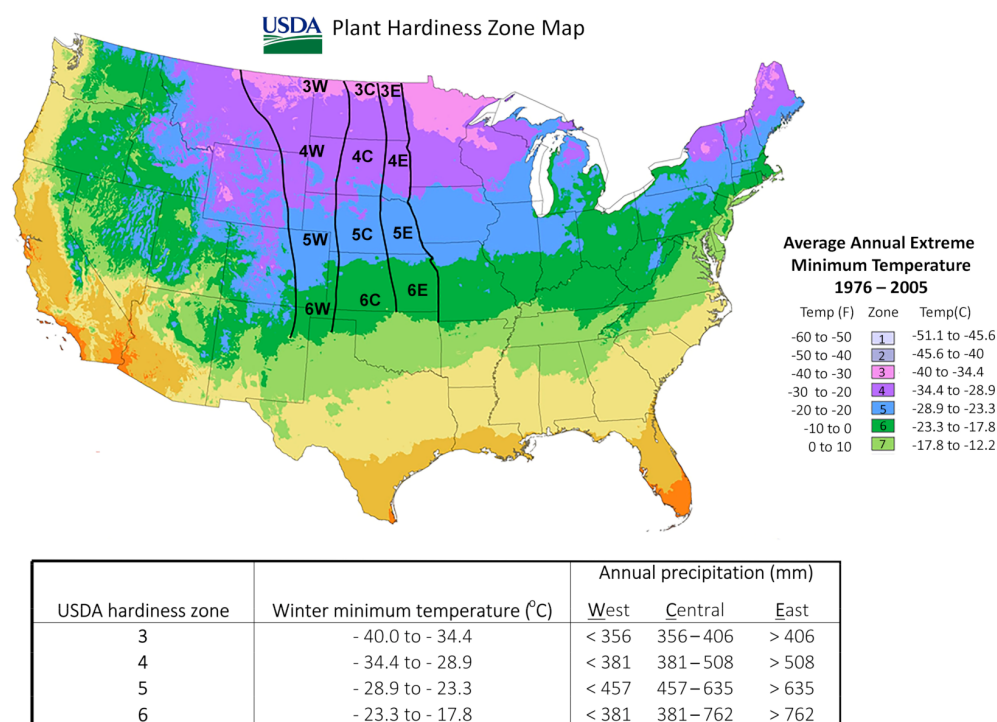


Figure 2. Twelve sub-regions delineated in Tree Advisor based on the 2012 USDA Hardiness Zone Map and PRISM 30 yr Normal Annual Precipitation: Period 1981–2010. Base map source [43].

Enhancement of ecosystem services from agricultural landscapes in the United States is frequently accomplished by using methods and practices developed by the U.S. Department of Agriculture (USDA) Natural Resource Conservation Service (NRCS). A USDA NRCS conservation practice is a structure or practice that is designed to address resource concerns regarding soil, water, air, plants, animals, humans and energy [9]. For instance, the Windbreak/Shelterbelt Establishment practice (380) lists several purposes from reduce soil erosion by wind to improve air quality by intercepting airborne particulate matter, chemicals, and odors [85]. The USDA NRCS conservation practices were reviewed to identify common purposes of woody plantings to include in the DST. In addition, regional planners and natural resource professionals were asked to provide recommendations on purposes to include in the DST. Based on this evaluation, 14 purposes were selected for use in Tree Advisor (Table 1), many of which are used across rural to urban landscapes [86,87]. This list of purposes is not meant to be all encompassing, but rather an initial set of primary purposes frequently used in the study region. In time, this list of purposes may be expanded.

For each purpose, Table 1 provides the functions that the plants need to provide in order to perform that purpose. These functions were identified through the USDA NRCS conservation practices and through a review of the scientific literature. For each function, we also reviewed the scientific literature to identify contributing plant attributes. The plant attribute column in Table 1 provides a summary of the important attributes identified that a tree or shrub should have to deliver the desired functions. Attribute categories included morphological and growth characteristics, environmental tolerances, wildlife benefits, potential economic products, and visual aesthetics. Key references document the scientific literature used for determining the attributes to include in the rating algorithms. This literature was also used to assess if an attribute was critical such that it needed to be weighted compared to other attributes. In Table 1, 2x indicates the attribute will be weighted double in the rating algorithm. For instance, flood tolerance is considered a critical attribute for the purposes of aquatic habitat, flood protection, and streambank stabilization.

Table 1. Purposes rated in Tree Advisor with their associated plant functions and attributes based on the scientific literature.

Purpose	Plant Functions	Plant Attributes	Key Literature
Alley cropping	Produce a tree/shrub crop which complements the income generated from a crop grown between rows of the trees.	Weighted: shorter crown to minimize shade over the alley crop (2x). Unweighted: tree produces a high-value product (required). Does not seriously reduce productivity of the alley crop via competition by shallow roots, deep shade, or high soil water use. User will need to determine management compatibility between the tree crop and the alley crop.	[88–92]
Aquatic habitat	Aquatic habitat can be improved by reducing summer water temperature and by increasing the supply of plant debris. Water temperatures of smaller streams can be moderated by shade. Fallen leaves provide important fodder for the aquatic food chain. Larger woody debris provides structural diversity that creates cover for a wide variety of aquatic organisms.	Weighted: high flood tolerance (2x); tall height (2x). Unweighted: fast-growing trees that can more quickly produce dense summer shade and debris.	[93–95]
Carbon sequestration	Carbon from atmospheric CO ₂ is photosynthesized into biomass and sequestered in the form of wood.	Weighted: fast growth (2x). Unweighted: large, long-lived.	[96,97]
Flood protection	Flood damage includes scour erosion of soil from, and deposition of debris in, agricultural fields on low floodplains. Protection is provided by trees and shrubs that slow out-of-bank floodwater flow and that screen and trap debris before it enters agricultural fields.	Weighted: high flood tolerance (2x). Unweighted: dense stems and foliage near the ground (assume floodwaters less than about 5 feet deep) and fast vegetative spread.	[23,98–101]
Native ecosystem restoration	Plants that are native to an area have characteristics that, on the whole, integrate better with the life histories and habitat requirements of other native organisms than non-native plants.	Unweighted: native status in the sub-region.	[102,103]
Particle drift reduction	Tree crowns slow wind and intercept airborne particles, thereby reducing the amount and distance of travel of dust, crop pollen, and pesticide-containing spray droplets into adjacent fields and other off-site areas.	Weighted: tall (2x). Unweighted: fast growth, high foliage porosity, and not prone to breakage by ice and wind.	[104–107]
Pollinator habitat	Produces food (pollen and/or nectar) at times of year when most other plants do not (typically winter and early spring) and provides protected winter and reproductive refugia.	Unweighted: provides relatively better pollinator habitat mainly through copious flowering (pollen and nectar food sources) in early spring.	[108–110]
Polluted runoff treatment	Vegetation provides surface roughness that slows overland flow and promotes infiltration, and thereby promotes deposition of sediment and sediment-bound pollutants, infiltration of dissolved pollutants, uptake and sequestration of nutrients by plants, and transformation of nutrients and degradation of pesticides by soil microorganisms.	Unweighted: develops many plant stems, has low shade density for allowing grass and forb undergrowth, has high water use to dry the soil and promote infiltration, is fast growing for a high debris production and nutrient uptake rate.	[24,93,111,112]
Streambank stabilization	Streambanks can be protected from erosion by water and ice by plant roots and shoots that armor the bank and roots that anchor the soil. However, eroding banks along incising stream channels will, first, require special engineering to halt the incision process before tree and shrub plantings can be effective.	Weighted: flood tolerance (2x). Unweighted: short shrubs that form dense and fast-spreading thickets, have shallow root systems, and can re-sprout vigorously after breakage.	[93,98,112–114]

Table 1. Cont.

Purpose	Plant Functions	Plant Attributes	Key Literature
Stormwater treatment	Stormwater is directed to vegetated areas where water infiltrates, particulates deposit on the surface, and dissolved pollutants (including mineral nutrients, and mineral and organic pollutants) are stripped out of the percolating water by interactions with soil minerals, organic matter, microorganisms, and plant roots. Vegetation is critical for maintaining soil infiltration capacity and soil interaction processes.	Unweighted: high water use, fast growth, and large size promote infiltration and soil transformations, including nutrient uptake and sequestration by the plants.	[28,93,111,112]
Wetland and restoration	Vegetation promotes wetland processes that improve water quality and wildlife habitat. Trees and shrubs diversify wetland habitat.	Unweighted: high flood tolerance.	[99,101]
Wildlife habitat	All tree and shrub plantings provide cover and/or food benefits in otherwise cultivated cropland or heavily grazed pastures. Some species provide particularly valuable cover conditions or food sources for birds and mammals.	Unweighted: bird and mammal habitat.	[16,52,115]
Visual aesthetics	Trees and shrubs may have visual qualities that landowners deem particularly desirable in a planting. Larger trees and shrubs are generally more noticeable in an agricultural setting. Some may provide additional visual interest by having bright yellow or red foliage in the fall, showy flowers in the spring, or year-round green foliage. It remains for the user to determine what kind(s) of visual interest (evergreen, fall color, or showy flowers) is (are) desired.	Weighted: particular visual interest (2x). Unweighted: larger size.	[116–118]
Visual and noise screen	Tree and shrub foliage can block undesirable views and dampen noise.	Weighted: year-round foliage (2x). Unweighted: tall, fast-growing trees with high foliage density.	[119–122]

With the relevant plant attributes identified, a table of 25 plant attributes was created along with a unique code for each attribute that is used in developing the rating algorithms for each purpose (Table 2). The attributes were translated into a numeric value based on the available data and regional context (Table 2). These values typically ranged on a scale from 0 or 1 up to 4 depending on the specific attribute. Where possible, a quantitative standard was used to establish the range; however, in many cases, a qualitative approach based on the available literature and expert opinion was used to determine the attribute numeric values. The notes column in Table 2 provides additional information on the attribute and attribute range.

Regional context was an important consideration for some attributes such as crown height and growth rate. The study region is at the fringe or outside of the native ranges of many species and has a relatively harsh climate for trees and shrubs [123]. Consequently, trees and shrubs generally do not grow as large or as fast as they do in areas closer to the center of their native ranges [14,124]. Again, regional expertise was consulted to develop these attribute ranges.

Using the tree and shrub list Appendix A (Table A1) and inventory of 25 selected plant attributes, a species-by-attribute database was created. Attribute data were compiled from regional and national databases and literature on woody plants [13–16,45–84] and inputted into the database as a numeric value based on the attribute range. In addition, text descriptions describing potential products, specific visual and bird/mammal habitat attributes, and potential hazards such as insect and disease susceptibility were inputted. Key attributes that can inform decision making regarding risk potential for encroachment into grasslands and other natural areas include growth rate, vegetative spread rate, seeding spread rate, resprout ability, and drought tolerance [41,125,126]. The database also includes text-based information on spread risk or invasiveness.

From the functional attribute assessment (Table 1), rating algorithms for each purpose were developed using one to six plant attributes (Table 3). Depending on the specific purpose, a maximum value for an attribute might be the desired feature while in other cases the minimum value may be the preferred value. For instance, in alley cropping, shorter species were rated higher which will cast less shade on the crop in the alley [88,90,92] while taller species were rated higher for aquatic habitats which will cast more shade on the stream, keeping water temperatures cooler and being more effective at providing coarse woody debris for aquatic habitats [93–95]. Based on the scientific evidence, some attributes were weighted double (2x) compared to other attributes (1x), and in one case (alley cropping), an attribute was considered required. The basic form of the rating algorithm is a summation of the attribute values divided by weights and multiplied by 10 to return a value between 0 (worst) and 10 (best). Six attributes included in the attribute database were not used in developing the rating algorithms since these attributes do not contribute significantly to the purposes and functions addressed in this prototype tool based on the literature review. These attributes include stem form, seeding spread rate, nitrogen fixation, drought tolerance, salt tolerance, and shade tolerance. These attributes may be used if additional purposes are added, if new information indicates they should be included to rate the existing purposes, or if the user desires this information for their decision making. The attribute data and algorithms were inputted into Microsoft Excel® to calculate the purpose ratings for each of the species. The rating algorithms were set up as formulas which referenced the attribute data in the spreadsheet. Individual worksheets were set up for each sub-region and rating values were calculated for each purpose for each species in a sub-region. Macros were used to develop a simple user interface for the spreadsheet to help users understand and navigate this draft DST. This DST was distributed to nine natural resource professionals and landowners in the region for preliminary evaluation. After a one-month period of use, feedback provided by the test group was reviewed based on three key themes (concept, usefulness, and limitations).

Table 2. Plant attributes used in Tree Advisor.

Attribute Code	Attribute ¹	Attribute Range	Attribute Range Description	Notes
Q	Native status	1 to 3	3 = native to the sub-region 2 = not native to the sub-region, but native to elsewhere in North America 1 = not native to North America	
C	Crown size/form	1 to 4	4 = large tree (typically single central trunk; mature ht > 9.1 m) 3 = small tree (typically single central trunk; mature ht < 9.1 m) 2 = large shrub (typically smaller than a small tree and multiple stems; mature ht > 2.1 m) 1 = small shrub (typically smaller than a large shrub and multiple stems; mature ht < 2.1 m)	
Z	Crown height	1 to 3	3 = tall trees (>9.1 m) 2 = short trees or tall shrubs (2.1–9.1 m) 1 = short shrubs (<2.1 m)	Based on height ranges found in regional plant guides and databases.
G	Growth rate	1 to 3	3 = fast 2 = medium 1 = slow	Relative height growth rate under good growing conditions. A 2 rating correlates roughly to a stem growth rate range of 0.3–0.6 m/yr.
L	Life span	1 to 3	3 = >100 years 2 = 40–100 years 1 = <40 years	Shrubs were assumed to have a life span < 40 yr for individual stems, whether plants or clonal sprouts, unless otherwise noted in databases.
A	Stem form ²	1 to 2	2 = multiple stems 1 = single stem	This category is intended to characterize the form naturally taken in the absence of trimming.
R	Foliage retention	1 to 2	2 = evergreen 1 = deciduous	
S	Shade density	1 to 3	3 = casts relatively dense shade under its crown 2 = casts medium shade under its crown 1 = casts light shade under its crown	Based on “Foliage Density” in USDA PLANTS.
P	Foliage porosity	1 to 3	3 = porous to wind 2 = moderately porous 1 = low porosity to wind	Porosity to wind during the growing season (i.e., summer).
O	Root structure	1 to 3	3 = deep lateral and taproot systems 2 = medium-depth lateral root system 1 = shallow lateral root system	Based on “Root Depth, Minimum” in USDA PLANTS and root structure information in regional plant guides and databases.
V	Vegetative spread rate	0 to 3	3 = fast 2 = moderate 1 = slow 0 = none	Propensity to reproduce vegetatively by root suckers or sprouts, rhizomes, stolons, and/or layering (i.e., by adventitious rooting of low branches that touch the ground).

Table 2. Cont.

Attribute Code	Attribute ¹	Attribute Range	Attribute Range Description	Notes
J	Seeding spread rate ²	1 to 2	2 = fast; typically, a prolific seeder 1 = slow	Propensity to reproduce from seed. Seeding spread rate integrates seed production, seed viability, and effectiveness of seed dispersal to describe how effectively a species can regenerate.
T	Stand form	1 to 3	3 = dense clonal thickets 2 = loose clonal colonies, clusters, or patches 1 = dispersed individuals	
U	Resprout ability	0 to 2	2 = high ability to sprout new shoots after cutting or breakage 1 = low ability 0 = no ability	High ability is assumed if data sources indicate both “Resprout Ability” and “Coppice Potential”.
N	Nitrogen fixation ²	0 to 1	1 = significant; improves growth of the tree and surrounding vegetation 0 = none or not significant	
W	Water use	1 to 3	3 = high 2 = medium 1 = low	Based on “Moisture Use” in USDA PLANTS which represents the ability to remove soil water relative to other plants of similar size under similar soil moisture availability.
F	Flood tolerance	1 to 3	3 = high; can survive flood lasting for half or more of the growing season 2 = moderate; can survive flood lasting for a couple of weeks to 40% of the growing season 1 = low; can survive only brief periods of flooding	Based on “Anaerobic Tolerance” in USDA PLANTS which is the relative tolerance to anaerobic soil conditions.
D	Drought tolerance ²	1 to 3	3 = high; can survive and grow where drought is frequent and periodically severe 2 = moderate; can grow well where drought is never more than occasional and moderate 1 = low; can grow well only where drought is never more than infrequent and mild	
K	Salt tolerance ²	1 to 3	3 = high; can grow well under relatively high saline soil conditions 2 = moderate; can grow well under no higher than moderate saline soil conditions 1 = low; grows well only under relatively low saline soil conditions	Where not mentioned directly in data sources, it is assumed to be low, or, moderate if its native range typically has alkaline soils.
X	Shade tolerance ²	1 to 3	3 = high; can grow well under deep shade 2 = moderate; can grow well under shade that is not more than partial 1 = low; will not grow well in partial or deep shade	Shade tolerance is assumed to be moderate if not mentioned explicitly in data sources.
B	Breakage resistance	1 to 2	2 = not prone to severe limb breakage in ice and windstorms 1 = prone to severe limb breakage in ice and windstorms	A species is assumed to be not prone to breakage if not mentioned explicitly in data sources.

Table 2. Cont.

Attribute Code	Attribute ¹	Attribute Range	Attribute Range Description	Notes
M	Bird and mammal habitat	1 to 2	2 = high 1 = average	A high rating identifies a species that has an especially high value compared to others of the same growth form (i.e., tree or shrub).
H	Pollinator habitat	1 to 2	2 = high 1 = average	High-value species provide important nectar and pollen sources for bees, esp. late fall and early spring when there are few other sources.
E	Product potential	0 to 2	2 = potential for significant commercial product or two or more local market products 1 = potential for a single local market product 0 = negligible or no product potential	Commercial products have significant potential for sale in geographically broad commodity markets. Local market products are most suitable for home use or sale in local farmers markets.
I	Visual quality	0 to 1	1 = Exhibits a quality that creates special visual interest in a conservation planting. 0 = No special visual quality	Identifies if a species has special visual qualities that may be desirable in a planting, such as conspicuous foliage or flowers.

¹ Attributes and attribute range descriptions are derived from USDA PLANTS [16] with supporting data from [13–16,45–84]. ² Attributes included in the database but not currently used in the rating algorithms.

Table 3. Rating algorithms for each purpose in Tree Advisor.

Plant Attributes						
	Product Pot.	Root Structure	Shade Density	Water Use	Crown Height	Weighting (n)
Attribute code	E	O	S	W	Z	
Max value	2	3	3	3	3	
Min value	0	1	1	1	1	
Weighting	Required	1x	1x	1x	2x	5
Best rating	Max	Max	Min	Min	Min	
Alley cropping rating ¹ = $((E - E_{Min}) \div (E_{Max} - E_{Min})) \times$ $[(O \div O_{Max}) + ((S_{Max} - S) \div (S_{Max} - S_{Min})) + ((W_{Max} - W) \div (W_{Max} - W_{Min})) + (2((Z_{Max} - Z) \div (Z_{Max} - Z_{Min}))) \div n] \times 10$						
	Flood tolerance	Crown height	Growth rate	Shade density		Weighting (n)
Attribute code	F	Z	G	S		
Max value	3	3	3	3		
Min value	1	1	1	1		
Weighting	2x	2x	1x	1x		6
Best rating	Max	Max	Max	Max		
Aquatic habitat rating ¹ = $((2 \times F \div F_{Max}) + (2 \times Z \div Z_{Max}) + (G \div G_{Max}) + (S \div S_{Max})) \div n \times 10$						
	Growth rate	Crown size/form	Life span			Weighting (n)
Attribute code	G	C	L			
Max value	3	4	3			
Min value	1	1	1			
Weighting	2x	1x	1x			4
Best rating	Max	Max	Max			
Carbon sequestration rating ¹ = $((2 \times G \div G_{Max}) + (C \div C_{Max}) + (L \div L_{Max})) \div n \times 10$						
	Flood tolerance	Crown size/form	Stand form	Veg. spread rate		Weighting (n)
Attribute code	F	C	T	V		
Max value	3	4	3	3		
Min value	1	1	1	0		
Weighting	2x	1x	1x	1x		
Best rating	Max	Min	Max	Max		
Flood protection rating ¹ = $((2 \times F \div F_{Max}) + ((C_{Max} - C) \div (C_{Max} - C_{Min})) + (T \div T_{Max}) + (V \div V_{Max})) \div n \times 10$						
	Native status					Weighting (n)
Attribute code	Q					
Max value	3					
Min value	1					
Weighting	1x					1
Best rating	Max					
Native ecosystem restoration rating ² = $(Q \div Q_{Max}) \div n \times 10$						
	Crown size/form	Growth rate	Foliage porosity	Breakage resistance		Weighting (n)
Attribute code	C	G	P	B		
Max value	4	3	3	2		
Min value	1	1	1	1		
Weighting	2x	1x	1x	1x		5
Best rating	Max	Max	Max	Max		
Particle drift reduction rating ¹ = $((2 \times C \div C_{Max}) + (G \div G_{Max}) + (P \div P_{Max}) + (B \div B_{Max})) \div n \times 10$						

Table 3. *Cont.*

Plant Attributes							
	Pollinator habitat						Weighting (n)
Attribute code	H						
Max value	2						
Min value	1						
Weighting	1x						1
Best rating	Max						
Pollinator habitat rating ³ = (H ÷ H _{Max}) ÷ n × 10							
	Stand form	Shade density	Water use	Growth rate			Weighting (n)
Attribute code	T	S	W	G			
Max value	3	3	3	3			
Min value	1	1	1	1			
Weighting	1x	1x	1x	1x			4
Best rating	Max	Min	Max	Max			
Polluted runoff treatment rating ¹ = ((T ÷ T _{Max}) + ((S _{Max} - S) ÷ (S _{Max} - S _{Min})) + (W ÷ W _{Max}) + (G ÷ S _{Max})) ÷ n × 10							
	Flood tolerance	Crown size/form	Veg. spread rate	Root structure	Stand form	Resprout ability	Weighting (n)
Attribute code	F	C	V	O	T	U	
Max value	3	4	3	3	3	2	
Min value	1	1	0	1	1	0	
Weighting	2x	1x	1x	1x	1x	1x	7
Best rating	Max	Min	Max	Min	Max	Max	
Streambank stabilization rating ¹ = ((2 × F ÷ F _{Max}) + ((C _{Max} - C) ÷ (C _{Max} - C _{Min})) + (V ÷ V _{Max}) + ((O _{Max} - O) ÷ (O _{Max} - O _{Min})) + (T ÷ T _{Max}) + (U ÷ U _{Max})) ÷ n × 10							
	Crown size/form	Growth rate	Water use				Weighting (n)
Attribute code	C	G	W				
Max value	4	3	3				
Min value	1	1	1				
Weighting	1x	1x	1x				3
Best rating	Max	Max	Max				
Stormwater treatment rating ¹ = ((C ÷ C _{Max}) + (G ÷ G _{Max}) + (W ÷ W _{Max})) ÷ n × 10							
	Flood tolerance						Weighting (n)
Attribute code	F						
Max value	3						
Min value	1						
Weighting	1x						1
Best rating	Max						
Wetland restoration rating ² = (F ÷ F _{Max}) ÷ n × 10							

Table 3. Cont.

Plant Attributes					
	Bird and Mammal Habitat				Weighting (n)
Attribute code	M				
Max value	2				
Min value	1				
Weighting	1x				1
Best rating	Max				
Wildlife habitat rating ³ = (M ÷ M _{Max}) ÷ n × 10					
	Crown height	Visual quality			Weighting (n)
Attribute code	Z	I			
Max value	3	1			
Min value	1	0			
Weighting	1x	2x			3
Best rating	Max	Max			
Visual aesthetic rating ¹ = ((Z ÷ Z _{Max}) + (2 × I ÷ I _{Max})) ÷ n × 10					
	Foliage retention	Crown size/form	Foliage porosity	Growth rate	Weighting (n)
Attribute code	R	C	P	G	
Max value	2	4	3	3	
Min value	1	1	1	1	
Weighting	2x	1x	1x	1x	5
Best rating	Max	Max	Min	Max	
Visual and noise screen rating ¹ = ((2 × R ÷ R _{Max}) + (C ÷ C _{Max}) + ((P _{Max} − P) ÷ (P _{Max} − P _{Min})) + (G ÷ G _{Max})) ÷ n × 10					

¹ Returns a value between 0 and 10, with 10 being the highest rating; ² returns a value of 3 or 7 (rounded), or 10, with 10 being the highest rating; ³ returns a value of 5 or 10, with 10 being the highest rating.

All responses from resource professionals and landowners were positive for the concept of an attribute-based system for rating species and they valued the range of purposes included in the tool. Regarding usefulness, all users found the DST to be beneficial for selecting woody species in the study region. They also found the tool to be salient and credible, important factors for actionable science [127]. The main limitation identified by respondents was that the DST was delivered in a less than easily accessible and user-friendly format.

Based on user feedback and an evaluation of the literature on effective DSTs [29,30,32–34], the next iteration of Tree Advisor was developed to work both on computers and mobile devices using a web browser (<https://www.fs.usda.gov/nac-plant-guide/>, accessed on 6 February 2022). To support transparency and credibility, PDF documents provide background information on the tool including the plant attributes and rating algorithms.

Performance was also considered. Online processing of the rating algorithms could be slow, particularly in areas without broadband, so it was decided to rely on a database with pre-calculated ratings from the original Microsoft Excel® spreadsheet. A MySQL relational database management system holds the species list by region and the ratings, and a Drupal Content Management System delivers the data to the user. This approach was also chosen to facilitate revising Tree Advisor. Modification of the attributes data and rating algorithms (i.e., updating attribute data, adding additional attributes in the algorithms) can be more easily accomplished in the Excel® spreadsheet and the resulting new ratings can be uploaded to the MySQL database.

3. Results

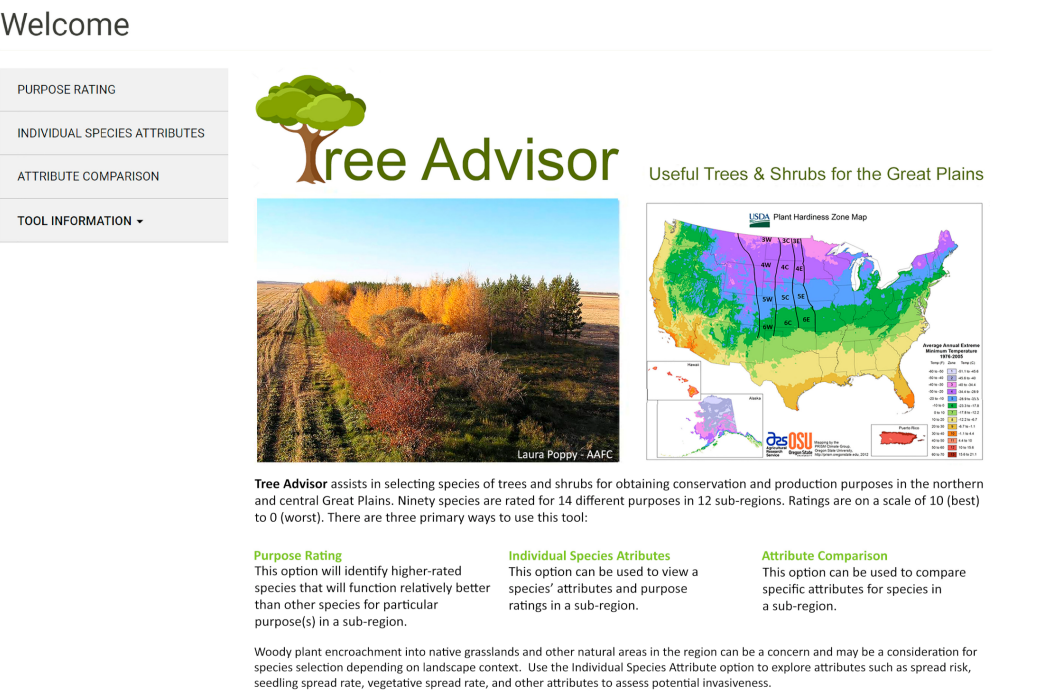
Tree Advisor was released online in October 2020 (Figure 3). The DST currently provides users with three ways to utilize the tool, allowing flexibility in use depending on the information desired. The primary method is to use the Purpose Rating module (Figure 4). After choosing a sub-region, a user will select a primary purpose which will identify higher-rated species of trees and shrubs that will function relatively better than other species for that purpose. Users can then select a secondary purpose to rate the primary purpose plants by this additional subordinate objective and the tool will return a list of the highest rated species for two purposes. A user can also consider additional functions by running the module again for other purposes and compile a list of top-rated species from both lists to identify species for a multifunctional planting.

Tree Advisor also has an Individual Species Attribute module which allows a user to view a species' attributes and purpose ratings in a sub-region and the Attribute Comparison module which returns data for a plant attribute for all species in the sub-region. These two modules also allow users to view data on the six attributes not included in the rating algorithms as well as the text descriptions describing potential products, specific visual and bird/mammal habitat attributes, spread risk, and potential hazards such as insect and disease susceptibility.

On the home page of Tree Advisor (Figure 3), users are encouraged to review attributes that may increase a species unwanted encroachment into a native grassland or other ecosystem if that is a concern for their project area. Some of these attributes include growth rate, vegetative spread rate, seeding spread rate, resprout ability, drought tolerance and spread risk, and these can be viewed using the Individual Species Attribute module (Figure 5). Through the planning and design process, these attributes can be considered in the landscape context of the planting project, and appropriate species, cultivars, or hybrids can be selected that eliminate or minimize invasive risk.

Tree Advisor has been presented and promoted at regional and national outreach events with natural resource professionals and landowners (e.g., Perennial Farm Gathering, Association for Temperate Agroforestry, Great Plains Society of American Foresters, Society of American Foresters Annual Meeting, and other regional workshops and webinars). The majority of these events were virtual due to safety measures issued in response to the COVID-19 pandemic. Through these engagements, we reached over 200 landowners and resource professionals across the United States. Since the release of Tree Advisor, 24 resource professionals and 15 landowners have contacted the authors to provide feedback on the DST. This feedback did not involve rigorous structured collection of detailed response data, but rather offered opinions on the concept, usefulness, and limitations of the DST.

In general, feedback from the landowners and natural resource professionals did not vary. Overall, landowners and natural resource professionals stated that the tool was intuitive and easy to use, and they appreciated that the tool did not require data input or training. Comments indicated that users felt more confident in selecting appropriate plants for specific purposes and designing for multifunctionality seemed more feasible. Five individuals from different ecoregions in the U.S. also requested that a similar tool be developed for their region. One limitation noted by some of the natural resource professionals and landowners was the lack of connection to specific site conditions. Some users stated they would like to have a tool where user-selected site conditions (e.g., soil type and moisture regime) could be used to refine the results.



Common Name	Scientific Name	Subregion	Native Status ①	Crown Size/Form ①	Crown Height ①	Growth Rate ①	Life Span ①	Stem Form ①
redcedar, eastern	Juniperus virginiana		3	3	2	1	3	1
Foliage Retention ①	Shade Density ①	Foliage Porosity ①	Root Structure ①	Vegetative Spread Rate ①	Seeding Spread Rate ①	Stand Form ①	Resprout Ability ①	Nitrogen Fixation ①
2	3	1	3	0	2	1	1	0
Water Use ①	Flood Tolerance ①	Drought Tolerance ①	Salt Tolerance ①	Shade Tolerance ①	Breakage Resistance ①	Spread Risk	Pest Risk	Other Risks
1	1	3	2	2	2	Weedy, invasive	Hosts Cedar-Apple & Cedar-Hawthorn Rusts	None known at this time
Bird & Mammal Habitat ①	B&M Habitat Quality Type	Pollinator Habitat ①	Product Potential ①	Product Type	Visual Quality ①	Visual Quality Type		
2	winter cover	1	0	None known at this time	1	Winter green foliage		

Purpose Ratings are on a scale of 10 (highest) to 0 (lowest)

Alley Cropping ①	Aquatic Habitat ①	Carbon Sequestration ①	Flood Protection ①	Native Ecosystem Restoration ①	Particle Drift Reduction ①	Pollinator Habitat ①	Polluted Runoff Filter ①	Stormwater Filter ①
0	6	6	3	10	6	5	3	5
Streambank Stabilization ①	Vision Noise Screen ①	Visual Aesthetics ①	Wetland Restoration ①	Wildlife Habitat ①				
3	8	9	3	10				

Figure 5. The Individual Species Attribute module provides a summary of a species attributes and purpose ratings.

4. Discussion

Ongoing feedback from users is encouraged, with this information being incorporated in future revisions where possible. The one limitation currently noted by users has been the inability to filter results by specific site conditions. This feature was considered early in the tool development but was not included in this prototype because some site variables can be manipulated by the decision maker. For instance, moisture regime for a site can be modified through irrigation which can overcome a species limitation on drier sites. An optional site conditions filter might be considered in future updates of the tool. In the meantime, attributes such as drought or salt tolerance indicated in the Individual Species Attributes module can be used by the user to refine selection results to the extent that the user can identify specific conditions of the planting site.

In addition to feedback from users, as tool developers we also identified some strengths, limitations, and challenges when developing Tree Advisor. One of the primary strengths from a functional and maintenance perspective is having the algorithm processing offline and uploading the ratings into a database, allowing for faster delivery and easier updating of the tool. Updating species attribute data and adding new attributes in the rating algorithms is relatively easy in the Microsoft Excel[®] spreadsheet and then the new ratings can be uploaded to the MySQL database. Other strengths include a tool that is simple to use, requires no training or data input, and provides actionable information in an efficient manner.

One of the limitations is that the end user still needs to have additional knowledge to implement an appropriate and effective vegetation-based intervention since plant selection is just one component in the decision-making process. Additional knowledge, such as proper siting of the practice and designing a suitable configuration is critical; however, we purposely kept Tree Advisor focused on one segment of the decision-making process based

on previous DST evaluation research. Other considerations will also need to be addressed in the planning process, such as determining the appropriate level of biodiversity in the intervention to meet desired objectives.

One of the main challenges in developing the tool involves populating the attribute database in a consistent manner based on the available data sources. Qualitative assessment and best professional judgement were often required for several of the attributes. For instance, there are limited data on environmental tolerances conducted in a systematic manner for a wide range of species. There is growing interest in attribute (or trait)-based plant ecology for decision making which may enhance the availability and uniformity in attribute data over time. Another consideration is the underlying scientific understanding of the plant attributes that contribute the functions for the performance of a particular purpose, particularly whether some attributes are more important than others. New research may provide guidance for developing more robust algorithms in the future. Another potential limitation is that this tool requires internet access, which can be limited in some rural areas in the U.S. This issue should decrease, as financial resources in the U.S. are being expended to enhance connectivity in rural areas [128].

Plant selection for long-term interventions can be enhanced by accounting for predicted climate changes [129,130]. In a changing climate, trees and shrubs must be able to survive and grow well under both current and future climate conditions. For current conditions, this DST can easily be modified by adjusting the sub-region boundaries as Plant Hardiness Zones and annual rainfall patterns are updated with more recent datasets. For example, the 2012 USDA Plant Hardiness Zones used in this DST were updated based on data from 1976 to 2005 [43]. For future conditions, an approximation can be made by selecting for species that grow well in a sub-region adjacent to the one in question (for example, a warmer and/or drier sub-region), depending on how plant hardiness zones and rainfall patterns are predicted to change in that sub-region in question over time.

Strategic, vegetative best management practices are one means for creating resilient landscapes that can provide for multiple purposes simultaneously. These long-term interventions require significant investment in planning, establishment, and maintenance to achieve the desired future outcomes. Decision support tools can play an important role in assisting natural resource professionals and landowners in selecting species to best meet their multiple objectives in an efficient and cost-effective manner. In this study, an effort was made to develop an evidence-based rating tool for determining which woody species would function relatively better for different purposes in the northern and central Great Plains. Based on this study and evaluation, Tree Advisor appears to meet the objectives established for this DST effort for our target region. Future work may help refine the tool, enhance the rating process, and provide more functionality such as a filtering process for site conditions. The tool development process and delivery approach used to create Tree Advisor may serve as a template for developing multifunctional plant decision support tools for other ecoregions.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Tree and shrub species used in Tree Advisor.

Scientific Name	Common Name	Scientific Name	Common Name
<i>Acer ginnala</i> Maxim.	Amur maple	<i>Acer grandidentatum</i> Nutt.	bigtooth maple
<i>Acer negundo</i> L.	boxelder	<i>Acer rubrum</i> L.	red maple
<i>Acer saccharinum</i> L.	silver maple	<i>Acer saccharum</i> Marshall	sugar maple
<i>Aesculus glabra</i> Willd.	Ohio buckeye	<i>Alnus incana</i> (L.) Moench	gray alder
<i>Amelanchier alnifolia</i> (Nutt.) Nutt. ex M. Roem.	Saskatoon serviceberry	<i>Amelanchier utahensis</i> Koehne	Utah serviceberry
<i>Amorpha fruticosa</i> L.	false indigo	<i>Aronia melanocarpa</i> (Michx.) Elliott	black chokeberry
<i>Asimina triloba</i> (L.) Dunal	pawpaw	<i>Betula nigra</i> L.	river birch
<i>Betula papyrifera</i> Marshall	paper birch	<i>Caragana arborescens</i> Lam.	Siberian peashrub
<i>Carpinus caroliniana</i> Walter	American hornbeam	<i>Carya illinoensis</i> (Wangenh.) K. Koch	pecan
<i>Catalpa speciosa</i> (Warder) Warder ex Engelm.	northern catalpa	<i>Celtis occidentalis</i> L.	hackberry
<i>Celtis laevigata</i> Willd.	sugarberry	<i>Cercis canadensis</i> L.	eastern redbud
<i>Chilopsis linearis</i> (Cav.) Sweet	desert willow	<i>Corylus americana</i> Walter	American hazelnut
<i>Corylus cornuta</i> Marshall	beaked hazelnut	<i>Cornus racemosa</i> Lam.	gray dogwood
<i>Cornus sericea</i> L.	Redosier dogwood	<i>Crataegus crus-galli</i> L.	cockspur hawthorn
<i>Crataegus mollis</i> Scheele	downy hawthorn	<i>Diospyros virginiana</i> L.	persimmon
<i>Elaeagnus commutata</i> Bernh. ex Rydb.	silverberry	<i>Fallugia paradoxa</i> (D. Don) Endl. ex Torr.	Apache plume
<i>Fraxinus americana</i> L.	white ash	<i>Fraxinus pennsylvanica</i> Marshall	green ash
<i>Gleditsia triacanthos</i> L.	honeylocust	<i>Gymnocladus dioica</i> (L.) K. Koch	Kentucky coffeetree
<i>Juglans major</i> (Torr.) A. Heller	Arizona walnut	<i>Juglans microcarpa</i> Berl.	little walnut
<i>Juglans nigra</i> L.	black walnut	<i>Juniperus scopulorum</i> Sarg.	Rocky Mountain juniper
<i>Juniperus virginiana</i> L.	eastern redcedar	<i>Maclura pomifera</i> (Raf.) C.K. Schneid.	Osage-orange
<i>Malus baccata</i> (L.) Borkh.	Siberian crab apple	<i>Morus rubra</i> L.	red mulberry
<i>Ostrya virginiana</i> (Mill.) K. Koch	hophornbeam	<i>Physocarpus opulifolius</i> (L.) Maxim., orth.	common ninebark
<i>Picea pungens</i> Engelm.	blue spruce	<i>Picea abies</i> (L.) Karst.	Norway spruce
<i>Picea glauca</i> (Moench) Voss 'Densata'	Black Hills spruce	<i>Pinus nigra</i> Arnold	Austrian pine
<i>Pinus ponderosa</i> Lawson and C. Lawson	ponderosa pine	<i>Pinus sylvestris</i> L.	Scotch pine
<i>Platanus occidentalis</i> L.	American sycamore	<i>Populus angustifolia</i> James	narrowleaf cottonwood
<i>Populus balsamifera</i> L.	balsam poplar	<i>Populus deltoides</i> W. Bartram ex Marshall	eastern cottonwood
<i>Populus tremuloides</i> Michx.	quaking aspen	<i>Prunus americana</i> Marshall	American plum
<i>Prunus angustifolia</i> Marshall	Chickasaw plum	<i>Prunus pumila</i> L. var. <i>besseyi</i> (L.H. Bailey) Gleason	western sandcherry
<i>Prunus serotina</i> Ehrh.	black cherry	<i>Prunus tomentosa</i> Thunb.	Nanking cherry
<i>Prunus virginiana</i> L.	chokecherry	<i>Pyrus ussuriensis</i> Maxim.	Chinese pear
<i>Quercus fusiformis</i> Small	Texas live oak	<i>Quercus macrocarpa</i> Michx.	bur oak
<i>Quercus palustris</i> Münchh.	pin oak	<i>Quercus rubra</i> L.	red oak
<i>Rhus aromatica</i> Aiton	fragrant sumac	<i>Rhus trilobata</i> Nutt.	skunkbush sumac
<i>Ribes aureum</i> Pursh	golden currant	<i>Robinia neomexicana</i> A. Gray	New Mexico locust

Table A1. Cont.

Scientific Name	Common Name	Scientific Name	Common Name
<i>Robinia pseudoacacia</i> L.	black locust	<i>Rosa woodsii</i> Lindl.	Woods' rose
<i>Salix amygdaloides</i> Andersson	peachleaf willow	<i>Salix bebbiana</i> Sarg.	Bebb willow
<i>Salix discolor</i> Muhl.	pussy willow	<i>Salix interior</i> Rowlee	sandbar willow
<i>Salix nigra</i> Marshall	black willow	<i>Sambucus nigra</i> L. ssp. <i>canadensis</i> (L.) R. Bolli	American black elderberry
<i>Sapindus saponaria</i> L. var. <i>drummondii</i> Hook. and Arn.	western soapberry	<i>Shepherdia argentea</i> (Pursh) Nutt.	silver buffaloberry
<i>Symphoricarpos occidentalis</i> Hook	western snowberry	<i>Syringa vulgaris</i> L.	common lilac
<i>Taxodium distichum</i> (L.) Rich.	bald cypress	<i>Thuja occidentalis</i> L.	arborvitae
<i>Tilia americana</i> L.	American basswood	<i>Ulmus americana</i> L.	American elm
<i>Viburnum lentago</i> L.	nannyberry	<i>Viburnum opulus</i> L. var. <i>americanum</i> Aiton	American cranberrybush

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