CHAPTER 3
VULNERABILITY OF AUSTIN'S TREES

Changes in climate have the potential to have profound effects on Austin's trees in both developed and natural areas. Many tree species that are currently present may experience declines in habitat suitability under warmer temperatures and altered precipitation patterns. Other species may experience improved habitat suitability under these conditions. Some species not currently present could potentially be planted in the area, as long as they are able to withstand periods of extreme cold that could still occur during some winters. In addition, climate change can have indirect effects on the urban forests in the region by changing insect pests, pathogens, invasive species, and the probability, severity, and extent of severe storms. Planted and naturally-occurring trees will differ in their capacity to adapt to stressors. This chapter summarizes expected changes in habitat suitability and the adaptive capacity of different species in Austin's developed and natural areas.

MODELED PROJECTIONS OF HABITAT SUITABILITY

Climate change has the potential to alter the habitat suitability for tree species. Scientists can project future habitat suitability using species distribution models (SDMs). SDMs establish a statistical relationship between the current distribution of a species or ecosystem and key attributes of its habitat. This relationship is used to make projections about how the range of the species will shift as climate change affects those attributes. SDMs are much less computationally expensive than process models, which model ecosystem and tree species dynamics based on interactive mathematical representations of physical and biological processes. Because of their relative computational ease, SDMs can typically provide projections for the suitable habitat of many species over a larger area. There are some caveats that users should be aware of when using them, however(Wiens, et al., 2009). SDMs use a species' realized niche instead of its fundamental niche. The realized niche is the actual habitat a species occupies given predation, disease, and competition with other species. A species' fundamental niche, in contrast, is the habitat it could potentially occupy in the absence of competitors, diseases, or predators. Given that a species' fundamental niche may be greater than its realized niche, SDMs may underestimate current niche size and future suitable habitat. In addition, species distributions in the future might be constrained by competition, disease, and predation in ways that do not currently occur. If so, SDMs could overestimate the amount of suitable habitat in the future. If some constraints are removed due to future change, the opposite could also occur. Furthermore, fragmentation or other physical barriers to migration may create obstacles for species otherwise poised to occupy new habitat. With these caveats in mind, SDMs can still be a useful tool to understand general projections of changes in habitat suitability across species.

Modeling Native Trees

Suitable habitats for tree species native to the eastern United States were modeled in the Austin region using the DISTRIB-II model, an SDM that is an updated version of the Tree Atlas toolset (Iverson, et al., 2019, Iverson, et al., 2008, Peters, et al., 2019, Prasad, et al., 2007). DISTRIB-II measures relative abundance, referred to as importance values, for 134 eastern tree species (note that only 31 of these were of interest to the Austin region because they are currently present or expected to gain habitat in the area). Inputs include tree species distribution data from the US Forest Service Forest Inventory and Analysis (FIA) program and environmental variables (pertaining to climate, soil properties, elevation, land use, and fragmentation), which are used to statistically model current species abundance with respect to current habitat distributions. DISTRIB then projects future importance values and suitable habitat for individual tree species using projections of future climate conditions on a 12 by 12-mile grid (Peters, et al., 2019).

For this assessment, the DISTRIB-II model uses an average of three downscaled climate models (CCSM4, Hadley, and GFDL) and two representative concentration pathways (4.5 and 8.5).

The table below shows the projected change in potential suitable habitat for 31 species within a 1 by 1 degree latitude/longitude area (30 to 31 °N and 97 to 98 °W) that includes the city of Austin. The table includes species that are either currently present in the region or expected to gain suitable habitat in the region for the years 2070 to 2099 compared to present values (table 3). Species were categorized based upon whether the results from the two climate-RCP scenarios projected an increase, decrease, or no change in suitable habitat compared to current conditions, or if the model results were mixed. Further, some tree species that are currently not present in the assessment area were identified as having potential suitable habitat in the future under one or both scenarios. When examining these results, it is important to keep in mind that model reliability was generally higher for more common species than for rare species.

Of the 31 species examined for the Austin region, suitable habitat for 14 of them was projected to decline under both high and low scenarios. Species expected to decline that are currently found in Austin based on urban FIA data include American sycamore, black walnut, bur oak, eastern redcedar, post oak, and mulberry.

For three of the species examined, model results were slightly unclear of the direction of change. There was a small projected increase for cedar elm under a low emissions scenario, a large increase under the high emissions scenario for chittamwood/gum bumelia, and a large decrease for honeylocust under the low emissions scenario. For each of the species, the alternate scenario suggested no change in habitat suitability.

Suitable habitat for 10 species was projected to remain relatively stable under both scenarios. Common species in Austin that fell under this category include American elm, Ashe juniper, boxelder, green ash, northern hackberry, live oak (*Q. virginiana*), and winged elm.

Four species were projected to experience a gain in suitable habitat. These were blackjack oak, pecan, sugarberry, and water oak.

Note that these projections are only available for native species and are based on data collected in natural areas. Because they were developed for natural areas, projections are not directly applicable to native species planted in highly developed cultivated settings.

Table 3.1 — Projected changes in habitat suitability for trees native to the 1x1 latitude/longitude area around the Austin region. Species with lower model reliability indicate less confidence in the direction of change. Note that some of the species listed may be native to part of the 1x1 degree latitude/longitude area but outside of Austin. See appendix 3 for more information.

Common Name	Scientific Name	Model Reliability	Change Class-low emissions (RCP 4.5)	Change Class-High Emissions (RCP 8.5)
DECREASE UNDER BOTH SCENARIOS				
American sycamore	Platanus occidentalis	Low	Small decrease	Small decrease
bitternut hickory	Carya cordiformis	Low	Large decrease	Large decrease
Black cherry	Prunus serotina	Medium	Small decrease	Small decrease
black oak	Quercus velutina	High	Small decrease	Small decrease
black walnut	Juglans nigra	Low	Small decrease	Small decrease
bur oak	Quercus macrocarpa	Medium	Small decrease	Large decrease
eastern redcedar	Juniperus virginiana	Medium	Small decrease	Small decrease
flowering dogwood	Cornus florida	Medium	Large decrease	Large decrease
loblolly pine	Pinus taeda	High	Small decrease	Small decrease
post oak	Quercus stellata	High	Small decrease	Small decrease
red mulberry	Morus rubra	Low	Small decrease	Small decrease
Shumard oak	Quercus shumardii	Low	Small decrease	Small decrease
slippery elm	Ulmus rubra	Low	Small decrease	Small decrease
white ash	Fraxinus americana	Medium	Small decrease	Small decrease
MIXED RESULTS				
cedar elm	*Ulmus crassifolia*	Medium	Small increase	No change
chittamwood/gum bumelia	*Sideroxylon lanuginosum ssp. lanuginosum*	Low	No change	Large increase
honeylocust	*Gleditsia triacanthos*	Low	Large decrease	No change
NO CHANGE				
American elm	*Ulmus americana*	Medium	No change	No change
Ashe juniper	*Juniperus ashei*	High	No change	No change
black hickory	*Carya texana*	High	No change	No change
boxelder	*Acer negundo*	Low	No change	No change
green ash	*Fraxinus pennsylvanica*	Low	No change	No change
hackberry	*Celtis occidentalis*	Medium	No change	No change
live oak	*Quercus virginiana*	High	No change	No change
Osage-orange	*Maclura pomifera*	Medium	No change	No change
water oak	*Quercus nigra*	High	No change	No change
winged elm	*Ulmus alata*	Medium	No change	No change
INCREASE				
blackjack oak	*Quercus marilandica*	Medium	Small increase	Small increase
pecan	*Carya illinoinensis*	Low	Small increase	Large increase

sugarberry	*Celtis laevigata*	Medium	Large increase	Large increase
water oak	*Quercus nigra*	High	Small increase	Small increase

Projected Changes from Heat and Hardiness Zone Shifts and Species Ranges

Model information is not available for all species and cultivars that are found in the Austin region or many of the species being considered for future planting. These species are usually either too rare in the region to be modeled reliably, have a range that extends outside of the US, are not native to North America, or are cultivars. To understand how climate change may affect these species, one approach is to examine hardiness and heat zone ranges of the species to see how they compare to projected future zones in the region. Species that are currently present in the area based on urban FIA(Nowak, et al., 2016) or expert knowledge were evaluated (table XXX). Species that are currently marginal for hardiness zone (lowest zone is 8 or higher) may experience benefits from milder winters. Species that are marginal for heat zone (highest zone is 10 or lower) may experience negative effects from hotter summers. See chapter 2 for projections of heat and hardiness zones in the area. Note that using heat and hardiness zones to estimate which species will benefit or fare worse in a changing climate is not as informative as species distribution models described above, because the SDMs take into account changes in precipitation, seasonal climate changes, and other habitat requirements such as soil texture. This is only meant to provide a coarse estimate of potential changes in habitat suitability based on temperature extremes.

To add another element to the analysis, we also examined species current ranges by county using the Biota of North American Program North American Plant Atlas (Kartesz, 2015). If a species is currently at the northern and/or eastern extent of its range in Travis County, it was considered to have a likely positive effect of climate change. If a species is at the southern and/or western extent of its range, it was considered to have a negative effect.

Based on this method, 23 species may experience a positive effect from an increase in hardiness zone over the next century (table 3.2). The most common species expected to experience a positive effect is live oak (*Q. virginiana*), followed by Texas mountain laurel. Other species that were commonly found in the urban FIA assessment that may experience positive effects include loquat, Mexican (Berlandier) ash, Jerusalem thorn (retama), Mexican white oak, and sweet acacia (Huisache).

Sixty species had either hardiness zone, heat zone, or range limits (or a combination thereof) that may suggest a negative effect from an increase in temperature. Many of Austin's most common species are included in this category, such as Ashe juniper, cedar elm, sugarberry/hackberry, yaupon, green ash, Texas red oak (*Q. buckleyi*), boxelder, white shin oak (*Q. sinuata* var. *breviloba*), pecan, western soapberry, bastard oak (*Q. sinuata* var. *sinuata*), crapemyrtle, winged elm, American sycamore, Texas live oak (*Q. fusiformis*), and many others.

Twenty-one of the species evaluated did not have a strongly anticipated effect of temperature. Species included in this category were Texas persimmon, honey mesquite, and Texas ash. However these species could be affected by other climate-related changes, such as shifts in precipitation or insect or disease outbreaks.

Table 3.2 — Potential effects of hardiness and heat zone (where available) changes and range position for species that are currently found in the Austin region or are being considered for planting lists in the area. Species hardiness/heat zone range is the range of zones for which the species is considered suitable for planting. Climate change was considered to have a positive effect on habitat suitability if the lowest zone for which the species was hardy was 8 or higher and/or it was at the northern and/or eastern extent of its range. Climate change was considered to have a negative effect on habitat suitability if the highest heat zone the

species can tolerate was 10 or lower and/or it was at the southern and/or western extent of its range. See chapter X for projected changes in heat and hardiness zones. [i]invasive species n/a: not available

Common name	Scientific name	Native ?	Estimated Trees-Austin	Hardiness zone	Heat zone	Position in range	Climate change effect
boxelder	*Acer negundo*	Yes	367,930	2 to 8	8 to 3	South	Negative
red buckeye	*Aesculus pavia* var. *Pavia*	Yes		6 to 9	n/a	Southwest	Negative
mimosa, silktree[i]	*Albizia julibrissin*	No	4,720	6 to 9	9 to 6	Center	Negative
Texas madrone	*Arbutus xalapensis*	Yes	6,189	7 to 11	12 to 3	North	No effect
anacacho orchid tree	*Bauhinia lunarioides*	No		9 to 11	n/a	North (rare)	Positive
paper mulberry[i]	*Broussonetia papyrifera*	No	335,755	6 to 11	n/a	Center	No effect
pecan	*Carya illinoinensis*	Yes	196,132	5 to 9	9 to 1	South	Negative
black hickory	*Carya texana*	Yes		5 to 9	n/a	Southwest	Negative
mockernut hickory	*Carya tomentosa*	NO		4 to 9	n/a	Southwest	Negative
sugarberry	*Celtis laevigata*	Yes	2,058,386	5 to 10	n/a	South	Negative
netleaf hackberry	*Celtis laevigata* var. Reticulata	Yes		3 to 9	n/a	East	Negative
common hackberry	*Celtis occidentalis*	Yes	161,569	2 to 9	9 to 1	South	Negative
eastern redbud	*Cercis canadensis*	Yes	6,248	3 to 9	9 to 6	South	Negative
Mexican redbud	*Cercis canadensis l. Var. Mexicana*	No		6 to 8	n/a	Northeast of range	Positive
Texas redbud	*Cercis canadensis var. Texensis*	Yes		5 to 9	n/a	Center	No effect
desert willow	*Chilopsis linearis*	No		7 to 11	n/a	East of range	Positive
Meyer lemon	*Citrus meyeri*	No		9 to 11	n/a	n/a	Positive
Brazilian bluewood	*Condalia hookeri* var. *Hookeri*	Yes		8 to 11	N/a	North or range	Positive
Mexican olive	*Cordia boissieri*	No		9 to 11	n/a	North or range	Positive
roughleaf dogwood	*Cornus drummondii*	Yes	59,882	4 to 9	n/a	South	Negative
American smoketree	*Cotinus obovatus*	Yes		4 to 8	n/a	South	Negative
Texas mountain laurel	*Dermatophyllum secundiflorum*	Yes	648,060	8 to 15	12 to 10	Northeast	Positive
Asian persimmon	*Diospyros kaki*	No		7 to 10	n/a	Center	No effect
Texas persimmon	*Diospyros texana*	Yes	2,014,199	7 to 9	n/a	North	No effect
loquat	*Eriobotrya japonica*	No	312,427	8 to 11	12 to 8	North	Positive
Texas kidneywood	*Eysenhardtia texana*	Yes		8 to 11	n/a	Northeast	Positive

Common name	Scientific name	Native ?	Estimated Trees-Austin	Hardiness zone	Heat zone	Position in range	Climate change effect
edible fig	*Ficus carica*	No	22,984	6 to 10	10 to 6	Center	No effect
Carolina buckthorn	*Frangula caroliniana*	Yes		5 to 9	n/a	Southwest	Negative
Texas ash	*Fraxinus albicans*	Yes	438,216	3 to 9	9 to 4	Center	No effect
Mexican ash (Berlandier ash)	*Fraxinus berlandieriana*	Yes	184,758	8 to ?	N/a	North	Positive
green ash	*Fraxinus pensylvanica*	Yes	751,788	3 to 9	9 to 1	South	Negative
velvet ash	*Fraxinus velutina*	Yes	59,326	6 to 9	9 to 6	East	Negative
Lindheimer's silktassel	*Garrya ovata var. Lindheimeri*	Yes		8 to 11	n/a	East	Positive
possumhaw (deciduous holly)	*Ilex decidua*	Yes		5 to 9	n/a	Southwest	Negative
yaupon	*Ilex vomitoria*	Yes	833,143	7 to 11	12 to 7	Southwest	Negative
Arizona walnut	*Juglans major*	Yes		n/a	n/a	East	Negative
little walnut	*Juglans microcarpa*	Yes		6 to 8	n/a	East	Negative
black walnut	*Juglans nigra*	Yes	105,106	4 to 9	9 to 3	South	Negative
Ashe juniper	*Juniperus ashei*	Yes	13,315,759	7 to 9	9 to 4	South	Negative
eastern redcedar	*Juniperus virginiana*	Yes	38,457	3 to 9	9 to 1	South	Negative
goldenrain tree[i]	*Koelreuteria paniculata*	No	6,363	5 to 9	9 to 1	n/a	Negative
crapemyrtle	*Lagerstroemia indica*	No	174,401	7 to 9	9 to 6	n/a	Negative
littleleaf/goldenball leadtree	*Leucaena retusa*	No		7 to 9	n/a	East	No effect
Japanese privet[i]	*Ligustrum japonicum*	No	17,322	7 to 10	10 to 7	Center	No effect
glossy privet[i]	*Ligustrum lucidum*	No	623,890	7 to 9	9 to 6	South	Negative
Chinese privet[i]	*Ligustrum sinense*	No	123,994	7 to 9	9 to 6	South	Negative
sweetgum	*Liquidambar styraciflua*	No		6 to 9	n/a	Southwest	Negative
osage orange	*Maclura pomifera*	Yes		4 to 9	n/a	South	Negative
southern magnolia	*Magnolia grandiflora*	No	6,363	7 to 10	11 to 1	West	Negative
Texas crab apple	*Malus ioensis var. Texana*	No		n/a	n/a	n/a	Unknown
chinaberry[i]	*Melia azedarach*	No	538,729	8 to 15	12 to 7	Center	Positive
catclaw mimosa (fragrant mimosa)	*Mimosa aculeaticarpa var. Biuncifera*	Yes		3 to 10	n/a	East	No effect
white mulberry[i]	*Morus alba*	No	13,790	4 to 8	8 to 1	Center	Negative
Texas mulberry	*Morus microphylla*	Yes		5 to 9	n/a	East	No effect
red mulberry	*Morus rubra*	Yes	124,975	5 to 9	9 to 4	Southwest	Negative
arroyo sweetwood	*Myrospermum sousanum*	No		8 to 10	n/a	n/a	Positive
Jerusalem thorn (retama)	*Parkinsonia aculeata*	Yes	10,199	9 to 12	12 to 10	North	Positive
red bay	*Persea borbonia*	Yes		7 to 11	12 to 8	West	Negative

Common name	Scientific name	Native ?	Estimated Trees-Austin	Hardiness zone	Heat zone	Position in range	Climate change effect
Chinese pistache[i]	*Pistacia chinensis*	No	17,322	6 to 9	9 to 6	North	Negative
Texas pistache	*Pistacia mexicana*	No		7 to 9	n/a	North	No effect
Mexican sycamore	*Platanus mexicana*	No		5 to 9	n/a	North of range	Positive
American sycamore	*Platanus occidentalis*	Yes	132,468	5 to 9	9 to 3	Southwest	Negative
eastern cottonwood	*Populus deltoides*	Yes	15,862	3 to 9	9 to 1	South	Negative
honey mesquite	*Prosopis glandulosa*	Yes	655,950	6 to 9	12 to 1	East-center	No effect
cherry laurel[i]	*Prunus caroliniana*	Yes	78,107	6 to 9	9 to 6	West	Negative
Mexican plum	*Prunus mexicana*	Yes		6 to 8	n/a	Southwest	Negative
escarpment black cherry	*Prunus serotina* var. *Eximia*	Yes		7 to 9	n/a	South	Negative
common hoptree (wafer ash)	*Ptelea trifoliata*	Yes		4 to 9	n/a	South	Negative
pomegranate	*Punica granatum*	No		8 to 11	12 to 4	n/a	Positive
Texas red oak	*Quercus buckleyi*	Yes	419,812	7 to 10	10 to 1	South	Negative
Texas live oak (escarpment live oak, plateau live oak)	*Quercus fusiformis*	Yes	101,848	6 to 10	10 to 6	Center	No effect
Lacey oak	*Quercus laceyi*	Yes		7 to 9	n/a	East	No effect
bur oak	*Quercus macrocarpa*	Yes	6,363	3 to 8	9 to 1	South	Negative
blackjack oak	*Quercus marilandica*	Yes		6 to 9	n/a	Southwest	Negative
chinkapin oak	*Quercus muehlenbergii*	Yes	10,959	4 to 8	8 to 2	South	Negative
water oak	*Quercus nigra*	Yes	4,597	6 to 9	9 to 7	Southwest	Negative
Mexican white oak	*Quercus polymorpha*	No	84,966	7 to 10	12 to 8	North	Positive
Shumard oak	*Quercus shumardii*	Yes	43,137	5 to 10	9 to 1	South	Negative
white shin oak (scalybark oak)	*Quercus sinuata var. Breviloba*	Yes	243,656	7 to 9	n/a	South	Negative
bastard oak	*Quercus sinuata* var. *Sinuata*	Yes	166,563	7	n/a	South	Negative
post oak	*Quercus stellata*	Yes	86,286	5 to 9	9 to 4	South	Negative
live oak (coast live oak)	*Quercus virginiana*	Yes	2,862,523	8 to 11	11 to 6	Center	Positive
fragrant sumac (skunkbush sumac)	*Rhus aromatica*	Yes		n/a	n/a	South-central	No effect
prairie sumac (flameleaf sumac)	*Rhus lanceolata*	Yes	77,093	5 to 8	n/a	Center	No effect
evergreen sumac	*Rhus virens*	Yes		8 to 11	n/a	East	Positive
black willow	*Salix nigra*	Yes		4 to 9	n/a	Southwest	Negative

Common name	Scientific name	Native ?	Estimated Trees-Austin	Hardiness zone	Heat zone	Position in range	Climate change effect
western soapberry	*Sapindus saponaria* var. *Drummondii*	Yes	192,371	6 to 9	n/a	Southeast	Negative
catclaw	*Senegalia roemeriana (acacia roemeriana)*	Yes		7 to 11	n/a	Northeast	Positive
chittamwood, gum bumelia	*Sideroxylon lanuginosum*	Yes	89,955	6 to 10	n/a	south	Negative
Eve's necklace	*Styphnolobium affine*	Yes		7 to 9	n/a	Center	No effect
baldcypress	*Taxodium distichum*	Yes	12,725	5 to 11	12 to 5	West	Negative
Montezuma cypress	*Taxodium mucronatum*	No		8 to 11	n/a	North of range	Positive
Carolina basswood	*Tilia americana var. Caroliniana*	Yes		6 to 9	n/a	West	Negative
Chinese tallowtree[i]	*Triadica sebifera*	No	28,029	8 to 10	10 to 8	Center	No effect
winged elm	*Ulmus alata*	No	134,185	6 to 9	n/a	South	Negative
American elm	*Ulmus americana*	Yes	72,039	3 to 9	9 to 1	West	Negative
cedar elm	*Ulmus crassifolia*	Yes	4,583,201	7 to 9	9 to 6	South/central	Negative
Chinese elm (lacebark elm) [i]	*Ulmus parvifolia*	No	78,107	5 to 9	9 to 1	South	Negative
slippery elm	*Ulmus rubra*	Yes	12,725	3 to 10	10 to 1	Southwest	Negative
Mexican buckeye	*Ungnadia speciosa*	Yes		7 to 9	n/a	Center	No effect
sweet acacia (huisache)	*Vachellia farnesiana (acacia farnesiana)*	Yes	4,597	8 to 10	12 to 10	North	Positive
rusty blackhaw	*Viburnum rufidulum*	Yes		5 to 9	8 to 1	Southwest	Negative
Texas Hercules' club (prickly-ash, tickle-tongue)	*Zanthoxylum hirsutum*	Yes		4 to 8	n/a	Center	No effect
lotebush	*Ziziphus obtusifolia*	Yes		8 to 11	n/a	East	Positive

ADAPTIVE CAPACITY OF URBAN TREES

The results presented above provide information on potential changes in tree species habitat suitability across a range of projected future temperature and precipitation regimes, but do not account for all factors that may influence tree species under a changing climate. For the most part, models such as the ones described above only consider direct effects of temperature and precipitation, and do not account for other changes, such as changes in flood regime, extreme weather events, insects and disease, and invasive species.

To understand the capacity of tree species and cultivars in the area to adapt to these other effects of climate change, we relied on a scoring system developed by Matthews et al. (2011) called "modifying factors." Other scoring systems have been developed (Roloff, et al., 2009), but we found the system developed by Matthews et al. to be the most comprehensive for all potential climate change-related stressors. Modifying factors can include life history traits or environmental factors that make a species more or less likely to persist on the landscape (Matthews, et al., 2011). Examples of modifying factors include fire or drought tolerance, dispersal ability, shade tolerance, site specificity, and susceptibility to insect pests and diseases (Table 3.3). These factors can then be weighted by their intensity, level of uncertainty about their impacts, and relative importance to future changes to arrive at a numerical score (see appendix 4). Modifying factors are highly related to the adaptive capacity of a species: the ability to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences (IPCC 2014). A species with a large number of positive modifying factors would have a high adaptive capacity, and a species with a large number of negative modifying factors would have a low adaptive capacity.

We used the modifying factors developed for the Chicago Wilderness vulnerability assessment to better capture the unique environment of urban areas (Brandt, et al., 2017). As in the Chicago assessment, we created separate scores for developed and natural areas. For the most part, we used the same categories and weights as in Chicago, but eliminated the road salt category as road salt is not used in Austin, and put extra weight on both flooding and drought in natural areas because these areas are more susceptible to these effects than in Chicago. We developed modifying factor scores for the same 104 species we evaluated for climate change effects in the previous section. Scores were then converted to categories of high, medium, and low adaptive capacity.

For planted/developed conditions, 29 species received a high adaptability score, 18 received a low adaptability score, and the remaining 57 received a medium adaptability score (Table 3.4). Common native species with high adaptability scores in planted environments include Texas mountain laurel, yaupon, possumhaw, hoptree/wafer ash, chittamwood/gum bumelia, and Eve's necklace. Factors that tended to enhance adaptive capacity included tolerance to a wide range of disturbances, ability to be planted on a wide range of sites, and easily propagated in a nursery. Common species that received low adaptability ratings were Ashe juniper, pecan, black walnut and several oak species. These species tended to receive low adaptability ratings because they were susceptible to pests or diseases and were intolerant of a variety of urban sites and/or pollution.

For natural areas (both native and naturalized), 41 species received a high adaptability score, 17 received a low adaptability score, and 46 received a medium adaptability score (Table 3.5). Many of the most adaptable species are considered invasive, such as Chinese tallowtree, Japanese and Chinese privet, Chinese elm, glossy privet, chinaberry, paper and white mulberry, mimosa/silktree, Chinese pistache, goldenraintree, and cherry laurel. Native species with high adaptability scores include sugarberry, sumac species, boxelder, possumhaw, roughleaf dogwood, live oak, yaupon, cedar elm, and hoptree/wafer ash.

Table 3.3 — Trait codes for adaptability tables. Traits are listed if they were among the main contributors to the overall adaptability score. N=applies to naturally-occurring trees; P=applies to planted trees. See appendix 4 for more information.

Factor	Code	Type	Description (if positive)	Description (if negative)
Air pollution	AIP	N, P	Tolerant of air pollution	Intolerant of air pollution
Browse	BRO	N,P	Resistant to browsing	Susceptible to browsing
Competition-light	COL	N, P	Tolerant of shade or limited light conditions	Intolerant of shade or limited light conditions
Disease	DISE	N, P	Disease-resistant	Has a high number and/or severity of known pathogens that attack the species
Dispersal	DISP	N	High ability to effectively produce and distribute seeds	Low ability to effectively produce and distribute seeds
Drought	DRO	N,P	Drought-tolerant	Susceptible to drought
Edaphic specificity	ESP	N, P	Wide range of soil tolerance	Narrow range of soil requirements
Environmental habitat specificity	EHS	N	Wide range of slopes/aspects/topographic positions	Small range of slopes/aspects/topographic positions
Flood	FLO	N, P	Flood-tolerant	Flood-intolerant
Fire regeneration	FRG	N	Regenerates well after fire	N/A
Fire topkill	FTK	N	Resistant to fire topkill	Susceptible to fire topkill
Ice	ICE	N,P	N/A	Susceptible to breakage from ice storms
Insect pests	INS	N, P	Pest-resistant	Has a high number and/or severity of insects that may attack the species
Invasive plants	INPL	N,P	N/A	Strong negative effects of invasive plants on the species, either through competition for nutrients or as a pathogen
Invasive potential	INPO	P	N/A	Species has the potential to become invasive and thus disfavored for planting
Land-use and planting site specificity	LPS	P	Can be planted on a wide variety of sites	Can only be planted in a narrow range of sites or as a specimen
Maintenance required	MAR	P	Little pruning, watering, or cleanup required	Requires considerable pruning, watering, or cleanup of debris
Nursery propagation	NUP	P	Easily propagated in nursery and widely available	Not easily propagated/not usually available
Planting establishment	PLE	P	Easily transplanted and requires little care to establish	Difficult to transplant or requires considerable care to establish
Restricted rooting conditions	RRC	P	Can tolerate restricted rooting conditions	Intolerant of restricted rooting conditions
Seedling establishment	SES	N	High ability to regenerate with seeds to maintain future populations	Low ability to regenerate with seeds to maintain future populations
Soil and water pollution	SWP	N,P	Tolerant of soil and/or water pollution	Intolerant of soil and/or water pollution
Temperature gradients	TEM	N,P	Wide range of temperature tolerances	Narrow range of temperature requirements
Vegetative reproduction	VRE	N	Capable of vegetative reproduction through stump sprouts or cloning	Not capable of vegetative reproduction
Wind	Win	N,P	N/A	Susceptible to breakage from wind storms

Table 3.4 — Adaptability scores for trees in natural areas. See table 3.3 for trait codes. [I]invasive species

Scientific Name	Common Name	Disturb score	Bio Score	Adapt Score	Adapt Class	Positive Factors	Negative Factors
Acacia roemeriana	Catclaw	-1.19	0.32	3.93	medium	DRO	FLO COL AIP
Acer grandidentatum	bigtooth maple	0.15	1.71	4.87	high	COL EHS	
Acer negundo	boxelder	-0.13	4.61	5.64	high	DRO FLO TEM COL DISP SES	AIP
Aesculus pavia var. *pavia*	Red buckeye	-1.48	2.14	4.60	high		AIP
Albizia julibrissin[i]	mimosa, silktree	-0.88	2.89	4.99	high	DRO FLO EDS EHS SES	DISE AIP COL
Arbutus xalapensis	Texas madrone	-1.02	1.29	4.54	high	DRO	FLO AIP SES
Bauhinia lunarioides	Anacacho orchid tree	-0.85	-1.50	3.32	low		FLO COL EHS
Broussonetia papyrifera[i]	paper mulberry	-0.42	2.79	5.10	high	FLO COL SES	
Carya illinoinensis	pecan	-2.46	-0.96	3.12	low		FTK COL
Carya texana	Black hickory	-1.90	0.43	3.52	medium	SES	FLO AIP COL
Carya tomentosa	mockernut hickory	-0.81	1.18	4.46	medium		FTK COL
Celtis laevigata	sugarberry	-0.92	4.50	5.74	high	COL ESP EHS DISP SES	AIP
Celtis laevigata var. reticulata	netleaf hackberry	-0.92	4.50	5.74	high	COL ESP EHS DISP SES	AIP
Celtis occidentalis	northern hackberry	-0.44	2.36	4.90	high	DRO	FTK
Cercis canadensis	eastern redbud	-0.50	2.36	4.98	high	FLO	AIP
Cercis canadensis L. var. mexicana	Mexican redbud	-1.27	2.25	4.67	high	DRO SES	FLO AIP
Cercis canadensis var. texensis	Texas redbud	-2.06	1.50	3.89	medium		AIP
Chilopsis linearis	Desert willow	0.42	0.75	4.46	medium	DRO FLO SES	AIP COL
Citrus meyeri	Meyer lemon	-1.75	-0.32	3.53	medium		FLO COL
Condalia hookeri var. *hookeri*	Brasil	-0.96	0.32	4.02	medium	DRO	FLO AIP COL
Cordia boissieri	Mexican olive	-1.46	-0.11	3.61	medium	DRO	FLO AIP COL
Cornus drummondii	roughleaf dogwood	-0.79	2.57	5.10	high	COL	FLO AIP
Cotinus obovatus	American smoketree	-0.85	-0.96	3.35	low	DRO	AIP EHS
Dermatophyllum secundiflorum	Texas mountain laurel	-0.10	1.29	4.43	medium	DRO EHS DISP	AIP
Diospyros kaki	Asian persimmon	-2.19	-0.11	3.36	low		FLO AIP DISP
Diospyros texana	Texas persimmon	-1.10	3.54	5.31	high	COL EHS DISP	AIP
Eriobotrya japonica	loquat	-1.62	1.50	4.34	medium		AIP
Eysenhardtia texana	Texas kidneywood	-1.02	0.75	4.09	medium	DRO EHS	FLO AIP COL
Ficus carica	edible fig	-2.35	-1.39	2.62	low		FLO AIP VRE

Scientific Name	Common Name	Disturb score	Bio Score	Adapt Score	Adapt Class	Positive Factors	Negative Factors
Frangula caroliniana	carolina buckthorn	-1.12	1.39	4.18	medium	COL SES	DRO AIP
Fraxinus albicans	Texas ash	-1.69	1.29	4.17	medium	SES	INS FLO
Fraxinus berlandieriana	Berlandier ash	-3.13	2.36	4.23	medium	FTK AIP VRE	INS DRO DISP SES
Fraxinus pennsylvanica	green ash	-1.37	1.18	4.46	medium	FLO	INS COL
Fraxinus velutina	velvet ash	-0.25	0.11	3.93	medium	DRO AIP SES	INS WIN COL VRE
Garrya ovata var. lindheimeri	Lindheimer's silktassel	-0.75	0.21	4.04	medium		FLO AIP
Ilex decidua	Possumhaw	0.69	2.25	4.89	high	FLO COL EHS SES	AIP DISP
Ilex vomitoria	yaupon	-0.50	3.86	5.68	high	COL ESP EHS DISP SES	AIP
Juglans major	Arizona walnut	-0.87	-0.32	3.61	medium	FLO	DRO AIP EHS
Juglans microcarpa	little walnut	-1.67	-1.39	2.73	low	FLO SES	DRO FTK AIP EHS DISP VRE
Juglans nigra	black walnut	-1.25	0.32	3.85	medium	SES	DISE COL
Juniperus ashei	Ashe juniper	-2.65	3.21	4.87	high	ESP EHS DISP SES	INS WIN FLO FTK AIP
Juniperus virginiana	eastern redcedar	-0.38	-0.32	4.03	medium	DRO	FTK COL
Koelreuteria paniculatan[i]	goldenrain tree	-0.21	1.71	4.70	high	DRO DISP SES	COL
Lagerstroemia indica	crapemyrtle	-0.75	3.00	5.16	high	DRO EHS DISP SES VRE	FLO COL
Leucaena retusa	littleleaf/goldenball leadtree	-0.71	1.71	4.33	medium	DRO DISP SES	FLO WIN AIP VRE
Ligustrum japonicum[i]	Japanese privet	-1.52	4.71	5.81	high	COL EHS DISP SES VRE	AIP
Ligustrum lucidum[i]	glossy privet	-0.40	3.00	5.22	high	TEM EHS DISP SES	
Ligustrum sinense[i]	Chinese privet	-1.52	4.71	5.81	high	COL EHS DISP SES VRE	AIP
Liquidambar styraciflua	sweetgum	-1.46	1.82	4.63	high	FLO EHS VRE	INS DRO FTK AIP COL
Maclura pomifera	Osage orange	-0.21	2.04	4.94	high	dro eds ehs	
Magnolia grandiflora	southern magnolia	-1.56	1.29	4.29	medium	COL SES	DRO FLO EHS
Malus ioensis var. texana	Texas crab apple	-2.19	-2.14	2.56	low		FLO AIP COL EHS
Melia azedarach	chinaberry	0.81	2.04	5.19	high	DRO FLO DISP SES VRE	COL
Mimosa biuncifera	Catclaw mimosa	0.63	0.21	4.24	medium	DRO EHS VRE	AIP COL
Morus alba[i]	white mulberry	0.13	2.46	4.98	high	DISP SES	
Morus microphylla	Texas mulberry	-1.73	1.07	3.93	medium	COL	AIP
Morus rubra	red mulberry	-1.71	1.93	4.44	medium	COL	FTK AIP
Myrospernum sousanum	Arroyo sweetwood	-0.63	0.00	3.61	medium	DRO SES	FLO AIP EHS
Parkinsonia aculeata	Jerusalem thorn (Retama)	0.12	-0.75	3.74	medium	DRO SES	COL VRE

Scientific Name	Common Name	Disturb score	Bio Score	Adapt Score	Adapt Class	Positive Factors	Negative Factors
Persea borbonia	Red bay	-0.98	1.39	4.46	medium		AIP
Pistacia chinensis	Chinese pistache	0.83	0.86	4.87	high	DRO WIN AIP EHS	FLO VRE
Pistacia mexicana	Texas pistache	-0.52	0.86	4.13	medium	DRO	DISE AIP
Platanus mexicana	Mexican sycamore	0.27	3.54	5.59	high	FLO AIP EHS DISP SES	
Platanus occidentalis	American sycamore	-1.46	-0.21	3.49	medium	FLO	DRO EHS
Populus deltoides	eastern cottonwood	-1.52	0.64	3.93	medium	TEM	DIS INS AIP
Prosopis glandulosa	honey mesquite	0.13	1.39	4.68	high	DRO SES FRE	AIP COL
Prunus caroliniana[i]	cherry laurel	-0.92	2.46	4.74	high	COL DISP SES	FLO VRE
Prunus mexicana	Mexican plum	-2.42	-1.39	2.94	low		DRO FLO AIP EHS VRE
Prunus serotina var. *eximia*	escarpment black cherry	-1.50	0.32	3.61	medium	DISP SES	WIN AIP ESP EHS
Ptelea trifoliata	Common Hoptree (wafer ash)	-1.58	1.39	4.29	medium	TEM COL DISP	FTK AIP VRE
Punica granatum	Pomegranate	-1.21	-0.21	3.20	low	DRO EHS SES	FLO COL DISP VRE
Quercus buckleyi	Texas red (Buckley) oak	-1.48	1.18	4.13	medium	TEM VRE SES FRG	DISE FLO FTK DISP
Quercus fusiformis	Texas live oak	-1.87	2.79	4.86	high	FTK SES VRE FRG	DISE INS FLO AIP
Quercus laceyi	Lacey oak	-0.33	-1.07	3.38	low	DRO SES	FLO AIP EHS DISP
Quercus macrocarpa	bur oak	0.23	1.39	4.73	high	DRO AIP	FLO
Quercus marilandica	Blackjack oak	-1.37	1.93	4.67	high	DRO SES VRE	DISE FLO AIP COL
Quercus muehlenbergii	chinkapin oak	-0.58	1.07	4.50	medium	DRO TEM	
Quercus nigra	water oak	-1.60	0.75	3.93	medium	FLO	DISE FTK AIP COL
Quercus polymorpha	Mexican white oak	0.02	0.32	3.87	medium	DRO SES	AIP DISP
Quercus shumardii	Shumard oak	-0.27	0.11	4.04	medium	DRO FLO TEM	DISE FTK COL
Quercus sinuata var breviloba	bastard oak (White shin)						
Quercus sinuata var. *sinuata*	White shin oak (scalybark oak)	-0.44	0.21	4.02	medium	DRO VRE FRG	AIP COL DISP
Quercus stellata	post oak	-1.42	0.75	4.17	medium	TEM	DISE FLO AIP COL
Quercus virginiana	live oak	-0.79	2.46	5.07	high	FTK VRE FRG	DISE AIP
Rhus aromatica	Fragrant sumac	0.33	3.86	5.72	high	DRO TEM ESP EHS DISP SES VRE	AIP
Rhus lanceolata	prairie flameleaf sumac	0.98	2.57	5.48	high	DRO TEM EHS DISP SES VRE FRG	AIP COL
Rhus virens	evergreen sumac	-0.73	3.43	5.34	high	DRO DISP SES VRE FRG	FLO AIP DISE
Salix nigra	black willow	-1.79	-1.29	3.26	low	FLO	DRO FTK AIP COL

Scientific Name	Common Name	Disturb score	Bio Score	Adapt Score	Adapt Class	Positive Factors	Negative Factors
Sapindus saponaria var. *drummondii*	western soapberry	1.56	-1.07	4.49	medium	DRO FLO AIP DISP VRE	FTK EHS SES
Sideroxylon lanuginosum	chittamwood, gum bumelia	-0.69	0.54	4.22	medium	DRO TEM	AIP COL
Styphnolobium affine	Eve's necklace	-0.17	-0.43	3.78	medium	DRO COL	FLO AIP DISP
Taxodium distichum	baldcypress	-1.31	-0.32	3.81	medium	FLO	DRO AIP EHS
Taxodium mucronatum	Montezuma cypress	0.98	-2.79	3.39	low	DRO FLO	AIP COL EHS DISP
Tilia americana var. caroliniana	Carolina basswood	-1.54	-0.86	3.49	low	COL	AIP EHS SES
Triadica sebifera[i]	Chinese tallowtree	0.60	4.71	6.00	high	DRO FLO WIN COL EHS DISP SES VRE	DISE AIP
Ulmus alata	winged elm	0.00	0.00	0.00	medium	FLO COL	DISE AIP
Ulmus americana	American elm	-2.19	2.36	4.64	high	EHS	DISE INSP DRO AIP
Ulmus crassifolia	cedar elm	-1.27	3.64	5.41	high	FLO ESP EHS DISP SES	
Ulmus parvifolia[i]	Chinese elm	0.67	2.89	5.44	high	DRO ESP EHS SES	
Ulmus rubra	slippery elm	-1.83	2.36	4.50	high	COL	DISE FTK AIP
Ungnadia speciosa	Mexican buckeye	-0.46	-0.11	4.03	medium	COL	AIP EHS SES
Vachellia farnesiana	sweet acacia (Huisache)	-1.21	-1.82	2.99	low	DRO	FLO COL
Viburnum rufidulum	rusty blackhaw	-0.38	1.07	4.36	medium	COL	VRE
Zanthoxylum hirsutum	Prickly-ash,Tickle-tongue	-0.69	2.68	5.07	high	EHS VRE	
Ziziphus obtusifolia	Lotebush	0.40	3.64	5.67	high	DRO EHS DSIP SES VRE	AIP

Table 3.5 — Adaptability scores for trees in developed areas. See table 3.3 for trait codes. [i]invasive species

Scientific Name	Common Name	Disturb score	Bio Score	Adapt Score	Adapt Class	Positive Factors	Negative Factors
Acacia roemeriana	Catclaw	-0.89	-0.09	3.63	medium	DRO	FLO COL AIP
Acer grandidentatum	bigtooth maple	0.82	0.22	4.64	high	TEM	
Acer negundo	boxelder	0.02	0.03	4.34	medium	DRO FLO TEM	INS INPO
Aesculus pavia var. *pavia*	Red buckeye	-1.18	0.09	3.81	medium		AIP
Albizia julibrissin[i]	mimosa, silktree	-0.77	-2.28	2.88	low	DRO FLO TEM EDS	DISE AIP INPO LPS RRC INPO
Arbutus xalapensis	Texas madrone	-1.30	1.09	4.25	medium	DRO RRC	FLO AIP PLE
Bauhinia lunarioides	Anacacho orchid tree	-0.34	-0.78	3.62	medium		FLO AIP
Broussonetia papyrifera[i]	paper mulberry	0.30	-0.63	4.12	medium	FLO TEM	INPO
Carya illinoinensis	pecan	-1.85	-0.31	3.15	low		AIP LPS RRC
Carya texana	Black hickory	-1.45	-1.53	2.92	low		FLO AIP NUP
Carya tomentosa	Mockernut hickory	-0.46	-0.59	3.68	medium		AIP
Celtis laevigata	sugarberry	-0.64	-0.59	3.66	medium	DRO FLO TEM	WIN AIP NUP
Celtis laevigata var. reticulata	Netleaf hackberry	-0.64	-0.59	3.66	medium	DRO FLO TEM	WIN AIP NUP
Celtis occidentalis	hackberry	0.25	1.66	4.64	high	DRO TEM LPS NUP	
Cercis canadensis	eastern redbud	0.00	1.75	4.65	high	FLO TEM LPS RRC	AIP
Cercis canadensis L. var. mexicana	Mexican redbud	-1.32	-0.09	3.66	medium	DRO	FLO AIP
Cercis canadensis var. texensis	Texas redbud	-1.36	1.13	4.03	medium	RRC LPS	AIP
Chilopsis linearis	Desert willow	0.34	-0.66	3.76	medium	DRO FLO	AIP
Citrus meyeri	Meyer lemon	-1.18	0.94	3.81	medium	NUP	FLO
Condalia hookeri var. *hookeri*	Brasil	-0.75	-0.28	3.53	medium	DRO	FLO AIP
Cordia boissieri	Mexican olive	-1.68	0.28	3.45	low	DRO	FLO AIP
Cornus drummondii	roughleaf dogwood	-0.20	0.75	4.34	medium	TEM	FLO AIP
Cotinus obovatus	American smoketree	-0.75	1.06	3.86	medium	DRO LPS RRC	AIP
Dermatophyllum secundiflorum	Texas mountain laurel	0.20	2.63	5.15	high	DRO LPS RRC NUP	AIP
Diospyros kaki	Asian persimmon	-1.86	-0.34	3.30	low		FLO AIP LUP
Diospyros texana	Texas persimmon	-0.52	0.78	4.43	medium	RRC	AIP
Eriobotrya japonica	loquat	-1.45	0.28	3.76	medium		AIP INPO
Eysenhardtia texana	Texas kidneywood	-0.48	0.28	3.84	medium	DRO	FLO AIP
Ficus carica	edible fig	-2.05	-1.28	2.84	low		FLO AIP
Frangula caroliniana	carolina buckthorn	-1.00	0.56	4.17	medium		DRO TEM

Scientific Name	Common Name	Disturb score	Bio Score	Adapt Score	Adapt Class	Positive Factors	Negative Factors
Fraxinus albicans	Texas ash	-0.82	2.16	4.69	high	TEM LPS RRS NUP	INS FLO
Fraxinus berlandieriana	Berlandier ash	-2.43	0.88	3.94	medium		INS DRO AIP INPO
Fraxinus pennsylvanica	green ash	-1.20	0.81	3.86	medium	FLO LPS NUP	INS MAIN
Fraxinus velutina	velvet ash	-0.14	1.97	4.44	medium	DRO AIP LPS RRS NUP	INS WIN MAIN
Garrya ovata var. lindheimeri	Lindheimer's silktassel	-0.30	-0.09	3.96	medium		FLO AIP
Ilex decidua	Possumhaw	1.14	0.75	4.95	high	FLO TEM	AIP
Ilex vomitoria	yaupon	0.32	2.09	5.27	high	ESP LPS RRC NUP	INPO
Juglans major	Arizona walnut	-0.77	-0.66	3.53	medium	FLO	DRO AIP
Juglans microcarpa	little walnut	-0.98	-0.66	3.47	low	FLO	DRO AIP
Juglans nigra	black walnut	-1.18	-1.78	2.88	low		DISE AIP COL LPS RRC
Juniperus ashei	Ashe juniper	-2.89	-0.84	2.88	low	RRC	INS FLO TEM PLE INPO
Juniperus virginiana	eastern redcedar				medium	DRO TEM LPS RRC	AIP
Koelreuteria paniculatan[i]	goldenrain tree	0.48	1.41	4.55	high	DRO TEM LPS RRC NUP	INPO
Lagerstroemia indica	crapemyrtle	-0.95	3.19	4.71	high	DRO TEM LPS RRC NUP	FLO AIP
Leucaena retusa	littleleaf/goldenball leadtree	-0.20	-0.94	3.57	medium	DRO	WIN AIP INPO
Ligustrum japonicum[i]	Japanese privet	-1.50	0.69	4.14	medium	TEM NUP	INPO
Ligustrum lucidum[i]	glossy privet	0.48	1.59	4.92	high	TEM LPS RRC NUP	INPO
Ligustrum sinense[i]	Chinese privet	-1.50	0.69	4.14	medium	TEM NUP	INPO
Liquidambar styraciflua	sweetgum	-0.48	-0.28	3.72	medium	FLO	INS DRO RRC
Maclura pomifera	Osage orange	0.25	2.66	5.15	high	DRO TEM RRC NUP	AIP
Magnolia grandiflora	southern magnolia	-1.43	0.41	3.97	medium	LPS NUP	DRO EDS RRC
Malus ioensis var. texana	Texas crab apple	-1.86	0.44	3.51	medium		FLO AIP
Melia azedarach	chinaberry	1.11	-1.41	4.12	medium	DRO FLO RRC PES	LPS NUP INPO
Mimosa biuncifera	Catclaw mimosa	0.45	-1.44	3.68	medium	DRO	AIP INPO
Morus alba[i]	white mulberry	0.36	-0.22	3.41	low	NUP	LPS INPO
Morus microphylla	Texas mulberry	-1.45455	-1.13	3.40	low		AIP
Morus rubra	red mulberry	-1.05	0.38	4.02	medium	TEM NUP	AIP
Myrospernum sousanum	Arroyo sweeetwood	-0.57	-0.94	3.57	medium	DRO	FLO AIP INPO

Scientific Name	Common Name	Disturb score	Bio Score	Adapt Score	Adapt Class	Positive Factors	Negative Factors
Parkinsonia aculeata	Jerusalem thorn (Retama)	0.59	1.69	4.98	high	DRO LPS RRC NUP	INPO
Persea borbonia	Red bay	-0.50	2.25	4.74	high	TEM NUP	AIP
Pistacia chinensis	Chinese pistache	1.23	0.56	4.86	high	DRO LPS RRC	FLO MAIN INPO
Pistacia mexicana	Texas pistache	-0.43	-0.38	3.69	medium	DRO	DIS AIP
Platanus mexicana	Mexican sycamore	0.93	-1.41	4.26	medium	FLO AIP	LPS RRC
Platanus occidentalis	American sycamore	-0.75	0.56	3.85	medium	FLO TEM NUP	DRO
Populus deltoides	eastern cottonwood	-1.43	-0.38	3.15	low	TEM NUP	DIS INS AIP LPS RRC
Prosopis glandulosa	honey mesquite	0.57	-1.97	3.63	medium	DRO	AIP INPO
Prunus caroliniana[i]	cherry laurel	-0.20	0.47	4.55	high	NUP	FLO RRC INPO
Prunus mexicana	Mexican plum	-2.27	0.47	3.72	medium		FLO DRO AIP
Prunus serotina var. *eximia*	escarpment black cherry	-1.18	-2.53	2.73	low	TEM	WIN AIP ESP LPS NUP
Ptelea trifoliata	Common Hoptree (wafer ash)	-0.66	1.22	4.48	medium	TEM RRC NUP	AIP
Punica granatum	Pomegranate	-0.93	0.94	3.82	medium	DRO RRC NUP	FLO
Quercus buckleyi	Texas red (Buckley) oak	-0.43	0.56	4.18	medium	TEM	DISE FLO
Quercus fusiformis	Texas live oak	-1.75	-1.94	2.76	low		DISE INS FLO AIP LPS RRC
Quercus laceyi	Lacey oak	-0.07	-0.16	3.94	medium	DRO	FLO SIP
Quercus macrocarpa	bur oak	0.55	0.84	4.49	high	DRO TEM AIP LPS NUP	FLO
Quercus marilandica	Blackjack oak	-1.16	-2.34	2.87	low	DRO TEM	DISE FLO AIP LPS RRC NUP
Quercus muehlenbergii	chinkapin oak	-0.27	1.22	4.48	medium	DRO TEM	AIP
Quercus nigra	water oak	-1.02	0.34	3.55	medium	FLO TEM NUP	DISE AIP
Quercus polymorpha	Mexican white oak	0.14	1.59	4.59	high	DRO LPS NUP	AIP
Quercus shumardii	Shumard oak	0.73	1.69	4.52	high	DRO FLO TEM LPS RRC NUP	DISE
Quercus sinuata var breviloba	bastard oak (White shin)						
Quercus sinuata var. *sinuata*	White shin oak (scalybark oak)	-0.30	-0.94	3.40	low	DRO	AIP
Quercus stellata	post oak	-1.39	-1.78	2.92	low	TEM	DISE FLO AIP LPS NUP
Quercus virginiana	live oak	-0.75	2.06	4.54	high	TEM LPS RRC NUP	DISE AIP
Rhus aromatica	Fragrant sumac	0.30	1.59	4.90	high	DRO TEM ESP LPS NUP	
Rhus lanceolata	prairie flameleaf sumac	1.14	-0.38	4.12	medium	DRO TEM	AIP
Rhus virens	evergreen sumac	-0.84	1.31	4.23	medium	DRO	FLO AIP DISE

Scientific Name	Common Name	Disturb score	Bio Score	Adapt Score	Adapt Class	Positive Factors	Negative Factors
Salix nigra	black willow	-1.55	-0.38	3.30	low	FLO	SRO AIP RRC
Sapindus saponaria var. *drummondii*	western soapberry	2.09	-1.88	4.69	high	DRO FLO TEMP AIP	NUP
Sideroxylon lanuginosum	chittamwood, gum bumelia	-0.36	1.75	4.53	high	DRO TEM	AIP
Styphnolobium affine	Eve's necklace	-0.16	1.78	4.89	high	DRO LPS NUP	FLO AIP
Taxodium distichum	baldcypress	0.20	2.28	5.00	high	FLO RRC NUP	AIP
Taxodium mucronatum	Montezuma cypress	0.86	-0.56	4.05	medium	DRO FLO	AIP
Tilia americana var. caroliniana	Carolina basswood	-1.23	0.19	3.86	medium	COL	AIP
Triadica sebifera[i]	Chinese tallowtree	0.20	1.78	5.00	high	DRO FLO WIN LPS RRC NUP	DISE AIP INPO
Ulmus alata	winged elm	-1.77	1.44	4.17	medium	FLO LPS RRC	DISE AIP INPO
Ulmus americana	American elm	-2.20	0.94	3.83	medium	TEM NUP	DISE DRO
Ulmus crassifolia	cedar elm	-1.66	1.97	4.43	medium	EPS LPS	AIP
Ulmus parvifolia[i]	Chinese elm	1.39	2.03	5.50	high	DRO TEM EDS LPS RRC NUP	INPO
Ulmus rubra	slippery elm	-1.36	0.00	3.92	medium	TEM	DISE AIP INPO
Ungnadia speciosa	Mexican buckeye	-0.16	1.97	4.95	high	DRO TEM RRC NUP	AIP
Vachellia farnesiana	sweet acacia (Huisache)	-0.89	-1.13	3.13	low	DRO	FLO INPO
Viburnum rufidulum	rusty blackhaw	-0.32	0.56	4.34	medium	TEM LPS	FLO RRC
Zanthoxylum hirsutum	Prickly-ash,Tickle-tongue	-0.36	-1.44	3.57	medium		AIP LPS INPO
Ziziphus obtusifolia	Lotebush	0.25	0.47	4.36	medium	DRO	AIP INP

OVERALL VULNERABILITY OF THE AUSTIN REGION'S TREES

Vulnerability is the susceptibility of a system to the adverse effects of climate change (Parry, et al., 2007). It is a function of potential climate change impacts and the adaptive capacity of the system. Overall vulnerability of trees in the Austin region can be estimated by considering the impacts on individual trees using model projections or changes in heat and hardiness zone and species range limits, together with the adaptive capacity of trees as described in the previous section. One hundred four species and cultivars were evaluated for their vulnerability, of which 58 were recorded as being present in the 2014 urban FIA data collection (Nowak, et al., 2016). This approach is meant to give a coarse picture of vulnerability, and readers should weigh the relative confidence in vulnerability estimates based on the level of information available.

Each species was given a separate vulnerability rating for natural areas vs. planted/developed sites (Table 3.6). For natural areas, the most vulnerable species were . These species make up a small proportion (less than 2 percent) of the total trees in Austin based on the recent urban FIA assessment. The least vulnerable species, making up about 11 percent of the total trees in Austin, included Texas persimmon, Texas Hercules' club (prickly-ash, tickle-tongue), lotebush, and several sumac species. Also rated as having low vulnerability were several invasive species (chinaberry, paper mulberry, privet species) and species native to areas farther south (Mexican redbud, Mexican sycamore). The majority of the species fell into the moderately vulnerable category, in large part due to the presence of Ashe juniper in that category.

In planted and developed sites, many of the same species that were rated as having high vulnerability in natural areas were also vulnerable. However, species that were less adapted to urban sites also were listed as highly vulnerable (e.g, post oak, black walnut, black hickory eastern cottonwood, and Ashe juniper). Thus, a greater proportion of trees found in Austin were considered vulnerable in developed sites (42 percent). In developed sites, native species that were considered to have low vulnerability included Texas mountain laurel, Mexican white oak, Jerusalem thorn (retama), red bay, Eve's necklace, Mexican buckeye, and Texas persimmon. Only 3 percent of the trees estimated to be present in Austin as of the last count were considered to have low vulnerability in developed areas.

Table 3.6 Vulnerability ratings for natural and developed areas for trees in the Austin region.

Scientific name	Common Name	Estimated Trees Present-Austin	Vulnerability-Natural Areas	Vulnerability-Developed Areas
Acer negundo	boxelder	367930	moderate	moderate-high
Aesculus pavia var. *pavia*	Red buckeye		moderate	moderate-high
Albizia julibrissin	mimosa, silktree	4720	moderate	high
Arbutus xalapensis	Texas madrone	6189	moderate-high	low-moderate
Bauhinia lunarioides	Anacacho orchid tree		moderate	low-moderate
Broussonetia papyrifera	paper mulberry	335755	low	low-moderate
Carya illinoinensis	pecan	196132	moderate-high	moderate-high
Carya texana	Black hickory		moderate-high	high
Carya tomentosa	Mockernut hickory		moderate-high	moderate-high
Celtis laevigata	sugarberry	2058386	moderate	moderate-high
Celtis occidentalis	common hackberry	161569	moderate	moderate
Cercis canadensis	eastern redbud	6248	moderate	moderate
Cercis canadensis L. var. mexicana	Mexican redbud		low	low-moderate
Cercis canadensis var. texensis	Texas redbud		low-moderate	low-moderate
Chilopsis linearis	desert willow		low-moderate	low-moderate
Citrus meyeri	Meyer lemon		low-moderate	low-moderate
Condalia hookeri var. hookeri	Brazilian bluewood		low-moderate	low-moderate
Cordia boissieri	Mexican olive		low-moderate	moderate
Cornus drummondii	roughleaf dogwood	59882	moderate	moderate
Cotinus obovatus	American smoketree		high	high
Dermatophyllum secundiflorum	Texas mountain laurel	648060	low-moderate	low
Diospyros kaki	Asian persimmon		moderate-high	moderate-high
Diospyros texana	Texas persimmon	2014199	low	low-moderate
Eriobotrya japonica	loquat	312427	moderate	moderate
Eysenhardtia texana	Texas kidneywood		low-moderate	low-moderate
Ficus carica	edible fig	22984	moderate-high	moderate-high
Frangula caroliniana	carolina buckthorn		moderate-high	moderate-high

Scientific name	**Common Name**	**Estimated Trees Present-Austin**	**Vulnerability-Natural Areas**	**Vulnerability-Developed Areas**
Fraxinus albicans	Texas ash	438216	moderate-high	moderate
Fraxinus berlandieriana	Mexian ash (Berlandier ash)	184758	low-moderate	low-moderate
Fraxinus pensylvanica	green ash	751788	moderate-high	moderate-high
Fraxinus velutina	velvet ash	59326	moderate-high	moderate-high
Garrya ovata var. lindheimeri	Lindheimer's silktassel		low-moderate	low-moderate
Ilex decidua	possumhaw (deciduous holly)		moderate	moderate
Ilex vomitoria	yaupon	833143	moderate	moderate
Juglans major	Arizona walnut		moderate-high	moderate-high
Juglans microcarpa	little walnut		moderate-high	moderate-high
Juglans nigra	black walnut	105106	moderate-high	high
Juniperus ashei	Ashe juniper	13315759	moderate	high
Juniperus virginiana	eastern redcedar	38457	moderate-high	moderate-high
Koelreuteria paniculata	goldenrain tree	6363	n/a	n/a
Lagerstroemia indica	crapemyrtle	174401	moderate	moderate
Leucaena retusa	littleleaf/goldenball leadtree		moderate-high	moderate-high
Ligustrum japonicum	Japanese privet	17322	low	low-moderate
Ligustrum lucidum	glossy privet	623890	moderate	moderate
Ligustrum sinense	Chinese privet	123994	low	moderate-high
Liquidambar styraciflua	sweetgum		moderate	moderate-high
Maclura pomifera	Osage orange		moderate	moderate
Magnolia grandiflora	southern magnolia	6363	moderate	moderate-high
Malus ioensis var. texana	Texas crab apple		moderate-high	moderate
Melia azedarach	chinaberry	538729	low	low-moderate
Mimosa aculeaticarpa var. biuncifera	Catclaw mimosa (fragrant mimosa)		low-moderate	low-moderate
Morus alba	white mulberry	13790	moderate	high
Morus microphylla	Texas mulberry		low-moderate	moderate
Morus rubra	red mulberry	124975	moderate-high	moderate-high
Myrospermum sousanum	Arroyo sweetwood		low-moderate	low-moderate
Parkinsonia aculeata	Jerusalem thorn (Retama)	10199	low-moderate	low
Persea borbonia	red bay		low-moderate	low
Pistacia chinensis	Chinese pistache	17322	moderate	moderate
Pistacia mexicana	Texas pistache		low-moderate	low-moderate
Platanus mexicana	Mexican sycamore		low	low-moderate
Platanus occidentalis	American sycamore	132468	moderate-high	moderate-high
Populus deltoides	eastern cottonwood	15862	moderate-high	high
Prosopis glandulosa	honey mesquite	655950	low	low-moderate
Prunus caroliniana	cherry laurel	78107	moderate	moderate
Prunus mexicana	Mexican plum		high	moderate-high
Prunus serotina var. eximia	escarpment black cherry		moderate	high
Ptelea trifoliata	common hoptree (wafer ash)		moderate-high	moderate-high
Punica granatum	pomegranate		moderate-high	moderate
Quercus buckleyi	Texas red oak	419812	high	moderate-high
Quercus fusiformis	Texas live oak (escarpment live oak, plateau live oak)	101848	moderate	moderate-high
Quercus laceyi	Lacey oak		moderate-high	moderate
Quercus macrocarpa	bur oak	6363	moderate	moderate
Quercus marilandica	Blackjack oak		moderate	moderate-high

Scientific name	Common Name	Estimated Trees Present-Austin	Vulnerability-Natural Areas	Vulnerability-Developed Areas
Quercus muehlenbergii	chinkapin oak	10959	moderate-high	moderate-high
Quercus nigra	water oak	4597	moderate	moderate
Quercus polymorpha	Mexican white oak	84966	low-moderate	low
Quercus shumardii	Shumard oak	43137	moderate-high	moderate
Quercus sinuata var. breviloba	white shin oak (scalybark oak)	243656	moderate-high	high
Quercus sinuata var. sinuata	bastard oak	166563	high	high
Quercus stellata	post oak	86286	moderate-high	high
Quercus virginiana	live oak (coast live oak)	2862523	low-moderate	low-moderate
Rhus aromatica	Fragrant sumac (skunkbush sumac)		low	low
Rhus lanceolata	prairie sumac (flameleaf sumac)	77093	low	low
Rhus virens	evergreen sumac		low	low-moderate
Salix nigra	black willow		high	high
Sapindus saponaria var. drummondii	western soapberry	192371	moderate-high	moderate
Senegalia roemeriana (acacia roemeriana)	Catclaw		low-moderate	low-moderate
Sideroxylon lanuginosum	chittamwood, gum bumelia	89955	moderate-high	moderate
Styphnolobium affine	Eve's necklace		low-moderate	low
Taxodium distichum	baldcypress	12725	moderate-high	moderate
Taxodium mucronatum	Montezuma cypress		moderate	low-moderate
Tilia americana var. caroliniana	Carolina basswood		high	moderate-high
Triadica sebifera	Chinese tallowtree	28029	moderate	moderate
Ulmus alata	winged elm	134185	moderate-high	moderate-high
Ulmus americana	American elm	72039	moderate	moderate-high
Ulmus crassifolia	cedar elm	4583201	moderate	moderate-high
Ulmus parvifolia	Chinese elm (lacebark elm)	78107	moderate	moderate
Ulmus rubra	slippery elm	12725	moderate	moderate-high
Ungnadia speciosa	Mexican buckeye		moderate	low
Vachellia farnesiana (acacia farnesiana)	sweet acacia (Huisache)	4597	moderate	moderate
Viburnum rufidulum	rusty blackhaw		moderate-high	moderate-high
Zanthoxylum hirsutum	Texas Hercules' club (prickly-ash, tickle-tongue)		low	low-moderate
Ziziphus obtusifolia	lotebush		low	low-moderate

SUMMARY

Results from species distribution modeling suggest that habitat suitability for many tree species may shift across the Austin region, leading to declines in some species and increases in others. Species at the southern and western extent of their range are generally projected to decline in suitable habitat. Species at the northern and eastern extent of their range or currently native to south of the area could experience an increase in suitable habitat, especially in areas where there is an urban heat island effect. Other factors that are not included in models, such as changes in extreme events, insects, and diseases, and may also affect the survival of particular trees and make them more or less adaptable to climate change-induced pressures than the models would suggest. Overall, the vulnerability of trees and the surrounding urban forest will need to be gauged based on the complex interaction of multiple stressors and benefits.

------start text box---

Key Points

- Modeling Native Trees: Species distribution modeling for native species suggests that suitable habitat may decrease for 14 of 31 primarily northern species, and remain stable for 10 species. Suitable habitat was 0expected to increase for four species.
- Projected Changes from Heat and Hardiness Zone Shifts and Species Ranges: For species for which no model information is available (rare, nonnative, or cultivars), shifts in heat and hardiness zones could have a positive effect on 23 species, while sixty species had either hardiness zone, heat zone, or range limits (or a combination thereof) that may suggest a negative effect.
- Adaptive Capacity of Urban Trees: Adaptive capacity of 104 species was evaluated using scoring systems for planted and natural environments, with many invasive species among those with the highest capacity to adapt to a range of stressors. For planted/developed conditions, 29 species received a high adaptability score (27.8 percent), 18 received a low adaptability score (17.3 percent), and the remaining 57 received a medium adaptability score (54.8 percent). For natural areas (both native and naturalized), 41 species received a high adaptability score (39.4 percent), 17 received a low adaptability score (16.3 percent), and 46 received a medium adaptability score (44.2 percent).
- Overall Vulnerability of the Austin Region's Trees: An analysis of vulnerability that combines model projections, shifts in heat and hardiness zones, and adaptive capacity showed that in planted and developed sites, many of the same species rated as having high vulnerability in natural areas were also vulnerable. Species that were less adapted to urban sites were also listed as vulnerable, indicating a greater proportion of trees were considered vulnerable in developed sites (42 percent).

------end text box---

Literature Cited

Brandt, L.A., A.D. Lewis, L. Scott, L. Darling, R.T. Fahey, L. Iverson, et al. 2017. Chicago Wilderness region urban forest vulnerability assessment and synthesis: a report from the Urban Forestry Climate Change Response Framework Chicago Wilderness pilot project. Gen. Tech. Rep. NRS-168. Newtown Square, PA: US Department of Agriculture, Forest Service, Northern Research Station. 142 p. 168: 1-142.

Iverson, L.R., M.P. Peters, A.M. Prasad and S.N. Matthews. 2019. Analysis of Climate Change Impacts on Tree Species of the Eastern US: Results of DISTRIB-II Modeling. Forests 10. doi:10.3390/f10040302.

Iverson, L.R., A.M. Prasad, S.N. Matthews and M. Peters. 2008. Estimating potential habitat for 134 eastern US tree species under six climate scenarios. Forest Ecology and Management 254: 390-406.

Kartesz, J.T. 2015. North American plant atlas. North American Plant Atlas.

Matthews, S.N., L.R. Iverson, A.M. Prasad, M.P. Peters and P.G. Rodewald. 2011. Modifying climate change habitat models using tree species-specific assessments of model uncertainty and life history-factors. Forest Ecology and Management 262: 1460-1472.

Nowak, D.J., A.R. Bodine, R.E. Hoehn, C.B. Edgar, D.R. Hartel, T.W. Lister, et al. 2016. Austin's urban forest, 2014. Resource Bulletin NRS-100. Newtown Square, PA: US Department of Agriculture, Forest Service, Northern Research Station. 55 p. http://dx. doi. org/10.2737/NRS-RB-100 100: 1-55.

Parry, M., M.L. Parry, O. Canziani, J. Palutikof, P. Van der Linden and C. Hanson. 2007. Climate change 2007-impacts, adaptation and vulnerability: Working group II contribution to the fourth assessment report of the IPCCCambridge University Press.

Peters, M.P., L.R. Iverson, A.M. Prasad and S.N. Matthews. 2019. Utilizing the density of inventory samples to define a hybrid lattice for species distribution models: DISTRIB-II for 135 eastern US trees. Ecology and Evolution 9: 8876-8899. doi:10.1002/ece3.5445.

Prasad, A.M., L.R. Iverson, S. Matthews and M. Peters. 2007. ongoing. A climate change atlas for 134 forest tree species of the eastern United States [database]. US Department of Agriculture Forest Service. Available: http://www. nrs. fs. fed. us/atlas/tree (November 2013).

Roloff, A., S. Korn and S. Gillner. 2009. The Climate-Species-Matrix to select tree species for urban habitats considering climate change. Urban Forestry & Urban Greening 8: 295-308.

Wiens, J.A., D. Stralberg, D. Jongsomjit, C.A. Howell and M.A. Snyder. 2009. Niches, models, and climate change: assessing the assumptions and uncertainties. Proceedings of the National Academy of Sciences 106: 19729-19736.