CHAPTER 1: THE CONTEMPORARY LANDSCAPE

The urban forest is defined as all publicly and privately owned trees within an urban area — including individual trees along streets and in backyards, as well as stands of remnant forest (Nowak et al. 2001). The urban forest of the Austin region can be viewed as two separate but interconnected types: natural areas and developed sites. These areas are managed and maintained in vastly different ways and often by different entities. The urban forest is shaped by ecosystems, landforms, and environmental gradients that existed prior to Euro-American settlement. The ecoregion is defined by the tallgrasses of the Blackland Prairies to the east, the forests, woodlands and savannas of the Edwards Plateau to the west, and is divided by the Balcones fault zone. While much of the region has been developed, its natural history influences current forest composition. In this section we will describe the structure and function of Austin's urban forest, the forces that shaped it, and current stressors. This information lays the foundation for understanding how shifts in climate may contribute to changes in Austin's trees and urban forests, and how climate may interact with other stressors present on the landscape.

LANDSCAPE SETTING

The city of Austin is a vibrant community, home to many unique cultures and physical landscapes. The city is experiencing rapid growth and change and is projected to continue on this path. Residents are concerned about the impacts of that growth, along with potential impacts from climate change, on their trees and green spaces. In 2019 the city underwent an Urban Forest Vulnerability Assessment to better understand the vulnerability of trees and urban forests to direct and indirect impacts of climate change. This vulnerability assessment follows up on the Urban Forest Inventory and Analysis (Nowak et al, 2014) and the City of Austin's Urban Forest Plan (City of Austin, 2014). This assessment includes all public and private land within the City of Austin and its extraterritorial jurisdiction which includes the Edwards Plateau and Blackland Prairies ecoregions, as defined by the Texas Parks & Wildlife mapping (Gould et al. 1960).

The City of Austin, located in Central Texas, is nestled at the junction of the Edwards Plateau and the Blackland Prairie. It is divided by the Balcones Escarpment fault line. (Texas Parks & Wildlife, 2013). The escarpment plays a role in regulating climate in the Austin area; although maximum elevation change is only a few hundred feet, it is the first topographic break inland from the Gulf of Mexico and thus influences weather, making the City of Austin prone to large flood-producing storms (Abbott and Woodruff, 1986). This and other differences in biotic and abiotic characteristics between ecoregions present unique challenges for the city's economic, environmental, climate change, and social planning.

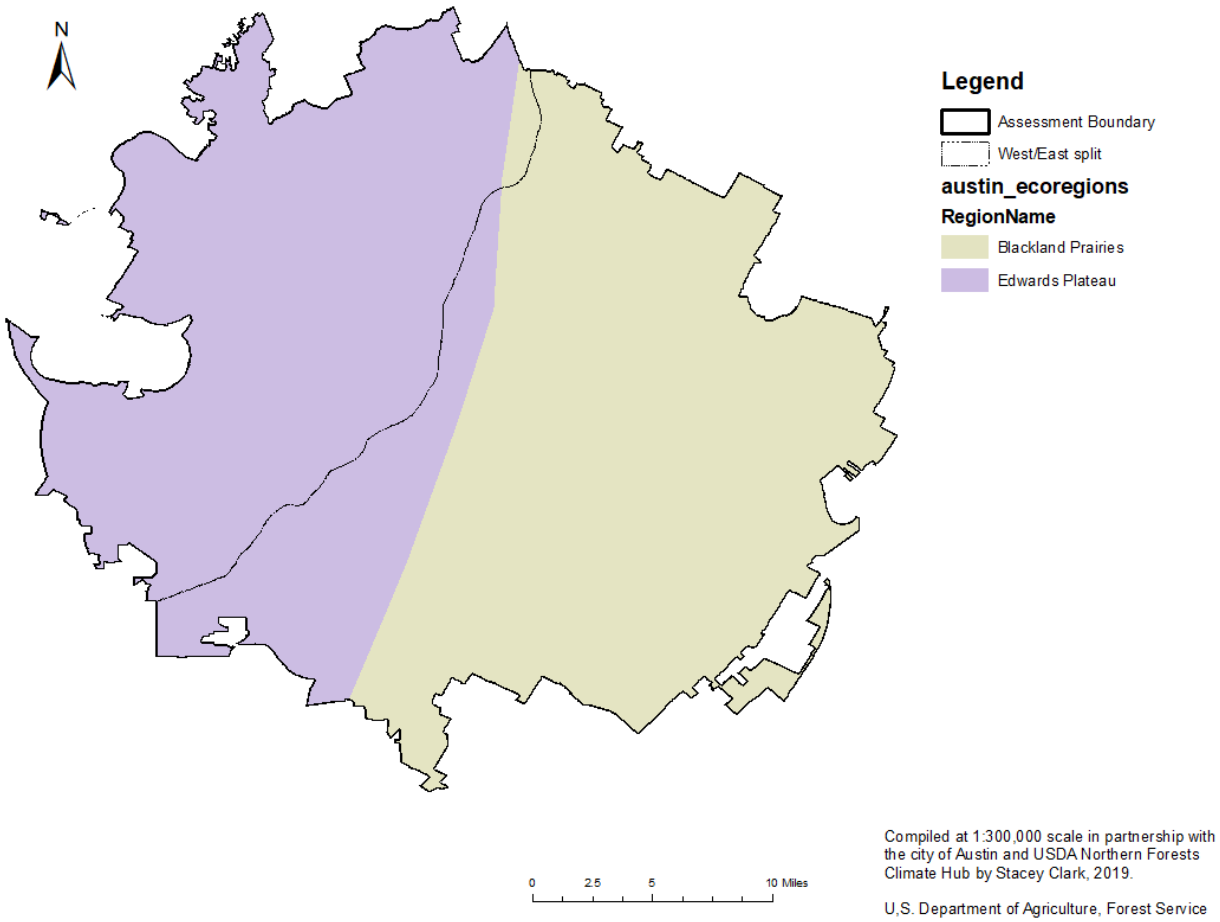

Fig 1.1—Ecological regions in the Austin, TX Assessment Area. Balcones Canyonlands and Live Oak/Mesquite Savanna are in the Edwards Plateau and Blackland Prairie and Floodplains and Low Terraces are in the Blackland Prairie Ecoregion. Source: Gould, F.W., Hoffman,G.O., and Rechenthin, C.A.1960. Vegetational areas of Texas. Created from map in Gould, F. W. 1975, updated by TPWD GIS Lab 1/09/2004. Downloaded 08-27-2019: https://tpwd.texas.gov/gis/data/baselayers/naturalsubregions-zip/view

----------Text Box----------

Box 1.1 More information on trees and natural areas in the Austin region

The resources below provide more information regarding the urban forest and natural areas in Austin:

Austin's Urban Forest (Nowak et al. 2014)
Provides an assessment of Austin's tree composition and their ecosystem service values.

Austin Urban Forest Master Plan (City of Austin 2013)

Other resources and plans that influence trees and vegetation in the Austin area:

- Land Development Code
www.austintexas.gov/department/austin-city-code-land-development-code

- Environmental Criteria Manual
library.municode.com/tx/austin/codes/environmental_criteria_manual?nodeId=ENCRMA

- ImagineAustin - Green Infrastructure Priority Program
www.austintexas.gov/page/GreenInfrastructure

- Climate Protection Resolution
austintexas.gov/page/climate-protection-resolution

- Invasive Species Management Plan
austintexas.gov/sites/default/files/files/Watershed/invasive/COA-ISMP-Final-7-11-12.pdf

- Watershed Protection Management Plan
www.austintexas.gov/department/watershed-protection-master-plan

- Austin/Travis County Community Wildfire Protection Plan
www.austintexas.gov/wildfireprotectionplan

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Landform, soils, and hydrology

Edwards Plateau

This ecoregion found in the western portion of Austin is an uplifted geological region of thick, mostly flat layers of bedrock composed primarily of hard early Cretaceous limestone (Riskind and Diamond, 1988). Its eastern and southern boundaries are defined by a now inactive fault zone, the Balcones Escarpment (Small et al. 1996). This ecoregion is largely a dissected limestone plateau that is hillier to the south and east (the "Hill Country"; see Diamond and True 2008) where it is easily distinguished from bordering ecoregions by the sharp fault line. The eastern edge is characterized by steep limestone karst terrane with a deep, cavernous aquifer (Edwards Aquifer) (Small et al. 1996).

Soil depth varies by topography: hilltops have shallow soils while flat areas and lowlands have thicker soils. Soil textures depend on the underlying parent material and surface vegetation. The Edwards Plateau is prone to high intensity rainfall events, which can lead to flash-flooding and erosion (Riskind and Diamond 1988). Due to karst topography (related to dissolution of limestone substrate) and resulting underground drainage, streams are relatively clear and cool in temperature compared to those of surrounding areas (Griffith, et al., 2004).

Major water sources in the Austin area include the Edwards Aquifer, the Colorado River and its network of perennial and intermittent streams, and springs, of which the largest (Barton Springs) flows from the base of the Balcones Escarpment. The predominant vegetation association is mature, closed-canopy Ashe juniper-oak forest, although more open woodlands and shrublands also occur in this area. The eastern edge of the Edwards Plateau ecoregion has been identified as a biodiversity "hot spot" with many endemic and imperiled species, including rare plants, cave and spring invertebrates, *Eurycea* salamanders, and the golden-cheeked warbler (*Setophaga chrysoparia*).

Blackland Prairie

This ecoregion found in the eastern portion of Austin is disjunct, distinguished from surrounding regions by its fine-textured, clayey soils and predominantly prairie potential natural vegetation (Griffith et al. 2004). Two subregions of Blackland Prairie are found in Austin: the Northern Blackland Prairie and Floodplains and Low Terraces.

The black clay soils are productive, which has led to conversion of much of the terrain into cropland and grazing pastures (Texas Parks and Wildlife, Blackland Prairie ecological region). This region now contains a higher percentage of cropland than adjacent regions; pasture and forage production for livestock is common (Griffith et al. 2004). Large areas of the region are being converted to urban and industrial uses (Griffith et al. 2004). Dominant grasses included little bluestem, big bluestem, yellow Indiangrass, and switchgrass (Griffith et al. 2004). Within the Austin area, the Blackland Prairie ecoregion contains the watersheds, tributaries, and riparian zones of the Colorado River, providing habitat for a variety of wildlife species.

Deciduous bottomland woodland and forest were common along rivers and creeks (Diamond and Smeins, 1993); today pecan, cedar elm, various oaks, and hackberry dot the landscape, with mesquite invading the edges. Historically important natural landscape-scale disturbances included fire and indigenous wildlife grazing (primarily bison and to a lesser extent pronghorn antelope). Fire and infrequent but intense, short duration grazing suppressed woody and invigorated herbaceous prairie species (Eidson and Smeins, 1999). Human settlement and wildfire suppression has also contributed to the invasion of exotic species, such as King Ranch bluestem, bermudagrass, Arrundo, and Chinaberry.

Natural Communities

Edwards Plateau: Historical

Fossilized pollen of oak, juniper, other tree species, grasses, and forbs from Friesenhahn Cave in northern Bexar County date to the last ice age, 14,000-20,000 years ago (Hall and Valastro Jr, 1995). Eyewitness accounts of early explorers, settlers, and scientists from 1700-1900 reported extensive forests dominated by Ashe juniper and other woody species along the eastern edge of the Edwards Plateau (O'Donnell, 2019). These accounts are supported by other documents, including field notes from original land grants, maps, and photographs. Along with land clearing and introduction of livestock, historic records suggest the extent and frequency of fires increased following European settlement (O'Donnell, 2019, Weniger, 1984), which undoubtedly altered the vegetation communities. In addition to the endangered golden-cheeked warbler, which breeds exclusively in the Ashe juniper-oak forests of Central Texas, observations of the passenger pigeon (*Ectopistes migratorius*) (Lockwood, 2010) , flying squirrel (*Pteromys volucella*) (Mueller, 1935), and black bear (*Ursus americanus*) were reported in forests of the Edwards Plateau during the 1800s.

In the Austin area, forests were logged in the late 1800s and early 1900s and are currently in various stages of recovery (Bray, 1904, Keddy-Hector, 1996). After clearing, much of the topsoil was lost due to subsequent goat and cattle overgrazing and erosion. On some steep slopes, this soil loss has greatly reduced the revegetation potential (City of Austin and Travis County, 2018). Current and past over-browsing by white-tailed deer has reduced understory flora diversity and species abundance (Russell and Fowler, 2004, Russell, et al., 2001). While oaks tend to resprout following fire, Ashe juniper does not and is slow to recover (Reemts and Hansen, 2008, Reemts and Hansen, 2013).

Edwards Plateau: Current

The dominant natural community type currently found in the Edwards Plateau is upland forest, dominated by Ashe juniper, Texas red oak (*Q. buckleyi*), escarpment live oak (*Q. fusiformis*), shin oak (*Q. sinuata var. breviloba*), escarpment black cherry (*Prunus serotina var. eximia*), Texas ash (*Fraxinus texensis*), and cedar elm (*Ulmus crassifolia*). In addition to seedlings of the canopy trees, common understory species include Texas mountain laurel (*Dermatophyllum secundiflorum*), Carolina buckthorn *(Frangula caroliniana*), yaupon holly (*Ilex vomitoria*), red

buckeye (*Aesculus pavia var. pavia*), Mexican buckeye (*Ungnadia speciosa*), Lindheimer silk-tassel (*Garrya ovata var. lindheimeri*), and elbowbush (*Forestiera pubescens*) (City of Austin and Travis County, 2018). Texas madrone (*Arbutus xalapensis*) becomes more common on the western edge of the Austin area.

Blackland Prairie: Historical

Historical accounts suggest the Blackland Prairie region was dominated by flood-tolerant trees along the Colorado River, such as ash, cottonwood, elm, pecan, and willow (De Espinoza 1709, DeCordova 1858). Kennedy (1844) described Onion Creek as flowing "through a fine rolling country of mingled prairie and woodland: about ten miles from its mouth there is a grove of the best description of cypress, to the extent probably of six thousand acres. There are, besides, cedar, live oak, black walnut, white, red, and post oak, hackberry, mulberry, wild peach, &c." Other creeks were also similarly wooded, with prairie in between. Portions of the Blackland Prairie in East Austin have sandy soil that have historically supported post oak woodlands (Terrell 1910).

Blackland Prairie: Current

Significant portions of the Blackland Prairie have been converted to rangeland or row crops over the last two centuries. Overgrazed upland pastures are dominated by honey mesquite (*Prosopis glandulosa*) and groves of eastern red cedar *(Juniperus virginiana*) and cedar elm (*Ulmus crassifolia*) are also common in these areas. Shrubland patches can be found in the uplands as well, dominated by legume species like retama (*Parkinsonia aculeata*), catclaws (*Senegalia berlandieri, S. roemeriana, S. wrightii*) and other thorny bushes such as toothache (*Zanthoxylum hirsutum*) and Brasilwood (*Condalia hookeri*). The region is identified as the most altered ecoregion in Texas with 1% of the native Blackland Prairie remaining today (Ramos and Gonzalez, 2011; Clymer Meadow Preserve website, 2013).

Agricultural development in the 19th and 20th centuries likely resulted in considerable degradation of riparian woodlands through both channelization and deforestation. Impacted floodplains left fallow and allowed to recover are typically dominated by cedar elm (*Ulmus crassifolia*), retama (*Parkinsonia aculeatea*), hackberry and sugarberry (*Celtis laevigata, C. occidentalis*), with green ash (*Fraxinus pennsylvanica*) dominating the wetter portions near creek banks and with cottonwood (*Populus deltoides*), American sycamore (*Platanus occidentalis*) and black willow (*Salix nigra*) represented in smaller numbers. Seemingly undisturbed riparian remnants are less common and have more complex woody communities that, in addition to the above species, include canopy species such as pecan (*Carya illinoiensis*), American elm (*Ulmus americana*), red mulberry (*Morus rubra*), Anacua (*Ehretia anacua*), gum bumelia (*Sideroxylon lanuginosum*), catalpa (*Catalpa speciosa*), osage orange (*Maclura pomifera*), black walnut (*Juglans nigra*), and honey locust (*Gleditsia triacanthos*). These remnants typically have an understory consisting mostly of roughleaf dogwood (*Cornus drummondii*), Carolina buckthorn (*Frangula caroliniana*), possumhaw (*Ilex decidua*), yaupon (*Ilex vomitoria*), chickasaw plum (*Prunus angustifolia*), Mexican plum (*Prunus mexicana*), and soapberry (*Sapindus saponaria*).

Natural Community Types within the Study Area

For purposes of this urban forest vulnerability assessment, the natural communities within the area of interest were divided into four types: Upland Forest, Upland Woodland, Upland Mixed Shrubland, and Floodplains and Terraces (See Fig 1.2). These natural community types have similarities in vegetation species composition, structure, and potential for disturbance (Table 1.1). The four natural community types each include a unique grouping of Vegetation Types, as described and mapped by the Texas Parks and Wildlife Department's Ecological Mapping Systems Data (Elliott et al. 2014). Only Vegetation Types that fell within the area of interest were included for grouping into one of the four natural community types, based on differentiating criteria of overstory cover and species composition, understory species composition, hydrology, productivity, and disturbance potential. If the description of a Vegetation Type didn't meet the criteria for one of the 4 natural community type categories, it was included in a 5th, non-assessed category called "Other" (e.g., grasslands, open water, urban, and cropland) (See Table A.1, appendix A).

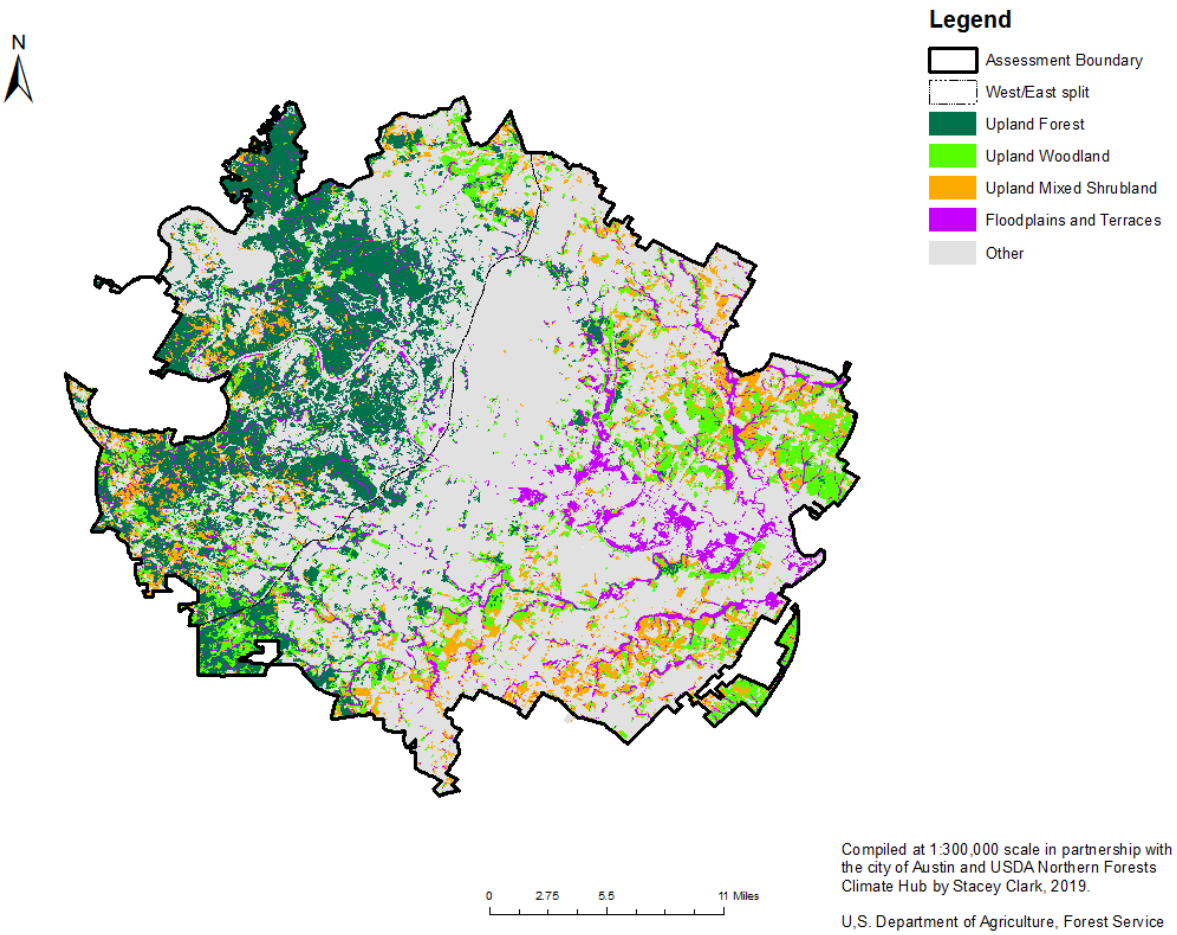

Fig 1.2—Map of the Natural Communities included in the Assessment: Upland Forest, Upland Woodland, Upland Mixed Shrubland, and Floodplains and Terraces. Natural Communities were mapped by grouping Vegetation Types from the Texas Parks and Wildlife Department's Ecological Mapping Systems Data (See Table A.1, Appendix A).

Table 1.1—Natural community types, the defining characteristics, and dominant or indicator woody species within each type.

Natural Community Type	Defining Characteristics	Dominant or Indicator Woody Species
Upland Forest	usually found on flats, steps, and lowlands in steeper slope areas with greater soil depth mesic microclimates high level of diversity in overstory mixed evergreen and deciduous tree species in the canopy typically >70% canopy tree cover shade, leaf litter, and rocky substrates can limit herbaceous vegetation	Trees: Ashe juniper, Texas red oak, Escarpment live oak, white shin oak, cedar elm, sugar hackberry, post oak, blackjack oak, Arizona walnut, Escarpment black cherry, Texas ash, gum bumelia, Texas redbud, Carolina buckthorn, rusty blackhaw, red buckeye, Mexican buckeye, Mexican plum, Texas madrone Shrubs: shrubby boneset, silktassel, yaupon, American beautyberry, agarito, Texas mountain laurel, possumhaw, elbowbush, Texas persimmon, catclaw mimosa, evergreen sumac, fragrant sumac
Upland Woodland	usually found on plateau tops and areas with more shallow soils historically fire driven, removing shrub layer but leaving overstory intact patchy shrub cover interspersed with pockets of herbaceous cover mixed evergreen and deciduous, or only deciduous, tree species in the canopy typically <70% tree cover overstory trees are usually not as tall as in Upland Forest	Trees: Ashe juniper, Escarpment live oak, cedar elm, sugar hackberry, post oak, white shin oak, blackjack oak, Shumard oak, live oak, mesquite Shrubs: Texas persimmon, Eastern redcedar, yaupon, agarito, Texas mountain laurel, whitebrush, flameleaf sumac, elbowbush, catclaw mimosa, gum bumelia, fragrant sumac, evergreen sumac
Upland Mixed Shrubland	usually found on xeric sites, slope edges, and along grasslands and woodlands in areas with very shallow soils trees do not dominate the canopy or tend to be stunted historically fire-driven mixed evergreen and deciduous woody species	Trees: Escarpment live oak, Ashe juniper Shrubs: Texas persimmon, mesquite, agarita, Texas mountain-laurel, Lindheimer's prickly pear, lotebush, fragrant mimosa, evergreen sumac, Texas colubrina, whitebrush, Lindheimer's silktassel, prairie sumac, Mexcian buckeye, elbowbush, kidneywood
Floodplains and Terraces	located in valley floors of large rivers and perennial streams, and buffer zones of headwaters erosional (riparian) sites are gravelly, cobbly, and rocky depositional (floodplain) sites have alluvial deposition historically driven by hydrology and floodplain dynamics loamy, clayey, and sandy bottomland soils are influenced by outwash from surrounding landscape species composition varies by stream order, successional stage, and flooding regime	Trees: sugar hackberry, cedar elm, Escarpment live oak, green ash, pecan, American elm, American sycamore, little walnut, western soapberry, Texas oak/Buckley oak, black walnut, Eastern cottonwood, Ashe juniper, Chinaberry, bald cypress, boxelder, Texas ash, Vitex, Chinese elm, wafer ash, Mulberry sp. Shrubs: Zanthoxylum sp., mesquite, black willow, Texas persimmon, common buttonbush, Eastern redcedar, possumhaw, desert willow, huisache, gum bumelia, roughleaf dogwood, yaupon, Baccharis, Chinese tallow, Japanese honeysuckle

Current Conditions in the Austin Region

Land use and Ownership

Trees and forests in Austin are arrayed across land cover, use, and ownership, including highly developed, privately owned commercial, mixed-use, or residential locations to publicly owned and managed natural areas. Developed areas makeup 39% of the total land area, natural areas including agricultural uses makeup 57% of the total land area, with the remaining land area being composed of open water (Table 1.2, Figure 1.3).

Table 1.2 – Land cover types (percent) in the assessment area, based on the National Land Cover Database.

Land Cover Type	Percent
Agriculture	10.91%
Developed, High Intensity	4.93%
Developed, Low Intensity	10.78%
Developed, Medium Intensity	10.01%
Developed, Open Space	13.57%
Natural area	46.63%
Open Water	2.62%
Other	0.56%
Grand Total	**100.00%**

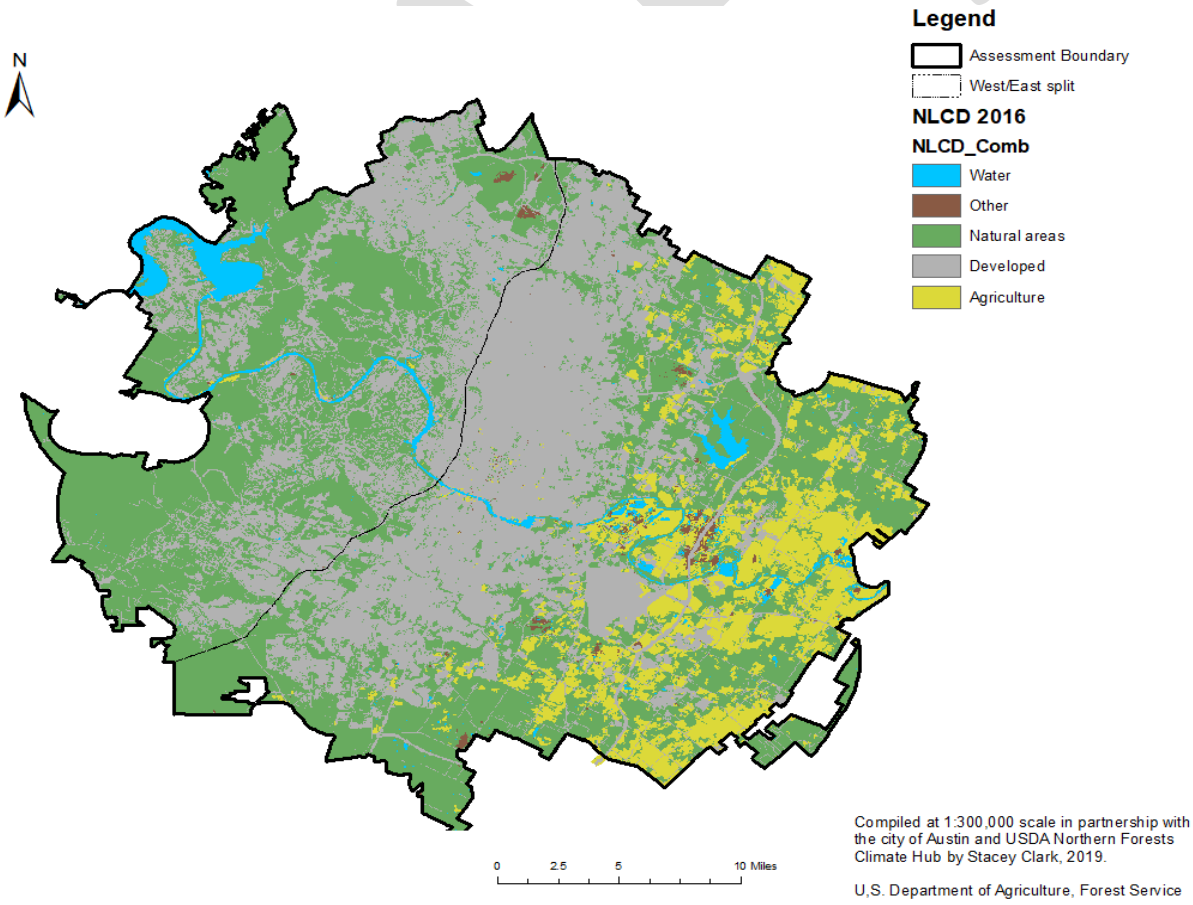

Figure 1.3—Land cover classes within the assessment area, based on the National Land Cover Database.

Roughly 24% of Austin's total land area is owned by the City of Austin. Figure 1.4 shows the distribution of parks owned by the City of Austin and areas of the Balcones Canyonlands Preserve (all ownerships) within the assessment boundary.

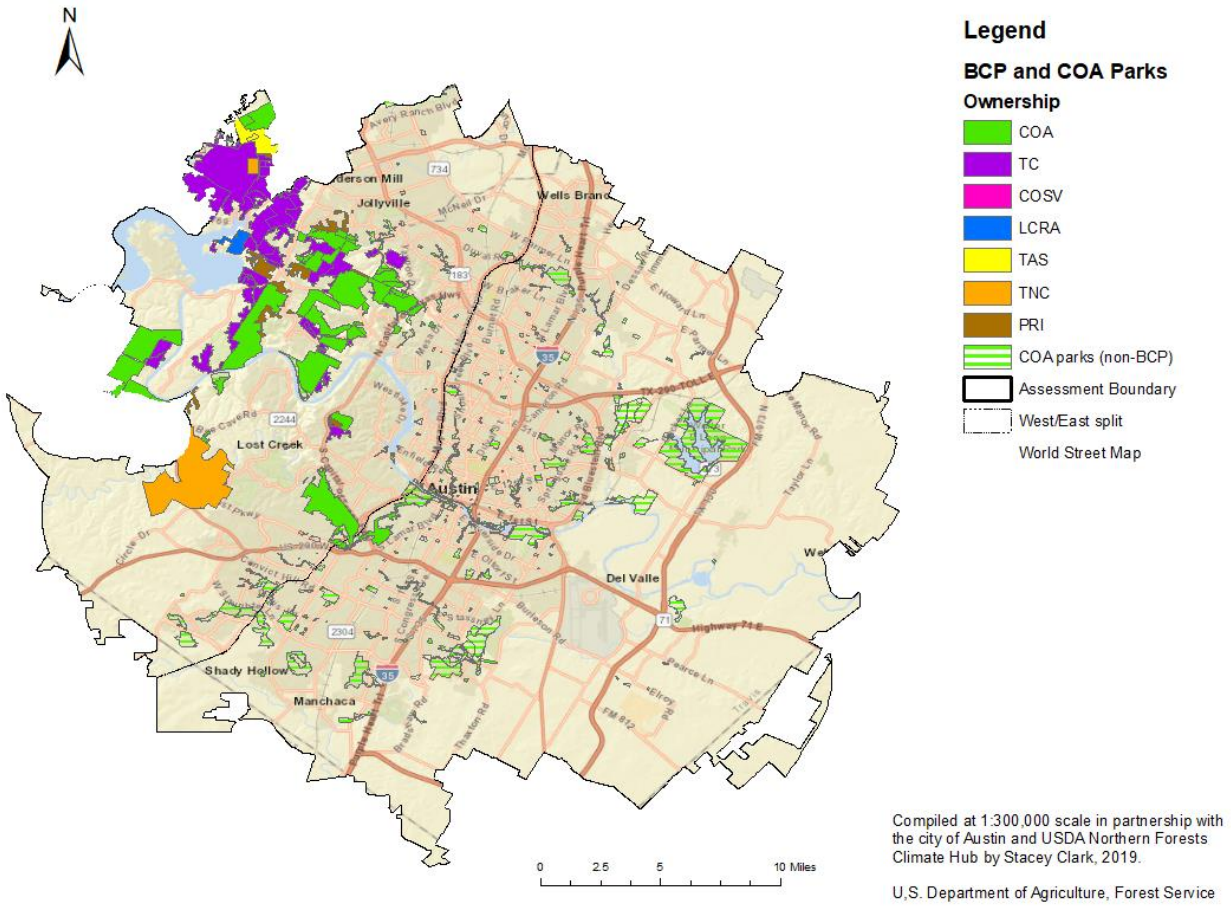

Figure 1.4—Map showing the distribution of parks owned by the City of Austin and areas of the Balcones Canyonlands Preserve (all ownerships) within the assessment boundary

Species composition patterns

The Austin region is a mixture of remnant (pre-settlement) trees, planted trees, and spontaneous recruitment from both sources. Urban forests often have higher tree species diversity than the surrounding native landscapes (Nowak, et al., 2016). Parks, natural areas, and other open spaces tend to have a higher proportion of remnant native vegetation, whereas planted trees (both native and non-native) dominate developed areas. Non-native, and invasive species are found throughout. Because East Austin was historically prairie with the exception of some floodplain forests, there are more tree species planted there that were not present historically. West Austin tends to be more of a mix of remnant native trees such as Ashe juniper, live oak and cedar elm alongside planted native and non-native trees.

Austin's Urban Forest Inventory and Analysis (FIA) report was published in 2014 (Nowak et al 2014). The analysis gives land managers benchmark data to project trends and advocate for management practices and resources to increase the resilience of the urban forest. The analysis finds that:

- Austin's urban forest contains 33.8 million trees.
- Tree canopy covers 30.8% of the city.
- The most common species are Ashe juniper, cedar elm, live oak, sugarberry, and Texas persimmon.
- The 10 most common trees in Austin account for 83.6% of all trees.
- 91.7% of trees are native to Texas.
- Trees with diameters less than 5 inches account for 61.3% of the tree population.
- The largest concentration of trees with a diameter greater than 15 inches are found along the Interstate 35 corridor; while these large diameter trees are only 3.4% of the total population they comprise 18.4% of the total leaf area.
- Large trees are a small proportion but a highly significant part of the ecosystem service benefits of the urban forest.

Evergreen forest comprised largely of live oak and ashe juniper cover 17.4% of the city. This land cover type is predominantly in the Edwards Plateau of West Austin. It contains 49.6% of Austin's trees and provides 48.5% of the leaf surface area (Nowak et al. 2016). Austin has more small trees than large trees which is a positive indicator of long-term sustainability of tree cover. The most common small diameter trees (less than or equal to 5") are Ashe juniper, cedar elm, Texas persimmon, sugarberry, live oak, yaupon holly, Texas mountain laurel, glossy privet (ligustrum), chinaberry, and green ash. The most common large diameter (diameter greater than or equal to 15") are Ashe juniper, live oak, cedar elm, pecan, sugarberry, red oak, honey mesquite, chinaberry and cottonwood. Many of the most common large diameter species are not represented in small diameter species composition (Nowak et al. 2016). If current large stature trees are not being replaced by other large stature trees, this may reduce the future potential canopy cover of Austin.

West and East Austin see a few major differences in species composition, with a total of four species forming 10% or more of species composition between both region (Table 1.3). In other words, two species (Ashe juniper and live oak) in West Austin make up 80% of species composition in the area, while four species (Ashe juniper, cedar elm, honey mesquite, and live oak) make up 60% of species composition in East Austin. The abundance of the most common species varies between these two regions. In West Austin, Ashe juniper make up the majority (68%) of species compared to a fifth in East Austin. Cedar elm is more common in East Austin at 18% compared to just 2% in the west. Honey mesquite makes up a tenth of species in East Austin, while live oak is similar at 12% and 14% in West and East Austin, respectively. There are also unique species found at lower abundances in each region. West Austin contains 11 species that aren't present in the east, while East Austin contains an additional 29 species compared to the west.

Table 1.3—composition of tree species by common name across west and east austin, texas. Source: Austin Urban Forest Inventory (Nowak et al. 2016).

Common Name	% of Total: West Austin	% of Total: East Austin	Common Name	% of Total: West Austin	% of Total: East Austin
American elm	< 1%	1%	Japanese privet	-	< 1%
American sycamore	1%	1%	Jerusalem thorn	-	< 1%
Ashe juniper	**68%**	**20%**	Live oak	**14%**	**12%**
Bald cypress	< 1%	-	Loquat	< 1%	-
Bastard oak	1%	-	Mescal bean	< 1%	< 1%
Berlandier ash	-	1%	Mexican white	-	< 1%

			oak		
Black walnut	< 1%	< 1%	Mimosa, silktree	-	< 1%
Boxelder	-	3%	Paper mulberry	1%	-
Buckley oak	4%	1%	Pecan	1%	2%
Bur oak	-	< 1%	Post oak	-	< 1%
Cedar elm	2%	**18%**	Prairie sumac	< 1%	-
Cherry and plum spp.	< 1%	-	Red mulberry	-	< 1%
Cherry laurel	-	< 1%	River birch	-	< 1%
Chinaberry	< 1%	1%	Roughleaf dogwood	-	< 1 %
Chinese elm	-	< 1%	Shumard oak	< 1%	1%
Chinese pistache	-	< 1%	Slippery elm	-	< 1%
Chinese privet	< 1%	2%	Southern magnolia	-	< 1%
Chinese tallow	< 1%	< 1%	Sugarberry	1%	8%
Chinkapin oak	< 1%	< 1%	Sweet acacia	-	< 1%
Chittamwood, gum bumelia	-	1%	Texas ash	1%	-
Crape myrtle	1%	1%	Texas live oak	-	< 1%
Eastern cottonwood	-	< 1%	Texas madrone	< 1%	-
Eastern red cedar	-	1%	Texas persimmon	1%	2%
Eastern redbud	< 1%	-	Texas red oak	-	< 1%
Edible fig	-	< 1%	Velvet ash	< 1%	1%
Florida thatch palm	-	< 1%	Water oak	-	< 1%
Glossy privet	< 1%	1%	Western soapberry	-	1%
Goldenrain tree	-	< 1%	White mulberry	< 1%	-
Green ash	< 1%	6%	Winged elm	-	1%
Hackberry	-	2%	Yaupon	1%	-
Honey mesquite	< 1%	**10%**	Other or unknown live tree	< 1%	-

Major stressors and threats to Austin's trees and natural areas

Land-use change, development and fragmentation

Development is the primary driver of forest change in the Austin region. From 2007 - 2017 Austin experienced 34.1% population growth and is projected to continue growing 30% each decade until 2050 (U.S. Census Bureau 2017). New zoning and development regulations are increasing mixed-used and multi-family developments, throughout Austin to accommodate for growth. These "urban infill" changes increase pressure on existing trees and natural areas, limit impervious space for new trees, and exacerbate the already challenging urban growing conditions by increasing the heat island effect, radiant heat, and reduced water infiltration.

Land use change and development alter natural species composition, distribution, and the functional capacity of the urban forest. While this can be detrimental, Austin has robust tree planting, tree preservation, landscaping, and related environmental regulations that provide mutually beneficial outcomes for the developer, the community, and the urban forest. Tree regulations and the environmental criteria manual prescribe tree species and planting specifications that help preserved and newly planted trees thrive in both current and future conditions. Austin's tree preservation ordinance was one of the first in the country to protect trees on both public and private property. Originally adopted in 1983, the ordinance was updated in 2010 to add protections for "Heritage" trees, a class of select species that are greater than 24 inches in diameter at breast height. As long as Austin has tree preservation and protection regulations, the trees on both public and private property will have the opportunity to provide the community with critical air, water, and public health benefits.

Land use change and development are also detrimental to genetic diversity and the buffering potential of remnant natural systems. Fragmentation of natural landscapes leads to isolated populations that are unable to migrate easily and exchange genetic material. This can reduce biological and genetic diversity (Fahrig, 2003, Harrison and Bruna, 1999, Robinson, et al., 1995). Fragmentation not only results in less connectivity among natural areas, but it also changes the structure of existing sites. As sites become fragmented and the amount of core ecosystem space is reduced, many plants and animals that rely on core habitat may be extirpated from the region (Saunders, et al., 1991). Additionally, habitat edges are more likely to be affected by pollution runoff from nearby roads and industry, and are more likely to contain invasive species. Consequently, they tend to be less biologically diverse than core areas, and offer less useful habitat for wildlife (Saunders et al., 1991).

Drought

Moderate and severe drought is a normal part of most Texas summers. Drought exacerbates stressful urban conditions including poor soil quality, inadequate soil volume, irregular supplemental water, and the urban heat island effect. The state of Texas experienced the worst drought ever recorded in 2011. The Texas A&M Forest Service estimated that 10% of trees were lost statewide in 2011, and weakened and stressed trees continued to succumb to secondary stressors in subsequent years. Drought stress makes trees more vulnerable to insects and disease. On the Edwards Plateau, Crouchet et al. (2019) reported a 20% crown mortality for Ashe juniper and 23% for live oak, with tree mortality decreasing with increasing tree size. In the Austin area, Ashe juniper and live oak are two of the most common tree species, with crown mortality estimated at 11% and 9%, respectively (Nowak et al. 2016).

Alteration of soil

Changes in land use has altered soils in the region. Although little research is available specific to the Austin region, studies from other urban areas shed light on the likely impacts. In other areas, atmospheric deposition of nitrate, ammonium, calcium, and sulfate ions has been detected in areas nearly 30 miles from the urban core (Lovett, et al., 2000). In heavily urbanized sites, soils tend to be compacted, which can decrease the rate at which water enters the soil, increasing rainwater runoff and making it more difficult for trees to grow (Gregory, et al., 2006). Development and industrialization have caused the deposition of heavy metals like lead, copper, and nickel (Pouyat, et al., 1995). Heavy metals are more abundant in dense urban cores and are associated with industrial areas, but are also deposited near roadways (Helmreich, et al., 2010). Runoff from limestone and concrete causes many urban soils to be more alkaline than is found in most natural areas (Ware, 1990). The most severely altered soil conditions occur in tree pits: cut outs in the sidewalks or along roads where trees are planted, which are frequently nutrient deficient, heavily compacted, and have some of the heaviest salt inputs (Craul, 1999).

Invasive plant species

Invasive plant species influence the structure, composition, and functioning of forests in the area. Nonnative invasive species comprise 5.1% of the tree population, about 1.7 million trees (Nowak et al. 2016). Two invasive trees comprise a significant portion of Austin's urban forest: chinaberry is found throughout Austin and is among the 10 most common small diameter and large diameter trees in Austin. Glossy privet (ligustrum) is one of the most

common small diameter trees. It is also found throughout Austin but causes the greatest adverse impacts in natural and riparian areas where its tendency to become a monoculture reduces biodiversity. Glossy privet further impacts the environment by shading out understory vegetation leaving bare soil prone to erosion during heavy rain or flood events. Nine of the 62 tree species found in Austin are on the regional invasive species list (Watershed Protection Department, n.d.).

Shifts in fire regime

Although historic fire regimes are often assumed, little supporting documentation prior to European settlement exists for either the Blackland Prairie or eastern edge of the Edwards Plateau (Stambaugh, et al., 2014). Based on historic eyewitness accounts (O'Donnell, 2019, Weniger, 1984), few fires were mentioned in the 1700s and those that were present appeared to have been small and used to hide or escape and to communicate (smoke signals). While the sample size is small and from a limited area, tree ring analyses collected from 158 tree slabs on the Balcones Canyonlands Preserve suggest an increasing fire frequency on the eastern edge of the Edwards Plateau following European settlement, with a peak in the 1950s, followed by a decreasing trend. Tree ring analyses on the Balcones Canyonlands National Wildlife Refuge show a similar trend (Murray, et al., 2013).

Combined with logging and introduction of domestic livestock, changing fire frequencies undoubtedly altered the structure and composition of the vegetation in the region, but the full effects are unknown. Bray (1904, 1904) discussed soil erosion and drying, oak resprouting, and regrowth of Ashe juniper from seed, using areas near what is today the Balcones Canyonlands Preserve as examples. Based on more recent research following a wildfire at Fort Hood Military Reservation, oaks vigorously resprouted, while Ashe juniper (which does not resprout) has been slow to recover (Reemts and Hansen, 2008, Reemts and Hansen, 2013). Comparable studies have not been not found for the Blackland Prairie.

Sixty percent of the structures in Austin are in the Wildland Urban Interface (WUI), areas where wildlands and communities mix. Austin Fire Department conducts prescribed burns in Wildlands (areas greater than 10 acres), and provides outreach to communities to help them establish Community Wildfire Protection Plans.

Insect pests and diseases

Both native and nonnative insect pests and diseases affect trees and forests, especially in developed areas. Trees and forests are often already under stress due to the "urban condition" which usually includes poor soil quality, inadequate volume, and the urban heat island. Stressed trees are more vulnerable to insects and diseases. In Austin, the primary forest health threats include oak wilt, emerald ash borer, Dutch elm disease, and bacterial leaf scorch.

Oak wilt - Oak wilt is a primary fungal pathogen that invades the vascular system of oak trees. While all oak trees are susceptible, the live oak and red oak are most commonly affected trees in Austin. Live oak comprise 8.4% and red oak comprise 1.2% of the tree canopy. Both species are found throughout Austin but are more prevalent in west Austin. Live oak trees are most commonly impacted by the underground spread of the fungus through root graft connections. Naturally occuring live oak stands with interconnected root systems are found throughout central and west Austin and they are planted throughout Austin. Red oak trees also become infected and play an important role in fungal spore dispersal and the creation of new infection areas. Increased temperatures could reduce the viability and duration of fungal mats (pressure pads) and spores, and the primary insect vector (Coleoptera: Nitidulidae) may be impacted positively or negatively by higher temperatures. General data and models to project insect transmission of oak wilt are lacking (Jagemann et al. 2018).

Emerald ash borer - The emerald ash borer insect was confirmed 200 miles from Austin in Fort Worth, Texas in 2018. This insect causes catastrophic loss to all ash species. A major interstate highway connects the two communities; emerald ash borer may already be in Austin but remain undetected. Ash is the 9th most common tree in Austin and comprises 4.2% of the tree canopy. The majority of naturally occuring ash (*Fraxinus pennsylvanica, F. texana*) exist in riparian areas and undeveloped areas. All of the Arizona ash (*F. velutina)* were planted and are

located in developed and maintained areas. Texas A&M Forest Service has a monitoring program to assist with early detection.

Dutch elm disease - Dutch elm disease (DED) is caused by a fungus that infects the vascular system of elm trees. While DED has not been confirmed in Austin, it has been found in several other communities throughout Texas. It is likely that the DED pathogen is more widespread throughout Texas but has simply avoided detection (Appel, 2009). American elm trees are the most vulnerable, they naturally occur in floodplains and low terraces, especially in east Austin. Cedar elm trees have intermediate susceptibility to DED and are found in naturally occurring stands throughout Austin and are also widely planted. Elm bark beetles are a primary vector, they breed in dead and dying elms, where the pathogen forms copious spores in the galleries. As the new populations of beetles emerge from the contaminated galleries, they disperse to feed in twig crotches on healthy elms.

Bacterial Leaf Scorch - Bacterial leaf scorch (BLS) is a chronic and eventually fatal disease caused by the bacterium *Xylella fastidiosa*. It is most commonly transmitted by insects with piercing mouthparts including the leafhopper, sharpshooter, or spittlebug, insects that pierce and suck leaf tissue (Hu, 2018). Leaf and dieback symptoms can appear similar to drought and are most noticeable in late summer early fall. Susceptible trees in Austin include oaks, pecan, sycamore, sugarberry, mulberry, elm, and olive. There is no cure for bacterial leaf scorch but antibiotic treatments and good cultural practices may help prolong the life of infected trees. High temperatures and drought amplify the stress of BLS, with greater temperatures and drought the impact from BLS on Austin trees is likely to increase.

CURRENT MANAGEMENT

Management of natural systems in the region

On the Edwards Plateau ecoregion, natural areas consist of the Balcones Canyonlands Preserve (BCP) and Water Quality Protection Lands (WQPL). Both BCP and WQPL are currently developing plans to prepare for climate change with the goal of protecting their vital watershed and habitat services. The BCP is a system of preserves managed under the terms and conditions of the Balcones Canyonlands Conservation Plan, a regional permit issued under the Endangered Species Act in 1996 by the U.S. Fish and Wildlife Service and jointly held by Travis County and the City of Austin. A number of cooperating partners own and manage lands dedicated to the BCP, including the Lower Colorado River Authority, the Nature Conservancy of Texas, Travis Audubon Society, and several private landowners. These partners collectively manage over 31,780 acres as mitigation for eight endangered species (two neotropical migratory songbirds and six karst invertebrates) and 27 species of concern (two perennial plants and 25 karst invertebrates). The BCP also provides habitat for many other native plants and animals and contributes to improved air and water quality and quality of life for the people of Austin. Management focuses primarily on protecting and enhancing Ashe juniper-oak forests and karst ecosystems, as well as shrublands. Regenerative strategies to help counter anticipated effects of climate change include promoting healthy soils (including mycorrhizal networks and soil organic matter); the diversity of native plant composition and structure (ground cover, shrub cover, canopy); mesic conditions (by providing shade and capturing, spreading, and sinking rainfall); invasive species removal; restoration of karst ecosystems; reforestation; and connectivity with other forests and protected areas.

The Water Quality Protection Lands (WQPL) conserve land in fee title and conservation easement in the Barton Springs contributing and recharge zones. The goal is to maintain and improve the quality and volume of water from project lands to recharge the Barton Springs segment of the Edwards Aquifer. Currently, the WQPL manages over 11,000 acres as fee simple. While most of WQPL is managed for grassland, management of woodlands in preparation for climate change may include promoting old-growth conditions, shaded fuel breaks, diversity planting, strategic thinning to encourage canopy diversity and resource availability, or even pre-transitioning to a more

drought-tolerant community type such as an open woodland or shrubland, depending on factors such as endangered species habitat, topography, aspect, soil conditions, access, canopy composition, and proximity to wildland-urban interface.

Selection and management of trees in developed sites

Trees that are planted in developed areas undergo much different stressors than trees in natural areas, and consequently their species composition and management differs as well. Trees selected for planting on streets and other developed areas need to withstand challenging environmental conditions such as urban heat island effects, air pollution, and soils with compaction, high pH, poor drainage, and heavy salt loads (Nowak 2012).

The primary factor municipal foresters and land managers in Austin consider when planting new trees is the right tree, right place concept. Primary factors that inform this in Austin include the availability of potable or reuse water for establishment, drought tolerance, heat tolerance, mature height, required maintenance, invasive potential, and wildlife benefit. Many urban foresters aim to plant no more than 30% of a given family, 20% of a genus, and 10% of a species (Santamour Jr, 2004). However, recent studies suggest a more nuanced approach to managing for enhanced diversity (Lacan & McBride 2008). Many municipal foresters have limited budget and capacity for structural pruning and are reluctant to plant trees that require regular pruning to encourage good shape or to prevent against breakage; instead, they prefer trees that are able to withstand storms with minimal maintenance.

Austin's Urban Forest Master Plan

The City of Austin completed an Urban Forest Master Plan (The Plan) in 2014 to guide comprehensive management for trees and vegetation on Austin's public property. The requirement for a Plan is both codified (Section 6-3-5) and recommended by the 2012 Imagine Austin Comprehensive Plan as a strategy to protect and expand green infrastructure. the Urban Forester and Urban Forestry Board coordinate with forestry programs in various departments to implement the plan. The Plan envisions that Austin's urban forest is a healthy and sustainable mix of trees, vegetation, and other components that comprise a contiguous and thriving ecosystem valued, protected, and cared for by the City and its citizens as an essential environmental, economic, and community asset. It provides baseline measurements of the vegetative resource, the community stewardship framework, and resource management policies and practices.

SUMMARY

Austin's urban forest, shaped by ecosystems, landforms, and environmental gradients, is made up of interconnected natural areas and developed sites. Rapid growth paired with climate change presents a concern for Austin's trees and green spaces. Composed of two ecoregions - Edwards Plateau and Blackland Prairie - and divided by the Balcones Escarpment fault line, Austin is prone to flood-producing storms and unique challenges due to differences in biotic and abiotic factors between the ecoregions. Understanding the structure and function of the landscape setting as well as current conditions, stressors, and management provides a foundation for how a shifting climate may impact Austin's trees, urban forests, and landscape stressors. In terms of tree species composition, the majority of West Austin (68%) is composed of Ashe juniper, followed by live oak (14%) while East Austin is composed of Ashe juniper (20%), cedar elm (18%), live oak (12%), and honey mesquite (10%). Current stressors and threats to Austin's trees and natural areas include land-use change, development, and fragmentation; drought; alteration of soil; invasive plant species; shifts in fire regime; and insect pests and diseases. Austin's Urban Forest Master Plan (2014) was developed to guide tree and vegetation management on Austin's public property. In addition, partners manage natural systems in the Austin region to preserve plant and wildlife habitat, improve air and water quality, protect and enhance urban forests and shrublands, and develop strategies to counter climate change effects.

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Key Points

- Austin is composed of two ecoregions: Edwards Plateau to the west and Blackland Prairie to the east.
- This urban forest vulnerability assessment divided Austin's natural communities into four types: Upland Forest, Upland Woodland, Upland Mixed Shrubland, and Floodplains and Terraces, which have similarities in vegetation species composition, structure, and potential for disturbance.
- Austin's urban forest is made up of 33.8 million trees with a tree canopy covering 30.8% of the city.
- The majority (91.7%) of trees are native to Texas, and the ten most common trees account for 83.6% of all trees.
- Natural areas, including agricultural uses, make up the majority of total land area (57%) while 39% of total land area is considered developed area and the remaining is composed of open water.
- Historically prairie, East Austin has more tree species that were not present in the past, while West Austin is a mix of remnant natuve trees, dominated by Ashe juniper alongside live oak, cedar elm, and other planted native and non-native trees.
- Development and land use change have led to transformation of the area's vegetation structure, composition, and function.
- Additional stressors and threats to Austin's trees and natural areas include drought, alteration of soil, invasive plant species, shifts in fire regime, and insect pests and diseases, including oak wilt, emerald ash borer, Dutch elm disease, and bacterial leaf scorch.
- When selecting trees to be planted in developed sites, which undergo different stressors compared to trees in natural areas, the primary factor considered is the right tree, right place concept.
- Managers in Austin's natural and developed areas are working to manage Austin's urban forest to sure it continues to provide habitat for wildlife and benefits to people.

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

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