RESTORATION OF FORMER GRASSLAND IN SOUTH-CENTRAL TEXAS

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Abstract.–In the past, grasslands and savannas were common in many areas of south-central Texas, including the San Antonio area. With the advent of European settlers and their livestock, much of this area was converted to agriculture and rangeland. Today, most of San Antonio is developed, but some preservation has occurred. Restored grassland, mechanically cleared of *Juniperus ashei* (juniper, Ashe juniper) and other woody species in 2013, was examined and compared to adjacent non-cleared woodland. The woodland examined was dominated by *Diospyros texana* (Texas persimmon) and *Juniperus ashei*. Richness in the woodland canopy was 15 species. The understory below the canopy had 25 woody species. In the restored grassland area, herbaceous plant cover was 41.8%, woody plant cover 5.8%, bare soil 2.9%, and litter cover 49.5%. Species richness was 71, with 60 herbaceous and 11 woody species (percent cover of each from <0.1-7.1%). The most common species in the restored grassland in descending order were *Nassella leucotricha* (Texas winter grass), *Calyptocarpus vialis* (straggler daisy), *Carex planostachys* (cedar sedge), *Sporobolus crypandrus* (sand dropseed), *D. texana*, and *Verbesina virginica* (frost weed). Several C_4 grass species were present with low cover but may increase in abundance over time. Four of the six most common restored grassland species were present below the woodland canopy and 12 woody species were present in the restored grassland as juveniles. Cost of restoration was approximately $38,500 ($7,500 supplies, $31,000 labor).

Keywords: restoration, grassland, savanna, Ashe juniper, prairie

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Understanding patterns of species recruitment and identifying factors that control recruitment are major ecological, conservation and management needs (Russell & Fowler 2002). Identification of minimally disturbed native prairie ecosystems for use as reference areas in restoration is difficult (see Kettle et al. 2000; Long et al. 2014; Ratajczak et.al. 2016; Millikin et al. 2016). Five main factors caused changes in North American native prairies: (1) the last glacial retreat (Van Devender 1995), (2) presence of Native Americans (Collins & Wallace 1990), (3) the arrival of the Europeans and their animals (Inglis 1964), (4) reductions of carnivores (Ripple et al. 2015)

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and (5) reduced fire frequency and intensity (Beschta & Ripple 2009; Leonard & Van Auken 2013; Nelson Dickerson & Van Auken 2016). In the future, global climate changes will no doubt have considerable effects (Grunstra & Van Auken 2015).

Increasing temperature was important in causing modifications in plant communities over the past 20,000 years, and changes were gradual compared to alterations seen today. Native grasslands and savannas in Central Texas were common in the past, but today they are sparse, especially tallgrass prairie (Glaser 2012; Harmon-Threatt & Chin 2016; Comer et al. 2018), with juniper/oak/persimmon (*Juniperus/Quercus/Diospyros*) or mesquite (*Prosopis)* woodlands replacing many of the prairie or grassland communities (Riskind & Diamond 1988). Changing management strategies and their effects on long-lived species and communities are difficult to follow, especially in private property states like Texas (Carpenter & Brandimarte 2014). Changes in environmental conditions cause ecological succession in plant communities including prairie habitats (Van Auken & Bush 2013). As European emigrants came to Texas, they converted grassland to cropland in areas where rainfall was sufficient and soils were deep. Where soils were shallow and rainfall was reduced, domestic animals were introduced. In this rangeland, the grasses were reduced by domestic herbivores, and grassland fires were reduced because of lack of fuel (Collins & Wallace 1990). Various woody species encroached or were introduced and the grasslands changed resulting in more savanna and woodland (Riskind & Diamond 1988; Diamond et al.1995; Van Auken 2000; 2009; Van Auken & Bush 2013).

The purpose of this study was to evaluate the effectiveness of restoration by determining the identity and relative cover of species present in a new grassland three years after mechanical removal of a *Juniperus/Diospyros* (juniper/persimmon) woodland and to compare it to adjacent non-cleared woodland. Plant species identity, density, basal area, and relative cover were variables measured or calculated.

MATERIALS & METHODS

Site description.–The study site was located within the City of San Antonio between the Blackland Prairie to the east, the Edwards Plateau to the north and northwest, and north of the South Texas Plains (Correll & Johnston 1979). Blackland Prairie vegetation exhibits local variation over short distance due to changes in topography and soil composition (Collins et al. 1975; Diggs et al.1999). Thus, Blackland Prairie, including much of the study site was probably a mosaic of grassland and savanna in the past. Until recently, most of the study site was *Juniperus/Diospyros* woodland with little conservation of native plant communities, especially prairie or grassland communities (Stimson 2008; Spencer 2010). There were woody species present typical of the South Texas Plains (Correll & Johnston 1979; Stimson 2008; Spencer 2010).

The study site was a 2.0-ha urban natural area owned and managed by the City of San Antonio since 2007. Until purchase by the city, the site was part of the Voelcker Dairy Farm grazed by cattle for more than 100 years. The general nature of the park can be seen in an aerial photograph taken in 2015 (Fig. 1). Historically not always woodland, the majority of the park is currently dominated by evergreen and deciduous trees and shrubs, with only small amounts of grassland. The restored grassland studied was just north of the park headquarters (see Fig. 1).

The study site was 350 m above mean sea level (AMSL) and approximately 20 km south of the Balcones Escarpment of the Edwards Plateau region of Central Texas (Correll & Johnston 1979; Leonard & Van Auken 2013). The parent material was residuum weathered from Austin Chalk, which is magnesium or calcium bedrock (USDA NRCS 2006). Soils were dark colored, calcareous, neutral or slightly basic and are identified as Austin silty clay and Whitewright-Austin complex that are 24.5 cm to 109.2 cm deep (USDA NRCS 2006). Average precipitation is 78.7 cm/yr with peaks in May and September (10.7 cm and 8.7 cm respectively), highly variable and usually zero in July and August (NOAA 2004). The

Figure 1. Aerial photograph of part of Hardberger Park including the study area in 2015. Depicted are three restoration plots by year of clearing most woody plants. A few large trees, including live oak (*Quercus fusiformis*), Ashe juniper (*Juniperus ashei)*, and Texas Persimmon (*Diospyros texana)*, were kept throughout the restoration plots and can be seen as dark spots in the aerial photograph. Ten transects (depicted by light dashed lines) were set up in the 2013 restored grassland. Woodland transects were placed in adjacent woodland and are described as Upper (Transect 1), Middle (Transect 2), and Lower (Transect 3) based on slight elevation differences on site.

study area had some plants typically found in the Edwards Plateau, Blackland Prairie, and South Texas Plains ecoregions (Correll & Johnston 1979; McMahan et al. 1984; Stimson 2008). The Buda formation (similar to the Austin Chalk) near the southern Edwards Plateau has woody plants consistent with many seen within the study site (Van Auken et al. 1979; Stimson 2008).

Restoration.–The current study site was approximately 2.0 ha and is adjacent to 25 ha of *Juniperus* woodland (Fig. 1). In the summer of 2013, most of the woody plants in the study area were cut down and mulched using a Barko 930 tractor (Brush Busters Land Clearing), but no herbicide was applied. A few large trees were retained. During the Fall of 2013 and the Spring of 2014, volunteers disseminated native grass and wildflower seed throughout the site. Seed mixes included Prairie Starter Mix, applied at approximately 11 kg/ha, and NativeTexas Mix, applied at approximately 23 kg/ha (Native American Seed, Junction, TX.). Species composition in the seed mixes included various C_3 and C_4 grasses and native herbaceous plants. Density and identity of seeds in the soil was unknown. The aerial photograph shown (Fig. 1) was from the City of San Antonio's GIS database and edited using ArcGIS 10.1. Associated costs for this 2-ha section of grassland restoration, including staff and volunteer time, was approximately $38,500.

Survey methods.–In Fall of 2015, ninety-four 1 m x 1 m quadrats were placed 10 meters apart along each of 10 transects that crossed the 2-ha reconstructed 2013 grassland. In each quadrat, each herbaceous and woody species was identified (Correll & Johnston 1979) and confirmed (USDA NCRS 2016) and density calculated. Percent cover of each species, litter, and bare ground were visually estimated (Van Auken et al. 2005). Total number of species (species richness) was tabulated and species diversity was calculated.

In the adjacent woodland, 25-m^2 quadrats were placed 10 m apart along three transects at slightly different elevations. Each overstory woody plant present in each quadrat was identified (Correll & Johnston 1979) and confirmed (USDA NCRS 2016) and density was calculated. In addition, five 20 cm x 50 cm quadrats were placed in each of the corners as well as one in the center of each 25-m^2 quadrat and the number of individuals of each understory woody species was counted and recorded (density and relative density were determined, see Van Auken et al. 2005). For each individual >1cm in diameter and 1.37 m tall, basal diameter was measured with calipers and recorded. Basal area for each individual was determined and total basal area of each species was calculated as well as relative basal area. Mean values for overstory and understory were calculated (relative values were calculated but not presented). Sampling of the restored grassland and woodland was adequate as demonstrated by leveling of density stabilization curves.

RESULTS

A ground-level photograph shows the 2013 restoration landscape two years after woody plant removal, in Fall of 2015, with associated woodland in the background (Fig. 2). In the woodland, overstory woody plant density was 2,540 plants/ha in the upper or high elevation site (Table 1). Overall, woody plants with the highest density were *Diospyros texana* (Texas persimmon), *Juniperus ashei* (Ashe juniper) and *Celtis laevigata* (sugar hackberry). *Sideroxylon lanuginosum* (gum bumelia) and *Condalia hookeri* (blue-wood condalia) were common in the two higher elevation transects while *Prosopis glandulosa* (mesquite) was common in the lower two elevation transects. Highest basal area species were *D. texana*, *J. ashei*, with *C. laevigata* slightly lower. *Prosopis glandulosa* basal area was high, but it was only present in the two lower elevation transects (Table 1). Woodland overstory species richness was 15. Shannon species diversity (H') was 0.620 for the woodland overstory, while Simpson (D) was 3.238. In the woodland understory, highest density of woody plants (juveniles or immatures), was *Smilax bona-nox* (green briar, a woody vine), *C. laevigata*, *Ulmus crassifolia* (cedar elm, and *S. lanuginosum* (Table 2). There were a total of 25 woody or succulent species including 12 trees, 9 shrubs, 2 woody vines and 2 cacti. There were two non-native species including *Nandina domestica* and *Ligustrum lucidum* found in the understory.

In the restored grassland, herbaceous plant cover was 41.8%, woody plant cover was 5.8%, bare soil was 2.9% and litter cover was 49.5%. Species richness was high with a total of 71 species, including 60 herbaceous and 11 woody species, with percent cover of each from <0.1-7.1%. Shannon species diversity (H') was high at 64.50 for the restored grassland, while the Simpson (D) value was 0.500. The most common species in descending order were *Nassella leucotricha* (Texas winter grass) at 7.1% cover, *Calyptcarpus vialis* (straggler daisy) at 6.9%, *Carex planostachys* (cedar sedge) at 4.7%, *Sporobolus crypandus* (sand dropseed) at 4.1%, *D. texana* at 4.0%, and *Verbesina virginica* (frost weed) at 3.4% (Table 3). Twenty-two other species

Figure 2. Photograph depicting landscape 2 years following tree and shrub removal in 2015 at a grassland restoration site in Phil Hardberger Park, San Antonio, Texas.

Table 1. Mean density (plants/ha) and basal area (m^2/ha) of overstory woody species identified in three woodland transects (at slightly different elevations) associated with the reconstructed prairie at Hardberger Park ("0" in the table indicates the species was not found in that transect, and "----" in the table indicates the species had a % density of < 1 and a comparable density in that transect).

Species	Upper Transect Density (plants/ha)	Upper Transect Basal Area (m^2/ha)	Middle Transect Density (plants/ha)	Middle Transect Basal Area (m^2/ha)	Lower Transect Density (plants/ha)	Lower Transect Basal Area (m^2/ha)
Diospyros texana	1009	4.9	1540	9.9	866	4.7
Juniperus ashei	922	8.8	267	3.2	287	1.4
Celtis laevigata	331	2	83	3.2	89	0.8
Sideroxylon lanuginosum	70	<0.1	66	0.4	11	0.1
Condalia hookeri	87	0.1	117	0.5	33	0.1
Eysenhardtia texana	52	0.2	22	0.1	0	0
Ulmus crassifolia	17	0.2	50	1	0	0
Ptelea trifoliata	17	---	0	0	0	0
Berberis trifoliolata	26	---	0	0	0	0
Forestiera pubescens	9	---	0	0	33	---
Prosopis glandulosa	0	0	66	2	100	2.8
Nandina domestica	0	0	5	---	---	---
Sapindus saponaria	0	0	10	---	11	0.1
Quercus fusiformis	0	0	10	---	0	0
Yucca elata	0	0	10	---	0	0
Totals	**2540**	**16.2**	**2246**	**20.3**	**1430**	**10**

Table 2. Density (plants/ha) and relative density (%) of understory woody species identified in three woodland transects (at slightly different elevations) associated with the reconstructed prairie at Hardberger Park ("0" in the table indicates the species was not found in that transect, and "----" in the table indicates the species had a % density of < 1 and a comparable density in that transect).

	Upper Transect		Middle Transect		Lower Transect	
Species	Density (plants/ha)	% Density	Density (plants/ha)	% Density	Density (plants/ha)	% Density
*Smilax bono-nox**	11492	64	2345	12	667	6
*Forestiera pubescens***	1796	10	782	4	778	7
Sideroxylon lanuginosum	1257	7	3517	19	111	1
*Mahonia trifoliolata**	898	5	1172	6	1222	11
Celtis laevigata	718	4	2540	13	4167	38
Diospyros texana	539	3	977	5	889	8
Juniperus ashei	359	2	391	2	444	4
Ligustrum lucidum	359	2	---	---	0	0
Quercus virginiana	180	1	391	2	833	8
*Eysenhardtia texana***	---	---	195	1	56	---
Ulmus crassifolia	---	---	5275	27	278	3
*Ptelea trifoliata***	---	---	---	---	0	0
Morus microphylla	0	0	---	---	0	0
*Cylindropuntia leptocalulis****	0	0	1172	6	611	6
Condalia hookeri	0	0	195	1	667	6
*Clematis drummondii**	0	0	---	---	0	0
*Opuntia compressa****	0	0	195	1	56	---
Sapindus saponaria	0	0	---	---	0	0
*Colubrina texensis***	0	0	195	1	0	0
*Aloysia gratissima***	0	0	0	0	111	1
Styphnolobium affine	0	0	0	0	56	---
Fraxinus pennsylvanica	0	0	0	0	56	---
Prosopis glandulosa	0	0	0	0	---	---
*Nandina domestica***	0	0	0	0	---	---
Yucca elata	0	0	---	---	0	0
Total	**17598**	**99**	**19342**	**99**	**11002**	**99**

*woody vine

**shrub

***cactus

Table 3. Mean percent cover in descending order of the main species found in the restored grassland. A total of 71 species were identified, 28 with cover equal or greater than 0.1 % is listed in the table. There were 43 species with cover values less than 0.1 % but not presented.

Species	Common Name	Mean % Cover
Nassella leucotricha	Texas wintergrass	7.1
Calyptocarpus vialis	Straggler daisy	6.9
Carex planostachys	Cedar sedge	4.7
Sporobolus cryptandrus	Sand dropseed	4.1
Diospyros texana	Texas persimmon	4.0
Verbesina virginica	Frost weed	3.4
Elymus canadensis	Canada wildrye	2.9
Setaria vulpiseta	Plains bristlegrass	2.8
Panicum obtusum	Vine mesquite	1.8
Bouteloua curtipendula	Side oats grama	0.9
Croton monanthogynus	Prairie tea	0.8
Tridens texanus	Texas fluffgrass	0.7
Bothriochloa laguroides	Silver beardgrass	0.7
Schizachyrium scoparium	Little bluestem	0.6
Abutilon incanum	Indian mallow	0.6
Berberis trifoliate	Agarita	0.4
Sorghastrum nutans	Indian grass	0.4
Amphiachyris dracunuloides	Prairie broomweed	0.3
Oxalis dillenii	Slender yellow woodsorrel	0.2
Aloysia gratissima	Whitebrush	0.2
unknown c3	C_3 grass	0.2
Condalia hookeri	Brazilian bluewood	0.2
Eriochloa sericea	Texas cupgrass	0.2
Parietaria pensylvanica	Pennsylvania pellitory	0.2
Ratibida columnifera	Upright prairie coneflower	0.2
Clematis drummondii	Drummond's clematis	0.1
Tragia glanduligera	Brush noseburn	0.1
Tripsacum dactyloides	Eastern gamagrass	0.1

had percent cover values equal to or greater than 0.1% (Table 3), and 43 other species had cover values less than 0.1% (not presented). There were 19 species of grasses identified including three C_3 and 16 C_4 species. Total cover for the C_3 and C_4 grasses was 10.2% and 12.3%, respectively.

DISCUSSION

Vegetation in world-wide grasslands has been estimated at about 24% of Earth's terrestrial surface, or more than 4.6 x 10^9 ha (Shantz 1954). Grasslands were the largest North American biome covering 370 x 10^6 ha in the U.S., Mexico and Canada (Sims 1988). Unfortunately, most grassland in central North America has been converted to farmland. Estimates suggest that less than 1% of the original, native tallgrass prairie remains (Glaser 2012; Harmon-Threatt & Chin 2016; Comer et al. 2018), consequently the need for restoration and conservation. San Antonio, in the south-central part of Texas, is situated in part on what is called the "Blackland Prairie" biome (Correll & Johnston 1979). Blackland Prairies are one of the poorest conserved and most degraded of all the grassland types (Comer et al. 2018), thus making comparisons of the re-vegetated community with other local grasslands difficult. A number of biomes meet in the San Antonio area of south-central Texas resulting in a diverse mix of plant species in the study area (Stimson 2008).

Blackland Prairie is considered tallgrass prairie, which had many tall grass species including little bluestem (*Schizachyrium scoparium)*, big bluestem (*Andropogon gerardii*), Indian grass (*Sorghastrum nutans*), Switch grass (*Panicum virgatum*) and others (Diamond and Smeins 1985; Sims 1988). Present in the San Antonio grasslands in the past were *Schizachyrium scoparium, Paspalum plicatulum* and *Sorghastrum nutans* communities over Alifisol soils (Diamond and Smeins 1985). Two of these species (*Schizachyrium scoparium* and *Sorghastrum nutans*, but no *Paspalum plicatulum* or *Andropogon gerardii*) were found in the restored area of our study but at low cover compared to mature tallgrass prairie (Collins et al. 1975; Sims 1988; Van Auken et al. 1992a, 1992b; Diggs et al. 1999). These species were not present in the woodland understory adjacent to the restored area of the Park. It is anticipated that these C_4 grass species will continue to increase in cover as the restored area develops in time. This would appear to be the trend, depending on conditions imposed on the restored area.

There is quite a bit known about *Juniperus* woodlands in Central Texas (Diamond et al.1995; Van Auken 2000, 2008), but not as much about grasslands or prairies in this area (Riskind & Diamond 1988; Van Auken et al. 1992A, 1992B), especially about how to restore and conserve them (Collins et al. 1975; Diggs et al. 1999; Leite et al. 2013; Morris et al. 2014; German et al. 2015). Grasslands are not static, and disturbances, especially fire, certainly seem to be required to maintain them (Tilman 1988; Collins and Wallace 1990; Howe 1994; Van Auken 2000; Foster & Collins 2009; Van Auken & Bush 2013; Keddy 2017), but little information is available about restoring them from woodlands. Mechanical or chemical treatments have been used to clear woodlands or shrub lands and have been shown to work well in South Texas woodlands (Scifres 1980; Smeins & Merrill 1988). While considerable work on fire and mowing of grasslands has been investigated and some reported (Collins and Wallace 1990), little work has been done investigating the effects of fire and mowing on South Texas Blackland Prairie. Chronic high levels of grazing can degrade grassland habitat quality (Martin and Cleveland 2011), and frequent fire and mowing can have depressive effects on grass production (Smeins 1972); while annual herbicide use can shift the plant community in Blackland Prairies to favor annual forbs over C_4 grasses (Hickman and Derner 2007).

Herbicide, mowing, and fire can be useful tools to maintain grasslands, but frequency of treatments needs to be examined and understood. Grasslands will not remain as grasslands unless certain conditions are met. The process of change in community composition and structure is community succession and occurs in all plant communities (Tilman 1988; Foster & Collins 2009; Van Auken & Bush 2013; Keddy 2017).

To date, the succession in the restored area has followed a predictable trend (Tilman 1988; Van Auken & Bush 2013; Keddy 2017). The restored area was bare soil for a short time, with many local annuals establishing in the 1-2 years after clearing (personal observation and Fig. 2). However, some C_4 grasses established and further development and spread of these grasses is expected as succession continues (Sims 1988; Van Auken et al. 1992a, 1992b; Van Auken and Bush 2013). In the future, a variety of additional C_4 grasses should establish and those present will increase in cover, with a plateau of the C_4 grasses occurring between 10 and 20 years after the establishment on the restoration site. However, management and certain treatments need to continue to prevent regression back into woodlands. Highlighting this need, seedlings or sprouts of twelve abundant woody species in the grassland were found during this study. In order to maintain the grassland, management treatments should include local mechanical or chemical treatment, rotational grazing, controlled burning, or a combination of these treatments to keep woody and invasive herbaceous plants from being recruited into the restored areas (Scifres 1980). Unfortunately, controlled burns and grazing are difficult to use at this time within the city limits. Future management of this grassland should include a combination of infrequent mowing (once every 5 years) and annual herbicide treatment of woody species. Treatments have to continue if the grassland is to remain rather than a savanna or even reconversion to woodland (Tilman 1988; Van Auken & Bush 2013; Keddy 2017).

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