Articles

Avian Responses to Vegetation Changes From Post Oak Savanna Restoration Efforts in Eastern Texas

Courtney McInnerney, Christopher E. Comer, Brian Oswald,* Roger J. Masse, Christopher M. Schalk

C. McInnerney
Arthur Temple College of Forestry and Agriculture, Stephen F. Austin State University, P.O. Box 6109, Nacogdoches, Texas 75962
Present address: Texas Parks and Wildlife Department, Woodville, Texas 75990

C.E. Comer
Safari Club International Foundation, 501 2nd Street NE, Washington, D.C. 20002

B. Oswald, C.M. Schalk
Arthur Temple College of Forestry and Agriculture, Stephen F. Austin State University, P.O. Box 6109, Nacogdoches, Texas 75962

R.J. Masse
State University of New York-Cobleskill, 106 Suffolk Circle, Cobleskill, New York 12043

Abstract

Once covering approximately 46 million hectares of the Midwestern United States extending from southern Wisconsin southward into Texas, canopy cover of oak savannas ranged from 10% to 70%, and were dominated by fire-resistant oak species such as bur oak *Quercus macrocarpa* and post oak *Quercus stellata,* with a well-developed, diverse herbaceous layer dominated by fire-adapted grasses and forbs. In response to the loss and degradation of oak savannas, associated wildlife populations have experienced long-term declines. For example, 70% of disturbance-dependent bird species in the United States have experienced declines, with most of these species being associated with grasslands, oak savannas, and open forest communities. Few studies have documented the success of restoration in post oak savanna systems in regard to breeding bird assemblages. Our objective was to quantify avian abundance, density, species richness, and assemblage structure under three site conditions (reference, restored, and partially restored [aka unrestored]) within post oak savannas at Gus Engeling Wildlife Management Area in eastern Texas. We conducted vegetation and avian transect surveys postrestoration (2016–2017) and compared our results with prerestoration baseline surveys conducted in 2009. Restoration initiated in 2010 was partially successful, with vegetation changes that closely resemble presettlement characteristics, with the appearance of obligate grassland species. Specifically, prerestoration, one dickcissel *Spiza americana* and no lark sparrows *Chondestes grammacus* were detected. By 2017, dickcissel density in the restored sites was similar to densities recorded on tallgrass prairie and other high-quality habitat in the southern portion of its range. Lark sparrows were also detected, but at low densities. We also observed the persistence and increase of several woodland and open woodland species over time. These patterns are likely attributed to the creation of a mosaic of microhabitats selected by these species, such as the persistence of mottes, as well as their increased edge-to-area ratios. Restoration sites that are larger in size and in closer proximity to other restored or remnant savannas should have a higher priority to increase their likelihood of recolonization by target species. Restoration efforts may still be successful in more isolated areas, such as Gus Engeling Wildlife Management Area, but conducting postrestoration monitoring will further elucidate site-specific restoration dynamics.

Keywords: avian abundance; fire; habitat restoration; restoration ecology; wildlife-habitat relationships

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* Corresponding author: boswald@sfasu.edu

Introduction

Oak savanna vegetation types presettlement covered some 46 million hectares (ha) of the Midwestern United States, extending from southern Wisconsin southward into Texas (Temple 1998). Oak savanna canopy cover ranges are typically from 10% to 40% (Asbjornsen et al. 2005), and dominated by fire-resistant oak species such as bur oak *Quercus macrocarpa* and post oak *Quercus stellata,* with a well-developed, herbaceous ground cover dominated by a diverse assemblage of fire-adapted grasses and forbs (Telfair 1999; Brawn et al. 2001; Burger et al. 2013). The woody components of oak savannas are found in mottes that occur in wet or undisturbed areas. These mottes (small stands of trees with $>$70% canopy cover) typically have an understory of shade-tolerant trees and shrubs (Burger et al. 2013).

Oak savanna structure and distribution is linked to periodic disturbance such as fire, grazing, and drought that reverse or slow the closure of the canopy (Harrington and Kathol 2008). The natural fire regime of oak savanna was established by periodic lightning strikes and ignitions by Native Americans (Burger et al. 2013) with fire intervals ranging from 2 to 16 y and a mean return interval around 6 y, until current anthropogenic activities altered the fire regime (Wolf 2004; Stambaugh et al. 2014). Fire eliminated woody regrowth and increased native plant species richness and diversity by reducing the buildup of organic matter and encouraging new herbaceous growth (Wolf 2004).

In response to this loss and degradation of oak savannas, associated wildlife populations have experienced long-term declines (Brawn et al. 2001). For example, 70% of disturbance-dependent bird species in the United States have experienced declines (Hunter et al. 2001; Sauer et al. 2014). Most of these bird species are associated with early successional vegetation types in grasslands, oak savannas, and open forest communities (Hunter et al. 2001).

Oak savannas can support large numbers of bird species because of the diversity of available microhabitats (e.g., tree canopies, grasses, and mottes) used as breeding sites. However, grassland breeding birds are highly susceptible to declines due to habitat loss and fragmentation. Specifically, habitat fragmentation reduces nest success, reproductive rates, as well as alters movements, interactions among species, and edge effects (Fletcher and Koford 2002).

Few studies have evaluated the success of restoration attempts (i.e., canopy reduction and reintroduction of fire) in post oak savanna systems, especially in regard to breeding bird assemblages (Davis et al. 2000). In Texas, a successfully restored oak savanna should support a suite of typical avian species that are intolerant to dense canopy cover or tree density and have adapted to grass-dominated systems. Bird species indicative of open-woodlands and savannas in Texas during the breeding season include painted bunting *Passerina ciris,* indigo bunting *P. cyanea,* dickcissel *Spiza americana,* and lark sparrow *Chondestes grammacus* (Holoubek and Jensen 2015).

Our objectives were to determine avian abundance, density, species richness, and assemblage composition in restored post oak savannas in eastern Texas, and compare these results with reference sites and adjacent, partially restored sites. Our surveys were also compared with 2009 prerestoration baseline surveys (Comer and Lundberg 2011). We expected to find vegetation structural changes on restored areas that more closely resembled presettlement oak savannas in the region (Telfair 1999; Brawn et al. 2001), such as a well-developed herbaceous ground cover layer and reduced canopy cover and a decrease in woody understory cover. In turn, we predicted that if the oak savanna restoration efforts achieved the desired outcomes at Gus Engeling Wildlife Management Area (WMA) management, we would see an increase in abundance of birds typical of oak savannas along with a decline in woodland avian species.

Methods

Study site

Our study was conducted at Gus Engeling WMA, a state-owned 4,434-ha post oak savanna research and demonstration area in Anderson County, Texas. Gus Engeling WMA is an isolated area containing remnant, restored, or unrestored post oak savanna surrounded by coastal bermudagrass *Cynodon dactylon* pastures, and second growth forests. Our study occurred across 1,000 ha in the northwest section of Gus Engeling WMA, which was delineated into eight compartments. This section was selected in 2007 for a restoration project because the area comprises Darco fine sand soils and Tonkawa fine sands, which are somewhat excessively drained, have low water storage availability and can support typical savanna vegetation types.

The eight compartments comprised three different treatments: reference, restored, and partially restored (hereafter, unrestored—see description below). Compartments F and G were 62 ha and 112 ha, respectively, and served as reference sites for desired post oak savanna conditions. They were established shortly after acquisition in the 1950s and have been maintained using prescribed fire with an average 3-y rotation, herbicide, and mechanical treatments (i.e., mowing, mulching, and tree removal). These sites contained mature scattered trees with a well-developed herbaceous ground cover layer. Starting in 2010, Compartments A and B were restored to post oak savanna conditions and are 57 ha and 136 ha, respectively. Lack of past disturbance in these compartments had resulted in an open woodland forest structure, with dense mature trees in the overstory and ground cover dominated by woody regeneration. A timber harvest was completed in 2010 to remove woody overstory and reduce canopy cover, followed by regular herbicide and prescribed fire treatments to control woody regeneration and encourage an herbaceous ground cover layer. Three prescribed fires had been applied by 2017. Following treatment, these compartments contained mature scattered trees, mostly in designated mottes, and herbaceous ground cover dominated by bunchgrasses.

The remaining four compartments were considered unrestored and ranged in size from 53 to 200 ha. These unrestored sites were similar to the prerestoration conditions in the restored sites, heavily encroached with woody vegetation and lacking the desired herbaceous ground cover. They exceeded typical canopy cover for post oak savanna but were subjected to a heavy thinning in 2015; canopy cover was reduced closer to the presettlement range but was still greater than the reference and restored sites. The ground cover layer was lacking the well-developed herbaceous component and instead consisted of dense oak regeneration.

Vegetation sampling

Baseline vegetation sampling. We quantified baseline vegetation structural characteristics during May–July of 2009 by randomly placing 50 plots in each of 8 compartments. At each random point, we established a single 25-m transect at a random azimuth. At the 5-m and 20-m points along a transect, we divided a variable radius plot into quadrants to determine tree species, trees per hectare, and basal area per hectare. Comer and Lundberg (2011) used the point-centered quarter-method to determine tree canopy cover. They measured herbaceous and woody ground cover using a 1-m^2 quadrat on alternating sides of each transect at 5-m intervals starting at 5m. They defined ground cover as any herbaceous or woody species that was shorter than 2 m. They estimated the ground cover by recording the five most dominant plant species based on the six Daubenmire cover classes: 0–5%, 5–25%, 25–50%, 50–75%, 75–95%, and 95–100% (Daubenmire 1959).

Vegetation sampling—postrestoration. In May–July of 2016, we quantified the vegetation structural characteristics at 228 points by randomly placing 15 points within 250 m of each breeding bird line transect, except in compartment F, where we placed 9 points on each shortened transect. At each point, we measured vegetation characteristics within an 11.3-m-radius circle (Martin et al. 1996). We measured all woody stems $\geq$8 cm at diameter at breast height within the plot to determine tree species, trees per hectare, and basal area per hectare. We estimated tree canopy cover at plot center using a spherical densiometer at each cardinal direction and obtained a mean value. Within each quarter of the circle, we used a randomly located 1-m^2 quadrat to estimate percent herbaceous and woody ground cover $<$2 m in height, using the same six Daubenmire cover classes.

Breeding bird surveys

We used line transects to determine breeding bird abundance following Comer and Lundberg (2011). We placed two, 500-m transects in each compartment using a random point generator and random azimuth. Each transect was $>$100 m from edges and roads, and $>$250 m from adjacent transects. The only exception was in compartment F, where the size of the reference post oak savanna did not allow for a 500-m transect that met the above requirements. In this case, we used two 150-m transects that were similarly randomly located. We surveyed these transects three times rather than once within a single survey period to account for the shorter transect lengths (Comer and Lundberg 2011).

In 2009, we surveyed transects from 1 May to 15 July (Comer and Lundberg 2011). We conducted contemporary transect surveys biweekly from 29 April to 10 July in 2016 and from 30 April to 8 July in 2017. We conducted surveys within the first 3.5 h of daylight (Comer and Lundberg 2011; McInnerney 2018). We detected birds based on sight or sound, identified birds to species and estimated their position by taking an azimuth using a compass and estimating distance using an optical range finder. We used azimuth and distance to calculate perpendicular distances of birds from transect lines. We also recorded the sex, time, and method of detection (sight or sound) for each individual. We only recorded birds at the location the individual was first detected. We did not record birds flying over the site but not landing. We detected birds within any distance of the transect if a distance could be estimated (Comer and Lundberg 2011; McInnerney 2018). We did not perform surveys on days when conditions were not conducive (e.g., rain, wind 16 km/h, smoke, or fog) for bird activity or detection.

Statistical analyses

We used 2-way analysis of variance (ANOVA) to examine differences in ground cover species by plant functional group (bunchgrasses, grasses or sedges, legumes, forbs, and woody) among 3 treatments and 2 y (2009 and 2016) using Statistical Analysis System (SAS Institute 2011; v.9.3). We tested data for normality using the Shapiro–Wilks test and homogeneity using the Levene's test. We transformed count data using square root and transformed percent data using the arcsine when assumptions were not met. When ANOVA suggested differences among treatments, we used Tukey's honestly significant difference post hoc test ($\alpha = 0.05$). We did not test for differences in tree species richness, trees per hectare, and basal area (m^2/ha) because of differences in sampling methodology, but instead plotted averages ($\pm$SD) to compare data with stated presettlement vegetation ranges.

We estimated breeding bird densities using Program DISTANCE 7.0. We defined density as the number of individuals per hectare, where D is density, n is the total number of individuals recorded within the compartment, and a is the total area of the compartment:

$$D = \frac{n}{a},$$

However, this formula does not account for individuals that are present but not detected during the sampling period. DISTANCE estimated the probability of detecting an individual given that the individual is within the area of the transect survey. The program used the perpendicular distance of each detected bird from the transect line to create a histogram of the number of detections based on distance to the transect (Diefenbach et al. 2003). The detection function then fits a curve to the data and provides the detection probability, P, at any given distance from the transect (Buckland et al. 2001).

To determine relative abundance, we fitted a detection curve function to the most frequently detected bird species, as well as to certain target species, using the raw detection data for each year (Buckland et al. 2001; Rosenstock et al. 2002). We classified abundant species as having $>$200 detections within each year. Target species included those that are considered grassland or savanna obligates (e.g., dickcissel and lark sparrow) and representative early successional species (e.g., painted and indigo buntings). The goodness-of-fit test and Akaike's Information Criterion corrected for small sample sizes (AIC_c) verified the model fit and model selection (Rosenstock et al. 2002; Burnham and Anderson 2004). We used the most parsimonious model for each species to calculate density for sample year (Diefenbach et al. 2003).

We also calculated richness of breeding bird assemblages found in restored and reference treatments (Ott and Longnecker 2010). Given the before-and-after comparison of breeding bird abundances pre- and postrestoration for all treatments, we used t-tests among treatments and years to compare species detections (per 1,000 m of transect surveyed) using SAS. We included species with insufficient detections to derive density estimates but that were detected in $\geq$4 compartments during $\geq$2 y. Data were square-root-transformed when normality or homogeneity assumptions were not met.

Results

Vegetation responses

In 2009, trees per hectare averaged 385.55 in the unrestored (aka partially restored) treatment, and 83.15

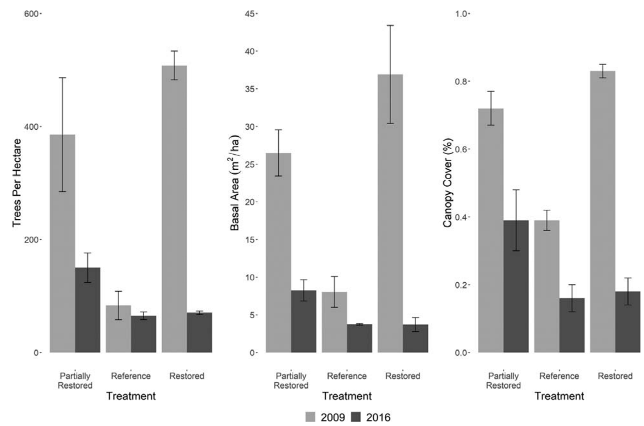

Figure 1. Means and standard deviations for tree density (trees per ha), basal area (m^2/ha), and canopy cover (decimal percent) by treatment (partially restored ["unrestored" in text], reference, restored) and year at Gus Engeling Wildlife Management Area, Anderson County, Texas, in summer 2009 and 2016. Vegetation sampling methods differed across survey periods. Refer to Methods for details on the sampling methodology.

in the reference treatment, and 507.95 in the restored treatment (Figure 1). In 2016, average trees per hectare were 150.23 in the unrestored treatment, 65 in the reference treatment, and 70.4 in the restored treatment (Figure 1). In 2009, average basal area was 26.48 m^2 in the unrestored treatment, 8.05 m^2 in the reference treatment, and 36.90 m^2 in the restored treatment (Figure 1). In 2016 average basal area was 8.26 m^2 in the unrestored treatment, 3.74 m^2 in the reference treatment, and 3.70 m^2 in the restored treatment (Figure 1). In 2009, average canopy cover was 72% in the unrestored treatment, 39% in the reference treatment, and 83% in the restored treatment (Figure 1). In 2016 average canopy cover was 39% in the unrestored treatment, 16% in the reference treatment, and 18% in the restored treatment.

In 2009, 87 plant species were detected in the ground cover layer, which decreased to 66 species in 2016 (McInnerney 2018; https://scholarworks.sfasu.edu/etds/205; Table S1, *Supplemental materials*), with 4.6 species/quadrat in 2009 and 3.5 species/quadrats in 2016. In 2009, the forb ground cover layer was greater in the reference treatment than the restored treatment, while the unrestored was similar to both treatments (Table 1). In 2016, the restored treatment was dominated by bunchgrasses, while the unrestored treatment was dominated by woody vegetation, and the reference treatment was predominately woody vegetation and forbs (Table 1). Legumes did not differ among treatments or years, but were a minor vegetation component of ground cover (Table 1).

Avian responses

Bird species richness differed over time with 39 species detected in 2009, 52 species in 2016, and 49 species in 2017 (McInnerney 2018; https://scholarworks.sfasu.edu/

Table 1. Mean ground-cover percentages based on vegetation class, treatment (Partially Restored, Reference, Restored), and year for vegetation surveys at Gus Engeling Wildlife Management Area, Anderson County, Texas, in summer 2009 and 2016. Variables that share a letter in each row are not significantly different from one another.

		Partially restored (a.k.a. unrestored)		Reference		Restored	
Cover type (%)	Statistic	2009	2016	2009	2016	2009	2016
Bunchgrass	Mean	5.0 A	9.7 A	6.7 A	10.3 A	1.9 A	21.6 B
	SE	1.3	1.8	0.9	3.8	0.5	0.4
	95% CI	5.0±2.6	9.7±3.6	6.7±1.8	10.3±7.4	1.9±0.9	21.6±0.7
	Range	3.0–8.8	6.2–14.9	5.8–7.7	6.6–14.1	1.4–2.4	21.2–22.0
Forb	Mean	7.4 AB	5.2 B	22.0 A	11.0 AB	1.7 B	12.1 A
	SE	3.2	1.1	5.0	5.7	0.4	3.7
	95% CI	7.4±6.3	5.2±2.1	22.0±9.9	10.3±11.2	1.9±0.7	12.1±7.3
	Range	2.8–16.9	2.7–7.9	17.0–27.0	5.3–16.8	1.4–2.0	8.4–15.8
Grass or Sedge	Mean	13.5 AB	8.1 A	13.2 AB	5.1 A	27.6 A	5.0 B
	SE	2.1	2.1	3.9	1.0	10.3	0.9
	95% CI	13.5±4.2	8.1±4.0	13.2±7.6	5.1±1.9	27.6±20.1	5.0±1.7
	Range	9.3–18.6	4.1–11.7	9.3–17.1	4.1–6.1	17.3–37.9	4.1–5.9
Legume	Mean	3.1 A	3.5 A	6.7 A	7.5 A	2.7 A	0.8 A
	SE	1.3	1.9	0.1	2.9	1.1	0.5
	95% CI	3.1±2.6	3.5±3.7	6.7±0.1	7.5±5.6	2.7±2.2	0.8±1.0
	Range	1.3–7.1	0.7–8.8	6.7–6.8	4.7–10.4	1.6–3.8	0.2–1.3
Woody	Mean	6.7 A	19.2 B	6.6 AB	11.8 AB	11.8 A	7.0 A
	SE	1.6	0.6	2.6	79.0	2.2	1.0
	95% CI	6.7±3.2	19.2±1.3	6.6±5.0	11.8±15.4	11.8±4.3	7.0±1.9
	Range	2.2–9.2	17.6–20.4	4.1–9.2	3.9–19.7	9.6–14.0	6.1–8.0

etds/205, Table S2, *Supplemental materials*). Overall species richness was similar across all treatments and years. Across all years, more woodland species were detected than early successional or grassland species (Figure 2). There was a greater number of species of early successional and grassland birds combined than woodland birds in restored and reference sites in 2016 and 2017. Compared with 2009, there was an increase in grassland and open woodland species for both the reference and restored sites in 2017.

Density estimates were derived for nine species: blue-gray gnatcatcher *Polioptila caerulea,* brown-headed cowbird *Molothrus ater,* Carolina chickadee *Poecile carolinensis,* dickcissel, indigo bunting, northern cardinal *Cardinalis cardinalis,* painted bunting, tufted titmouse *Baeolophus bicolor,* and yellow-billed cuckoo *Coccyzus americanus* (Table 2). Based on these density estimates, we were able to determine which species increased or decreased from baseline surveys. Dickcissels were not detected in 2009, but increased in the reference and restored sites by 2017. Blue-gray gnatcatcher density generally increased in all treatments from prerestoration to postrestoration. Northern cardinal density decreased slightly in the restored sites but increased moderately in unrestored sites. Yellow-billed cuckoos declined in density in all treatments and did not occur at all in reference sites postrestoration. In the restored sites, woodland species (e.g., Carolina chickadee and tufted titmouse) and early successional species (e.g., indigo bunting and painted bunting) exhibited no change or inconsistent responses in their density estimate (Table 2).

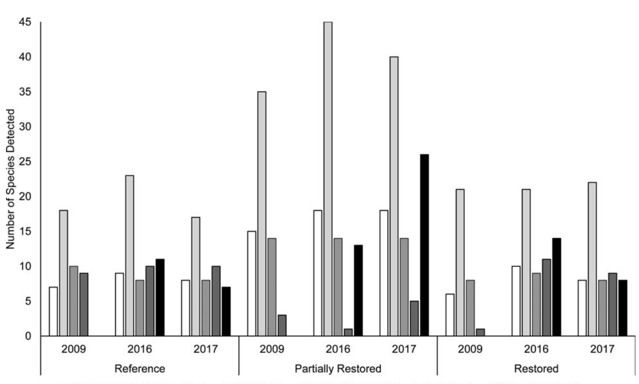

Figure 2. Avian species richness of habitat guilds among treatment partially restored ["unrestored" in text], reference, restored, and years at Gus Engeling Wildlife Management Area in Anderson County, Texas, during the 2009, 2016, and 2017 breeding seasons.

For six species that had >200 detections in a survey year, we calculated relative abundance based on km of transect surveyed (Table 3). Blue grosbeak *Passerina caerulea* and great-crested flycatcher *Myiarchus crinitus* were not detected in 2009 but were present in subsequent surveys ($P < 0.02$ and $P < 0.002$). In 2016 and 2017, scissor-tailed flycatchers *Tyrannus forficatus* were detected more frequently in reference and restored treatments than in the unrestored treatment ($P = 0.01$). Summer tanagers *Piranga rubra* declined in the restored sites in 2017, but this trend was not significant ($P = 0.34$). Carolina wrens *Thryothorus ludovicianus* were detected nearly consistently across all sites and years with the only exception being the reference treatment in 2016 where they were detected less frequently than in the unrestored treatment ($P < 0.05$).

Table 2. Select avian species and breeding bird assemblage, density estimates (birds/ha), standard error (SE), 95% confidence interval (CI), and detection probability (*P*) for each year at Gus Engeling Wildlife Management Area in Anderson County, Texas, during the breeding seasons of 2009, 2016, and 2017 by treatment (partially restored, reference, restored). Density estimates and detection probabilities are from Program DISTANCE. Dashes (-) indicate instances when detections were too low to calculate density estimates.

Species	Breeding bird assemblage	Year	Partially restored (a.k.a. unrestored)					Reference					Restored				
			Density	SE	95% CI		*P*	Density	SE	95% CI		*P*	Density	SE	95% CI		*P*
Blue-gray gnatcatcher	Woodland	2009	1.4	0.2	1.0	2.0	0.29	1.9	1.0	0.6	5.5	0.16	1.4	0.3	0.9	2.3	0.20
		2016	3.4	0.4	2.6	4.5	0.16	5.2	3.2	1.1	25.8	0.13	1.0	0.5	0.3	3.1	0.26
		2017	6.4	0.6	5.3	7.8	0.17	2.8	0.7	1.5	5.1	0.24	3.0	0.5	2.0	4.3	0.15
Brown-headed cowbird	Grassland	2009	0.7	0.3	0.3	1.9	0.18	1.4	0.7	0.3	5.9	0.53	-	-	-	-	-
		2016	0.5	0.2	0.2	1.2	0.38	3.7	1.8	0.9	15.0	0.35	1.2	0.4	0.6	2.3	0.33
		2017	0.6	0.1	0.4	0.9	0.56	1.3	0.2	0.8	2.0	0.62	-	-	-	-	-
Carolina chickadee	Woodland	2009	1.7	0.3	1.3	2.4	0.22	1.2	0.6	0.4	3.8	0.61	1.0	0.5	0.3	3.7	0.28
		2016	1.9	0.4	1.2	2.8	0.16	-	-	-	-	-	0.9	0.3	0.3	2.5	0.34
		2017	1.6	0.5	0.8	3.0	0.24	1.5	0.4	0.8	2.8	0.35	1.8	0.7	0.7	4.5	0.20
Dickcissel	Grassland	2009	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		2016	-	-	-	-	-	-	-	-	-	-	0.7	0.3	0.2	2.0	0.46
		2017	-	-	-	-	-	2.9	2.4	0.6	14.1	0.17	5.4	1.2	3.0	9.8	0.30
Indigo bunting	Early successional	2009	1.1	0.5	0.4	3.1	0.31	2.8	1.3	0.8	10.2	0.50	-	-	-	-	-
		2016	1.8	0.5	1.0	3.2	0.26	1.7	0.4	0.9	3.2	0.50	0.7	0.4	0.2	3.2	0.44
		2017	2.8	0.5	1.9	4.2	0.27	2.5	0.5	1.3	4.6	0.53	0.4	0.2	0.1	1.5	0.61
Northern cardinal	Habitat generalist	2009	2.9	0.3	2.4	3.5	0.35	2.6	1.9	0.6	11.8	0.30	4.3	1.2	2.1	8.4	0.22
		2016	3.6	0.5	2.7	4.8	0.20	2.5	0.9	1.2	5.6	0.30	1.8	0.9	0.6	5.0	0.21
		2017	5.3	0.8	3.8	7.3	0.21	1.0	0.4	0.5	2.4	0.53	2.2	0.5	1.1	4.3	0.27
Painted bunting	Early successional	2009	1.8	0.5	0.9	3.3	0.28	6.8	3.2	2.0	23.4	0.25	2.3	0.8	1.2	4.8	0.16
		2016	2.2	0.4	1.5	3.3	0.22	9.1	4.2	2.3	35.6	0.29	2.8	0.7	1.5	5.2	0.32
		2017	3.0	0.3	2.4	3.7	0.30	10.3	5.4	2.2	48.4	0.30	2.0	0.5	0.9	4.3	0.37
Tufted titmouse	Woodland	2009	2.0	0.3	1.5	2.6	0.44	0.8	0.2	0.3	1.9	1.00	3.2	0.7	2.0	5.2	0.29
		2016	1.4	0.2	1.0	2.0	0.23	0.9	0.5	0.3	3.4	0.31	1.7	0.6	0.7	3.8	0.19
		2017	2.1	0.7	1.1	4.0	0.17	0.2	0.2	0.0	1.3	0.92	3.2	1.4	1.2	8.7	0.12
Yellow-billed cuckcoo	Open woodland	2009	1.5	0.2	1.1	2.0	0.30	1.1	0.5	0.3	3.7	0.45	2.2	0.2	1.8	2.6	0.32
		2016	0.5	0.1	0.3	0.8	0.40	-	-	-	-	-	0.9	0.5	0.3	3.0	0.18
		2017	0.4	0.1	0.2	0.7	0.56	-	-	-	-	-	1.5	1.0	0.4	5.8	0.15

Table 3. Mean select avian species number of detections per 1,000 m of transect surveyed and standard deviations (SD) based on year and treatment (partially restored, reference, and restored) at Gus Engeling Wildlife Management Area in Anderson County, Texas, during the breeding seasons of 2009, 2016, and 2017. Detections followed by the same letter within the same row are not different ($P < 0.05$) among treatments in a certain year. Letters within each column for each species and inside parenthesizes that are the same letter are not different ($P < 0.05$) comparing survey years in each treatment.

Species	Breeding bird assemblage	Year	Partially restored		Reference		Restored				
			Mean	SD	Mean	SD	Mean	SD	*F*	*P*	*df*
Blue grosbeak	Open woodland	2009	0.0 A(A)	0.0	0.0 A(A)	0.0	0.0 A(A)	0.0	3.63	0.02	2/23
		2016	0.1 A(A)	0.1	0.9 A(A)	0.7	0.3 A(A)	0.4			
		2017	0.3 A(A)	0.3	0.6 A(A)	0.3	0.7 A(A)	0.4			
Carolina wren	Open woodland	2009	1.5 A(A)	0.8	2.6 A(A)	1.4	2.9 A(A)	0.7	4.86	0.004	2/23
		2016	1.4 A(A)	0.3	0.3 B(A)	0.2	0.5 AB(A)	0.4			
		2017	0.7 A(A)	0.3	0.3 A(A)	0.4	0.9 A(A)	0.7			
Eastern kingbird	Grassland	2009	0.2 A(A)	0.3	2.0 A(A)	2.2	0.2 A(A)	0.3	2.21	0.09	2/23
		2016	0.0 A(A)	0.0	0.6 B(A)	0.3	1.2 C(A)	0.3			
		2017	0.2 A(A)	0.2	0.7 A(A)	0.9	0.2 A(A)	0.3			
Great-crested flycatcher	Open woodland	2009	0.0 A(A)	0.0	0.0 A(A)	0.0	0.0 A(A)	0.0	5.75	0.002	2/23
		2016	1.0 A(B)	0.7	1.6 A(B)	0.3	0.8 A(B)	0.3			
		2017	0.6 A(AB)	0.3	0.2 A(A)	0.3	0.1 A(AB)	0.1			
Scissor-tailed flycatcher	Grassland	2009	0.0 A(A)	0.0	6.1 A(A)	7.1	0.0 A(A)	0.0	3.69	0.01	2/23
		2016	0.0 A(A)	0.0	7.3 B(A)	5.5	2.5 AB(B)	0.4			
		2017	0.1 A(A)	0.2	7.4 B(A)	4.6	1.9 AB(AB)	0.7			
Summer tanager	Woodland	2009	2.3 A(A)	1.0	2.7 A(A)	2.4	2.9 A(A)	1.3	1.24	0.34	2/23
		2016	2.3 A(A)	0.6	1.2 A(A)	0.4	2.5 A(A)	0.1			
		2017	2.9 A(A)	0.3	1.5 B(A)	0.8	1.3 B(A)	0.4			

Discussion

When restoring habitats, successful restoration should be defined with pre- and postrestoration monitoring used to determine whether objectives are met (Miller and Hobbs 2007). At Gus Engeling WMA, we predicted that grassland birds would increase in abundance and occurrence in response to post oak savanna restoration efforts. The 2010 restoration at Gus Engeling WMA was partially successful as reflected in changes to both the vegetation and avian assemblage. The strongest evidence of success was the appearance of typical grassland obligate species (i.e., dickcissel and lark sparrow) following these restoration efforts. By 2017, dickcissel density in the restored sites was similar to densities recorded on tallgrass prairie and other high-quality habitat in the southern portion of its range (Dechant et al. 2002). These grassland species were either absent or occurred at lower densities prior to restoration efforts.

Both pre- and postrestoration vegetation characteristics were compared with historical and acceptable ranges to test the success of restoration efforts. There is considerable debate about the appropriate amount of canopy cover in a true oak savanna, but the widely accepted range is 10–40% (Asbjornsen et al. 2005). The baseline prerestoration canopy cover at Gus Engeling WMA was 72% and 83% in the unrestored and restored treatments, with the reference treatment the only one to fall within the range of historical conditions with an average canopy cover of 39%. Although canopy cover at Gus Engeling WMA in 2016 ranged from 16% (restored treatment) to 39% (unrestored treatment), the mean canopy cover for all treatments fell within the typical range for an oak savanna. Similarly, basal area in the reference and restored treatments closely resembled presettlement oak savannas, which typically had overstory basal area between 3 and 7 m^2/ha (Barrioz et al. 2013; Burger et al. 2013). The basal area for the unrestored treatment is nearing the historical overstory basal area of 7 m^2/ha.

Many herbaceous species that are key components of quality oak savannas were recorded, including little bluestem, beggar tick *Desmodium* spp., lespedeza spp., and broomsedge *Andropogon virginicus*. However, the herbaceous layer differed among treatments. The restored treatment exhibited the most well-developed bunchgrass component, dominated by little bluestem, while the reference treatment was more diverse, with fewer bunchgrasses and greater forb diversity. The lower bunchgrass cover may reflect the extremely deep, droughty sands that underlie the reference compartments and prevent the growth of dense grass cover. The reference compartments consist of mostly Tonkawa soil series—very deep, excessively drained sands that do not have the structure or water retention to support a diverse herbaceous ground cover layer. The restored compartments consist of mostly Darco soil series—deep, loamy, fine sands that are somewhat excessively drained but can better support the herbaceous ground cover layer of oak savannas. Finally, the vegetation response to the 2015 thinning in partially restored (unrestored) treatment sites consisted primarily of dense woody regeneration. Confounding comparisons, the basal area, canopy cover, and ground cover in the unrestored treatment reflected the heavy thinning that was completed in 2015, which changed the compartments from the prerestoration baseline. However, these sites still represented degraded or unrestored treatments because they had not been completely restored to presettlement vegetation characteristics.

Interestingly, dickcissels were absent in the reference treatment in 2009, but their density increased to nearly 3/ha by 2017 despite very little change in vegetation characteristics in these compartments. The reasons these grassland birds colonized reference areas are unknown, but may reflect changes in total area of habitat at the WMA. Dickcissel is considered moderately area sensitive; the minimum patch size for dickcissel occurrence was approximately 10 ha in Illinois and Nebraska (Herkert 1991; Helzer and Jelinski 1999). The 2009 prerestoration oak savanna covered $<$200 ha, while the postrestoration oak savanna covered $>$400 ha. Although 200 ha is sufficient to support dickcissels, it may be that the larger area was more attractive to these birds. In addition, the restored compartments may provide better nesting habitat for dickcissels (i.e., dense, tall grassy cover) than the reference compartments (Dechant et al. 2002).

Painted buntings are early successional species that occupy a variety of habitats. Generally, they select habitats with a high edge-to-area ratio with nearby open areas used as foraging sites (Vasseur and Leberg 2015), and occupy edges of tree clusters in otherwise open habitats (Kopachena and Crist 2000).The mottes were unaltered during the restoration efforts, increasing the edge-to-area ratio at the restored sites. The subsequent oak regeneration increased the woody growth at these sites that are used for singing perches by painted buntings. The positive, cascading effects of the restoration efforts on microhabitats utilized by painting buntings likely explain their increased density over time. It should be noted that bird densities can vary on a year-to-year basis as a result of changes in large-scale habitat resources (Wiens 1974). Further survey years could be utilized to determine an average density for these bird assemblages.

Despite a reduction in basal area and canopy cover, the density of woodland species remained consistent in the restored treatment. Mottes provide sufficient woody cover needed by these species and many woodland species were detected in, nearby, and traveling between mottes (personal observation). In their study modelling avian responses to oak savanna restoration, Barrioz et al. (2013), found that woodland species with a wide geographic range utilize vegetation types that span ecological gradients ranging from mature woodlands to oak savannas. Similarly, Vander Yacht et al. (2016) found that disturbance-dependent birds respond positively to open oak woodland and savanna restoration efforts while late-successional woodland birds had minimal negative responses. The persistence of woodland species despite these restoration efforts suggests that oak savannas serve as ecotones between forests and prairies and provide habitat for birds from multiple assemblages (Barrioz et al. 2013).

Overall, the vegetation structure and avian assemblage resemble those expected for presettlement oak savanna communities (Asbjornsen et al. 2005). The future of disturbance-dependent and grassland bird conservation relies on the ability to create or restore a mosaic of grassland vegetation types at landscape scales (Davis et al. 2000). When selecting sites for potential restoration efforts, it is important to examine surrounding landscapes and identify potential source populations for target avian species. Restoration areas that are larger in size and in closer proximity to other restored or remnant savannas should have a higher priority to increase their likelihood of recolonization by target species. Restoration efforts may still be successful in more isolated areas, such as Gus Engeling WMA, but it is important to monitor pre- and postrestoration efforts to understand and document the dynamics of restoration.

Supplemental Material

Please note: The *Journal of Fish and Wildlife Management* is not responsible for the content or functionality of any supplemental material. Queries should be directed to the corresponding author for the article.

Table S1. Complete list of plant species detected in 2009 and 2016 based on compartments at Gus Engeling Wildlife Management Area (McInnerney 2018).

Found at DOI: https://doi.org/10.3996/JFWM-20-028.S1 (341 KB PDF).

Table S2. Complete list of bird species detected at the Gus Engeling Wildlife Management Area based on compartment and year (McInnerney 2018).

Found at DOI: https://doi.org/10.3996/JFWM-20-028.S2 (334 KB PDF).

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