TEXAS A&M NRI
NATURAL RESOURCES INSTITUTE

Quantifying Holistic Benefits of Native Vegetation Restoration

A summary of ecological data analyses

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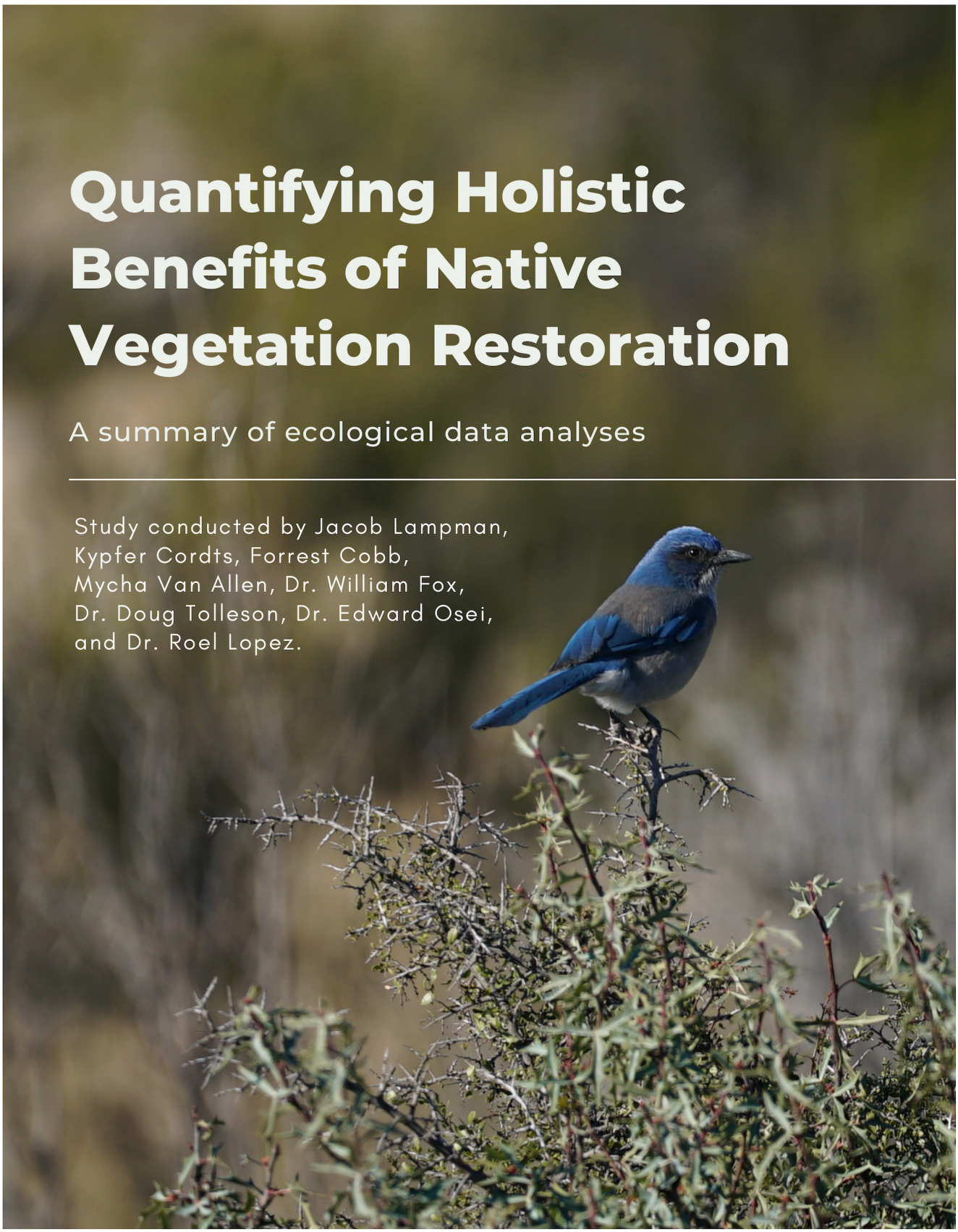

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

Native grasslands in Texas have been steadily disappearing since the arrival of the first settlers. Unfortunately, the combination of habitat loss, degradation by invasive species, and other factors has significantly impacted grassland ecosystems across North America and has left considerable species in danger of extinction (Comer et al., 2018). Specifically, degradation of native grasslands due to invasive, non-native species has become a global concern and sparked interest in restoring areas to native plant dominated communities (Gowdy et al., 2022, Smith et al. 2020). Grassland restoration activities have had positive impacts in increasing biodiversity, soil health, and increased carbon sequestration (Bai and Cotrufo, 2022; Castagneyrol and Jactel, 2012). In addition, there are economic benefits for industries to perform restoration of degraded sites (Thomas et al., 2016).

Texan by Nature, in collaboration with EOG Resources Inc., developed this project to quantify the environmental and economic benefits of restoring rangeland with native vegetation in the Eagle Ford Shale play. Texas A&M Natural Resources Institute (NRI) and Texas A&M University Rangeland, Wildlife, and Fisheries Management Department supported this project by providing data collection and data summary in support of final analysis by EcoMetrics. This report provides the summary of data collection. The results of this case study are intended to assist EOG Resources and other operators in making decisions for future restoration projects.

METHODS

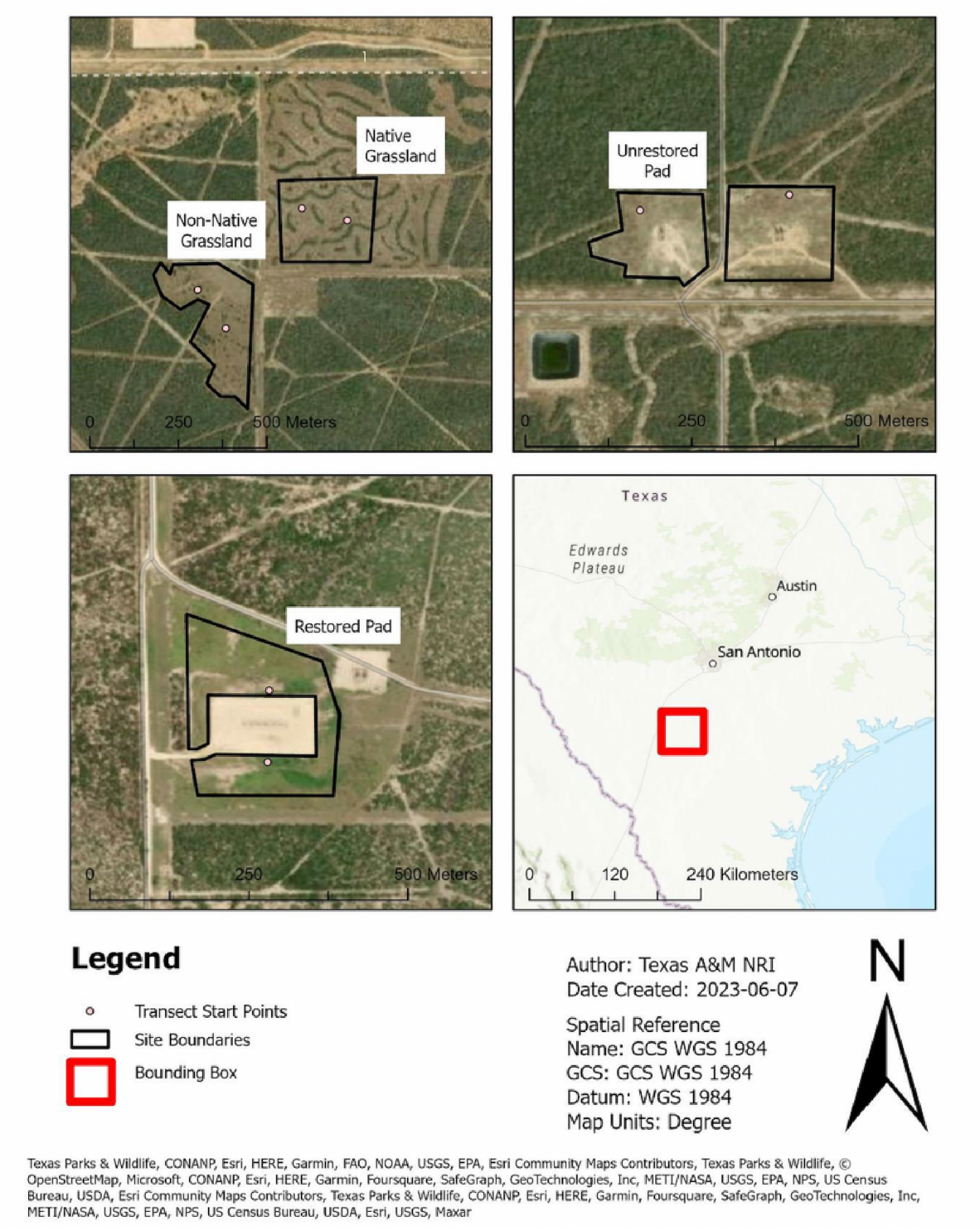
Study Area

Four demonstration sites were selected within La Salle County, Texas after an initial site visit conducted on March 28, 2022. Sites were selected within the Sid-Williams, Zizinia, and Yates properties based on previous management practices employed, site history, soil texture, woody cover, and dominant native versus non-native cover type. The study area consisted of four demonstration sites: a native restored grassland, a non-native restored grassland, a native restored well pad, and an unrestored well pad (hereafter; Native Grassland, Non-native Grassland, Restored Pad, and Unrestored Pad; Table 1). The two grassland sites were located within proximity, while the unrestored well pad was 3 km south and the restored well pad is another 15 km further south (Figure 1).

Table 1. Description of study sites within La Salle, County, TX.

Treatment Site	Size (ha)	Grazing	Previous Management
Native Grassland	5.4	Yes	Brush management and seeded with native grasses
Non-native Grassland	5.4	Yes	Brush management and seeded with non-native grasses
Restored Pad	3.4	No	Imported topsoil and seeded with native grasses
Unrestored Pad	3.5	Yes	No management

Figure 1. Four treatment study sites on three private properties in La Salle County, TX.



Previous Management

The Native Grassland was previously hydro-mulched, root plowed, root raked, and dragged. Forty-three native grasses and forbs from the "Scorched-earth recovery mix" from Native American Seed were planted using a row planter. The Non-native Grassland also performed similar brush management and was previously seeded with guineagrass (*Panicum maximum*) and kleingrass (*Panicum coloratum*). The Restored Pad was restored using a Brillion seeder to plant a mix that included bristlegrasses (*Setaria* sp.), sand dropseed (*Sporobolus cryptandrus*), sideoats grama (*Bouteloua curtipendula*), Kinney false rhodesgrass (*Chloris crinita*), Falfurrias Germplasm big sacaton (*Sporobolus wrightii*), Hidalgo Germplasm multiflower false rhodesgrass (*Trichloris pluriflora*), switchgrass (*Panicum virgatum*), and Blackwell switchgrass (*Panicum virgatum* var. Blackwell). The Unrestored Pad was not seeded and left to recover naturally.

Vegetation and Soil Surveys

Vegetative Cover and Plant Species Sampling

Vegetation was sampled utilizing the Line-Point Intercept method, which is a rapid and accurate method for quantifying soil cover that, in addition to vegetation, includes cover by litter, rocks and biological soil crusts (Herrick et al. 2009). With this method, cover is measured along a linear transect line and is based on the number of "hits" on a target species out of the total number of points measured along that line. Points along the transect line are recorded every meter along the 50 meter transects starting at meter 1. All species which intersect that point are recorded in the order encountered starting from the top canopy and moving down to groundcover.

We used the Vegetation GIS Data System (VGS) as the means for collecting and ensuring data quality control for the sites (University of Arizona, 2021). The VGS system supports data collection for the Line-Point Intercept method of vegetation sampling among several others. Transects were surveyed twice, once during peak spring (May) and once during peak fall growth (September), to provide both an inventory of plant species and to provide inputs for the modeling component of the project. These data were analyzed in R using the 'Vegan' package to calculate Shannon's Diversity Index and Simpson's Diversity Index (R Core Team, 2021; Oksanen et al., 2022).

Plant Biomass Sampling Protocol

Standing plant biomass was collected within sampling hoops at five randomly selected points along each 50 m transect. All standing plant material within each 1/4 m2 sampling hoop was cut to ground-level, collected, bagged, and labeled by transect. All biomass samples were dried and weighed to obtain the final biomass measurements per m2 (Herrick et al. 2009).

Soil Sampling Protocol

Soil samples

We collected 5 soil samples for lab analysis at randomly selected points along each transect to a depth of 30 cm. Soil samples were bagged, labeled, and sent to the Texas A&M Soil, Water, and Forage Lab for further analysis and testing. Soil samples were analyzed for pH, electrical conductivity, phosphorus, calcium, magnesium, sodium, and total organic matter.

Bulk density

We collected 1 bulk density measurement (Db [g/cm3]) at each transect. A 4.6 cm (1.8 in) diameter by 5.1 cm (2 in) height metal ring was driven into the soil. Height from the top of the ring to the soil surface was measured and recorded before excavation. We then excavated the ring with soil intact using a hand trowel and removed any excess soil from the bottom of the sample. The distance measurements from the ground surface to the top of the ring were repeated, and the difference in distance with the removal of the soil were multiplied by the cross-sectional area to calculate the volume of the soil (USDA 2014). Soil was deposited into sampling bags and labeled. Finally, soils were dried and weighed to obtain the final bulk density measurement (USDA 2014).

Soil Infiltration

A minimum of 2 single-ring infiltrometer measurements were taken at each sampling point (Herrick et al. 2009, USDA 2014). Before infiltration tests were conducted, the soil surface was cleared and vegetation trimmed as close to the surface as possible. We then drove a 15 cm diameter by 15 cm height metal infiltrometer ring into the ground to a depth of 8 cm. With the ring in place, 2.5 cm (1 inch [444 mL]) of distilled water was added and the time recorded for water to fully infiltrate into the soil (when no pooled water remains, and soil is glistening). This was performed twice for the final infiltration reading. Final results were recorded as mm/hr water infiltration (USDA 2014)

Modeling

The APEX Model

Agricultural Policy Environmental eXtender (APEX; Williams, 2000) is the biophysical model chosen for estimating carbon sequestration rates in this project. APEX is a comprehensive field scale model that was developed primarily to assess the effects of management strategies on crop or vegetation growth, livestock grazing, and water quality. APEX allows simultaneous simulation of multiple contiguous subareas (fields) for a wide range of soil, landscape, climate, crop rotations, and management practice combinations. Other components include weather, hydrology, soil temperature, erosion-sedimentation, nutrient and carbon cycling, tillage, dairy management practices, crop management and growth, pesticide and nutrient movement, and costs and returns of various management practices. The carbon fate and transport functions of the CENTURY model (Parton et al., 1987; Parton, 1996; Cerri et al., 2004) have also been incorporated into APEX, which allows APEX to simulate carbon dynamics in the soil-plant system. APEX includes routines for detailed grazing and other land management scenarios.

APEX has been utilized for a wide variety of applications in numerous countries over the past 30 years (see Gassman et al., 2010 for a review of past studies). It is particularly suited for detailed simulations where other models are incapable of the same degree of robustness.

APEX Model Application
In the current study, we generated broad estimates using basic computer modeled simulations. The carbon sequestration rates were simulated using a yet-to-be-released version of APEX (APEX 1905) due to its superior capability to represent the variety of vegetations that were identified. The basic procedure for soil carbon estimations using APEX are as follows:

1. Calibrate and validate APEX for the demonstration sites using data assembled from soil and vegetation sampling efforts.
2. Establish baseline (status-quo) soil organic matter profile and dynamics.
3. Calculate soil organic carbon sequestration rates as the annual rate of change of soil organic carbon stores.
4. Calculate other (additional metrics) as an annual rate including runoff, and soil

Biodiversity Surveys

General Design

All non-plant species data were collected using the following survey design as part of the biodiversity portion of the project. Sample units for biodiversity sampling were determined using the same 50 m transects utilized in the vegetation and soils data collection efforts. Transects were delineated using a nylon rope marked and numbered at 10 m intervals along the length of the patch of grassland/pad site we are sampling from on each property. The sampling effort was 3 days on each sampling unit for a total of a 12-day sampling period in May, July, and September of 2022.

Data Collection and Methods

This sampling methodology is designed to survey an extensive range of terrestrial wildlife taxa (including invertebrates and vertebrates), in a small area, with limited time. Due to the limitations of area and time, a rapid assessment was necessary to get an accurate representation of the wildlife diversity for this study.

Small Mammals
Small mammals were sampled using Sherman live traps (SH; H. B. Sherman Traps, Inc, Tallahassee, FL). One hundred fifty Sherman live traps were placed along and near transects on each site for 3 days. Traps were baited with a seed mixture of grain and fruit to ensure that granivorous, herbivorous, and frugivorous species were attracted to the traps. Traps were checked daily after sunrise and closed during the day to prevent overheating. Traps were reopened just before sunset to capture animals during the night when they are most active (Piers et al., 2020).

Captured animals were identified by species and sex, weighed, measured, and fecal and ectoparasite samples were taken. All individuals were identified to species in the field using a comprehensive field guide and photographs taken with a phone camera. Individuals were marked with an 'X' on the belly with a permanent marker to indicate recapture, and then released in the field where it was caught.

All trapping followed accepted, humane trapping practices published by the American Society of Mammologists. All animal handling procedures were conducted under the Texas A&M University Institutional Animal Care and Use Committee, IACUC 2022-0135.

Herpetofauna
Herpetofauna were surveyed through a visual encounter survey (VES). VES has been determined to be the best method for finding more individuals and identifying more species of reptiles and amphibians than other methods. (Heyer, W. R., 1994, Doan, 2003, McDiarmid, R. W., et al., 2012). We conducted a VES along transects starting after the small mammal processing was completed each morning. This method was repeated in the evening, starting at 1800 hrs. Individuals were collected, identified, photos taken, and released where the animal was caught. Any sign of herpetofauna presence, including but not limited to tracks, fecal, and shed observations was also recorded. All individuals were identified by species in the field or the lab from photographs taken during collection and detailed field notes taken by observers using a comprehensive field guide.

Invertebrates
A VES was performed along the transects starting just after the small mammal processing was completed each morning. We actively searched for insects and arachnids along the transects by looking through the vegetation, lifting rocks and logs to observe as many invertebrates as possible taking pictures for more detailed identification (Sumesh 2021).

Sweep netting was conducted along the transect after the VES. We swept for ten paces and collected the individuals caught in the net and placed them in a pre-prepared kill jar containing three cotton balls doused with of Raid©. This was repeated every ten paces until the transect was complete.

Finally, a night light trap was set using a blacklight (50 watts) and a white shower curtain. The shower curtain was hung off the back of a closed tailgate with rope, and positioned the truck so the light trap would be visible near the middle of the sample area. The blacklight was turned on from 2245 - 2345 hrs.

Samples were placed in a jar of 70% ethanol, and labeled them by site (Hussain et al., 2018). Specimens were identified using a dissecting microscope, a comprehensive field guide (NWF Field Guide to Insects and Spiders of North America by Evans, 2008), a dichotomous key (Photographic Atlas of Entomology and Guide to Insect Identification by J. Castner, 2000), and BugGuide.net.

Birds

A VES was conducted, both by sight and sound, along the transects to survey birds. Indirect observations were also recorded, such as fecal, feather, or eggs (Basit et al., 2021), and used binoculars (10x) and took pictures with phone cameras to aid identification. We used comprehensive field guides (TOS Handbook of Texas Birds by Lockwood & Freeman, 2014 and Identification Guide to North American Birds by Peter Pyle, 1997) and the Merlin Bird ID app for species identification.

Bats

Bats were surveyed and identified through acoustic monitoring. Acoustic monitoring is a preferred method of monitoring bat populations and activity across vegetation types because acoustics can monitor at times when bats are most active and for a continuous timeframe (Parsons and Szewczak, 2009). We set up one Wildlife Acoustics Song Meter SM4 acoustic device on each site determined by randomly generated coordinates based on the transect locations.

Devices were placed on telescopic poles and secured microphones 1 m above the ground placed in the direction away from trees or oil well noise. Devices were set to run for 9 days between 1800 - 0600 hrs.

We used the acoustic software, Sonobat 4.4.5 North America: Bat Call Analysis Software (Szewczak, 2022) to identify to species all passes detected.

Meso and Large Mammals

Camera trapping and a VES were used to collect all other mammal data. We used Syndesmos DH-2 4K 30mp game cameras and set them in high-traffic areas based on game trails and tracks. Two cameras were also placed at each site on telescopic poles, <400 m apart and 60 cm above the ground. Cameras were set for 9 days with 3 burst trigger and a 2 min interval. Cameras were active 24 hrs per day and were not checked until the end of the survey period to avoid disturbance. No bait or attractant was used (Woodgate et al. 2018; Cremonesi et al. 2021).

We also conducted a VES along the transects and recorded any sign of mammal presence, including but not limited to tracks, scat, and fur. Species were identified using a comprehensive field guide (The Mammals of Texas by David J. Schmidly, 2016).

RESULTS & DISCUSSION

Vegetation

The vegetation surveys were composed of 8 transects of 4 treatment types: Native Grassland, Non-native Grassland, Restored Pad, and Unrestored Pad. Transects were conducted in the Spring (May) and then again in the Fall (September) to compare phenological differences in species composition, diversity, and biomass. The surveys recorded 56 taxa (50 species, 6 genera level) comprising 48 native taxa and 7 non-native taxa (one taxon at the genus level was unknown). Two additional taxa (one forb and one grass) could not be identified to genus. The Fall surveys recorded more taxa (43 taxa, 36 natives) than the Spring surveys (33 taxa, 28 natives). The Native Grassland had the greatest native percentage rate on point intercepts (97.25%) across all transects followed by the Restored Pad (60.75%), Non-native Grassland (47.25%), and Unrestored Pad (44.75%). The average native percentage was higher in the Fall (68%) than in the Spring (57%), especially for the Non-native Grassland site and for Unrestored Pad.

Each treatment site had a different set of dominant species. For the Native Grassland, native bristlegrasses (*Setaria*) were the dominant species alongside two woody taxa (Table 2) and one other grass (*Trichloris pluriflora*). The other three treatment sites were each dominated by a different species of invasive grass with buffelgrass (*Pennisetum ciliare*) being the most common overall. The Non-native Grassland had three woody species that were abundant (*Prosopis glandulosa*, *Aloysia gratissima*, & *Senegalia berlandieri*) implying woody encroachment. However, woody species are also more likely to be hit due to their larger size. Of the four treatments, only the unrestored pad sites had a forb as a dominant species (*Parthenium confertum*).

Table 2. Top 5 dominant species for each treatment type (May and September combined) based on number of hits. The percentage of hits for each species is recorded in parenthesis. Red Text denotes non-native species. Superscripts denote growth form (G=grass; W=woody shrub/tree; F=forb).

Dominant Species by Treatment

Native Grassland	Non-native Grassland	Restored Pad	Unrestored Pad
Plains bristlegrass *(Setaria vulpiseta)* *(28%)*^{G}	**Guinea grass** *(Panicum maximum)* *(44%)*^{G}	**Buffelgrass** *(Pennisetum ciliare)* *(34%)*^{G}	**Bermudagrass** *(Cynodon dactylon)* *(31%)*^{G}
Rio Grande bristlegrass *(Setaria ramiseta)* *(16%)*^{G}	**Plains bristlegrass** *(Setaria vulpiseta)* *(14%)*^{G}	**Plains bristlegrass** *(Setaria vulpiseta)* *(13%)*^{G}	**Pink pappasgrass** *(Pappophorum bicolor)* *(17%)*^{G}
Prairie acacia *(Acaciella angustissima)* *(15%)*^{W}	**Honey mesquite** *(Prosopis glandulosa)* *(10%)*^{W}	**Pink pappasgrass** *(Pappophorum bicolor)* *(12%)*^{G}	**Buffelgrass** *(Pennisetum ciliare)* *(15%)*^{G}
Multiflowered false rhode *(Acaciella angustissima)* *(15%)*^{W}	**Whitebrush** *(Aloysia gratissima)* *(7%)*^{W}	**Sideoats grama** *(Bouteloua curtipendula)* *(6%)*^{G}	**Coastal sandbur** *(Cenchrus spinifex)* *(14%)*^{G}
Whitebrush *(Aloysia gratissima)* *(5%)*^{W}	**Guajillo** *(Senegalia berlandieri)* *(4%)*^{W}	**Kleberg's bluestem** *(Dichanthium annulatum)* *(4%)*^{G}	**Gray's feverfew** *(Parthenium confertum)* *(4%)*

Three measures of alpha diversity were calculated for each transect: richness (total number of taxa), Shannon's Diversity Index (H'), and Simpson's Diversity Index (1-D) (Table 3). The latter two indices include species richness in their calculations of diversity but also account for evenness (i.e., the relative abundance or total number of individuals in each taxon in the system). Shannon's Index uses both richness and evenness to score each site by quantifying system uncertainty. Sites with higher scores can be interpreted as having more entropy (and are thus more diverse) than sites with lower scores. By contrast, Simpson's Diversity Index can be interpreted as the probability that two samples collected at random will belong to different species. Therefore, the more diverse an area is, the closer to 1 the score will be. Although the two indices are often highly correlated, their difference in mathematical approach means that they often produce different rankings.

Table 3. Summary of the diversity indices for vegetation for each treatment site.

Treatment	**Richness** (# of species)	**Abundance** (# of identifications)	**Shannon Diversity** (H')	**Simpson Diversity** (1-D)
Native Grassland	27	243	1.89	0.71
Non-native Grassland	21	190	1.72	0.69
Unrestored Pad	24	242	1.78	0.70
Restored Pad	31	270	1.88	0.71

All four treatments were surprisingly close in both diversity indices (especially Simpson's). The Non-native Grassland and Unrestored Pad had the greatest variance in diversity with both treatment types boasting the highest and lowest scores for H' depending on the season. The Unrestored Pad was extremely variable with native species percentages ranging between 22% to 92%, richness between 5 to 17 taxa, and H' from 1.12 to 2.21. But the Non-native Grassland had the most interesting trends. This site seemed to be heavily oppressed by invasive grasses in both seasons but more native grasses (especially plains bristlegrass, *Setaria vulpiseta*), forbs, and woody plants were identified in the Fall. Overall, the Native Grassland had the highest average diversity and was the most consistent across the year, followed by the Restored Pad. The Unrestored Pad and Non-native Grassland exhibited the same average diversity across the three indices but had different patterns of seasonality, composition, and native cover.

In addition to Line-Point transects, standing vegetation biomass was collected every 10 m along each transect. Biomass is an important indicator of rangeland production and can reflect the amount of energy stored in the vegetation. Results from these sampling events were also used as input into the APEX model to estimate current and future carbon stores. Biomass was greatest at the Restored Pad for both Spring and Fall surveys, followed by the Native Grassland (Table 4).

Table 4. Biomass (g/m2) of vegetation sampled in May and September 2022.

Treatment	Spring Biomass	Fall Biomass	Average
Native Grassland	2.35	0.41	1.38
Non-native Grassland	1.19	0.28	0.74
Unrestored Pad	1.09	0.25	0.67
Restored Pad	4.02	0.6	2.31

Soil

Soil chemistry and bulk density samples were collected along the same vegetation transects. Samples were collected in May and September 2022 from eight transects - representing two replicates of each treatment. Study sites were selected based on similar soil types, however there were minor soil description differences (Table 5).

Table 5. Soil description at each transect and treatment type.

Transect	Treatment	Latitude	Longitude	Soil Description
1	Native Grassland	28.643	-98.888	CEB: Charco-Altita complex, nearly level
2	Native Grassland	28.643	-98.888	CUA: Cotulla clay, 0 to 3 percent slopes
3	Non-native Grassland	28.641	-98.891	CUA: Cotulla clay, 0 to 3 percent slopes
4	Non-native grassland	26.641	-98.891	CUA: Cotulla clay, 0 to 3 percent slopes
5	Unrestored Pad	28.614	-98.880	CDB: Chacon clay loam, gently undulating
6	Unrestored Pad	28.614	-98.878	CDB: Chacon clay loam, gently undulating
7	Restored Pad	28.477	-98.837	BOB: Bookout clay loam, 0 to 3 percent slopes
8	Restored Pad	28.476	-98.837	BOB: Bookout clay loam, 0 to 3 percent slopes

Results from laboratory analyses are used to calibrate the APEX model to represent current conditions and are used for carbon sequestration estimates. However, analysis results are also descriptive of the current conditions. The laboratory results reported that the greatest organic carbon and organic matter occurred in the Non-native Grassland, followed by the Native Grassland, Unrestored Pad, and Restored Pad (Table 6). Nitrates are a measurement of available nitrogen in the soil and represents another metric of rangeland production. Nitrate measurements were greatest at the Unrestored Pad and Native Grassland. The Unrestored Pad had very high values during the Spring sampling event, while the Fall samples resulted in much lower and more expected values. However, this still had an impact on the average. The reason for the unusually high measurements is unknown, but outliers were removed when calibrating the model. Infiltration rate is the velocity at which water enters the soil. Infiltration is an indicator of the soil's ability to allow water movement into and through the soil profile. The fastest infiltration rates occurred at the Native Grassland and Restored Pad.

Table 6. Mean results of soil samples analyses (May and September combined) at each treatment type.

Treatment	Native Grassland	Non-native Grassland	Unrestored Pad	Restored Pad
Organic Carbon (%)	1.8	2.09	1.63	1.39
Organic Matter (%)	3.09	3.6	2.8	2.4
pH	7.6	7.75	7.76	7.66
Nitrates (g/mt)	7.21	3.44	24.91	3.85
Electrical Conductivity (mmho/cm)	0.12	0.1	0.26	0.37
Bulk Density (t/cubic meter)	1.22	1.19	1.44	1.25
Infiltration Rate (in/hr)	8.94	4.17	4.98	5.34

Carbon

Measured vegetation and soil data was used to inform and calibrate the model Agricultural Policy Environmental eXtender (APEX) to estimate ecological metrics associated with each treatment. APEX is designed to simulate the agronomic and ecological implications of alternative practices and policies, as well as biophysical attributes of a variety of landscapes. To ensure reasonable and robust estimations from APEX, measured data was used to calibrate the model for the intended purposes. APEX version 1905 was set up for separate simulations of all eight sampling sites. Given the geographic coordinates of the sites, corresponding soil data files from the USDA-NRCS SSURGO database were identified. A separate APEX folder was developed for each site, including all files required for APEX simulating the specific sites. For each of the four treatments, the vegetation simulated were selected from species that were identified in the vegetation sampling events. However, these selections were modified during the calibration procedure. The following are the resulting vegetation mixes that were chosen for all four treatments after the calibration process was completed (Table 7).

Table 7. Vegetation mixes selected for each treatment in APEX 1905.

Native Grassland	Non-native Grassland	Unrestored Pad	Restored Pad
Setaria vulpiseta	*Panicum maximum*	*Cynodon dactylon*	*Pennisetum ciliare*
Acacia angustissima	*Setaria vulpiseta*	*Pappophorum bicolor*	*Setaria vulpiseta*
Setaria ramiseta	*Prosopis glandulosa*	*Pennisetum ciliare*	*Pappophorum bicolor*
Trichloris pluriflora	*Aloysia gratissima*	*Cenchrus spinifex*	*Bouteloua curtipendula*
Aloysia gratissima	*Acacia berlandieri*	*Parthenium confertum*	*Dichanthium annulatum*
Bouteloua curtipendula	*Amaranthus* sp.	*Euphorbia stictospora*	*Trichloris pluriflora*
Acacia berlandieri	*Setaria ramiseta*	*Isocoma coronopifolia*	*Polanisia dodecandra*
Mimosa microphylla	*Euphorbia stictospora*	*Setaria vulpiseta*	*Euphorbia stictospora*
Acacia rigidula	*Pappophorum bicolor*	*Acacia rigidula*	*Solanum elaeagnifolium*
Pennisetum ciliare	*Cenchrus spinifex*	-	-
Abutilon sp.	-	-	-

Model calibrations are conducted to ensure that a model mimics as closely as possible, the real world processes and mechanisms that it seeks to simulate. Depending upon the scope of measured data available, model output may be calibrated against specific values or averages or other appropriate statistics of these values. In the present application, only two sampling events were obtained. Consequently, the expectation was that APEX simulations would mimic the relative values of the observed ecological indicators between treatments sites, more so than actually reflecting the absolute values reported. APEX reports simulated values for hundreds of agronomic and ecological indicators at daily, monthly, and annual time scales, as well as annual and monthly averages across the entire simulation horizon. In contrast to calibrations, treatment scenario simulations were performed by simulating each treatment on identical soils. This process ensures that the results solely reflect the impacts of the treatments, and not confounded by the differences in soil attributes at the eight sampling sites. Simulated values represent average annual values, averaged over the 25-year simulation period (Table 8, 9). Estimated carbon sequestration rates were greatest in the Native Grassland and Restored Pad (Table 8). Water in the soil profile was similar between all four treatments with the Unrestored Pad having the most water in the soil profile and root zone, but also the most surface runoff and sediment loss in runoff (Table 9). The Native Grassland and Restored Pad had the least amount of runoff.

Table 8. Estimated soil and carbon sequestration values over a 25-year simulation using APEX 1905.

Treatment	Native Grassland	Non-native Grassland	Unrestored Pad	Restored Pad
pH	7.55	7.6	7.6	7.68
Nitrates (g/mt)	0.18	0.18	0.3	0.18
Electrical Conductivity (mmho/cm)	0.12	0.12	0.12	0.12
Biomass (mt/ha)	5.8	6.63	2.78	2.91
Bulk Density (mt/m-3)	1.22	1.22	1.22	1.22
Organic Carbon (%)	1.92	1.71	1.89	1.63
Carbon Sequestration Rate (mt/ha/yr)	0.09	0.05	0.07	0.09

Table 9. Estimated soil water and runoff values over a 25-year simulation using APEX 1905

Treatment	Native Grassland	Non-native Grassland	Unrestored Pad	Restored Pad
Soil Water in Profile (mm)	386.65	387.75	395.15	389.75
Soil Water in Root Zone (mm)	13.5	15	22.45	16.95
Surface Runoff (mm)	3.11	7.88	8.85	3.04
Sediment Loss in Runoff (mt/ha/yr)	0.06	0.15	0.27	0.07

Biodiversity

The biodiversity surveys were composed of 12 transects on the same 4 treatment types. Each treatment type had three transects. Surveys were conducted for 3 days at each treatment type during May, July, and September of 2022. The total of all surveys recorded 109 taxa (93 species, 2 genus-only identifications, & 14 order-only identifications) and 15,785 observations. Due to differences in detection methodology, mammals were split into three guilds (bats, small mammals, and meso-large mammals) while reptiles and amphibians were lumped together as herpetofauna due to the low number of amphibians. All invertebrates were identified to Order. Since there was only one order of mollusks and arachnids each, they were included with insects for most calculations.

Richness (number of unique taxa) was variable across treatments, with the Unrestored Pad having the greatest number, followed by Native Grassland (Table 10). The Non-native Grassland had the fewest species. Species abundance and activity was also variable among treatments, with the Restored Pad having the most observations, followed by the Native Grassland. The Restored Pad had the greatest number of observations of bats and invertebrates which inflated overall abundance.

Similar to richness and abundance, there was also high variability in the two diversity indices used to estimate biodiversity. These indices are another metric to interpret data and show similar rankings to that of richness and abundance. Indices may be compared between treatments but cannot be compared between taxa within the same treatment due to the different survey methodologies used to collect that data. The greatest bird diversity occurred at the Unrestored Pad and the Native Grassland. The Native Grassland contained the highest diversity of bats, small mammals, reptiles and amphibians, and invertebrates. Meso-mammal diversity was greatest in the Non-native Grassland. The Restored Pad had the lowest diversity in every category except for herpetofauna (H and 1-D) and meso-mammals (1-D).

Table 10. Summary of the number of unique taxa and individuals identified, and associated diversity indices for each treatment.

Treatment	Taxa and Guilds	# of Unique Taxa	# of Observations	Shannon Diversity Index	Simpson Diversity Index
Native Grassland	Birds	42	278	3.226	0.95
	Bats	5	411	0.723	0.33
	Small Mammals	5	103	1.261	0.68
	Meso-Large Mammals	7	119	0.913	0.44
	Herpetofauna	8	19	1.645	0.78
	Invertebrates	14	2,988	1.855	0.81
	Total	***82***	***3,928***	-	-

Non-native Grassland	Birds	27	134	2.895	0.93
	Bats	5	456	0.516	0.24
	Small Mammals	4	19	1.136	0.66
	Meso-Large Mammals	5	31	1.176	0.66
	Herpetofauna	3	4	NA	NA
	Invertebrates	13	1,287	1.768	0.78
	Total	***58***	***1,931***	-	-

Restored Pad	Birds	26	180	2.456	0.86
	Bats	5	1,001	0.314	0.12
	Small Mammals	4	120	0.676	0.33
	Meso-Large Mammals	6	113	0.895	0.46
	Herpetofauna	6	20	1.446	0.73
	Invertebrates	13	5,429	1.322	0.56
	Total	***61***	***6,863***	-	-

Unrestored Pad	Birds	52	226	3.535	0.96
	Bats	5	432	0.576	0.25
	Small Mammals	7	52	1.236	0.62
	Meso-Large Mammals	7	53	0.946	0.42
	Herpetofauna	1	6	0	0
	Invertebrates	14	2,294	1.515	0.65
	Total	***87***	***3,063***	-	-

High variability existed within every metric used to measure biodiversity. The Unrestored Pad had the greatest richness, the Restored Pad had the greatest abundance, and the Native Grassland had the greatest number of taxa with the highest diversity index values. Despite this, the Native Grassland scored consistently well across all four measures diversity (richness, abundance, Shannon's Index, and Simpson's Index) while the other three sites only scored well on specific aspects.

When results between the two sites seeded with native species (Native Grassland and Restored Pad) are joined and compared to the non-native species sites (Non-native Grassland and Unrestored Pad), there is a notable difference in the number of individuals identified. Species richness was very similar (Native: 92 taxa, Non-native: 94 taxa), but there was a significant difference in abundance (Native: 10,791 observations, Non-native: 4,994 observations) based on Chi-square tests ($X2$ [114, N=15,785] = 704.468, $p<0.0001$). More individuals were found in every taxon in native restored sites compared to those dominated with non-native vegetation. However, diversity indices largely favored the non-native dominated sites in almost every taxon. Because abundance was much greater at the native restored sites, it reduced community evenness which impacted diversity indices. So, while the non-native sites generally have higher diversity values, the native sites appear to be supporting more individuals for most species, which is a good indicator of ecological health.

As stated before, high variability existed in almost every metric to measure biodiversity. There is no one metric to accurately capture biodiversity in an ecosystem, which is why numerous metrics are used. Determining a summary level value to measure biodiversity is difficult because sampling different taxonomic groups or guilds requires different methodologies. These data represent a snapshot in time based on current conditions of the site. Additional sampling over time and in more locations would increase accuracy and precision of collected data. However, there are some different explanations for the variability of results we see within biodiversity. For example, the primary reason the Unrestored Pad had the greatest number of unique taxa found was the high number of bird species identified. This pad was surrounded by woody species that may have created an edge effect that attracted birds. In addition, the Restored Pad pump jack was actively making noise during surveys while the Unrestored Pad was quiet. Not only does this impact the ability of surveyors to detect birds, but noise pollution has been shown to decrease avian diversity and vocal activity (Senzaki et al., 2020).

Additionally, although the vegetation surveys showed that the restored sites generally had greater native plant coverage and were more diverse on average, there were notable deviations from these trends. For example, one of the Restored Pad surveys showed markedly lower native species cover and diversity than many of the surveys of unrestored pad. Therefore, even during the short sampling period, the Restored Pad was not always dominated by native vegetation which could have a large impact on the number and type of wildlife species identified.

Finally, invertebrates contained the greatest number of observations between taxa. Due to this large number of observations, invertebrates were only identified to Order because of time and logistical constraints. By doing this, it had an impact on calculated diversity indices. Research has shown that although native and non-native plant species generally host generalist insects from most orders, native plant species generally harbor far greater taxonomic diversity below Order in the form of specialists and less adaptable generalists (Bellard et al., 2013). As a result, the diversity indices for the invertebrates are most likely biased towards the sites with greater non-native vegetation cover due to the coarse level of taxonomic richness and the resulting greater unevenness among the taxa.

CONCLUSION

Seeding the Native Grassland and the Restored Pad had a positive impact on native plant cover and diversity. They were both dominated by native species compared to the Non-native Grassland and the Unrestored Pad. Additionally, the Native Grassland had the highest average diversity and was the most consistent across the year, followed by the Restored Pad. However, there were notable deviations from these trends. Including, buffelgrass becoming the most identified species during Fall surveys at the Restored Pad. This suggests that without maintenance, invasive species such as buffelgrass may continue to outcompete native species.

Changes in soil composition and soil organic carbon takes many years following a restoration project (Smith 2004). In addition, the rate of carbon sequestration is largely predicated upon the same factors that influence primary plant production, soil attributes, topography, land cover, management, and climate. Thus, to adequately estimate carbon sequestration rates, computer models must carefully account for all these factors. This is why modeling is necessary in these studies. Measured soil and vegetation values were used to calibrate the APEX model and provide data to ensure robust estimations. The greatest estimated carbon sequestration rates existed in the Native Grassland and Restored Pad. Native grasses have complex root systems that are ideal for storing carbon in the soil. Their root structures also help stabilize the soil, increase moisture levels, and retain nutrients. These sites also had the least amount of surface runoff and therefore will retain more water on the landscape and improve carbon sequestration potential through increased biomass and improved soil microbial activity.

High variability existed within every metric used to measure biodiversity. The Unrestored Pad had the greatest richness, the Restored Pad had the greatest abundance, and the Native Grassland had the greatest number of taxa with the highest diversity index values. Despite this, the Native Grassland scored consistently well across all four measures diversity (richness, abundance, Shannon's Index, and Simpson's Index) while the other three sites only scored well on specific aspects. Determining a summary level value to measure biodiversity is difficult because sampling different taxonomic groups or guilds requires different methodologies. These data represent a snapshot in time based on current conditions of the site. Additional sampling over time and in more locations would increase accuracy and precision of collected data. However, there was a significant difference in the abundance of the two native restored sites. Invertebrates are often the most sensitive to restoration activities due to their short regeneration times and ability to respond rapidly to ecological changes (Litt et al. 2014) and the large number of invertebrates found on the restored sites may be a direct result from restoration activities.

In conclusion, the Native Grassland and Restored Pad were restored with native vegetation that is adapted to and evolved in this ecosystem and it showed positive impacts to the vegetation community, carbon sequestration potential, erosion, and biodiversity. There are numerous benefits of restoring rangeland and disrupted land from invasive, non-native species to those that are native, and those benefits have been well documented (Bai and Cotrufo 2022, Castagneyrol and Jactel 2012). Specifically, in the same county Gowdy et al. (2022) restored a buffelgrass dominated grassland and had positive results in improving biodiversity of butterflies and birds. Results from this project provided data for another case study that reduces the knowledge gap of restoration in the Eagle Ford Shale/South Texas Tamaulipas Brushland region of Texas. As well as another case study for showing the ecological benefits of using native species in restoring rangeland and oil well pads.

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