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Abstract
Invasive grasses are in most cases introduced species able to outcompete native species. Buffelgrass (*Cenchrus ciliaris*), Guineagrass (*Urochloa minima*), and Old World bluestems (*Dichanthium* spp.) are typical examples of invasive species in southeastern United States. However, native grasses such as tanglehead (*Heteropogon contortus*) can become invasive and dominant in absence of cattle grazing just like any invasive species. Tanglehead and Kleberg bluestem (*Dichanthium ischaemum*) increased ($p < 0.05$) from 1.4 and 1.8% in 1999 to 2.7 and 3.6% in 2002 and then to 8.1 and 9.4% in 2009, respectively. Monocultures of invasive species have very little value for wildlife, and in the case of mature tanglehead its palatability for cattle is very low. Prescribed fire may be used to improve palatability of tanglehead for cattle, and cattle grazing may be used to improve plant species richness for wildlife. To evaluate the effects of prescribed fire and cattle grazing on cattle preference and the botanical composition of a plant community dominated by tanglehead, we burned 3 patches of approximately 0.5 ha in a pasture of 107 ha in October 2016. Two months before the prescribed burning was executed, 10 mother cows were placed in the pasture to graze continually. We fitted GPS collars on 8 cows and location readings were collected every 10 minutes. GPS recordings indicate that cattle used burned patches 4.5 times more after burning compared to before burning. Percent forage utilization of tanglehead was 52% in the burned patches compared to 6% in the control areas. Plant species richness increased from 2.53 to 8.33 plant species per 0.25 m^2, before and after burning, respectively, an increase of 330%. Prescribed fire and cattle grazing are valuable tools to increase tanglehead palatability and utilization by cattle and plant species richness for wildlife.

Introduction
Invasive species are a principal threat to plant and animal diversity worldwide. Grasses are approximately 15% of all invasive plant species in the U.S. (D'Antonio et al. 2011, Wied et al. 2020). South Texas is a very diverse region in the United States, rivalling even rich tropical areas like the Everglades (Fulbright and Bryant 2002), however it has experienced grass invasions at the expense of native species diversity (Flanders et al. 2006, Smith 2010).

Tanglehead is considered a valuable forage species for cattle (*Bos* spp.) production in Australia (Orr et al. 1991), and a decreaser in other areas of its distribution range (Hueze et al. 2017). Palatability of mature tanglehead for cattle is very limited. In the mid 1990's, an aggressive expansion of tanglehead occurred across the Coastal Sand Plain ecoregion of South Texas, which is characterized by beef cattle production and wildlife-related recreational enterprises (Fulbright and Bryant 2002). Avoidance of tanglehead by cattle has been repeatedly reported (Tjemeland 2011).

The objectives for this research were to determine the effects of prescribed fire and cattle grazing on 1) the composition of a plant community dominated by tanglehead; and 2) cattle use of tanglehead-dominated areas treated with prescribed fire.

Methods and Study Site
The study site was a 95.5 ha pasture on a private ranch (26°51'08.3" N, 98°36'57.2" W; 156 m above sea level [masl]) located in Jim Hogg County, 55 km south of Hebbronville, Texas, USA. The ranch sits on the western edge of the Coastal Sand Plain of South Texas, an area that increased from 7.1% to 17.8% tanglehead cover from 2008 to 2014 (Mata et al. 2018). Climate for this region is semiarid and subtropical with high variation in annual rainfall, but averaging between 500 and 800 mm. The two major soil associations on the site are Delmita and Nueces-Sarita associations that consist of gently sloping deep fine sandy loams or fine sands. Both are used primarily for range production and are characterized by brushy grasslands yielding from 2,240 $kg \cdot ha^{-1}$ dry forage in dry years to 4,480 $kg \cdot ha^{-1}$ in wet years (USDA-NRCS 2017). Native grasses that can constitute 70% of potential forage standing crop include tanglehead, spiked crinkleawn (*Trachypogon spicatus* [L.f.] Kuntze), seacoast bluestem (*Schizachyrium littorale* [Nash] E.P. Bicknell), and pan-American balsam

scale (*Elionurus tripsacoides* Humb. & Bonpl. ex Willd. This site supports a high diversity of native forbs such as American snoutbean (*Rhynchosia americana* [Houst. ex Mill.] M.C. Metz), soldier weed (*Waltheria indica* L.), cardinal feather (*Acalypha radians* Torr.), croton (*Croton* spp.), hoary milkpea (*Galactia canescens* Benth.), and spotted beebalm (*Monarda punctata* L.). Honey mesquite (*Prosopis glandulosa* Torr.) mottes containing other brush species such as granjeno (*Celtis ehrenbergiana* [Klotzsch] Liebm.), brasil (*Condalia hookeri* M.C. Johnst.), blackbrush acacia (*Vachellia rigidula* [Benth.] Seigler & Ebinger) and Texas persimmon (*Diospyros texana* Scheele) are somewhat regularly distributed (Bielfelt 2013).

No grazing had occurred on the site for three years prior to the initiation of the study. Ten pregnant cows continuously grazed the pasture beginning on August 24, 2016. Ranch employees only supplemented cows with mineral tubs and a small amount of range cubes to condition them to follow the feed truck with the sound of a siren. This constituted a stocking rate of 9.5 ha/animal unit/yr. Eight cows were fitted with Lotek LifeCycle® GPS collars (Lotek Wireless, Inc., Newmarket Ontario, Canada) to collect GPS locations every 10 minutes from August 24, 2016 to March 6, 2018. We used GPS points recorded during the prime grazing hours of 1 hour before sunrise to 3 hours after sunrise, and 3 hours before sunset to 1 hour after sunset (Howery et al. 1996).

In August 2016, we marked six experimental plots in tanglehead-dominated areas, based on classified aerial imagery produced by Mata et al. (2018). Three plots were randomly selected for prescribed burning (n = 3, mean area = 7.83 ha) and three plots as control (n = 3, mean area = 8.3 ha) in a completely randomized design with two treatments (burn and control) and three repetitions each. The original design for this study called for three new plots to be burned annually to create a mosaic of treatment patches in different stages of regrowth. However, due to low amounts of precipitation in fall 2017, the ranch owner decided the amount of forage was inadequate to conduct a fire and sustain the stocking rate agreed upon at the start of the experiment. Therefore, no burns occurred in 2017, and we only sampled the plots burned in 2016 for the remainder of the study.

To assess the vegetation community and fine fuel load prior to prescribed burning, we generated twenty random points for each of the burn plots in ArcMap 10.X (ESRI, the Redlands) and sampled each point using a 0.25 m^2 frame. Percent cover of species, litter, and bare ground were visually estimated. We clipped all vegetation inside the frame to 5 cm above the soil surface and weighed it immediately. We placed representative portions of each sample weighing 100 grams in paper bags, stored them in a drying room at 40 °C for a minimum of 2 weeks, and re-weighed them to calculate the dry forage standing crop (Pieper 1988).

Prior to conducting each prescribed burn, we recorded air temperature, wind speed, wind direction, and relative humidity using a Kestrel® 4500 Weather Meter. The wind was blowing out of the southeast, and the north edge of each patch was burned first to create a backing fire, then the west edge, and after an adequate buffer was made with the already-burned areas, the south and east edges were lit to quickly burn the remaining portion. One week after the burns were conducted, we placed one grazing exclosure (2.4 m wide, 2.4 m long, and 1.3 m tall) in each of the study plots over selected patches of tanglehead in both the control and burn plots. These exclosures served as the focal points of the vegetation sampling. We sampled inside and outside the exclosures four times over the course of the study in March 2017, June 2017, October 2017, and February 2018; 4, 6, 11, and 15 months after burning, respectively. Each time we sampled vegetation, we relocated grazing exclosures to a new patch of tanglehead elsewhere in the plot. We sampled vegetation using a 0.25 m^2 frame to record percent cover of species, litter, and bare ground using ocular estimation. We sampled vegetation inside each exclosure by placing the frame on vegetation representative of the entire inside area, and likewise sampled vegetation within a 5 m distance outside each exclosure to calculate percent utilization. The variables studied using these vegetation data were plant species richness, tanglehead cover, total plant cover, bare ground, forage utilization, and forage standing crop.

This study had two treatments (burn and control), three replications (n = 6), and four sampling periods (n = 4). We conducted a repeated measures analysis of variance to analyze vegetation data using sampling period as a repeated measure. This analysis tests for assumptions and accommodates violations along with accounting for the non-independence of my experimental design, as all samples came from the same plots throughout the study.

The number of GPS locations recorded from cattle collars in the burned areas relative to the total number of locations in the burned and control patches for each block was analyzed as a binomial random variable with a

generalized linear model to test for differences in probability of use in burned areas over time. We modeled non-independence over time with a heterogeneous compound symmetry structure for which the generalized chi-square/df = 0.99, indicating adequate model fit. Probability of use during each month following burning was compared to probability of use averaged over the 3 months sampled prior to burning (September-November 2016) with a t-test (following a significant overall F test on the null hypothesis that probability of use in burned areas did not change over time).

Results

Average plant species richness in the burned plots increased from 2.5 species per 0.25 m^2 in the three months before burning to 8.42 species per 0.25 m^2 in the 16 months after burning. Average plant species richness across all sampling periods was higher ($p = 0.0566$) in burned plots than control plots.

Average cover of tanglehead across all sampling periods was 29.75% and 55.75% for burned plots and control plots, respectively. Bare ground percentage was significantly higher in burned plots than control plots for three out of four sampling periods, there was a significant ($p = 0.0118$) prescribed fire effect, and no period effect ($p = 0.1459$). However, a weak interaction ($p = 0.0595$) between prescribed fire and sampling period was observed. February 2018, the last sampling period, was the only sampling period in which bare ground was similar ($p = 0.168$) in burned plots and control plots with average values of 25% and 13%, respectively. In March 2017, June 2017, and October 2017 bare ground was higher ($p = 0.0008$ to 0.0072) in burned plots compared to control plots with average values of 51% and 10%, of 33% and 5%, and of 42% and 5%, respectively. Average bare ground percentage across all sampling periods was 37.8% in burned plots and 8.25% in control plots.

Forage utilization in burned plots was higher ($p = 0.0016$ to 0.0813) with a range of 30% to 73% for burned plots and 0% to 31% for control plots across the first 3 sampling periods. The effect of burning and grazing on forage utilization decreased after one year and three months, and utilization was no different ($p = 0.8248$) in burned and control plots in February 2018. When looking at changes across periods for utilization, the period effect was not significant ($p = 0.2781$) for the control, but was significant ($p = 0.0335$) for the prescribed fire treatments. An interaction ($p = 0.0529$) occurred between treatment and sampling period.

The average percentage of points recorded in the burned plots during the three months prior to burning was 30.2%. Percentage of points recorded in the burned plots was higher ($p = 0.0001$ to 0.0194) in six out of the seven months following burning (November 2016 – May 2017), and ranged from 44.9 to 60.2%. Cattle increased their utilization of the burned plots by 13-30% percent for seven months after burning, and the higher utilization persisted for over a year.

Total white-tailed deer observations in the burned and control plots were 35 and 34, respectively. Total northern bobwhite observations in the burned and control plots during the study were 71 and 16 coveys, respectively.

Discussion [Conclusions/Implications]

The combination of prescribed fire and cattle grazing is an effective treatment to increase plant species richness and bare ground on tanglehead-dominated landscapes. Average plant species richness increased nearly threefold after burning and was nearly twice as high as control areas, and bare ground was significantly higher in burned areas than control areas in the majority of sampling periods. These results are compelling because species richness and bare ground are among the primary parameters that decrease with the presence of monotypic tanglehead stands. Bielfelt and Litt (2016) reported a decrease in cover and richness of native plant species along a gradient of increasing tanglehead cover, as well as a more contiguous canopy and less bare ground. Bare ground used for foraging and brood-rearing is an important component of northern bobwhite habitat (Doxon and Carroll 2010), and Buelow et al. (2011) observed northern bobwhites avoided dense patches of tanglehead while off a nest site, instead preferring areas with more bare ground and food-producing forbs than random locations would indicate**.**

Forage utilization was higher in the burned areas compared to the control plots and lead to a 30% increase in cattle use of burned areas for up to seven months after burning; these effects persisted for over a year. Burned plots of mature tanglehead had significant increases in utilization by cattle, most likely due to the tenderness of regrowth vegetation and high levels of crude protein typical in re-emerging vegetation, as well as greater accessibility due to a reduction in mature stems. The accumulation of coarse stems in grasses reduces

utilization by cattle (Wallis de Vries and Daleboudt 1994), and their removal by burning creates a grazing habitat with greater accessibility to high quality forage, ultimately increasing foraging activity on those areas (Clark et al. 2017).

Application of prescribed fire on tanglehead-dominated areas can increase cattle utilization by up to four times in addition to improve native plant species richness, providing foraging and brood-rearing areas for northern bobwhite while maintaining adequate nesting cover. The benefits of prescribed burning lasted for over a year in our study. Patch-burning and grazing capitalized on the high productivity and resiliency of tanglehead for livestock forage while mitigating its invasive effects on the native plant community and improving the habitat for bobwhite quail.

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