Effects of Fire Intensity and Abiotic Factors on Persistence of an Encroaching Woody Species

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Introduction

Over the past century, rangelands worldwide have experienced changes in vegetation cover and structure, many transitioning from grass-dominated to shrub-dominated systems (Archer *et al.* 2017; Fuhlendorf *et al.* 2017). In North America, such transitions are primarily a consequence of livestock management and fire exclusion practices of Euro-American settlers (Bray 1904; Archer 1989; Fuhlendorf and Smeins 1997). These shrub-dominated systems are often less productive for wildlife and livestock and may have crossed a threshold which cannot be reversed via common restoration practices such as prescribed fire (Ansley and Castellano 2006; Ratajczak *et al.* 2016). Oftentimes, the inability of prescribed fire to succeed at crossing this threshold is the result of insufficient fuel loading or inadequate fire intensity due to prescription parameters (Havstad and James 2010; Twidwell *et al.* 2016). However, recent work has demonstrated that burning under more extreme conditions (e.g. higher temperatures, lower fine fuel moisture) can slow or change the course of encroachment (Twidwell *et al.* 2013; Twidwell *et al.* 2016).

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Many encroaching shrub species are capable of persisting after fire via resprouting from protected buds (Bond and Midgley 2001). Such mechanisms pose challenges for land managers, particularly because resprouting often results in a higher number of stems per individual plant. Mesquite (*Prosopis spp*.) shrubs are well-known for their ability to persist to varying degrees following disturbance due to fire, chemical, and mechanical treatments. Due to historical livestock management and fire suppression practices, honey mesquite (*Prosopis glandulosa*) has increased in dominance and abundance in the southern Great Plains since the beginning of Euro-American settlement (Bray 1904; Archer 1989). Although prescribed fire has increased in acceptance as a method to reduce encroachment of mesquite, low-intensity fires performed during the dormant season rarely cause mortality (Wright and Bailey 1980; Ansley *et al.* 1998), especially when they are performed as a single treatment rather than as part of a comprehensive management plan. However, recent studies have demonstrated that more intense fires conducted outside the dormant season are capable of reducing resprouters (including mesquite), particularly during periods of drought (Twidwell *et al.* 2016). We evaluated impacts of fire intensity and abiotic factors on persistence of honey mesquite, a species of concern for managers in the southern Great Plains.

Methods

Study site

The Texas A&M AgriLife Sonora Research Station (SRS) is located in the Edwards Plateau ecoregion of Texas, approximately 56 km south of Sonora, Texas. The site is characterized by rolling topography and highly variable precipitation patterns. Soils are of the Tarrant silty clay series, of the clayey-skeletal, montmorillonitic, thermic family of Lithic Haplustolls, at an elevation of 730 m. The generally bimodal precipitation is highly variable, ranging from 156-1054 mm (median = 557 mm), with most of the rainfall resulting from spring and autumn thunderstorms. Herbaceous vegetation is comprised mainly of discontinuous mid- and shortgrass species. The portion of SRS used for this study was treated with an extreme prescribed fire in August of 2000 and deferred from livestock herbivory for a growing season prior to the experiment.

We created 10 m x 10 m plots centered around 72 individual mesquite shrubs and randomly assigned each a treatment combination of fire intensity (no fire, low intensity, and high intensity) and root collar exposure (yes or no). Due to the low and discontinuous ambient fuel load present at the site prior to our experiment, hay was spread evenly across each plot prior to ignition. Previously cut and dried juniper was added to high-intensity plots prior to ignition to create more intense fires. Fuel additions were performed to plots the same day a plot was burned. Fires were ignited individually in a “ring fire” pattern using two drip torches beginning at the downwind corner and meeting at the upwind corner. Burns were executed between July 30-August 4, 2018. Weather parameters (temperature, relative humidity, and wind speed) were collected using a handheld weather station. Soil moisture (%) was measured immediately prior to ignition using a handheld soil moisture probe at three random points within the plot. On-site temperatures during the fires ranged between and 33.2° C and 38° C, with relative humidity of 20.3% to 30.2%, and wind speeds from zero to 13.4 kilometers per hour. Year to date precipitation was 103.6 mm (data from on-site RAWS station). Shrub persistence was measured visually as proportion of the canopy that was green when sampled on October 23, 2018 (12 weeks post-fire).

Statistical Analysis

We used beta regression because our variable of interest is a proportion. Beta regression is commonly used for rates and proportions for values between 0 and 1. These types of response variables are typically asymptotic, and heteroskedastic with more variability around the tails of the distribution (Ferrari and Cribari-Neto 2004). Using regression based on the beta distribution is more appropriate than transforming the response variable because the beta density is flexible, assuming a number of shapes depending on the parameters. It is robust in handling the effects of heteroskedasticity and the regression parameters can be interpreted in terms of the mean response variable (Ferrari 2004). Our response variable was the proportion of canopy that was green when sampled on 10/23/2018. Predictor variables were fire intensity (HIGH versus LOW), whether the root collar was exposed (Dig1) or not (Dig0), the average soil moisture of the plot at the time of burning, wind speed in miles per hour, relative humidity, and temperature at the time of the fires. All analyses were performed in the R statistical computing environment (R Core Team 2017) with the betareg package (Cribari-Neto and Zeileis 2010) to fit the regression models and the mfx package to estimate marginal effects (Fernihough 2014).

Results

Fire intensity, root collar digging, and soil moisture all had a significant effect on the proportion of the canopy that was green on 10/23/2018 (12 weeks post-fire). Estimates of explanatory variables are reported below along with their odds ratios (Table 1). Odds ratios show the strength and direction of the association between a unit change (or change in level with categorical variables - i.e. from low intensity to high intensity) in an explanatory variable and the proportion of green canopy. Odds ratios greater than 1 show an increase in proportion of green canopy with a change in level or unit increase. Odds ratios less than one depict a decrease. Going from high intensity to low intensity fire had the strongest positive association (Figure 1) with the proportion of green canopy (OR= 5.44, $p<0.001$). A unit change in soil moisture also increased the proportion of green canopy (OR=1.18, $p<0.001$). Digging out the root collar (Figure 2) decreased the proportion of green canopy (OR=0.34, $p=0.002$). Because odds ratios are difficult to interpret with regards to the mean value of the response variable, we also calculated marginal effects of the explanatory variables on the response variable.

Table 1: Estimated coefficients of explanatory variables and associated odds ratios.

Coefficients (mean model with logit link):					
	Estimate	Std. Error	OR*	z value	Pr(>|z|)
(Intercept)	-10.21	6.2	3.64	-1.64	0.1
INTENSITYLOW	1.69	0.35	5.44	4.75	<0.001
as.factor(Dig)1	-1.09	0.31	0.34	-3.49	<0.001
Soil_Avg	0.16	0.05	1.18	3.15	0.002
air_temp	0.05	0.05	1.06	1.02	0.306
RH	-0.03	0.04	0.96	-0.85	0.392
wind_mph	0.07	0.06	1.07	1.05	0.295

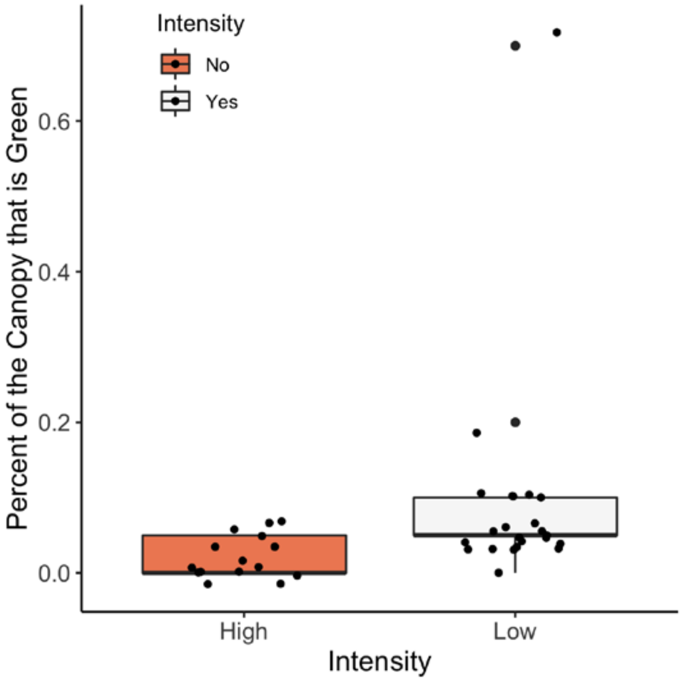

Figure 1: Boxplot showing effects of high- and low-intensity fires on percent of green canopy present 12 weeks post-fire (October 23, 2018).

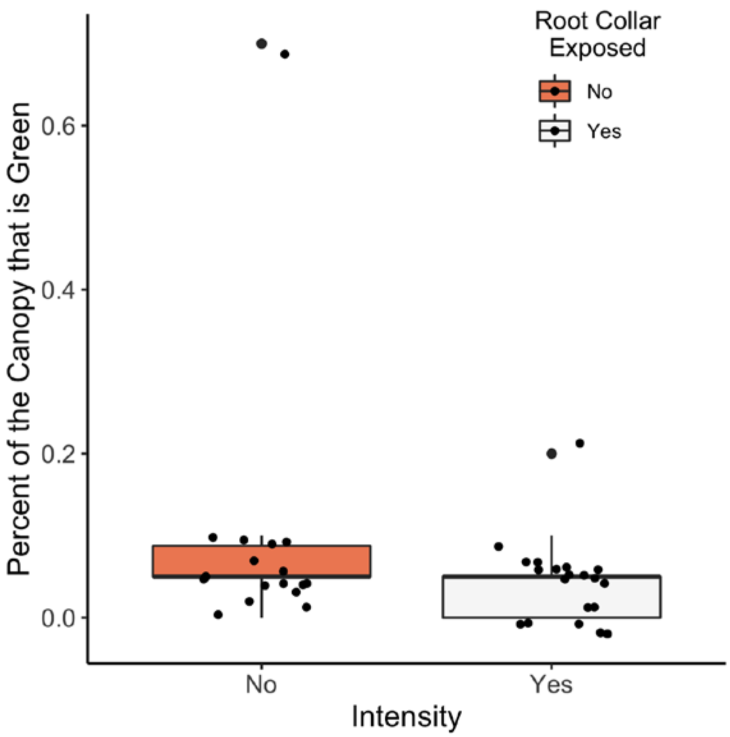

Figure 2: Boxplot showing effects of root collar exposure on percent of green canopy present 12 weeks post-fire (October 23, 2018).

Marginal effects are the change in the response variable (proportion of canopy green on 10/23/2018) for a change in the explanatory variables. For categorical variables, the marginal effect is the mean change in proportion of the canopy that is green when you go from a base variable, which is not displayed in the list of marginal effects (dF/dx), to the listed variable. The base (omitted) category for intensity is HIGH and the base (omitted) category for digging is 0, or no digging. Thus, being categorized as low relative to high intensity increased the proportion of the canopy that is green by 0.06 (± 0.01). Having stems dug out to expose root collars decreased the proportion of the canopy that is green by 0.05 (± 0.01). A 1% increase in average soil moisture recorded in a plot increased the proportion of the canopy that was green by 0.01 (±0.003).

Table 2: Estimated marginal effects, or the amount of change observed in proportion of canopy green as a result of a change in a given explanatory variable.

Marginal Effects:				
	dF/dx	Std. Err.	z	P>|z|
INTENSITYLOW	0.06	0.01	4.2	<0.001
as.factor(Dig)1	-0.05	0.01	-3.01	0.002
Soil_Avg	0.01	0.003	2.9	0.004
air_temp	0.002	0.002	1.02	0.308
RH	-0.002	0.002	-0.85	0.395
wind_mph	0.003	0.003	1.04	0.297

Discussion:

Our data reveal that high intensity fires have a strong negative effect on persistence of mesquite shrubs, supporting previous work performed on a suite of resprouters (including mesquite) in the southern Great Plains (Twidwell et al 2016). Encroachment of this native species has proven difficult to control with traditional (low-intensity) fire, even in regions capable of producing significantly more fine fuel than our semi-arid study site (Ansley and Castellano 2006). Further, our results highlight the importance of fire intensity in that shrubs burned at low intensities had higher proportions of green canopy 12 weeks post-fire, even under conditions of low soil moisture. The negative impact of root collar exposure on proportion of green canopy is consistent with buds-protection-resources (BPR) theory (Clarke *et al.* 2013). By digging to expose the root collar, buds previously insulated by soil were exposed to lethal heat. The added impact of low soil moisture during the fire reinforces the suggestion that fires during periods of drought stress enhance the effects of fire (Twidwell *et al.* 2016). Our results may be especially useful to managers of lands that have been encroached by these resprouting native shrubs. By incorporating high-intensity fires into a comprehensive management strategy, mesquites may be reduced or managed.

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