The Influence of Time Since Burn on Herpetofaunal Abundance, Evenness, Richness and Diversity in a Post Oak Savannah

By

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ABSTRACT

As populations of reptiles and amphibians are at a global decline, land managers have limited resources dedicated to the control of herpetofaunal populations. Controlled burning is a common management tool, but the existing studies of the effect of fire on reptiles and amphibians remains sparsely scattered among many environment types and are often not thorough enough to provide accurate predictions on the effects of herpetofaunal populations to specific habitat types. I evaluated the effects of fire on the reptile and amphibian community at Gus Engeling Wildlife Management Area in east Texas. The site has continuous burn treatments throughout the property, meaning the site burns often enough in some sections to create various degrees of burn times to study the effects on wildlife. There were 27 trap arrays installed across the property with 4 traps per array. I trapped during the first 12 days of every month starting in June and ending in August in 2016 and 2017. When checking traps, I recorded age, sex, weight, and marked each specimen by branding and pit tagging snakes and toe clipping lizards and amphibians. These were then subsequently released, some of which were recaptured and identified by the markings. I had a total of 246 individual captures from 21 species, across 1,795 array nights. Looking at my herpetofaunal captures I used an ANOVA to calculate abundance, evenness, richness, and diversity. Then I performed linear regressions on this data, which covered the topics of total abundance, evenness, richness, and diversity. It was also performed on the abundance from catch data of the most captured species, to determine if any of these showed significance. The species used for the regressions were any that comprised 10% or more of my captures, which include six-line racerunner, ground skink, fence lizard, coachwhip, and the grouping of true toads (bufonidae). The results suggest that time since burn had a subtle but significant negative relationship on the overall reptile and amphibian populations. The only exception to this was toad abundance, which showed a slight increase with time since burned. Abundances for six-lined racerunners and fence lizards declined with time since burn, while coachwhips and ground skinks were unaffected by time since burn. My results suggest that burning will minimally affect reptiles and amphibians. My research provides land managers with a better understanding of how prescribed burning impacts this neglected group of animals. Specifically managers can conduct prescribed burning to control populations like deer and other game species without drastically impacting herpetofauna. Should land managers desire to help the growth of reptiles and amphibians, they should adopt a more mosaic burn regime, as this will best benefit all herpetofauna.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Figure **Page**

INTRODUCTION

Among avid herpetologists it is understood that reptiles and amphibians comprise the most abundant vertebrate group for ecosystems they occupy (Welsh and Lind 2002, Welsh and Hodgson. 2011). Unfortunately, while many reptiles and amphibians inhabit all terrestrial habitats outside of arctic regions, they are amongst the most threatened species of vertebrate groups (Lesbarrères et al. 2014). Populations of reptiles and amphibians are globally declining. According to the International Union for Conservation of Nature (IUCN) 41% of all amphibians are threatened with extinction. For reptiles, 19% of the species are threatened with extinction and 12% have gone extinct. Together, they have the highest percent of threatened species among the vertebrate groups according to the IUCN, and they have lowest proportion of the least concern of species among vertebrate groups (Lesbarrères et al. 2014).

This group of wildlife is threatened from sources such as global climate change, anthropogenic disturbance, and the spread of herpetofaunal diseases (Gibbons et al. 2000). The largest reason for their decline is habitat loss (Gibbons et al. 2000, Muchet et al. 2014). As climates are drastically changing in temperature, reptiles and amphibians are not able to adapt quickly enough to allow them to survive habitats that are becoming less suitable, contributing to their eventual loss (Gibbons et al. 2000, McCain, 2010). Human development has contributed significantly to the decline of the herpetofaunal community by destroying its habitats and polluting water systems (Gibbons et al. 2000, Harper et al. 2008). Disease is also taking a huge toll on the herpetofaunal community. The fungus *Batrachochytrium* spp., which is found globally, especially affects amphibians. This fungus can cause chytridiomycosis, which damages the skin and nervous system functions, leading to death (Padgett-Flohr 2007, Bletz et al. 2013, Holden et al. 2014).

Some herpetofauna act as indicator species to show the environmental health of a region through their growth and abundance within that ecosystem (Gardner et al. 2007, Scherer et al. 2012, Brum et al. 2013). As habitats become altered, degraded or vanish, so do abundance and species richness, which have a direct impact on carrying capacity (Harper et al. 2008). Amphibians are great indicators because they are sensitive to changes of the environment (Gardner et al. 2007, Scherer et al. 2012, Brum et al. 2013). They are important to their habitat because they predate on both aquatic and terrestrial invertebrates, but also act as prey themselves (Polis et al. 1985, Gardner et al. 2007, Pittman et al. 2013). Since herpetofauna are great indicators of overall ecological health, the effects of fire on an environment can be studied by looking at reptiles and amphibians.

Fire can alter habitats in many ways. For example, fire is known to reduce the humidity in the air, and also eliminate ground litter (decaying logs and leaves). Leaf litter controls soil erosion, determines nutrient cycling, improves overall ecological environment, and retains moisture (Zhang et al. 2014). Fire can increase erosion rates, leading to runoff of minerals and pollutants, and decreased available moisture quality

(Lane et al. 2010, Smith et al. 2011). Amphibians are sensitive to moisture changes; in fact many amphibians need moisture for reproduction (Rodríguez et al. 2005). The needed moisture for these animals comes from many sources, such as water in the immediate vicinity, but as terrestrial animals they also absorb water from moist soil (Reynolds and Christian 2009). This ability to absorb moisture stems from the fact that they have an epidermis that is water-permeable, which allows them to absorb water, but also increases the dangers of water loss for amphibians (Jorgensen 1997). This need for a controlled moisture level is more greatly shown by studies that indicate that the populations of juvenile amphibians were more common in experimental plots that had higher moisture content than those of lower amounts (Grover 1998). This is shown by the fact that amphibians live their lives both terrestrially and aquatically, and their larval stage is heavily dependent on moisture (Pittman et al. 2013). Experimental manipulation of moisture and cover also showed increased activity levels and abundances of salamanders (Grover 1998).

For a post-oak savannah, fire plays a very important role. In areas where fires have opened up canopy there are benefits to some species, but negative impacts to others (Mushinsky 1985). Because much of the post-oak savannah of the United States requires restoration, most land is subject to steady burns and is often an on-going project (Santos and Thorne 2010). Niche requirements for herpetofaunal species of this habitat is complex because alterations require either reintroduction of post-oaks and other native vegetation, or more likely, burning existing flora away with controlled burn regimes (Singhurst et al. 2003, Axelrod 1985). All restoration of this habitat type is a long-term commitment and requires many tools beyond that of controlled burning (Peterson and Reich 2001, Dey et al. 2016). Information gathered about the herpetofauna that occupy a post-oak savannah is beneficial to understanding how changes to this habitat impact the local fauna.

Fire is used to manage both local flora and fauna of an ecosystem. Prescribed burning is often used to remove exotic species, reduce hazardous fuel loads, and maintain biological diversity while improving wildlife habitat (Williams et al. 2012). The intensity of the burn will determine how much of the habitat is altered. How much the landscape is altered will depend on whether the burn was prescribed during the wet or dry part of the season (Perry et al. 2009, Polo et al. 2013). Fire is frequently used as a management tool as it often keeps woody plant densities low, which drastically reduces the build-up of a large fuel load while allowing native grasses to grow where normally they would be choked out (Dunn 1998, Ryan et al. 2013). Controlled burning can also keep invasive/exotic species from becoming too dominant or getting out of control (Polo et al. 2013). In (Bruton et al. 2013) it was observed that herpetofaunal diversity was more significant in areas that allowed passive regrowth of natural habitat than those that were cleared regularly or had cultivated landscapes. That and other studies have suggested that regular clearing created a disproportionate abundance of some species, with a decrease in others of similar habitat components. This relates to expected results of captures from areas on the property with regards to time since burn and natural regrowth (Bruton et al. 2013, Smith et al. 2013). Some studies show plants can tolerate or are resistant to the presence of fire. Habitat structure and vegetation show little change over time in areas where there is frequent low intensity prescribed burns or a history of frequent low intensity burning. With frequent burning, vegetation can become resistant and can adapt to the presence of fire and can to be able to tolerate the presence of fire. Vegetation can recover rapidly after a low intensity surface fire and therefore the vegetation will only change minimally (Eivazi and Bayan 1996, Francl and Small 2013).

Prescribed burning is often used to manage fauna as well as flora. Herpetofauna mortality is very low for most species during a burn (Erwin and Stasiak, 1979). Reptiles and amphibians are able to avoid the fire in advance by sensing the heat/smoke and burrowing under soil and avoid the direct heat, thus reducing mortality (Erwin and Stasiak, 1979). Although mortality has not been extensively documented directly after a fire, its indirect effects on reptiles and amphibians often result in mortality weeks, months and even years after the fires have occurred (Costa et al. 2013). A possible explanation for the decrease in herpetofauna after a burn is the opening of the canopy, which allows for an increase in reptile and amphibian predation, especially from birds of prey (Perry et al. 2009, Costa et al. 2013). At the same time, the ground cover that is needed to hide under has been eliminated by the burn and can take weeks, months, or even years to accumulate (Perry et al. 2009, Costa et al. 2013). However, the indirect effects of fire on reptiles and amphibians are still poorly understood (Mushinsky 1985, Ruthven et al. 2002, Ruthven et al. 2008, Ashton and Knipps 2011).

Burning vegetation in an area can have both potential positive and negative impacts on herpetofauna. One positive effect includes the increased basking area, which can help in the thermoregulation for reptiles (Perry et al. 2012). Negative effects include a loss of canopy cover, which normally provides needed predatory shelter (Brown 2001, Perry 2012). Fire also eliminates leaf litter and old ground cover, both of which provide essential habitats for reptiles and amphibians by holding in moisture, which is necessary for herpetofaunal population increase (Brown 2001). Loss of moisture content negatively impacts the amphibian community because proper humidity levels are necessary for homeostatic needs and bodily functions. Removing this cover by means such as fire would be expected to dramatically decrease numbers of these organisms (Perry et al. 2009, Costa et al. 2013, Schneider and Kashian 2014).

Reptiles and amphibians play an important ecological role in every ecosystem they are a part of (Gibbons et al. 2000). For example, they play an important role in many food webs, both as predators and prey (Polis and Myers 1985). Predatory herpetofauna helps to control populations of rodents and insects (Preston and Johnson 2012). For example, the coachwhip *(Masticophis flagellum)* is a common predator that lives in a variety of habitats. In studies done by (Jones and Whitford 1989) and by (Halstead et al. 2008), it was found that coachwhips are diurnal predators that hunt by stalking live prey. They have been known to eat several species of lizards, small mammals and occasionally scavenge for eggs. Although *M. flagellum* most commonly consumes lizards, the consumption of other food sources can occur based on availability of other prey (Jones and Whitford 1989, Halstead et al. 2008). In regards to other prey availability, as shown in the study by (Kirchner et al. 2001), mice are commonly observed for post burn abundance. Some genus of mice, such as *Peromyscus*, showed a significant increased with prescribed burning (Kirchner et al. 2011). Also a possibility of the diet for coachwhips is the six-lined racerunner, which had a significant population increase following burn (Mushinsky 1985).

The six-lined racerunner (*Cnemidophorus sexlineatus)* is an insectivorous lizard. The juvenile six-lined racerunners depends on ground dwelling insects such as ants, while the adults tended to eat grasshoppers and other jumping/flying insects (Paulissen 1987). In a study by Cancelado and Yonke 1970, it was found that prescribed burning affected populations of true bugs (*Hemiptera*), especially the families of Cicadellidae (leafhoppers), Lygaeidae (milkweed/seed bugs), and Miridae (plant bugs). Their study showed a significant increase in the availability of Hemiptera, specifically Cicadellidae, such that the number of insects was almost double the population of unburned areas (Cancelado and Yonke 1970). While another study showed that fires impact on insects varied by species with many, ant, beetles, fly, and cricket/grasshopper species benefiting from prescribed burns (Hanula and Wade 2002). These studies show that there is not a loss of possible food sources for many reptiles and amphibians (Cacnelado and Yonke 1970, Hanula and Wade 2002).

As potential prey for other fauna, reptiles and amphibians often play a significant role in the ecological food chain. For example, Poulin et al. (2001) show some bird species prey on herpetofauna. Both frogs and lizards depend upon maintaining crypsis and brief movements into inaccessible microhabitats to escape avian predators (Rudh and Qvarnstrom 2013). Seasonal availability of avian prey, i.e. frogs and lizards, depends on changes in cover and abundance of alternate food types (Perry et al. 2009, Costa et al 2013). Herpetofauna intake peaked during dry seasons, and decreased during wet seasons

(Poulin et al. 2001). Fire has the potential to change the availability of ground cover, creating an absence of these protective areas for small reptiles and amphibians (Brown 2001).

Fire affects microhabitats in innumerable ways that might impact herpetofaunal hunting and daily routines. For example, fire has been documented to remove litter in many landscapes (Ryan et al. 2013). Litter can be an important component in the persistence of certain herpetofauna. Increased litter increases escape cover, augments crypsis for sit-and-wait predators, increases humidity and decreases temperatures (Ryan et al. 2013).

For example, ground skinks *(Scincella lateralis)* respond positively to increase litter amount in Alabama (Sutton et al. 2014). There are several factors that could contribute to this result. The presence of litter as a structural component also makes it more difficult for wolf spiders *(Gladizosu pulchra)* to prey on ground skinks. Ground skinks can change their behavior responses with regard to interactions with predators as a result of body temperatures, with cooler temperatures resulting in fleeing from predators at longer distances perhaps as a result of decrease sprint speeds (Smith 1997, Rubbo et al.2001). Likewise, increasing litter complexity reduces the distance that lizards flee from a potential predator, which may provide an energetic advantage over longer flight distances in more open habitats (Martin and Lopez 2000). The distance of ground skinks in South Carolina was also strongly related to the ability of lizards to balance thermoregulation with humidity (and therefore water loss), making the amount of litter a key determinate of habitat suitability for ground skinks (Parker 2014).

Leaf litter is positively associated with the presence of the copperhead *(Agkistradon contortrix,* Fitch 1960). There is strong evidence that the entire evolution of the copperhead is tied to the presence of leaf litter, because of factors as diverse as evolutionally derived crypsis and feeding behavior are all impacted by leaf litter presence (Fitch 1960). Likewise, many species of viper use caudal luring to attract prey when they are young. This strategy relies on crypsis of the upper body while the tail is highly visible. While leaf litter is necessary for caudle luring efficiency, of caudal luring may be impacted by light levels (Rabatsky, and Ferrell 1996). Thus there is potential for there to be an interaction between leaf litter levels and canopy cover for foraging success.

To contribute knowledge of the effects of fire on herpetofauna, more research must be conducted on the herpetofaunal community, and especially the effects of fire on the reptile and amphibian population. Therefore, the objective of this study was to observe how herpetofaunal communities respond to time since burn, based on their renewed or declining population growth/ abundance, at a site in eastern Texas.

METHODS

Study Site

This study was conducted at Gus Engeling Wildlife Management Area (GEWMA), which is located in the northwest portion of Anderson County, Texas (Figure 1). This property, was acquired between 1950 and 1960, is approximately 4,465 ha in size, and is currently managed by the Wildlife Division of Texas Parks and Wildlife Department (TPWD). Prior to being owned by TPWD, Gus Engeling WMA had a history of fire suppression and was severely overgrazed by cattle. After the property was acquired by TPWD, it went largely unmanaged for woody plant growth until 2005, when prescribed burning was initiated. Prior to this initiation the historic post oak savannah turn into extremely dense woodland. Without the presence of fire the under brush was able to grow uncontrollably, therefore, turning the savanna into a dense forest.

Gus Engeling WMA has a subtropical humid climate and hot summers and mostly mild winters characterize the region. Gus Engeling WMA is largely comprised of Post Oak Savannah. In this specific type of savannah, or lightly forested grassland, oaks (*Quercus* spp.) are the dominant trees. Eleven species of oak can be found throughout the property, and Queen City Sand is the dominant soil type (Singhurst et al. 2003). These savannahs were maintained historically through wildfires set by lightning and indigenous peoples, grazing by bison and other native ungulates, low precipitation, and/or poor soil. However, the suppression of fire resulted in historic savannah grasslands transitioning into a more forested habitat (Axelrod 1985).

There are many bodies of water in GEWMA, ranging from small creeks to ponds, lakes, marshes, bogs and swamps (Singhurst et al. 2003). This diversity of water sources and their locations influence the habitat types that can be found on the property, such as sandy xeric grasslands, lowland swamps, and marshes. The diversity of habitats on this property makes Gus Engeling WMA a hot spot for reptiles and amphibians. Ninety-nine species of reptiles and amphibians have been found on the property (Himes and Telfair II 2004; Kazmaier, Unpublished data).

Traps and Specimen Processing

I used 27 pitfall trap arrays across the property, each array consisted of 2 pitfall traps, 2 funnel traps, and drift fences leading into each trap (Figure 2). The pitfall traps consisted in 18.9-L buckets that were placed in the ground, with an elevated cover board on top. The pitfall trap works when a small animal (e.g., lizard, frog, mouse, etc.) does not detect the presence of the trap and falls into it. The funnel traps consisted in medium sized meshed Minnie minnow traps, that were 45.7 cm x 30.4 x by 20.3 cm (J.K. Enterprises, Big Lake, MN). The Minnow traps were made of 0.63-cm extruded steel mesh with large, single-entry cones. The cone opening was 2.54 cm across. The minnow traps were intended to catch larger-sized snakes.

The drift fences were 7.6 m long and 15.2 cm high. Each drift fence radiated outward from the center of the array at a 120° angle to make a Y-shaped formation. This was to maximize the chance that a reptile or amphibian would be caught in one of the traps, as they would encounter the array no matter which direction they came from. Once an animal came across a drift fence, no matter which way they were oriented, they would be likely to follow the fence into a trap. There was a pitfall trap at the center in every array and the other traps placed at the end of each drift fence. A small cover board with the dimensions of 61 cm x 61 cm was placed on top of each pitfall trap and each minnow trap (Figure 3). This set-up was designed to keep out the sun and reduce exposure-related mortalities. When arrays were open, a wet sponge was placed in each pitfall and minnow trap. This was done to reduce the risk of desiccation for any herpetofauna, and sponges were moistened daily to help keep the humidity up in the traps. There were also a few centimeters of soil at the bottom of every pitfall trap to allow any captured individuals to burrow and hide if they needed to.

Each trap was checked daily for the first 12 days of every month, from June until August in 2016 and 2017. The traps were opened on the 1st of every month and closed on the 13th of every month. Opening the traps involved unscrewing the bucket lids, placing some soil at the bottom of the bucket, inserting a wetted sponge in both the pitfall traps and minnow traps, and closing the minnow trap doors. Closing the traps involved taking out the sponges, screwing the lids on the buckets and opening the minnow trap doors.

When captured, all encountered individuals were weighed with an electronic balanced calibrated scale to the nearest 0.1 g, and their snout vent and tail lengths measured to the nearest millimeter. Snout-vent length (SVL) is defined as the length from the tip of the snout to the cloaca. Tail length (TL) is the length from the cloaca to the tip of the tail. Because of their respective differences in length, a ruler was used for the lizards and the snakes were placed in a squeeze box (Quinn and Jones 1974). Each individual was branded, so as to determine when recaptures occurred. This was done to help identify if an organism was caught multiple times and to help determine the diversity of my captures.

Several different forms of marking were used in this study, depending on the species caught. In order to brand snakes, a handheld battery-operated cauterizer was used to brand a mark onto subcaudal or ventral scales (Winne et al. 2006). When large enough, passive Intergraded Transponder (PIT) tags were used for snakes to help determine if the snake was a recapture (Dodd Jr., 2016). Toe clipping was applied to lizards, toads and frogs (Grafe et al. 2011). In cases of toe clipping, a single toe was removed to provide a cohort mark this varied by each month and year combined. Thus, I could identify frogs, toads and lizards as a recapture during each period, but not as an individual.

The sex of each individual was recorded whenever possible. In the case of snakes, this was determined by using sexing probes when the specimens were large enough. For lizards, sex was determined by examining sexual morphological features such as skin color. After measuring and marking individuals were released a minimum of 3 m from the trap they were captured in. This distance was far enough away to prevent them from running right back into the trap, but still close enough that they would be familiar with their surroundings. Each trap was manually cleaned on a daily basis, by removing any small mammals, arachnids and insects that could have harmed or killed any of the captured vertebrates.

Because of conditions beneficial to their proliferation, fire ants invaded this study site and became a problematic invasive species at some of the arrays. This observation was similar to research findings of comparable ecosystems (Todd et al. 2008). To rectify this issue, commercial ant bait was applied. This was accomplished by sprinkling ant bait pellets or powder around the traps to reduce the number of ants and prevent them from killing captured amphibians and reptiles, as suggested in Allen et al. (2004). Such ant baiting reduced mortality and increased capture success at another research site in Texas (Terry Blakenship, Welder Wildlife Refuge, personal communication).

Because of unforeseen complications a few traps could not be opened. This applied to arrays in the summer of 2016 during the months of July and August. Some trap closures in July were only a few days because of fire ant invasion, while others were closed an entire trapping week in August because of major flooding.

Analytical Methodology

Gus Engeling WMA provided prescribed fire records, and these data served as the basis for the required calculations. Days since burn were computed by subtracting the burn date of the area around the array from the midpoint date from each trapping season. The resulting value serves as the independent variable for all calculations and graphs. Days since burn and trap array numbers are correlated to these data in Table 1.

After acquiring trap and capture data in the field, I calculated richness, abundance, diversity and evenness for statistical analysis. Richness (*S*) is defined as the total number of species captured per array per sampling period, and abundance is the number of captured individuals in each array per sampling period divided by the number of array days the traps were open in that period. Richness and abundance were used to calculate evenness and diversity of all captures across all sampling periods. Evenness is how equally individuals are distributed across a species, while diversity is the species richness weighted by the abundance.

Because herpetofauna sampling often produces low capture rates (a sparse species matrix), which may obscure patterns in regression analyses, I did two sets of analyses. First, I used an ANOVA to compare the number of days since burn between drift fence array samples for which I did and did not capture herpetofauna. Using an ANOVA allows me to compare two distinct categories of data that have similar underlying values; in this case the ANOVA is comparing captures to non-captures between my drift fence arrays. Second, for drift fence array samples for which I did capture herpetofauna, I regressed abundances of species that represent more than 10% of the total number of individuals captured (true toads, six-lined racerunner, coachwhip, ground skink, fence lizard), total abundance, species richness, Modified Simpson's Diversity Index, Shannon's Diversity Index, and species evenness against days since burn. Because I viewed these analyses as exploratory, and had low expected capture rates I set $\alpha = 0.10$ (Behrens 1997).

Diversity was calculated in two ways. First, I used the Modified Simpson's Index (Magurran 1988, Magurran 2013), where

$$\text{modD} = 1 - \Sigma\, pi^2$$

and, pi = proportion of the i^{th} taxon to the total sample.

Because different diversity indices can yield different results, I also calculated a Shannon Diversity Index for each array (Magurran, 1988, Magurran 2013), where

$$H' = -\sum pi\ ln\ pi$$

Evenness was calculated to evaluate all species in the sample were accounted for in accordance with H' (Magurran 1988, Magurran 2013), where

$$\text{Evenness} = \frac{H'}{H'_{max}}$$

And, $H'_{max} = \ln S$

The array days were calculated by summing the days that each array was open for each sampling period for June, July and August 2016 and 2017.

RESULTS

In 2016, research was conducted over 823 array days, with a total of 115 individual captures and 21 species (Table 2). In 2017, there were 972 array days and a total of 131 individual captures and 16 species (Table 2).

The number of days since burning for drift fence array samples where I did not capture herpetofauna (mean = 1735 days, standard deviation = 2262, n = 48) was greater than the number of days since burning for drift fence array samples where I did capture herpetofauna (mean = 847 days, standard deviation = 1365, n = 102; p = 0.003) according to the ANOVA results.

I ran a linear regression for each of the following community metrics: toad abundance, six-lined racerunner abundance, coachwhip abundance, fence lizard abundance, ground skink abundance, total herpetofauna abundance, modified Simpson's diversity index, Shannon's diversity index, species richness, and species evenness. The results are as following, using β for the regression coefficient value. There is a significant relationship between time since burn and toad abundance, with a slight increase of abundance as time since burn increased (β = 1.39E-4; $F_{1, 148}$ = 3.563; P = 0.062; R^2 = 0.034; Figure 4). There is a significant relationship between time since burn and the Six-lined Racerunner Abundance, which declines slightly with regard to increasing days since burn (β = -9.85E-5; $F_{1, 148}$ = 3.319; P = 0.071; R^2 = 0.032; Figure 5). There is a significant relationship between time since burn and the Modified Simpson's Index, which declines slightly with regard to increasing days since burn (β = -4.43E-5; $F_{1, 148}$ = 4.957; P = 0.028; R^2 = 0.047; Figure 6). There is a significant relationship between time since burn and the Shannon's Diversity Index, which declines slightly with regard to increasing days since burn (β = -6.75E-5; $F_{1, 148}$= 4.466; P= 0.037; R^2 = 0.043; Figure 7). There is a significant relationship between time since burn and the Species Richness, which declines slightly with regard to increasing days since burn (β = -1.14E-4; $F_{1, 148}$ = 5.222; P = 0.024; R^2 = 0.050; Figure 8). Lastly, there is a significant relationship between time since burn and the species Evenness, which declines slightly with regard to increasing days since burn (β = -7.88E-5; $F_{1, 148}$ = 3.555; P = 0.062; R^2 = 0.034.; Figure 9).

There was not a significant relationship between time since burn and coachwhip abundance (β = -4.29E-5, $F_{1, 148}$ = 1.281; P = 0.260; R^2 = 0.013; Figure 10). There was not a significant relationship between time since burn and the ground skink abundance, which declines slightly with regard to increasing days since burn (β = -2.76E-5; $F_{1, 148}$ = 0.309; P = 0.580; R^2 = 0.003; Figure 11). There was not a significant relationship between time since burn and the Fence Lizard Abundance which declines slightly with regard to increasing days since burn (β = -5.63E-5; $F_{1, 148}$ = 2.541; P = 0.114; R^2 = 0.025; Figure 12). There was not a significant relationship between time since burn and the total abundance captured which declines slightly with regard to increasing days since burn (β = -6.57E-5; $F_{1, 148}$= 0.262; P= 0.610; R^2 = 0.003; Figure 13).

DISCUSSION

The results indicate a subtle but significant negative relationship between time since burn and the herpetofaunal community metrics at Gus Engeling WMA. While my P values indicated significance my R^2 values suggest that I have low predictability in knowing how herpetofauna populations will respond in future scenarios.

Evaluating the impacts of fire on a herpetofaunal community can be complex. This is particularly true for communities at the intersection between forests and prairies, like the historic post oak savannah habitat at Gus Engeling Wildlife Management Area. In such systems, opening up habitat via fire should benefit some species, like the six-lined racerunner *(Cnemidophorus sexlineatus*; Mushinsky 1985), but it might negatively impact litter-adapted species, such as ground skinks.

These differential impacts are likely strongly divided along taxonomic lines, with reptiles more likely benefiting from warmer, dryer conditions shortly after fire. While amphibians benefit more from the cooler, moister conditions associated with litter accumulation and long periods of time post burn (Grundel et al. 2014). Indeed many amphibian communities globally depend on high amounts of leaf litter (Gardner et al. 2007).

This study helps with providing extra information for the conservation of herpetofauna in a post oak savannah, by providing details on how various species react to fire. I would most likely state the distinct difference between toad abundance with time since burn in comparison to that of other species shows how this data could be significant in conservation planning. By introducing my data it helps scientists to better understand how to create models of management that would benefit each species to the greatest extent. However, it is well understood that often there are hurdles to conservation of endangered species that come from government regulations (Nie 2004). With sufficient involvement of conservation agencies it is much easier to manage for and prevent loss of herpetofauna by using my data and other similar studies as a tool to understand how fire impacts reptiles and amphibians.

This implies that conservation of herpetofauna, as a whole, will require a proactive management approach. In other words, maximum benefit for the overall community will come from a mosaic strategy, where there is a variation in fire return interval across the landscape. This is currently the strategy at Gus Engeling Wildlife Management Area. Additionally, because savannah habitats provide characteristics that benefit woodland and grassland species, conversion of the dense woodland habitat common for much of Gus Engeling Wildlife Management Area to more savannah-like conditions should provide maximum benefit to herpetofauna (Grundel et al. 2014).

The implications of this study on land managers depends much upon the managers themselves to manage for herpetofauna, but also articulates the fact that fire management has a minimal, but in some cases significant, impact on herpetofauna. Often reptile and amphibian conservation is not a priority, as management is directed towards game species, and is limited by the lack of resources or desire to prioritize herpetofauna

(Reynolds 1996, Ruhl 1998, Nie 2004). Reptiles and amphibians are also the victims of poor conservation efforts because of historical bias against them in places like folklore and other negative cultural values placed upon them (Ceriaco 2012). Should land managers have the capabilities to preserve this important species, my study should help them understand that a proper burn regime would include variations in the seasons of burn as well as in the times since burn for areas of their properties (Laris 2002). The method of mosaic burns are performed to create patches of varying habitats within an area that are beneficial to diversity of herpetofauna (Parr 1999). However, maintaining a proper level of control on this type of environment requires constant surveillance and modification to suit the changes that occur regularly (Parr 2006). Should land managers that review this information desire for management purposes they should understand that reptiles and amphibians behave differently than other common animals with regard to burn regimes (Parr 1999).

For the land managers of similar sites to Gus Engeling Wildlife Management Area this study provides information on the effects of fire for herpetofauna during restoration efforts for post-oak savannah. The continued burning of the dense woodland to return the sparse density of trees notable in savannah grassland is an ongoing project in many areas of the United States and the world (Santos and Thorne 2010). My study provides data that shows the effects of time since burn on herpetofauna, but this information can be used to show that restoration of post-oak savannah efforts do not have to be restricted by concern for herpetofaunal communities as a whole. Most post-oak savannah restoration requires long-term commitments that are dedicated to restoration-based management, wile only using prescribed burning as one of many tools (Peterson and Reich 2001; Dey et al. 2016). Given this information future burns can allocate time to mosaic burns that allow reptiles and amphibians to adapt to the changing environment. However, more data would be needed to cover time ranges that my study could not cover to provide an accurate prediction of future herpetofauna changes in diversity.

There were unavoidable physical and conditional limitations to the success of my project. Physical limitations included loss of trap availability due to flooding, fire ant infestation, and trap damage. To address these issues I often had to augment my collection methods. For example, with the flooding I had traps that were closed for extended periods of time due to lack of access. The red imported fire ants (*Solenopsis invicta*) infestations were problematic because they are an exotic and invasive species, as well as aggressive predators that often prey on herpetofaunal nests, compete for food sources, and cause direct mortality (Lofgren et al. 1975, Vinson 1997, Wojcik et el. 2001, Allen et al. 2004). I had to close two traps because of fire ant infestations while commercial ant bait was applied, and while the application of commercial ant bait significantly reduced ant-related mortalities in my traps, ant infestations were a persistent problem. This could be because red imported fire ants have been known to have population increases post-burn, and are often one of the first predators to occupy the area (Allen et al. 2004, Todd et al. 2008).

Conditional limitations included a large gap between the days since burn of 2500 and 5500. This was unavoidable because I did not have any available sections of Gus

Engling Wildlife Management Area that allowed data collection within this range. The other limitation was that the study comprised a short duration of 2 years, but likely needs a longer study period for accurate predictions on herpetofaunal populations.

Many studies have used artificial cover to evaluate herpetofaunal communities with considerable success (Grant et al. 1992, and Tietje et al. 1997). Thus, it may be assumed that the addition of artificial cover with many trapping arrays could have clarified my results. However, cover objects employed at Gus Engeling Wildlife Management Area for 2 years resulted in the detection of only 3 individual herpetofauna (Caruana, unpublished data), perhaps because of persistent invasion of the cover objects by fire ants. Thus, despite their utility in other areas, such sampling methods did not seem to work on Gus Engeling Wildlife Management Area. Although applying the commercial ant bait did significantly reduce the ant-related mortality of the amphibians and reptiles that were captured, ant infestations were a persisting problem.

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Table 1. Trap Array Days Since Burn - Number of days since burn for each drift fence array within each month and year sampling period used to investigate the influence of fire on herpetofaunal communities at Gus Engeling Wildlife Management Area, Anderson County, Texas.

Days Since Burn 2016 / 2017

	2016			**2017**		
TrapNumber	June	July	August	June	July	August
S13A1	481	511	542	104	134	165
S13A2	481	511	542	104	134	165
S13A3	96	126	157	461	491	522
S13B1	482	512	543	98	128	159
S13B2	482	512	543	98	128	159
S13B3	482	512	543	98	128	159
S13C1	5962	5992	X	6327	6357	6388
S13C2	5962	5992	X	6327	6357	6388
S13C3	5962	X	X	6327	6357	6388
W11A1	481	511	542	119	149	180
W11A2	481	511	542	119	149	180
W11A3	861	891	922	119	149	180
W11B1	1944	X	X	127	157	188
W11B2	1944	1974	2005	127	157	188
W11B3	1944	1974	X	127	157	188
W11C1	1944	1974	X	127	157	188
W11C2	1944	1974	X	127	157	188
W11C3	1944	1974	X	2309	2339	2370
W13A1	1195	1225	1256	98	128	159
W13A2	481	511	542	98	128	159
W13A3	481	511	542	104	134	165
W13B1	481	511	542	119	149	180
W13B2	861	891	922	119	149	180
W13B3	1190	1220	1251	1555	1585	1616
W13C1	1193	1223	X	98	128	159
W13C2	1193	1223	X	98	128	159
W13C3	1193	1223	1254	98	128	159

Table 2. Total Individuals Captured - The total number of individuals of each species of herpetofauna captured during each trapping period (June, July, and August) for each season (2016-2017). Combined are all Bufonidae (true toads) into one group and all Ranidae (true frogs) into a second group.

Species	2016			2017		
	June	July	August	June	July	August
True Toads *(Bufo spp.)*	6	9	0	2	20	11
True Frogs *(Rana spp.)*	21	4	0	4	2	1
Green Tree Frog *(Hyla cinera)*	1	1	0	0	0	0
Gray Tree Frog *(Hyla versicolor)*	0	1	0	0	0	0
Eastern Narrowmouth *(Gastrophynes carolinsis)*	1	0	0	1	1	0
Green Anole *(Anolis carolinensis)*	1	0	0	1	0	0
Six-lined Race Runner *(Cnemidophorus sexlineatus)*	6	8	4	13	2	4
Fence Lizard *(Sceloporus undulatus)*	6	0	1	4	7	2
Ground Skink *(Scincella lateralis)*	8	3	1	12	5	5
Five-lined Skink *(Eumeces fasciatus)*	1	1	1	0	0	1
Copperhead *(Agkistrodon contotrix)*	3	5	1	0	3	2
Texas Rat Snake *(Elaphe obsolata)*	2	0	1	0	1	1
Coachwhip *(Mastiocophis flagellum)*	3	5	2	3	9	4
Yellow-belly Racer *(Coluber constrictor)*	2	1	0	0	1	0
Eastern Hognose *(Heterodon Platirhinos)*	1	1	0	0	0	0
Flathead Snake *(Tantilla gracilis)*	0	1	0	2	0	0
Western Ribbon Snake *(Thamnophis proximus)*	0	1	0	0	0	0
Three-toed Box Turtle *(Terrapene triunguis)*	0	1	0	0	0	0

Figure 1. Texas County Map - Location of Anderson County, Texas, with a blow-out of the locations of Gus Engeling Wildlife Management Area and the town of Palestine with in Anderson County. Note the high level of overall fragmentation in Anderson County.

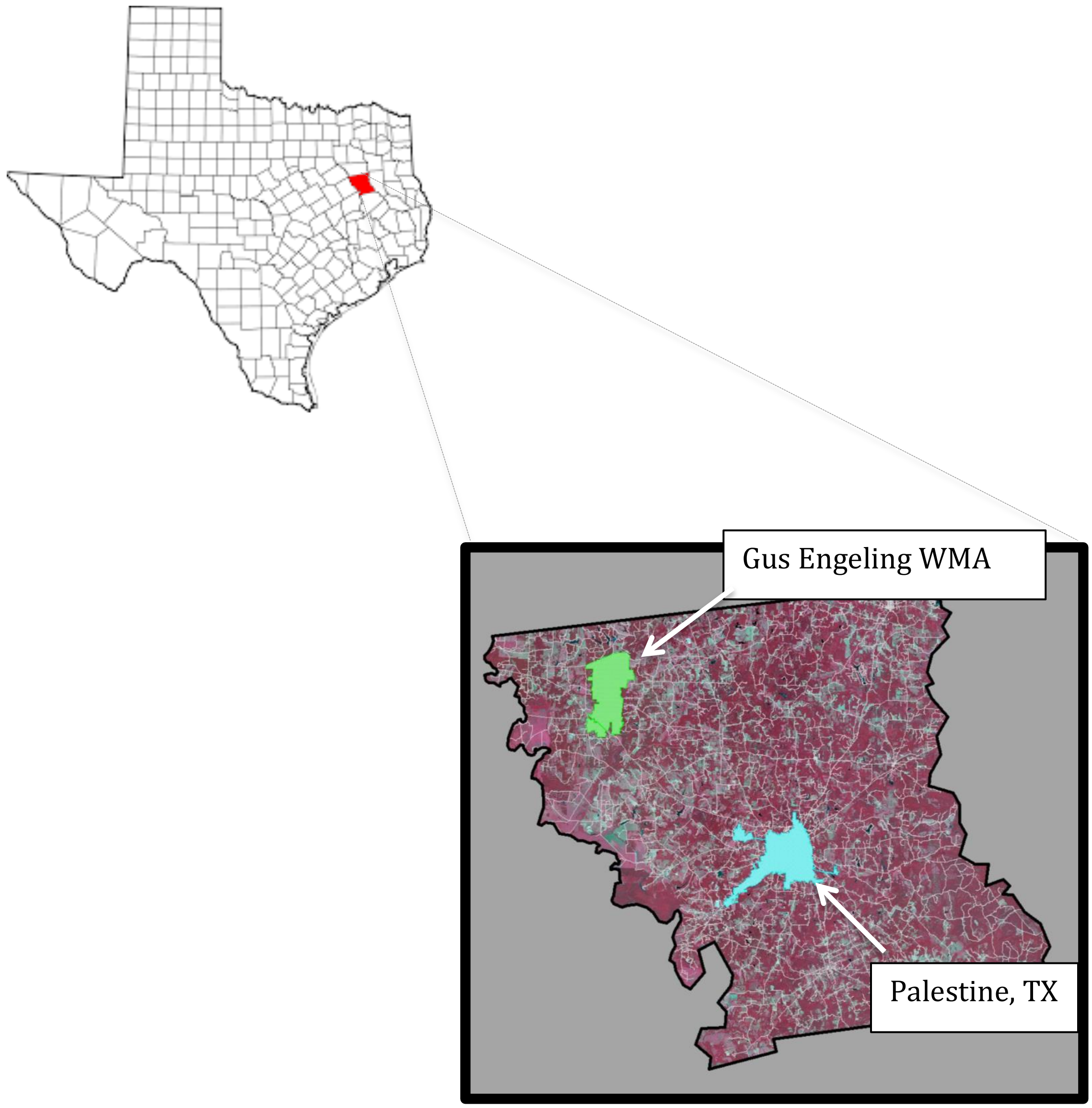

Figure 2. Map of Gus Engeling Wildlife Management Area with Trap Arrays

Location of 27 trapping arrays used to investigate the influence of time since burn on herpetofaunal communities at Gus Engeling Wildlife Management Area, Anderson County Texas, 2016-2017.

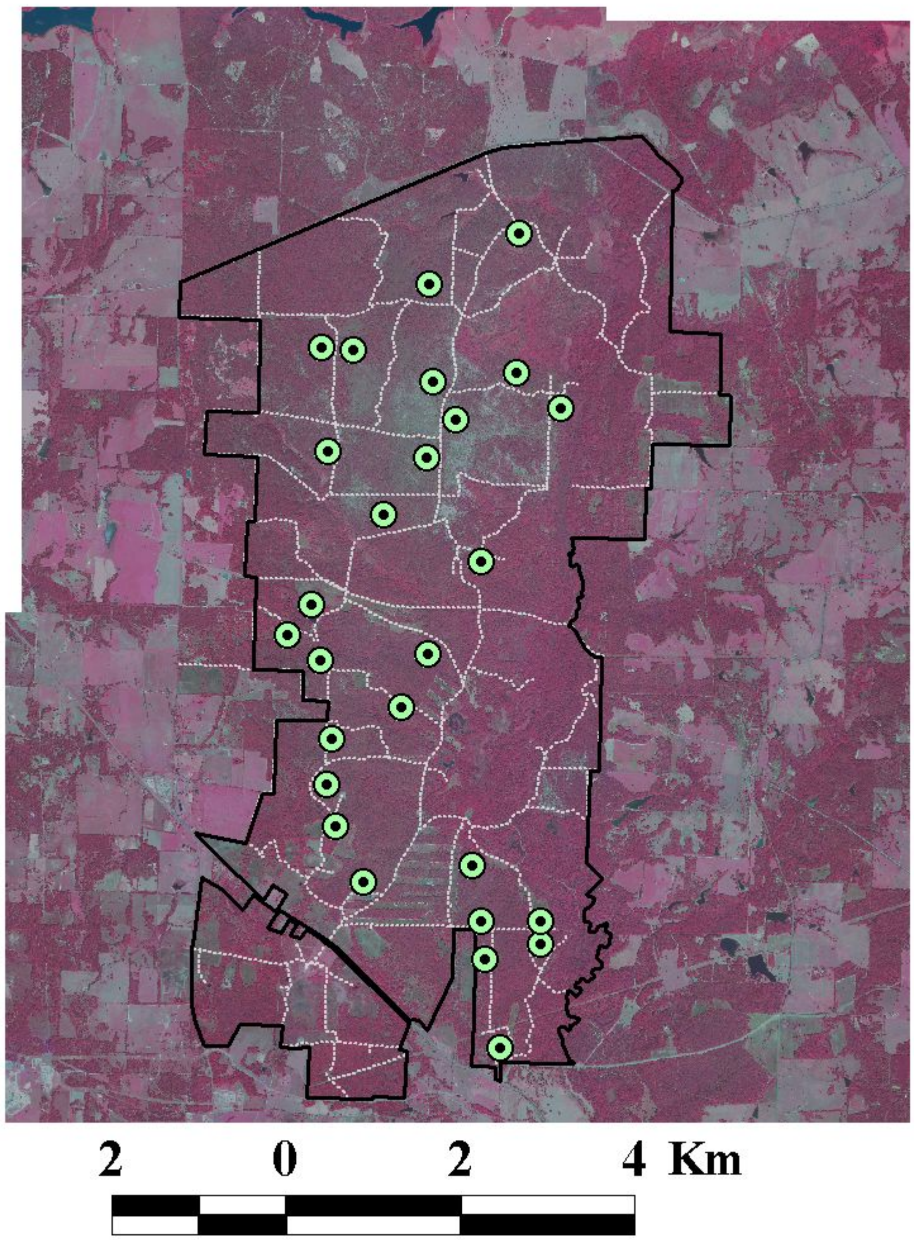

Figure 3. **Design of Trap Arrays -** Diagram the layout of the trapping array used to investigate of time since burn on herpetofaunal community at Gus Engeling Wildlife Management Area, 2016-2017. The design consists of a y-shaped arrangement of aluminum flashingdrift fences with a pitfall trap in the center and at the end of one arm. Funnels traps ended at 2 remaining arms shade boards protected all 4 traps.

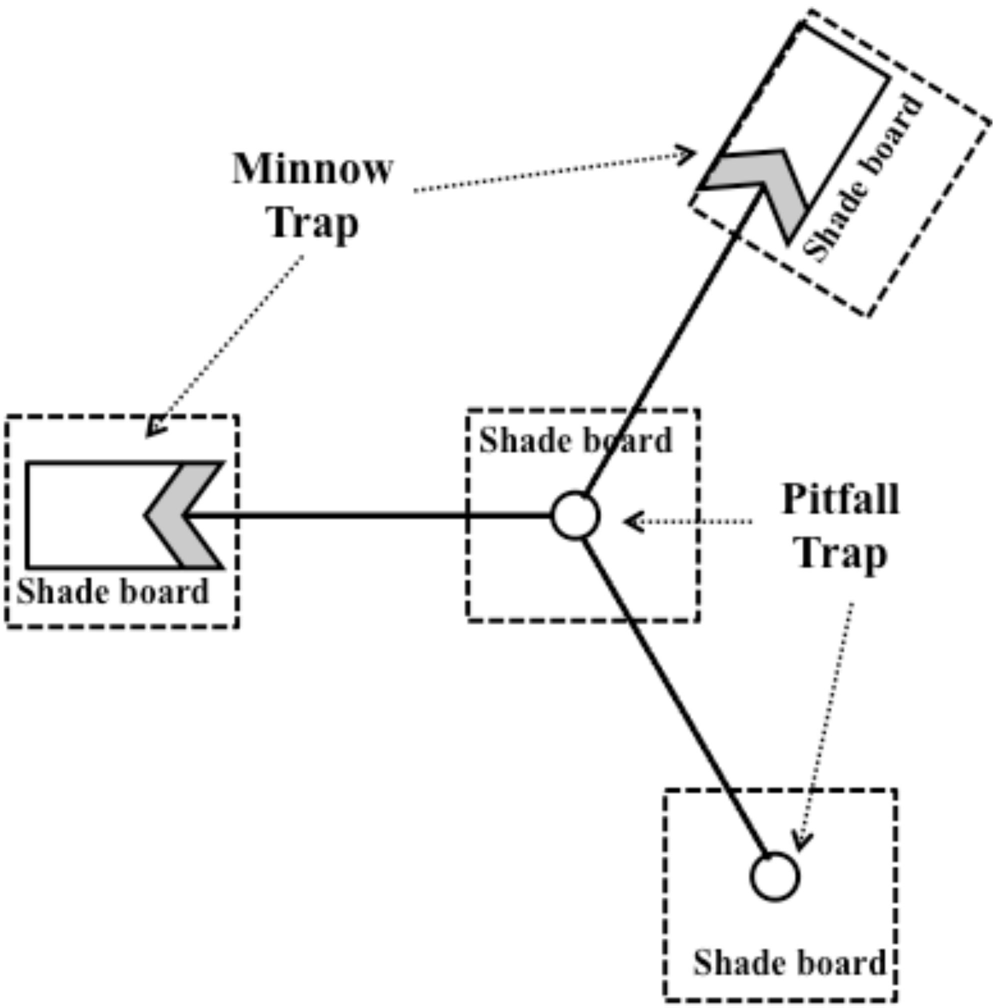

Figure 4. Linear Regression of Toad Abundance

Relationship between time since burn (days) and toad abundance captured in sampling arrays, at Gus Engeling Wildlife Management Areas, Anderson County, Texas, 2016-2017. Significance established, with the regression coefficient of 1.39E-4, giving a positive slope where (P = 0.062; R^2 = 0.034).

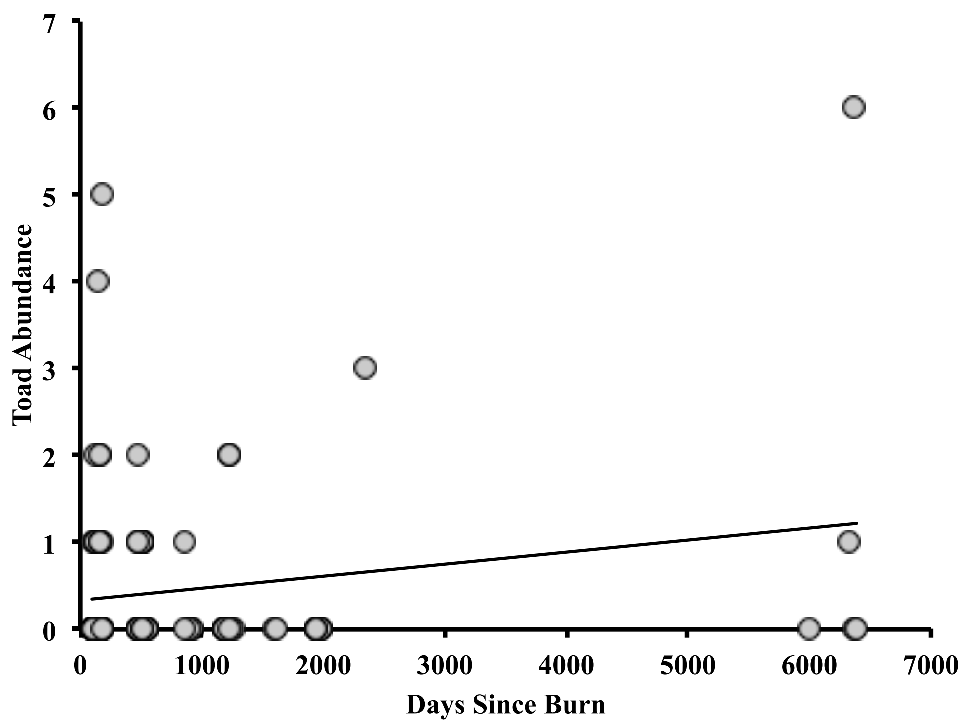

Figure 5. **Linear Regression of Six-lined Racerunner Abundance**

Relationship between time since burn (days) and six-lined racerunner abundance captured in sampling arrays, at Gus Engeling Wildlife Management Area, Anderson County, Texas, 2016-2017. Significance established, with the regression coefficient of 9.85E-5, giving a declining slope where (P = 0.071; R^2 = 0.032).

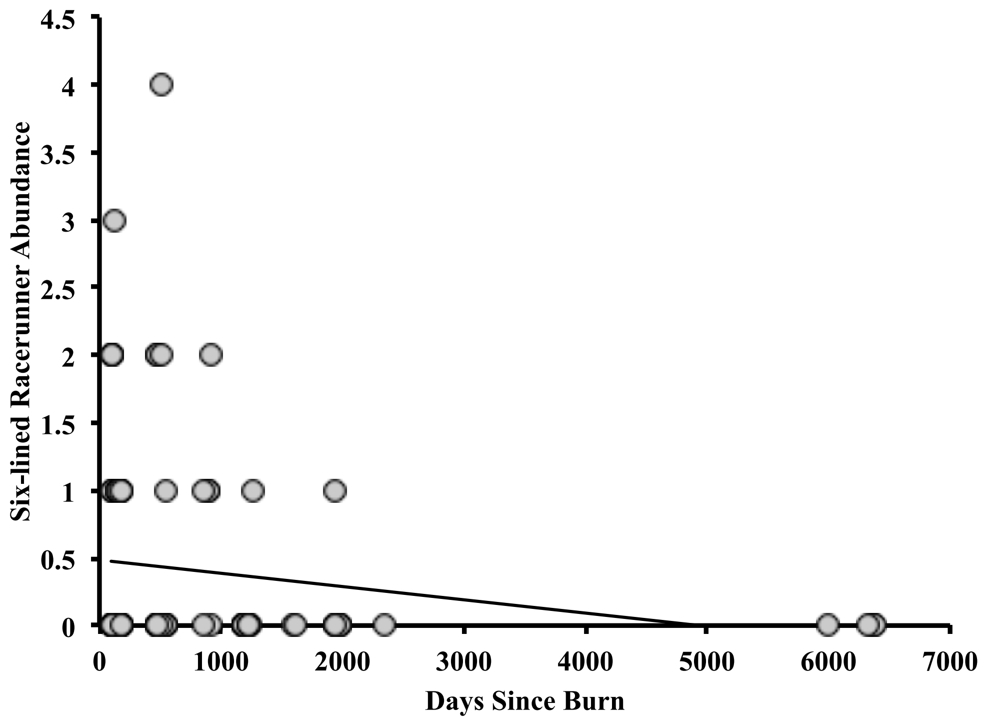

Figure 6. Linear Regression of Modified Simpson's Diversity Index

Relationship between time since burn (days) and Modified Simpson's Diversity Index for reptiles and amphibians captured in sampling arrays at Gus Engeling Wildlife Management Area, Anderson County, Texas, 2016-2017. Significance established, with a regression coefficient of -4.43E-5, giving a declining slope where (P = 0.028; R^2 = 0.047).

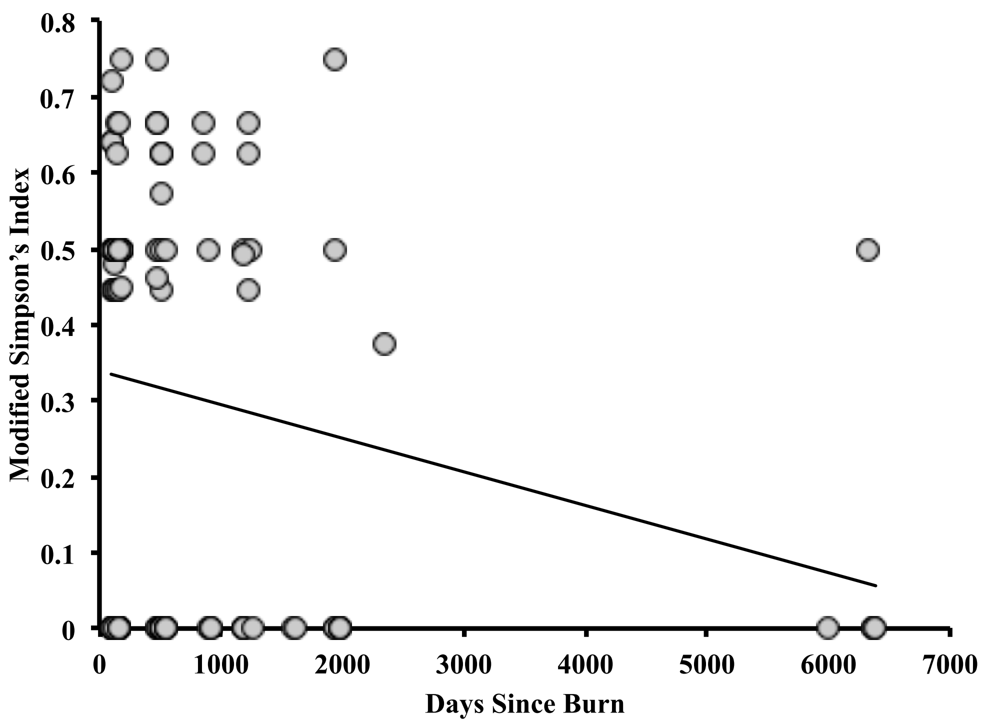

Figure 7. Linear Regression of Shannon's Diversity Index

Relationship between time since burn (days) and Shannon's Diversity Index for reptiles and amphibians captured in sampling arrays at Gus Engeling Wildlife Management Area, Anderson County, Texas, 2016-2017. Significance established, with a regression coefficient of -6.75E-5, giving a declining slope where (P = 0.037; R^2 = 0.043).

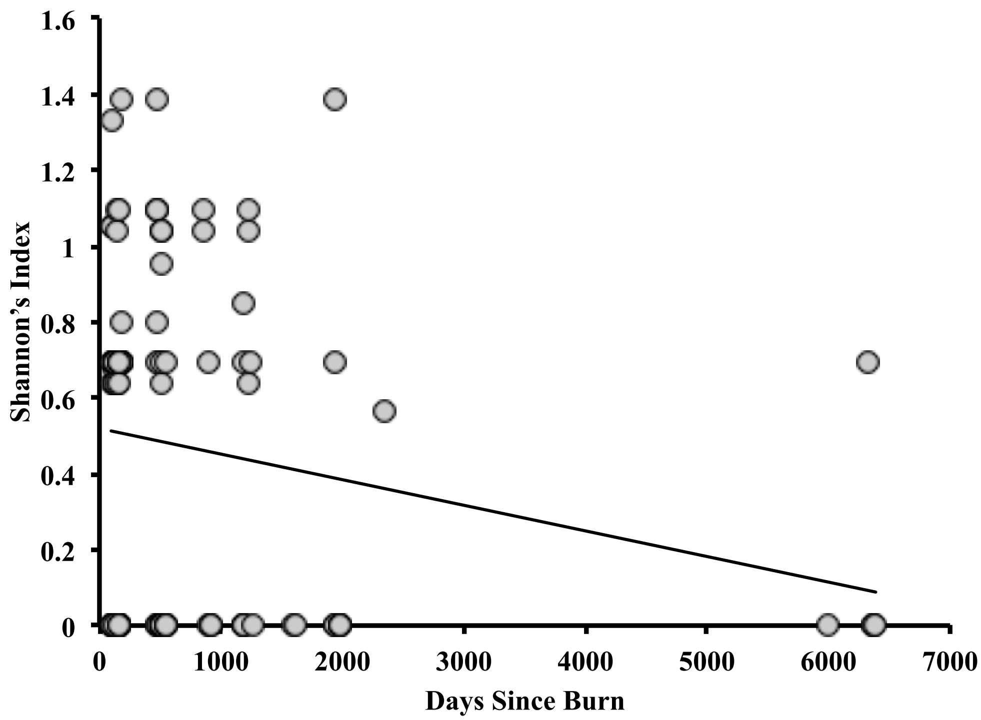

Figure 8. Linear Regression of Species Richness

Relationship between time since burn (days) and species richness for reptiles and amphibians captured in sampling arrays, at Gus Engeling Wildlife Management Area, Anderson County, Texas, 2016-2017. Significance established, with the regression coefficient of -1.14E-4, giving a declining slope where (P = 0.024; R^2 = 0.050).

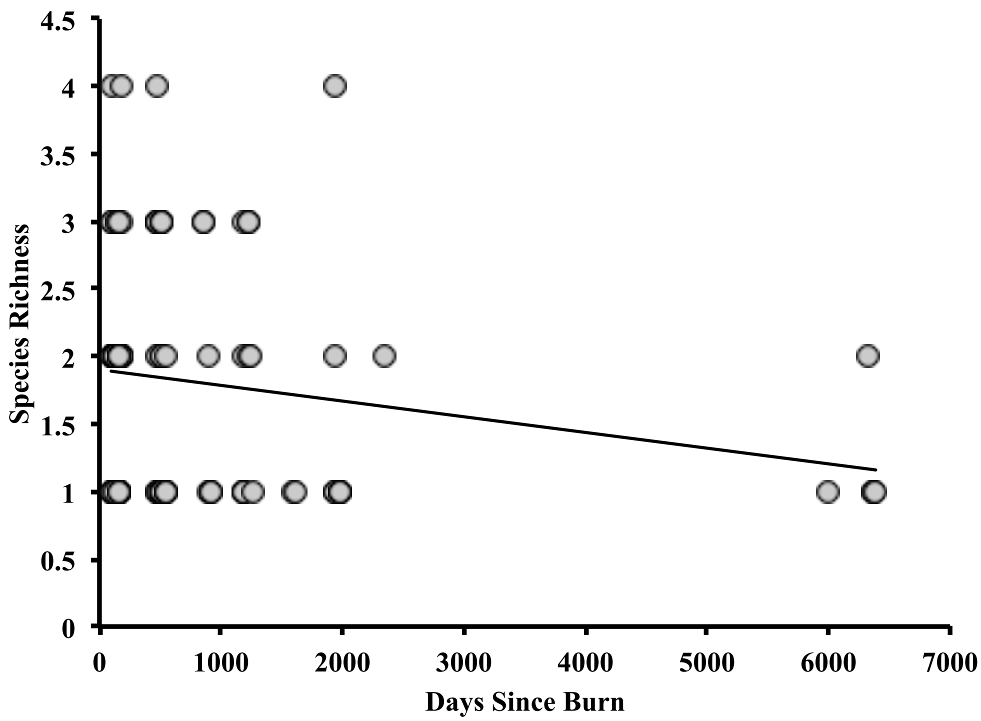

Figure 9. Linear Regression of Species Evenness

Relationship between time since burn (days) and species evenness for reptiles and amphibians captured in sampling arrays at Gus Engeling Wildlife Management Area, Anderson County, Texas, 2016-2017. Significance established, with the regression coefficient of -7.88E-5, giving a declining slope where (P = 0.062; R^2 = 0.034).

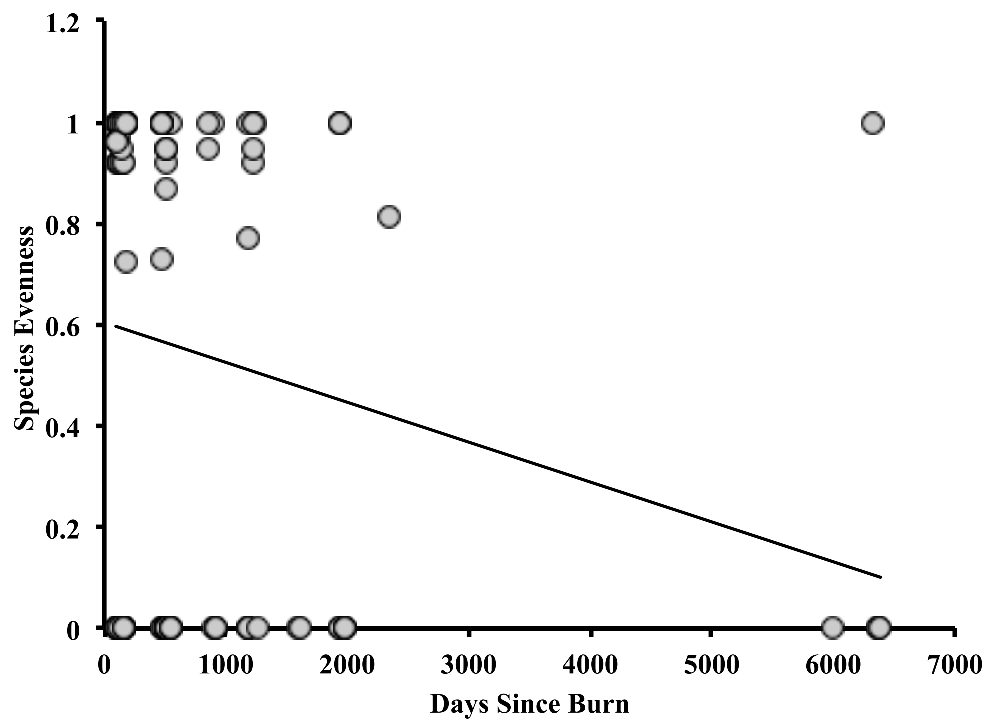

Figure 10. Linear Regression of Coachwhip Abundance

Relationship between time since burn (days) and coachwhip abundance captured in sampling arrays, at Gus Engeling Wildlife Management Area, Anderson County, Texas, 2016-2017. No significance was detected, and no slope established, where (β = -4.29E-5, P = 0.260; R^2 = 0.013)

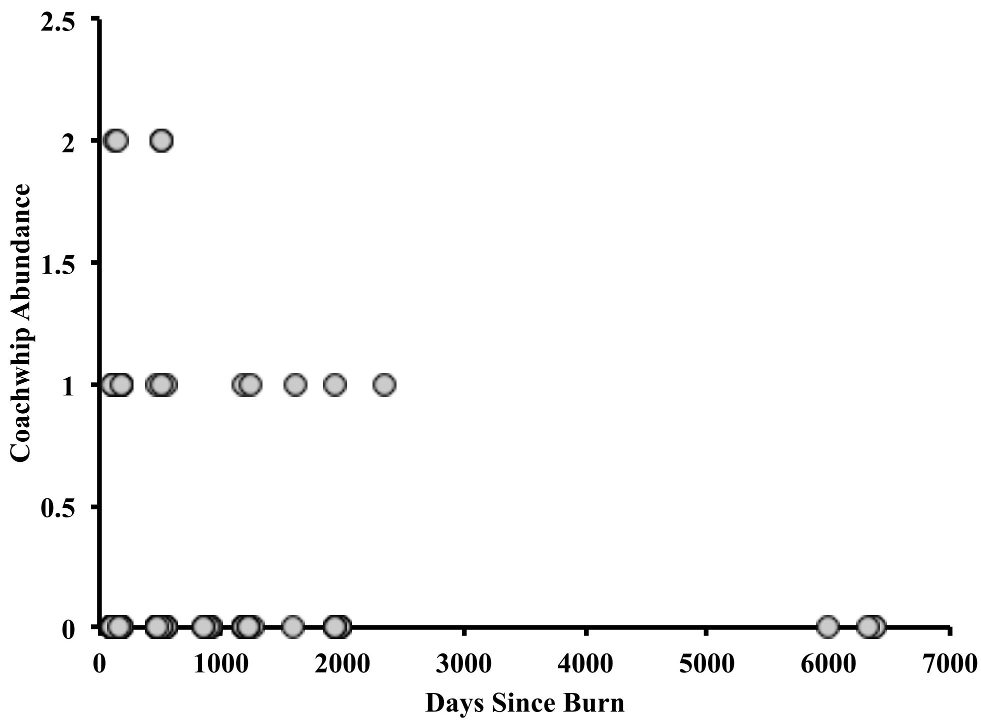

Figure 11. Linear Regression of Ground Skink Abundance

Relationship between time since burn (days) and ground skinks abundance captured in sampling arrays, at Gus Engeling Wildlife Management Area, Anderson County, Texas, 2016-2017. No significance was detected, and no slope established, where (β = -2.76E-5, P = 0.580; R^2 = 0.003)

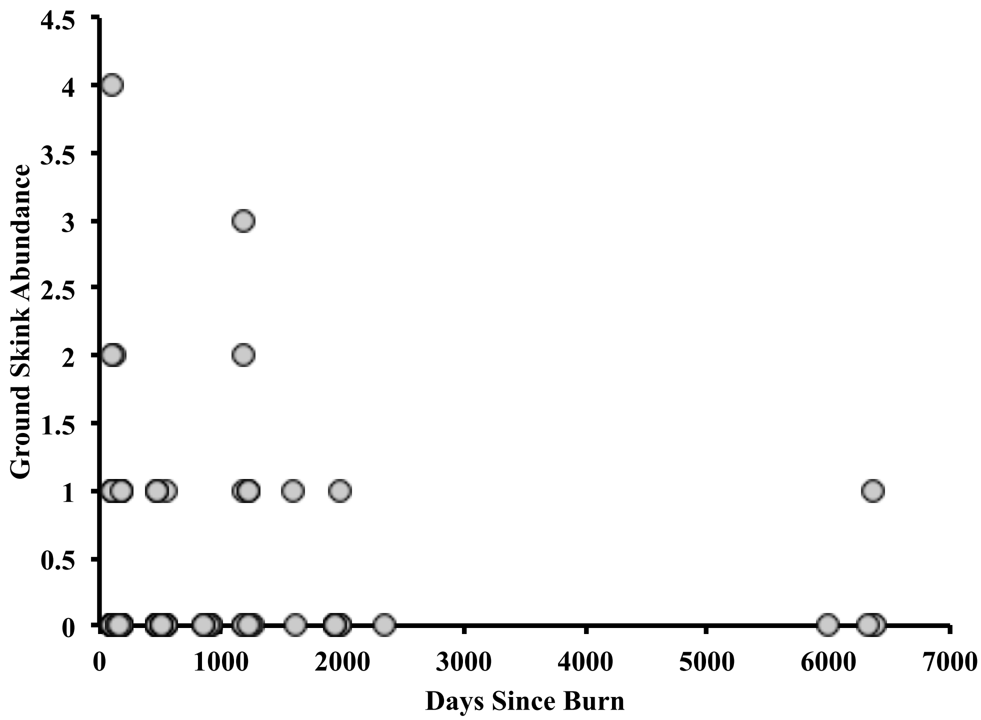

Figure 12. Linear Regression of Fence Lizard Abundance

Relationship between time since burn (days) and fence lizard abundance captured in sampling arrays, Gus Engeling Wildlife Management Area, Anderson County, Texas, 2016-2017. On the verge of significance, with the regression coefficient of -5.63E-5, giving a slight declining slope, where ($P = 0.114$; $R^2 = 0.025$)

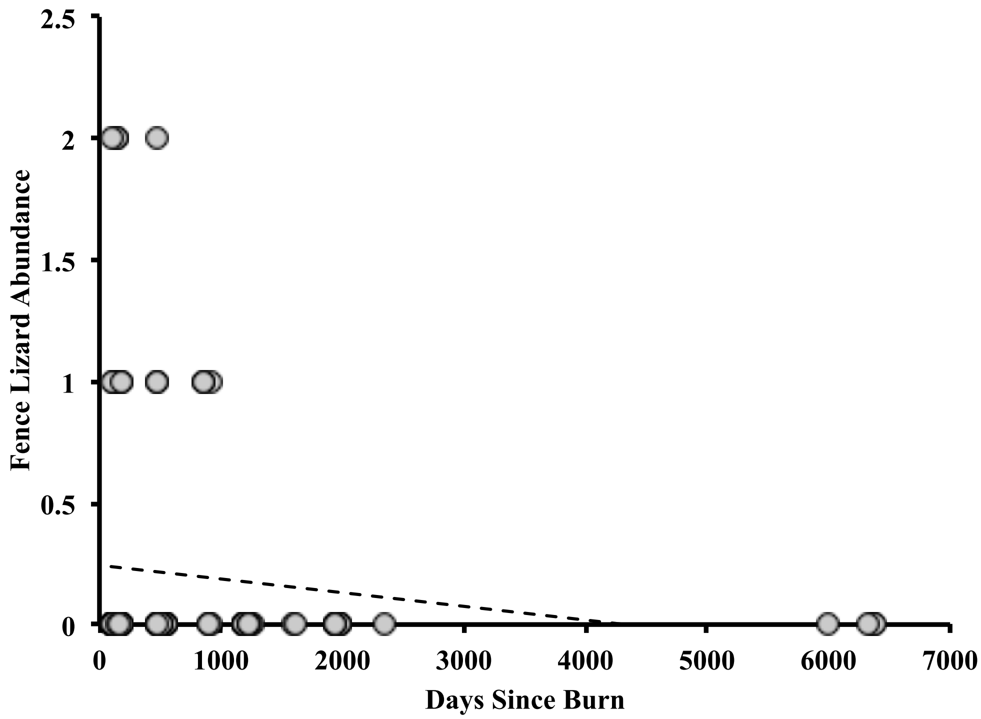

Figure 13. Linear Regression of Total Abundance

Relationship between time since burn (days) and total abundance of reptiles and amphibians captured in sampling arrays at Gus Engeling Wildlife Management Area, Anderson County, Texas, 2016-2017. No significance was detected, and no slope established, where (β = -6.57E-5, P = 0.610; R^2 = 0.003)