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The Effects of Fire Refugia on Co-Flowering Communities, Floral Abundance, and Flowering Phenology in an Old Growth Longleaf Pine Forest

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THE EFFECTS OF FIRE REFUGIA ON CO-FLOWERING COMMUNITIES, FLORAL
ABUNDANCE, AND FLOWERING PHENOLOGY IN AN OLD GROWTH LONGLEAF
PINE FOREST

By

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ABSTRACT

Many ecosystems depend on fire to maintain appropriate habitats and to trigger important life history events, such as flowering or seed germination. Historically, fires were often patchy, but due to fire suppression and other human actions, burns have become more homogenous. However, heterogeneity in fire may be important for both plant reproduction and pollinators. We created small protected patches within prescribed fires in a longleaf pine savanna and then measured co-flowering community and floral abundance in both burned and protected plots. Co-flowering community and floral abundance were both significantly different between treatments, with significantly more flowers blooming in burned plots. Flowering phenology also showed marginally non-significant differences between treatments, with phenological events occurring slightly later in burned plots. Fire appears to be important for stimulating flowering and increases the amount of floral resources available to pollinators. However, unburned patches might help extend the flowering season, and could provide other benefits for the animals that rely on floral and seed resources.

CHAPTER 1

THE EFFECTS OF FIRE REFUGIA ON CO-FLOWERING COMMUNITIES, FLORAL ABUNDANCE, AND FLOWERING PHENOLOGY IN AN OLD GROWTH LONGLEAF PINE FOREST

Introduction

Many communities fundamentally depend on the presence of fire. In fire-dependent communities, fire helps maintain community structure and species diversity (Robinson et al. 2013). For example, fire patterns maintain gaps and open patches in rosemary scrub, and fire history can influence both the presence of canopy gaps and patches, and the diversity of the plant community in these patches (Menges et al. 2017). Fire can also be important for triggering important life history events, such as seed set (e.g. Wagenius et al. 2020) and germination (e.g. Le Breton et al. 2020). The distribution of adult longleaf pine in longleaf pine savannas is also influenced by the frequency and heterogeneity of fire (Platt et al. 1988b, Robertson et al. 2019).

Fires are often heterogeneous (Román-Cuesta et al. 2009, Robinson et al. 2013, Blomdahl et al. 2019). Heterogeneity within fires could be important for species persistence, and community structure and diversity (Robinson et al. 2013, Warchola et al. 2018, Blomdahl et al. 2019). We know that in some cases, fire refugia, or unburned areas within a fire's perimeter (Meddens et al. 2018) can be important for sheltering fire sensitive organisms and repopulating burned areas (Swan et al. 2016, Mutz et al. 2017, Blomdahl et al. 2019, Le Breton et al. 2020). Heterogeneous burns have also been suggested as important for maintaining structure in longleaf pine savannas and many other fire-adapted ecosystems (Blomdahl et al. 2019, Robertson et al. 2019) and species diversity in sagebrush steppe (Wroblewski and Kauffman 2003). Unburned patches have also been suggested to provide a place for more fire vulnerable tree species and life-stages to survive in study plots near Yosemite National Park (Blomdahl et al. 2019). However, very few of these studies focus on the potential multitrophic effects of fire and fire refugia (McLauchlan et al. 2020).

One way fire and fire refugia could have multitrophic effects is by changing either flowering phenology, floral abundance, or both. Fire has already been shown affect the timing and synchrony of flowering within and among years (Platt et al. 1988a, Tunes et al. 2017, Mola and Williams 2018, Wagenius et al. 2020), as well as plant and floral display size (LoPresti et al.

2018, Wagenius et al. 2020) and flower abundance (Platt et al. 1988a, Mola and Williams 2018, Wagenius et al. 2020). Fire also affects community composition and structure in both flowering communities and plant communities more generally (Wroblewski and Kauffman 2003, Menges et al. 2017, Welte and Joern 2018, Blomdahl et al. 2019, Robertson et al. 2019). This suggests that even small, ephemeral fire refugia change the amount and distribution of resources for pollinators.

Pollinator abundance has already been shown to increase in burned areas after wildfire (Mola and Williams 2018). Prescribed fire in combination with mechanical thinning also increased pollinator abundance and diversity in some cases (e.g. Campbell et al. 2007) Both of these changes were attributed to an increased abundance of flowers or flowering plants in burned areas. Plant-pollinator networks and both plant and pollinator richness and community composition can also be changed by fire (Welte and Joern 2018). However, if the habitat does not continue to be maintained by fire, pollinator abundance decreases (Schultz and Crone 1998, Henderson et al. 2018, Warchola et al. 2018).

Longleaf pine savannas are dependent on frequent fire for persistence of the native plant community (Agee 1998, Glitzenstein et al. 2012). Less than 3% of the original extent of longleaf pine savanna is left (Noss et al. 1995). Remaining high quality habitat is managed with frequent (1-3 year interval) prescribed fire, which can be applied to increase or decrease habitat heterogeneity according to management objectives. Fire is thought to maintain high plant diversity in long leaf pine savannas (Glitzenstein et al. 2012). The plant community recovers quickly after individual fires, as most plants are perennial and resprout within a week to a month of burning (MSW, KMR pers. obs.).

In addition to having a generally open canopy, old growth longleaf pine savannas have distinctive canopy gaps that influence the pattern and intensity of fires. These gaps are created by tree deaths and contribute to overall plant diversity in longleaf pine savannas (McGuire et al. 2001). These gaps are less likely to carry fire than the vegetation under the tree canopy because of lower pine needle litter loads, and this patchiness in fire has been demonstrated to be important for longleaf pine regeneration (Robertson et al. 2019). The pattern of gaps and tree patches in longleaf pine savanna also shape the heterogeneity of the understory plant community (Mugnani et al. 2019). This suggests that fire patchiness might be able to influence co-flowering communities, and likewise influence resources for pollinators.

Prescribed fire managers generally know under what conditions prescribed burns result in patchy versus continuously burned areas, such that improved understanding of effects of patchy burning on plants and pollinators could provide important guidance for conservation management. If small fire refugia are important to the persistence of pollinators such as butterflies, land managers could use heterogeneous burns as part of their effort to achieve conservation goals.

To determine how small refugia in long-leaf pine savannas influence floral resources for pollinators, we conducted an experiment that created protected plots (fire refugia) within a longleaf pine ecosystem that has had continuous frequent fire (mostly 1-2 year intervals) throughout its known history and presumably in presettlement times (Rother et al. 2020). For this experiment, we asked: (1) Is floral abundance different between burned and protected plots? (2) Are co-flowering communities different between burned and protected plots? and (3) Are the flowering phenologies different between burned and protected plots? To answer these questions, we created small protected plots within prescribed fires in an old growth longleaf pine savanna and monitored flowering for a year following fires. Based on previous research that suggest that lightning season fires can increase the number of flowering individuals as well as shift peak flowering dates later in the season (Platt et al. 1988a), we predicted that flower abundance would be greater in burned plots than in protected plots, and that co-flowering communities would be different in burned and protected plots. We also expected that plants would flower later and with greater synchrony (i.e. a shorter duration) in burned plots than in protected plots.

Methods

Study System

Our research was conducted at the Wade Tract, an 83-hectare tract of old growth longleaf pine savanna on Arcadia Plantation in southern Georgia. The Wade Tract is divided into two burn units (east and west), both of which have been burned annually for most years in the past decade and has been continuously burned with mostly 1-2 year interval fires throughout its known history and presumably since presettlement times (Rother et al. 2020). Prescribed fires at the Wade Tract are generally allowed to be patchy and are managed to minimize crown scorch

and ignition of scars of mature trees on the property. Tall Timbers Research Station has detailed records of prescribed fires at the Wade Tract over the last 30 years and dendrochronological evidence of fires during the past century (Rother et al. 2020).

The Wade Tract is notable not only for its old growth trees, but for its understory plant community. Minimal disturbance either from agriculture or hunting improvements has allowed the native understory plant community to remain intact. Most native understory species in longleaf pine savannas are long-lived perennials, so the Wade Tract's understory can be considered an old growth community as well. More than 500 species of flowering plants have been recorded at the Wade Tract (W.J. Platt and colleagues, unpublished data).

Experimental Methods

To test the effect of fires on floral abundance and the identity of species in flower, we created paired burned and protected plots throughout our field site in 2018. Each plot was 10 m in diameter, with plot pairs established in adjacent canopy gaps. We did not control distance between plots and the edge of the dirt road that separates the two burn units, though most of them were greater than 20 m from the road and greater than 50 m from each other. Treatments were assigned randomly within each pair. Leaf litter was raked from fire breaks around each protected plot before burning. Before 2018, all plots had similar fire histories.

The prescribed fire for the west burn unit was conducted in March 2018. This burn spread mostly during the early evening under mild fire conditions, and the resulting fire left many unburned patches behind. Three plots designated to burn did not, so their locations were moved to the burned area nearest their original site. This maintained seven pairs of burned and protected plots in the west burn unit. In contrast, when the east burn unit was burned in May 2018, relative humidity was very low (only 19%) resulting in three protected plots burning during the initial fire. Areas that were naturally skipped by the fire might have remained unburned because of differences in hydrology, vegetation or other confounding factors. Since the purpose of our experiment was to compare burned and protected plots, all burned plots pairs without surviving protected plots were dropped from the experiment, leaving only four pairs of plots in the east unit, and 11 pairs of plots total for the experiment (Fig. 1). Because burn time and severity differed between burn units, we always included burn unit as a factor in our analyses.

We monitored floral abundance and co-flowering community for animal-pollinated plant species until prescribed burns were carried out again in the spring of 2019. We surveyed plots for flowers at least once a week during the growing season portions of the year following the prescribed fires (April-November 2018 and March and April 2019). Within each plot we identified all plant species with open flowers and then counted the number of flowers present per species, with a few exceptions. For Asteraceae, in most cases we counted capitula (individual inflorescences of ray and/or disc flowers). For species in the genera *Eupatorium* and *Solidago*, counting capitula was impractical, so we counted flowering individuals instead. For other species with large inflorescences (e.g. in genera *Asclepias*, *Angelica*, *Rhus*, and *Callicarpa*), we counted umbels or individual inflorescences instead of individual flowers.

While we preferred to identify plants to species, *Pityopsis*, *Rubus*, and some *Desmodium* species were impractical to ID in the field, so in some instances we binned plants of the same genus together for data analysis. Some *Desmodium* species were identifiable and others were divided into groups based on morphology. Voucher specimens of most species identified were collected and deposited in the Robert K. Godfrey Herbarium at FSU. We used Wunderlin and Hansen (2011) to identify all plants.

Statistical Methods

Abundance and composition of the floral community. We used a GLMM with a poisson distribution to compare the floral abundance of burned and protected plots (*lmer* and *car* packages in R v3.6.3, R core team 2020, Bates et al. 2015, Fox and Weisberg 2019). We modeled the log total number of flowers found per visit by burn treatment and week of year, with burn unit as a fixed effect. Because floral abundance had a distinct peak in September, we also included a term for (week of year)² to better model the peak in our data. We also included the interactions between burn treatment and time of year in our model, because we expected that the effect of burn treatment would change over time. Plot pair (i.e. experimental block) was included as a random effect in the model to account for site heterogeneity and repeated measures. The log total number of flowers was used to improve normality of residuals and homoscedasticity in our model.

To test whether co-flowering communities differed between burned and protected plots, we used nonmetric multidimensional scaling (NMDS) with two axes and 20 tries to visualize differences in composition among plots and their changes over time, and then ran a PERMANOVA (permutational multivariate analysis of variance) on a distance matrix using Bray-Curtis community dissimilarity scores (*vegan* package in R v3.6.3, R core team 2020, Oksanen et al. 2019) to test for statistical differences between treatments. Rare species can have an outsized effect on community analyses, so we removed species that fell below the inflection point of the rank abundance curve for our data before we did our community analysis. This left us with a dataset of the 55 most common species observed in our plots.

Different species flower at different times of the year, so we divided our data into five seasonal flowering guilds. This allowed us to ask whether burned and protected treatments differed in species composition at different points over the growing season. It is possible that effects of burning would only be apparent in spring and summer, and have faded by fall. The seasonal flowering guilds were determined based on field observations and visual inspection of the flowering duration by week of year for dominant species (Fig. 2). We split the data into partitions for spring 2018 (week of year 14 to 28) early summer 2018 (week of year 29 to 35), late summer 2018 (week of year 36 to 42), fall 2018 (week of year 43 to 47), and spring 2019 (week of year 10 to 16).

In addition to changing the co-flowering communities, burn treatment may have affected the homogeneity of the co-flowering communities among plots. For example, burned plots may all have had a similar co-flowering community, whereas the protected plots may have been more heterogeneous, with different co-flowering communities in different plots. We used PERMDISP (permutational analysis of dispersion) to test for differences in the homogeneity of species flowering in the burn treatments (*vegan* package in R v3.6.3, R core team 2020, Oksanen et al. 2019). Burned and protected treatments might also become more or less heterogeneous with time of year. To test this, we also used PERMDISP on the same seasonal flowering guilds as for PERMANOVA.

Flowering phenology. While all other analyses were conducted with plot as the unit of observation, to test the effects of fire on flowering phenology (the timing of flowering) we used each species as a unit of observation. We pooled the data on the timing of flowering for each

species across plots within burn treatments, to calculate the first, last and peak flowering dates and duration of flowering for that species. First and last flowering dates were calculated as the week of year of the first or last observation of a species' open flower, across all plots within a treatment and burn unit. Peak flowering was calculated as the week of year with the highest abundance of flowers for a species, across all plots within a treatment and burn unit. Duration of flowering was calculated as the number of weeks between the observation of the first and last open flower.

We then compared first, last, and peak flowering dates, and flowering duration between burn treatments using a t-test, with degrees of freedom equal to one less than the number of species for which we were able to calculate phenology data. For these analyses we only used species that were observed in both treatments and had a total of five or more separate observations recorded (48 species in the west burn unit, and 39 species in the east burn unit). Because previous research suggests that the season of burn can affect how plants respond to fire (Platt et al. 1988a) and the timing and severity of the fires differed between the two burn units, we tested for effects on phenology in each burn unit separately.

Since we hypothesized that refugia might increase the landscape-level duration of flowering, we also calculated each species' overall range of flowering dates with treatments combined to compare with burned only treatments, to represent a more homogenous burn. Again, we used a t-test to compare flowering duration in burned plots to the combined flowering duration of protected and burned plots. We tested each burn unit separately, with the degrees of freedom equal to the number of species with at least five separate observations and in both plot types.

Results

Abundance and Composition of the Floral Community

We collected data on 87 species and eight additional species groups identifiable only to the genus level, and counted more than 138,000 open flowers and inflorescences over the course of the experiment (Table 1). We observed an average of 4.2 species flowering per plot visit, with between 0 - 16 species flowering in the same plot at one time. The average number of species

flowering per visit was 4.5 in burned plots and 3.9 in the protected plots. On average, we observed 132 flowers, inflorescences, or capitula per plot visit. Burned plots averaged 165 flowers, with a minimum of 0 flowers and a maximum of 1801 flowers. Protected plots averaged fewer flowers than burned plots, with an average of 101 flowers per plot visit, but a similar range, with floral abundance spanning 0 - 1821 flowers per plot.

We modeled floral abundance by treatment, and time of year, and their interactions, with burn unit as a fixed effect. Burned plots started out in April and May 2018 with slightly less flowers than protected plots, but slowly increased in abundance until peak flowering. At peak flowering in mid-September, burned plots had significantly more flowers than protected plots, but by the end of the flowering season in November, floral abundance in burned and protected plots had once again converged (Fig. 3, Table 2). Floral abundance was significantly affected by week of the year (GLMM, $X^2 = 51.704$, $df = 1$, $p < 0.001$) and the interaction between treatment and week of year (GLMM, $X^2 = 17.046$, $df = 1$, $p < 0.001$). The effect of treatment alone on floral abundance was marginally nonsignificant (GLMM, $X^2 = 2.892$, $df = 1$, $p = 0.09$). Burn unit did not have a significant affect on floral abundance (GLMM, $X^2 = 0.552$, $df = 1$, $p = 0.457$).

Co-flowering communities differed in both composition and heterogeneity in burned and protected treatments. Burning initially resulted in a more homogenous co-flowering community, but co-flowering communities became more heterogeneous over time. However, most of the variation among plots was not explained by burn treatment.

Co-flowering community composition was significantly different by burn treatment, week of the year, and the interaction between treatment and time; but these differences explained a relatively low proportion of the variation among plots (PERMANOVA, Table 3, Fig. 4). Initially, the co-flowering community was more similar among burned plots than among protected plots (i.e., lower beta-diversity), but by the end of our experiment, burned plots had become more heterogeneous than their protected partners, though again this appears to explain relatively little of the variation among plots when the whole year's data is considered (PERMDISP, Table 3, Fig. 4).

Burned and protected co-flowering communities also differed by burn treatment when we used presence-absence values instead of abundances (PERMANOVA, Table 3), suggesting that burning affected composition, not just relative abundances. Co-flowering community showed a

larger difference by week of year for presence-absence data than for abundance data, reflecting the effects of prescribed fire on the propensity of some species to flower in a year, as opposed to effects of fire on the relative abundances of flowers (especially for species with high floral abundances).

When we ran the NMDS, PERMANOVA and PERMDISP analyses for each seasonal flowering guild (Fig. 5), we found that burn treatment and week of year showed significant differences in each seasonal flowering guild (Fig. 5), but that late summer 2018 (Fig. 5c) and fall 2018 (Fig. 5d) seasonal flowering guilds did not show a significant interaction between burn treatments and week of year, or a significant difference in heterogeneity of co-flowering communities among plots (PERMDISP $p > 0.05$, Table 3) in burned and protected treatments. In spring of 2019 (Fig. 5e), seasonal flowering guilds were still different between burned and protected plots (PERMANOVA: $p = 0.001$, Table 3), suggesting that the two co-flowering communities had not yet converged by the time prescribed fires were carried out in 2019.

Spring 2018 (Fig. 5a) and early summer 2018 (Fig. 5b) seasonal flowering guilds were more similar to each other among plots in the burned treatment than in the protected treatment (PERMDISP, Table 3). By spring of 2019, the plots in the burned treatment became significantly less similar to each other than their protected counterparts (PERMDISP, $p < 0.001$, Table 3).

Floral Phenology

Some species had very strong responses to the burned and protected treatments. *Tephrosia virginiana* flowered a month after fire and only in areas that had been burned. *Penstemon australis* was already flowering before the May fire, but these same plants regrew and flowered again after the prescribed burn. Ericaceous species, particularly *Vaccinium* and *Gaylussacia*, as well as *Rubus* species flowered early in the year, and were already fruiting when prescribed fires were applied at the Wade Tract. Unlike the *Penstemon* and *Ceanothus*, they did not reflower after fire.

When burn treatment affected flowering phenology, it pushed phenological events later in the year in burned plots. Overall, peak flowering date was the only phenological event that differed significantly between burned and protected treatments, with peak flowering occurring slightly later for burned plots (t-test: $t = -2.1366$, $p = 0.04$, $df = 86$, Table 4, Fig. 6). Because

there is some evidence that the time of year a fire happens in can change the effect of fire on flowering phenology in longleaf pine savannas (Platt et al. 1988a), we also looked at how flowering phenology changed in each individual burn unit. In the east burn unit, which was burned in May, we found that both first and peak flowering dates were significantly later in the burned treatment than in the unburned treatment (t-test, Table 4, Fig. 7). The difference between flowering duration in burned and protected treatments was marginally nonsignificant, with flowering duration being slightly shorter in burned plots (t-test, $t = 1.7242$, $df = 38$, $p = 0.093$, Table 4, Fig. 8). The west burn unit, burned in March, showed a marginally nonsignificant shift to average later first flowering dates in the burned treatment (t-test: $t = 1.7833$, $df = 47$, $p = 0.081$, Table 4, Fig. 9), but no other differences in phenological timing or duration (Fig. 10) between burned and protected treatments.

Even though average flowering duration was not different in burned and protected treatments, the combination of burned and protected treatments did extend flowering duration for the whole community compared to the flowering duration of the burned treatment alone. For the west burn unit, combining burned and protected plots extended flowering duration by 1.67 weeks, which is a marginally nonsignificant difference from the burned flowering duration alone (t-test: $p = 0.08$, $df = 47$). However, for the east unit, the fire treatment combination significantly extended flowering duration (3.25 weeks longer, t-test, $p = 0.01$, $df = 38$).

Discussion

At our study site, fire, appears to increase floral abundance, at least at peak flowering in September. We also found that co-flowering community composition was different in burned and protected plots. Though our treatments explained very little of the variation we saw between co-flowering communities, the heterogeneity of longleaf pine understory communities (Glitzenstein et al. 2012) could mean that even a small signal is suggestive of some effect of fire on co-flowering community. Fire also initially increased homogeneity within the burned treatment, but this effect disappeared by the next year. This suggests that fire homogenizes co-flowering communities, but these communities regain their heterogeneity relatively quickly. In some cases, flowering phenology can be shifted by fire, and at our study site, fire tended to shift first and peak flowering later in the season and to shorten flowering duration. This matches

evidence from similarly timed fires in at least one other experiment, where fires between the months of April-September tended to shift peak flowering later in the season and shorten the duration of flowering, compared to dormant season fires (Platt et al. 1988a).

A reduction in flowering duration accompanied by an increase in floral abundance could improve reproductive success in flowering plants (Platt et al. 1988a, Wagenius et al. 2020). However, this depends on if increased floral abundance is driven only by an increase in size of flowering individuals or the number of flowering individuals. An increased number of flowers on the same number of plants, could result in reduced outcrossing, genetic diversity, and reproductive success with fire (LoPresti et al. 2018). However, if the increase in floral abundance is because more individuals are flowering at once than outcrossing, genetic diversity, and reproductive success might increase with fire. Evidence from Platt et al. (1988a) suggests that in longleaf pine savanna there is an increase in the number of stems as well as in flowers, so it is possible that fire is beneficial for plant reproduction as well as for providing potential pollinator resources. However, our study did not count individual plants, so further study in this system might include documenting number and size of individuals as well as number of flowers.

Likewise, synchronization of flowering could be beneficial or detrimental to flowering plants. If synchronization happened among species more than within species, more species flowering at once could result in pollen mismatches and reduced seed set (Platt et al. 1988a). Evidence suggests that fires between April-September synchronize flowering among species in the longleaf pine savanna understory (Platt et al. 1988a).

Other studies have shown that fire, and particularly variation in fire can affect general vegetation community composition and structure at the Wade Tract. Aggregation of longleaf pine patches suggests that longleaf pine generally regenerate in canopy gaps (Platt et al. 1988b, Robertson et al. 2019). This is probably in part because canopy gaps are more likely to be skipped by fire, allowing seedlings more opportunities to survive until they are large enough to survive a fire (Platt et al. 1988b, Robertson et al. 2019). These surviving seedling patches can influence community structure for 250 years or longer (Robertson et al. 2019). A previous study at the Wade Tract found that plant communities differ between canopy gaps and longleaf pine patches, particularly plants in the families Asteraceae and Fabaceae, and the genus *Rubus* (Mugnani et al. 2019). These community differences could be mediated by the amount of needle

cast from longleaf pine, which can affect fire severity and nutrient availability (Mugnani et al. 2019).

While differences between burned and protected co-flowering communities in canopy gaps were measurable in our study, they explained very little variation. In part this could be because fire has never been removed from the Wade Tract. Given that a fire return interval of 1-3 years is reasonable to expect in longleaf pine savanna (Glitzenstein et al. 2012), it seems reasonable that the differences between burned and protected plots after a year might still be small. Frequent fire and the lack of permanent refugia for fire-sensitive plant species in any of our study plots suggest that there is a strong filter selecting for plants that are well-adapted to fire.

Changes in flowering driven by fire could also affect availability of resources to pollinators. Changes in timing and duration of flowering could cause phenological mismatch between plants and pollinators (Tunes et al. 2017). However, data we gathered on the duration of flight season for butterflies at the Wade Tract suggests that phenological mismatch may not be a problem for pollinators in this system (Appendix C).

Changes in abundance of flowers have been shown to drive changes in both abundance and community composition of pollinators in other studies. A study in central California found that bumblebee abundance increased after fire, and that this was driven by increased floral abundance in burned areas (Mola and Williams 2018). Using prescribed fire and mechanical thinning increased pollinator abundance by increasing herbaceous understory and decreasing woody basal areas in a southeastern pine savanna (Campbell et al. 2007). Not all pollinator guilds had in equal response to this restoration, notably butterflies and a nonsignificant response (Campbell et al. 2007). A combination of grazing and intermediate level of prescribed fire increased plant and pollinator species richness and floral abundance in a tallgrass prairie. This increased the stability of plant-pollinator networks in the prairie community (Welti and Joern 2018). A study done in South Africa found that pollinators increased in abundance in fire refugia instead of burned areas, but again, this pattern was driven by increased flowering in fire refugia as compared to the burned areas (Adedoja et al. 2019). This suggests that if increasing floral abundance is key in increasing pollinator abundance.

Our preliminary data on butterfly response to unburned patches suggests that while butterflies do respond to increased floral abundance, so in general they benefited from burned

patches but not unburned patches (Appendix C). However, we only observed the presence and behavior of adult butterflies. Unburned patches could be important for long term survival of butterfly species in longleaf pine savanna, if vulnerable lifestages (e.g. eggs, larvae, and pupae) need unburned areas to survive fire. For example, a study in tallgrass prairie found that prescribed fire increased abundance of the regal fritillary, a rare butterfly, as long as there were nearby unburned patches to provide immigrants to newly burned areas (Henderson et al. 2018). Another study found that while prescribed fire is necessary to maintain habitat for the Fender's Blue, a rare butterfly found in Oregon's Willamette Valley, nearby unburned patches are also important because they provide shelter for fire vulnerable lifestages (Warchola et al. 2018). Without this shelter, the populations would be lost (Warchola et al. 2018).

APPENDIX A

TABLES

Table 1: The list of all plants identified in our plots at the Wade Tract. Plants identified to genus or family were usually done so due to difficulty identifying in the field or to a limited number of observations. Plant or genus names in bold indicate species or genera used to define seasonal flowering guilds.

species or genus	Species List			notes
	burned only	unburned only	both	
<i>Sisyrinchium angustifolium</i>	n	n	y	
<i>Vaccinium</i> spp.	n	n	y	<i>Vaccinium darrowii</i> or <i>Vaccinium myrsinites</i>
<i>Rubus</i> spp.	n	n	y	<i>Rubus cuneifolius</i> , <i>Rubus pensylvanicus</i> , or <i>Rubus trivialis</i>
<i>Ceanothus americanus</i>	n	n	y	bloomed before and after fire
<i>Polygala nana</i>	n	y	n	
<i>Vaccinium arboreum</i>	n	n	y	
<i>Ruellia ciliosa</i>	n	n	y	
<i>Cnidocolus stimulosus</i>	n	n	y	
<i>Scutellaria multiglandulosa</i>	n	n	y	
<i>Penstemon australis</i>	n	n	y	bloomed before and after fire
<i>Mimosa quadrivalvis</i>	n	n	y	
<i>Asemeia grandiflora</i>	n	n	y	
<i>Castanea pumila</i>	n	n	y	male and female flowers bloom at different times
<i>Dyschoriste oblongifolia</i>	n	n	y	
<i>Tephrosia virginiana</i>	n	n	y	
<i>Asimina angustifolia</i>	n	n	y	Some of these might be <i>Asimina parviflora</i> (W. Platt, pers. comm.)
<i>Stillingia sylvatica</i>	n	n	y	
<i>Rhynchosia tomentosa</i>	n	n	y	
<i>Lithospermum virginianum</i>	n	n	y	
<i>Tephrosia spicata</i>	n	n	y	
<i>Commelina erecta</i>	n	n	y	
<i>Galactia erecta</i>	y	n	n	
<i>Verbesina aristata</i>	n	n	y	
<i>Clitoria mariana</i>	n	n	y	
<i>Galium pilosum</i>	n	n	y	
<i>Tragia urens</i>	y	n	n	
<i>Crotalaria rotundifolia</i>	n	n	y	
<i>Rhynchosia difformis</i>	n	n	y	
<i>Chrysopsis mariana</i>	n	n	y	

Table 1 - continued

species or genus	Species List			notes
	burned only	unburned only	both	
<i>Callicarpa americana</i>	n	y	n	
<i>Stylisma patens</i>	n	n	y	
<i>Galactia mollis</i>	n	n	y	
<i>Piriqueta caroliniana</i>	n	n	y	
<i>Eryngium yuccifolium</i>	y	n	n	
<i>Asclepias tuberosa</i>	n	n	y	
<i>Tephrosia florida</i>	y	n	n	
<i>Rudbeckia hirta</i>	n	n	y	
<i>Spiranthes tuberosa</i>	n	n	y	
<i>Physalis heterophylla</i>	y	n	n	
<i>Stylosanthes biflora</i>	n	n	y	
<i>Silphium asteriscus</i>	n	n	y	
<i>Rhynchosia reniformis</i>	n	n	y	
<i>Ipomoea pandurata</i>	y	n	n	
<i>Eupatorium rotundifolium</i>	n	n	y	counted flowering individuals
<i>Eupatorium album</i>	n	n	y	counted flowering individuals
<i>Crotolaria purshii</i>	n	y	n	
<i>Desmodium floridanum</i>	n	n	y	
<i>Hibiscus aculeatus</i>	n	y	n	
<i>Centrosema virginianum</i>	n	n	y	
<i>Strophostyles umbellata</i>	n	n	y	
<i>Vernonia angustifolia</i>	n	n	y	
<i>Physalis walteri</i>	n	n	y	
<i>Rhus copallinum</i>	n	n	y	
<i>Elephantopus elatus</i>	n	n	y	
<i>Eupatorium hyssopifolium</i>	n	n	y	counted flowering individuals
<i>Hypericum</i> sp.	y	n	n	<i>Hypericum</i> species with 5 petals
<i>Hypericum hypericoides</i>	n	n	y	
<i>Asclepias verticillata</i>	n	n	y	
<i>Buchnera floridana</i>	y	n	n	<i>Buchnera americana</i> and <i>Buchnera floridana</i> are indistinguishable without molecular tools (W. Platt pers. comm), ID follows Wade Tract species list provided by Tall Timbers.
<i>Hypericum crux-andreae</i>	n	n	y	
<i>Sericocarpus tortifolius</i>	n	n	y	
<i>Chamaecrista fasciculata</i>	n	n	y	
<i>Euphorbia discoidalis</i>	n	n	y	
<i>Dalea albida</i>	y	n	n	
<i>Hieracium gronovii</i>	n	n	y	

Table 1 - continued

species or genus	Species List			notes
	burned only	unburned only	both	
<i>Chamaecrista nictitans</i>	n	n	y	
<i>Oenothera filipes</i>	n	n	y	
<i>Agrimonia incisa</i>	n	y	n	
<i>Lobelia puberula</i>	n	n	y	
<i>Solidago odora</i>	n	n	y	counted flowering individuals
Small leaved <i>Desmodium</i> spp.	n	n	y	<i>Desmodium ciliare</i> , <i>Desmodium marilandicum</i> and possibly others.
Oval and linear leaved <i>Desmodium</i> spp.	n	n	y	<i>Desmodium paniculatum</i> , <i>Desmodium obtusum</i> and possibly others.
<i>Salvia azurea</i>	n	n	y	White flowered in all my plots, but some blue <i>S. azurea</i> were also present at the Wade Tract
<i>Conyza canadensis</i>	n	y	n	
<i>Lespedeza angustifolia</i>	n	n	y	
<i>Angelica dentata</i>	n	n	y	
prostrate or viney <i>Desmodium</i> spp.	n	y	n	<i>Desmodium lineatum</i> and others.
<i>Ageratina aromatica</i>	n	n	y	
<i>Helianthus angustifolius</i>	n	y	n	
<i>Symphyotrichum concolor</i>	n	n	y	
<i>Symphyotrichum adnatum</i>	n	n	y	
<i>Houstonia procumbens</i>	n	n	y	
<i>Gelsemium sempervirens</i>	n	y	n	
<i>Viola septemloba</i>	n	y	n	
<i>Gaylussacia</i> spp	n	n	y	<i>Gaylussacia dumosa</i> , <i>Gaylussacia nana</i> , or <i>Gaylussacia tomentosa</i>
<i>Vaccinium stamineum</i>	n	y	n	
<i>Crocianthemum carolinianum</i>	n	n	y	
<i>Gamochaeta purpurea</i>	n	y	n	
Unidentified Convulvaceae	n	y	n	
<i>Toxicodendron pubescens</i>	n	n	y	
<i>Rhynchosia reniformis</i>	n	n	y	
<i>Pityopsis</i> spp	n	n	y	<i>Pityopsis aspera</i> or <i>Pityopsis graminifolia</i>
<i>Symphyotrichum</i> spp.	n	n	y	<i>Symphyotrichum oolentangiense</i> or <i>Symphyotrichum dumosum</i>
<i>Galactia regularis</i>	n	y	n	could also be <i>Galactia volubilis</i> , but is more likely to be <i>G. regularis</i> .

Table 2: Output for GLMM of log of floral abundance by burn treatment and time of year, with burn unit as a fixed effect, and plot ID as a random effect to count for repeated measures at each plot. Significant values are in bold.

GLMM Results			
Variables	X ²	df	p-value
burn	2.892	1	0.090
week of year	51.704	1	p <<< 0.001
(week of year) ²	11.329	1	0.001
unit	0.552	1	0.457
burn*week of year	17.046	1	p <<< 0.001
burn*(week of year) ²	13.567	1	p < 0.001
week of year*(week of year) ²	32.321	1	p <<< 0.001
burn*week of year*(week of year) ²	4.861	1	0.027

Table 3: PERMANOVA and PERMDISP results for community analyses. Significant values are in bold. Significant PERMANOVA results suggest that co-flowering communities are different. Pseudo r² values suggest that though co-flowering communities are significantly different, burn treatment and time of year explain a relatively low proportion of the variation. Significant PERMDISP results suggest that one co-flowering community is more heterogeneous than the other.

data	Permanova Results			
	treatment	p-value	pseudo r ²	Permdisp
Full dataset	burn	0.001	0.01	p<0.001
	week of year	0.001	0.03	
	interaction	0.001	0.006	
Spring 2018 (weeks 14-28)	burn	0.001	0.03	p=0.003
	week of year	0.001	0.09	
	interaction	0.001	0.03	
Early summer (weeks 29-35)	burn	0.001	0.07	p<0.001
	week of year	0.001	0.08	
	interaction	0.009	0.008	
Late summer (weeks 36-42)	burn	0.01	0.03	p=0.1
	week of year	0.001	0.05	
	interaction	0.56	0.008	
Fall (weeks 43-47)	burn	0.001	0.05	p=0.34
	week of year	0.001	0.05	
	interaction	0.19	0.009	
Spring 2019 (weeks 10-16)	burn	0.002	0.04	p<0.001
	week of year	0.001	0.09	
	interaction	0.04	0.02	

Table 4: T-test results showing shifts in phenology between burned and protected plots. Bold text indicates significant values, suggesting that burn treatment can shift the timing of phenology in some circumstances. Burn units were tested separately because fires differed in timing and severity between the two units.

unit	Phenology								df
	start		peak		end		duration		
	t-value	p-value	t-value	p-value	t-value	p-value	t-value	p-value	
all	-1.3744	0.1729	-2.1366	0.035	-1.0285	0.307	0.13786	0.891	86
east	-3.3465	0.002	-2.61	0.013	-1.0146	0.317	1.7242	0.093	38
west	1.7833	0.081	-0.64822	0.52	-0.48921	0.627	-1.2552	0.216	47

Table 5: PERMANOVA results for butterflies that rested, nectared, oviposited or patrolled within plots between May-November 2018. Bold font indicates significant effects.

PERMANOVA, butterfly-plot interactions		
test	p-value	pseudo r ²
burn	0.5	0.002
WOY	0.001	0.1
burn*woy	0.66	0.001
unit	0.002	0.009
burn*unit	0.28	0.002
pair	0.001	0.04
burn*pair	0.49	0.02

Table 6: PERMANOVA results of butterfly community divided by seasonal flowering guild. Bold font indicates significant responses.

Seasonal Butterfly Communities											
Spring 2018			Early summer 2018			Late summer 2018			Fall 2018		
test	p-value	pseudo r ²	test	p-value	pseudo r ²	test	p-value	pseudo r ²	test	p-value	pseudo r ²
burn	0.026	0.005	burn	0.73	0.003	burn	0.633	0.005	burn	0.45	0.01
WOY	0.001	0.016	WOY	0.001	0.02	WOY	0.001	0.03	WOY	0.01	0.03
burn*woy	0.461	0.002	burn*woy	0.29	0.005	burn*woy	0.136	0.01	burn*woy	0.7	0.006
unit	0.48	0.002	unit	0.003	0.014	unit	0.477	0.006	unit	0.25	0.01
burn*unit	0.2	0.003	burn*unit	0.15	0.006	burn*unit	0.027	0.02	burn*unit	0.16	0.02
pair	0.078	0.027	pair	0.001	0.09	pair	0.002	0.11	pair	0.059	0.15
burn*pair	0.064	0.028	burn*pair	0.016	0.05	burn*pair	0.681	0.06	burn*pair	0.005	0.16

APPENDIX B

FIGURES

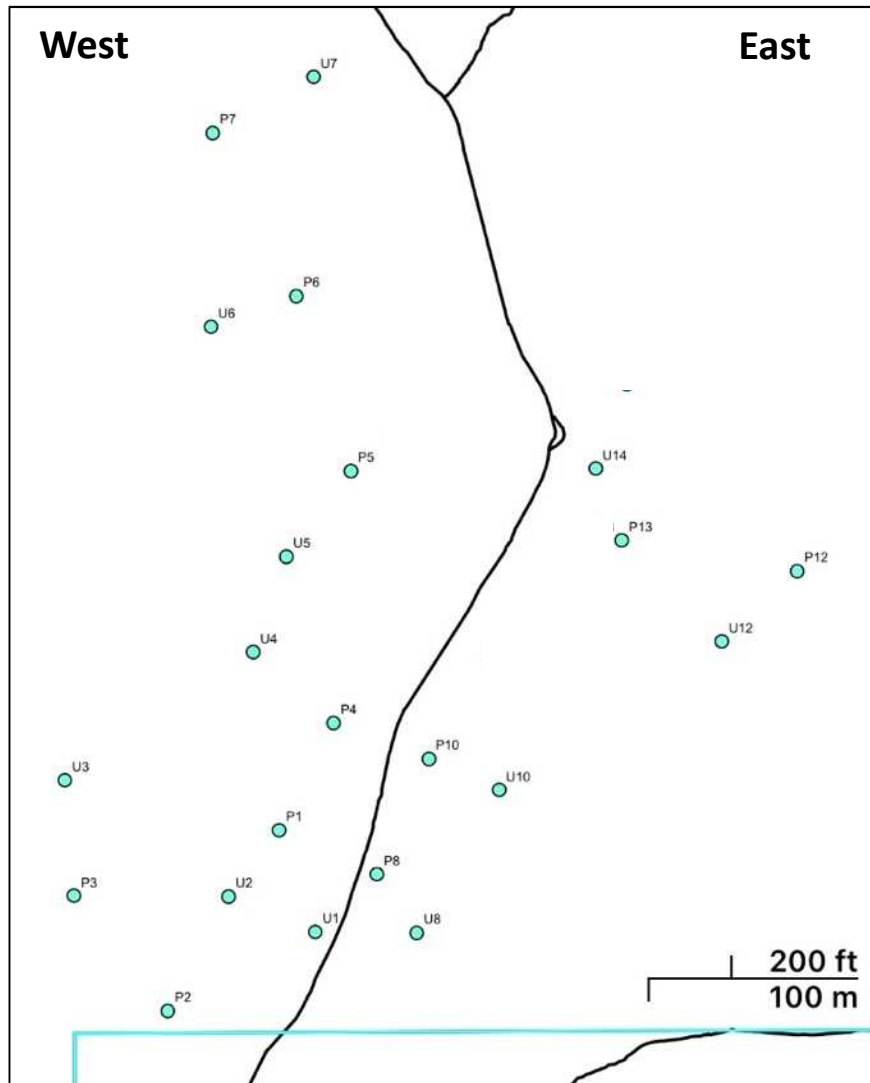


Figure 1: This map shows our study site at the Wade Tract. The east and west burn units are separated by a dirt road (black lines). Plots are represented by green dots. Plot numbers that start with P were protected from fire in 2018, and plots that start with U were burned (unprotected) in 2018. Plot pairs share the same number (e.g. P1 and U1 are a plot pair), with the exception of the last pair, which is P13 and U14. P11, P9, and P14 were all burned when in the prescribed fire on the east unit, and their partners were dropped from all further study.

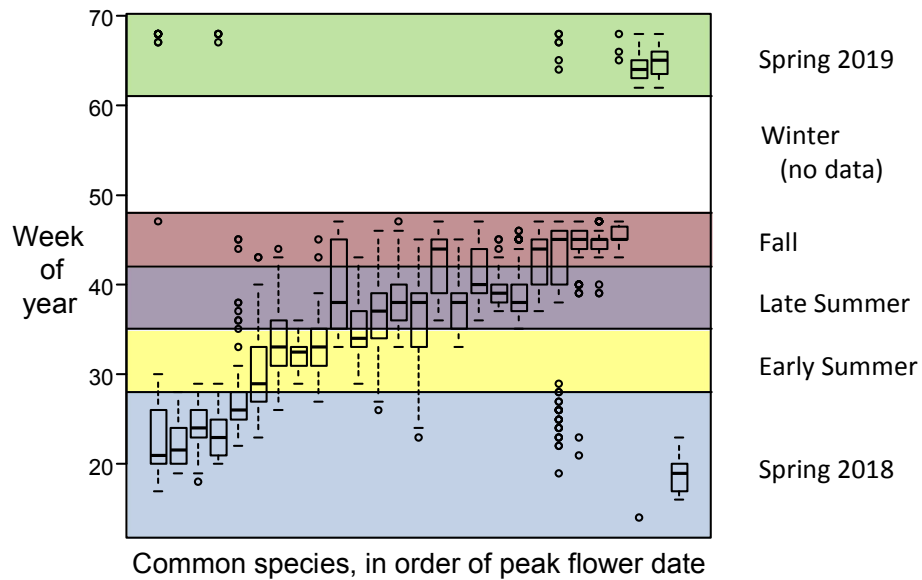


Figure 2: This plot shows the division of seasonal flowering guilds, which were determined by the flowering phenology of the most common species flowering at the Wade Tract between April 2018 and April 2019. These seasonal flowering guilds were used to better understand the effect of time since fire on the identity of flowering species in burned and protected treatments.

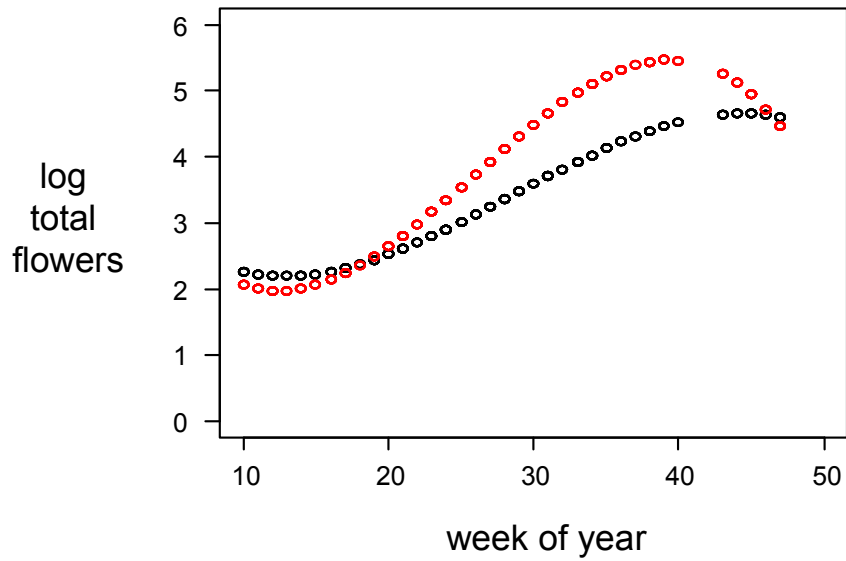


Figure 3: GLMM model of the log total abundance of flowers (all species pooled) showed that floral abundance varied across the season and with burn treatment. The red line models floral abundance for the burned treatment and the black line models floral abundance for the protected treatment. The gap in data at week 41 and 42 is because we unable to collect data for two weeks after Hurricane Michael.

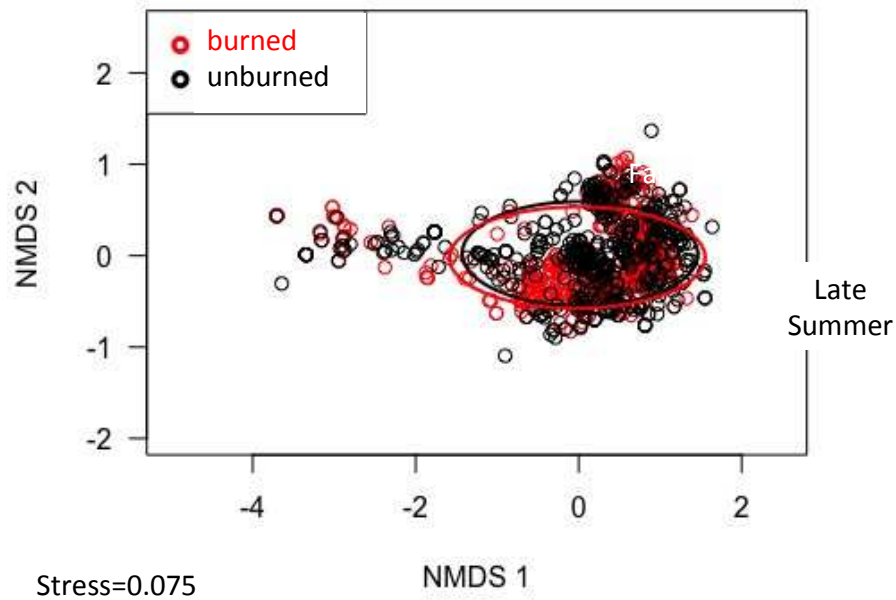


Figure 4: NMDS plot comparing co-flowering communities in burned and protected treatments. While co-flowering communities look similar in this plot, PERMANOVA analyses found the treatments to be significantly different ($p < 0.001$, pseudo $r^2 = 0.01$).

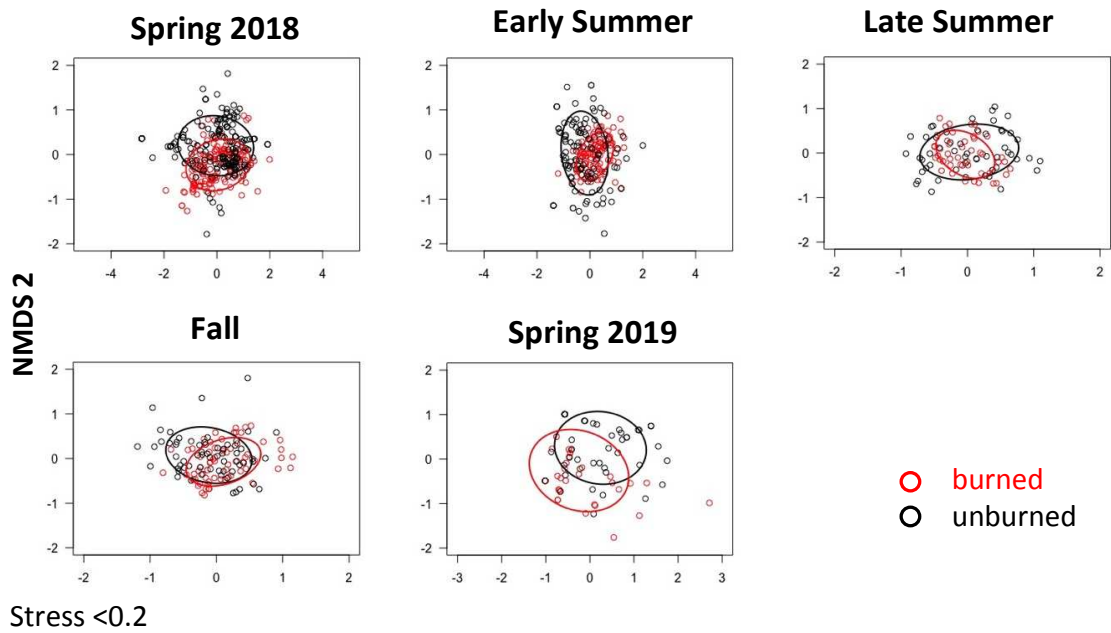


Figure 5: NMDS plots visualizing the difference in co-flowering communities between burned and unburned treatments for each seasonal flowering guild. The seasonal flowering guild for spring 2018 (a) covers week 14-28, early summer (b) covers week 29-35, late summer (c) covers week 36-42, fall (d) covers week 43-47, and spring 2019 (e) covers weeks 10-16 in 2019.

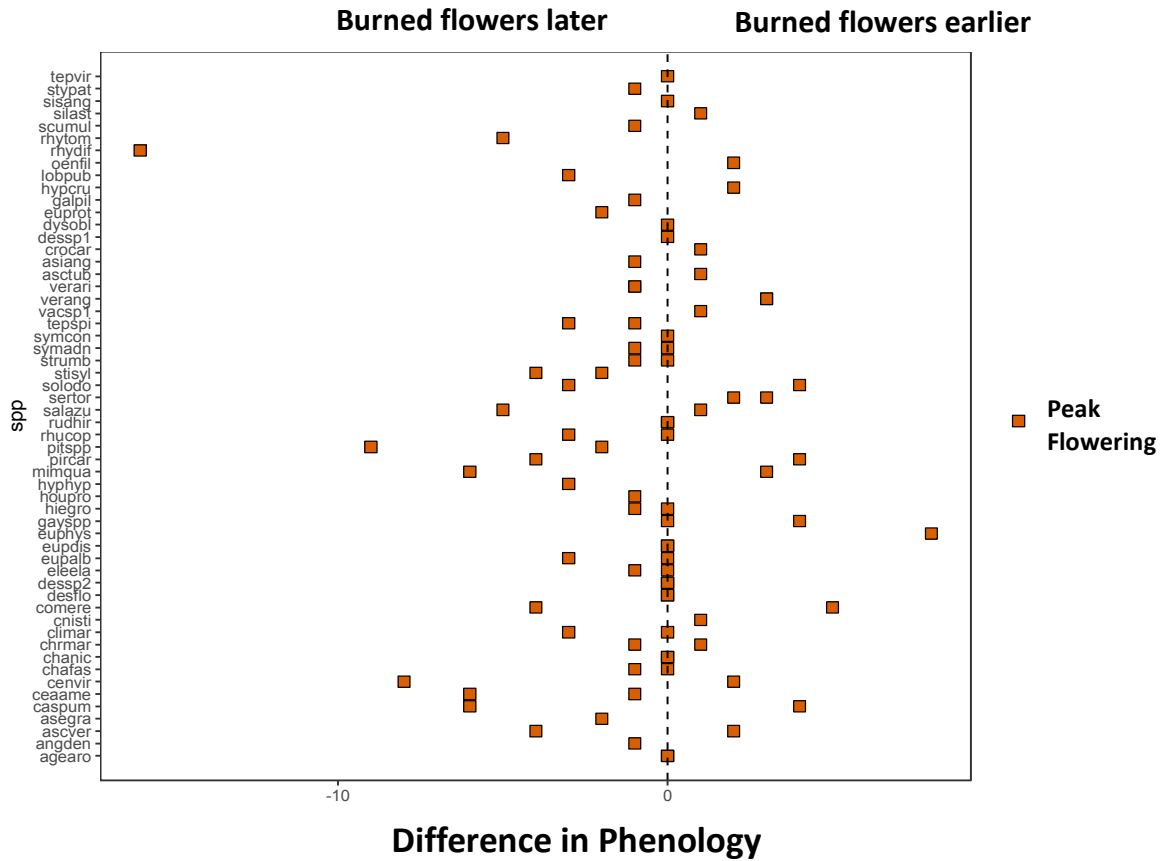


Figure 6: This figure shows the difference in peak flowering between burned and protected plots for all species that were observed five or more times in each treatment. Points to the left of zero indicate a peak flowering time that occurred later in burned plots than protected plots. Points to the right of the zero indicate a peak flowering time that occurred earlier in burned plots than in protected plots. Only peak flowering was significantly different between treatments for the whole community (t-test $p=0.04$, $df=86$).

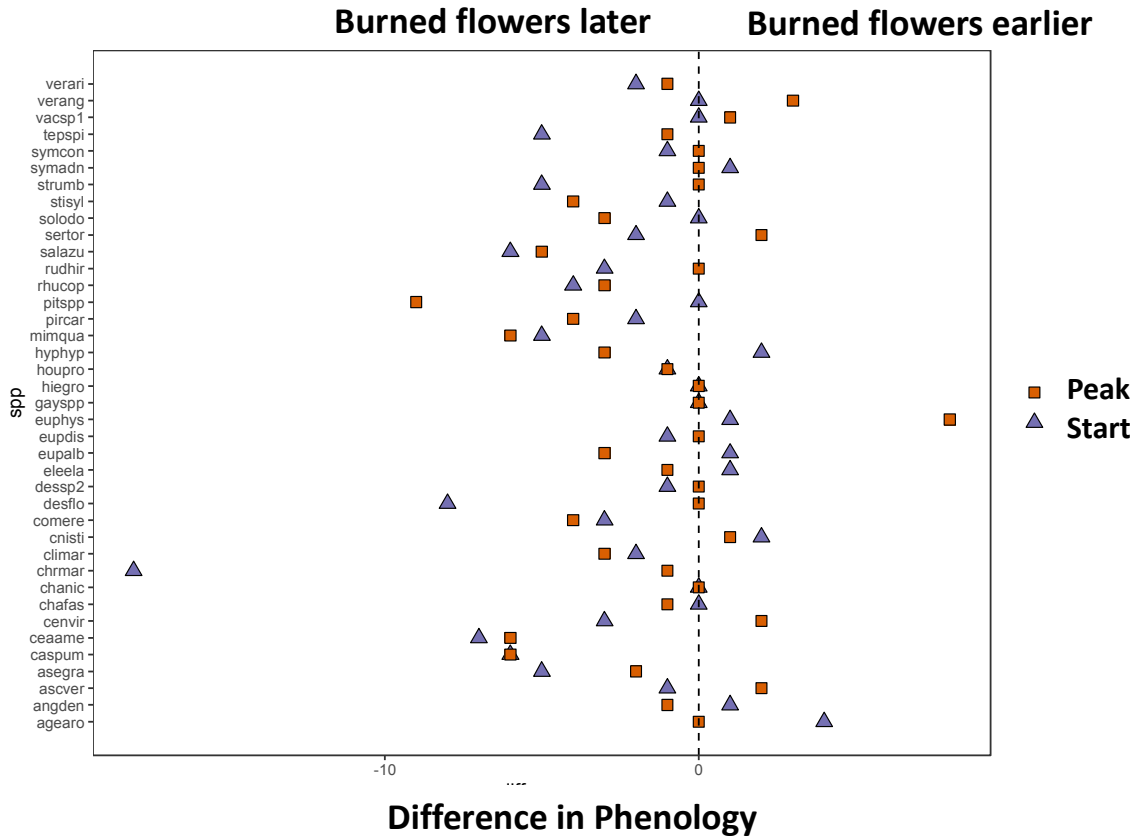


Figure 7: This figure shows changes in start and peak flowering dates in burned and protected plots for all species that were observed five or more times per treatment in the east burn unit. Points to the left of zero indicate a flowering phenology measure that occurred later in burned plots than protected plots. Points to the right of the zero indicate a flowering phenology measure that occurred earlier in burned plots than in protected plots. First flowering and peak flowering were both significantly different between treatments for the east burn unit (First flowering: t-test $p = 0.001$, $df = 38$, peak flowering: t-test $p = 0.01$, $df = 38$).

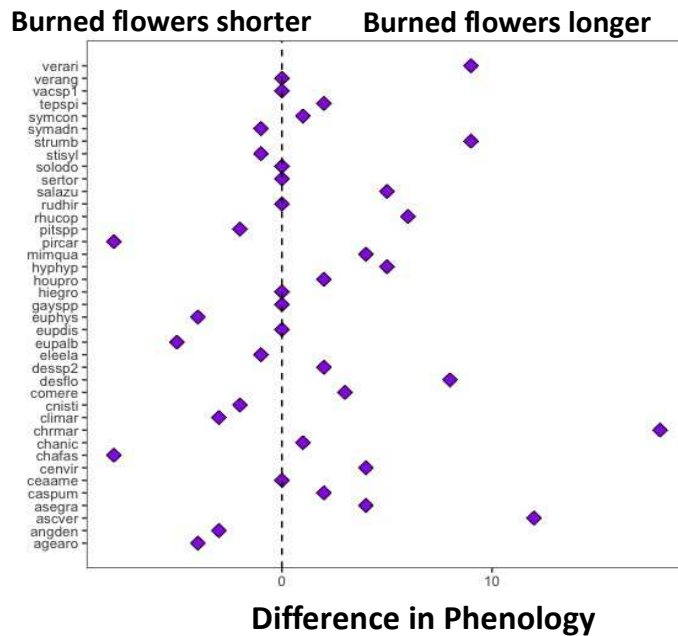


Figure 8: This figure shows changes in flowering duration between burned and protected plots for all species that were observed five or more times per treatment in the east burn unit. Points to the left of zero indicate flowering duration was shorter in burned plots than protected plots. Points to the right of the zero indicate flowering duration was longer in burned plots than in protected plots. Flowering duration was marginally nonsignificantly different between treatments in the east burn unit (t-test $p = 0.1$, $df = 38$).

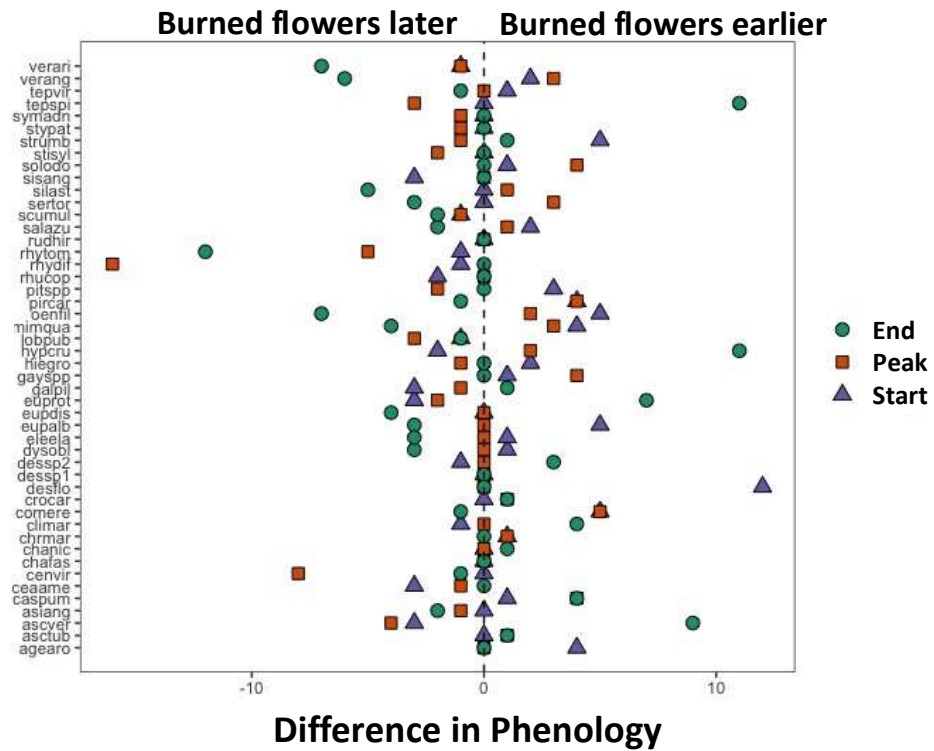


Figure 9: This figure shows changes in phenology between burned and protected plots for all species that were observed five or more times per treatment in the west burn unit. Points to the left of zero indicate a flowering phenology measure that occurred later in burned plots than protected plots. Points to the right of the zero indicate a flowering phenology measure that occurred earlier in burned plots than in protected plots. There was no significant difference in phenology between treatments in the west burn unit (t-test $p > 0.05$, $df = 47$).

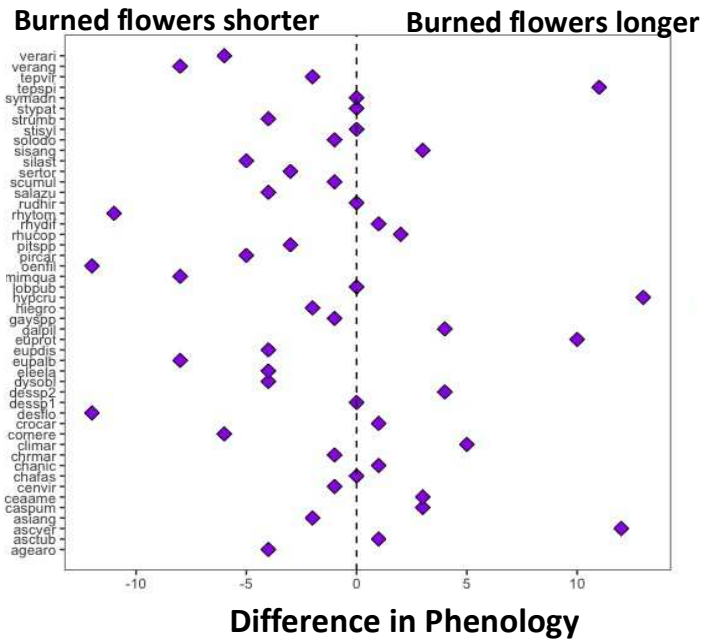


Figure 10: This figure shows changes in flowering duration between burned and protected plots for all species that were observed five or more times per treatment in the west burn unit. Points to the left of zero indicate flowering duration was shorter in burned plots than protected plots. Points to the right of the zero indicate flowering duration was longer in burned plots than in protected plots. Flowering duration was not significantly different between treatments in the west burn unit (t-test $p > 0.05$, $df = 47$).

APPENDIX C

BUTTERFLY COMMUNITY RESPONSE TO BURNED AND PROTECTED PLOTS

Introduction

In addition to characterizing the flowering responses of plants in our burned and protected plots, we also recorded data on adult butterfly composition, abundance and behavior in our plots. Preliminary analyses of these data provide information on how butterflies respond behaviorally to small refugia within burned areas. We carried out weekly surveys of butterflies during the growing season and asked:

1. Do butterfly abundance and community composition differ between burned and protected treatments?
2. Does butterfly abundance differ with flower abundance?

Methods

We visited each plot in our experiment once a week to count and observe adult butterflies from May-November of 2018. We used 15 minute timed observations, recording the species, behavior, and species of plants the butterfly interacted with, for each butterfly that entered the plot and made contact with a plant. The behaviors recorded were: rest (sitting on a plant), feed (drinking nectar from a flower), and oviposit (depositing eggs on plants). We also recorded temperature, wind speed (estimated using the Beaufort scale), cloud cover, presence of precipitation, and time of day, since these factors might all affect the presence of butterflies. Butterflies were identified using Glassberg (1999).

Statistical methods

Butterfly community. We used nonmetric multidimensional scaling (NMDS) to visualize the butterfly community data by burn treatment. We did a PERMANOVA (vegan package, R v. 3.6.3, R core team 2020, Oksanen et al. 2019) on a pairwise distance matrix using Bray-Curtis community dissimilarity scores to test for statistical differences between burn

treatments. Rare species can have an outsized effect on these analyses, so we used rank abundance curves to determine which species to include.

Because we found that fire affected the abundance of and identity of flowers in the plots, and that these effects varied across the season and with time since fire, we also divided our butterfly data into time spans that matched our seasonal flowering guilds (Fig. 2). We visualized each seasonal butterfly guild separately using NMDS, and tested for statistical difference with PERMANOVA, testing whether the butterfly community differed by burn treatment, time of year, burn unit, plot pair, and any interactions between time of year, burn unit, or plot pair and fire.

Butterfly and floral abundance. We used a GLMM (*lmer* and *car* packages, R v. 3.6.3, R core team 2020, Bates et al. 2015, Fox and Weisberg 2019) to ask whether butterfly abundance responded to either burn treatment or floral abundance. Because butterflies seemed likely to respond to floral abundance and we knew that burning affected floral abundance, we examined whether butterflies responded behaviorally to effects of burning on flowers, or any additional effects of burning. To do this we used AIC to compare three GLMM models of butterfly abundance. All models included time of year, (week of year)² to allow the model to represent a seasonal peak in butterfly abundance, temperature and their interactions. All models also include burn unit as a fixed effect, and plot pair as a random effect to account for heterogeneity among and repeated measures of the plots. We specified a poisson distribution (for modeling count data) and we included both plot pair and visit as random effects to account for the dispersion in our data. First we considered a model that also included floral abundance. Second we considered a model that included burn treatment. Finally we considered a model that included both burn treatment and floral abundance. We also tested the effects of cloud cover and wind speed on butterfly abundance, but they did not improve our model and were thus not included.

Results

Butterfly Community

Butterfly community composition did not vary by burn treatment ($p = 0.5$, pseudo $r^2 = 0.002$, Table 5). Butterfly community composition did change over time ($p = 0.001$, pseudo $r^2 = 0.1$, Table 5). There was no interaction between time of year and burn treatment ($p = 0.66$, pseudo $r^2 = 0.001$, Table 5).

To see if the composition of the butterfly community and the burn effects changed over time we also looked at the data within discrete time blocks matching our floral seasonal guilds (Fig 2). The butterfly community only showed a significant difference by burn treatment in the seasonal flowering guild directly after fires, and burn treatment explained a small amount of the variance in community composition (spring 2018, weeks 14-28) ($p = 0.026$, pseudo $r^2 = 0.005$). Time of year had a significant effect on butterfly visitors in every time block (Table 6). Burn units had significantly different butterfly communities for the early summer seasonal flowering guild (week 29-35, $p = 0.003$, pseudo $r^2 = 0.014$), but showed no effect for any other seasonal flowering guild. In the late summer seasonal flowering guild, burn treatment and burn unit showed a significant interaction ($p = 0.027$, pseudo $r^2 = 0.02$). Butterfly community showed a marginally significant response to plot pair identity in the spring and fall seasonal flowering guilds, and a significant effect of plot pair identity for both of the summer seasonal flowering guilds (table 6). The interaction between plot pair and burn treatment was significant in the early summer and the fall seasonal flowering guilds, and marginally significant in the spring seasonal flowering guild (Table 6).

Butterfly and Floral Abundance

Burn treatment had a significant affect on butterfly abundance ($p = 0.042$, $df = 1$), and floral abundance also had a significant effect of butterfly abundance which each was included in separate models. The model with floral abundance had a lower AIC, and if both floral abundance and burn treatment were included in the model, only floral abundance had any affect, suggesting that butterflies responded primarily to burns through the increase in floral resources.

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BIOGRAPHICAL SKETCH

Molly Wiebush

EDUCATION/CERTIFICATIONS

Florida State University Tallahassee, FL
Master of Science, expected June 2020

Thesis title: The importance of small-scale fire refugia for flowering phenology and butterfly presence in an old growth longleaf pine forest, mentors: Dr. Nora Underwood and Dr. Brian Inouye

Colorado State University Fort Collins, CO
Bachelor of Science, Biology with concentration in Ecology, December 2012

College of Idaho Caldwell, ID
Bachelor of Arts, Lawrence Henry Gipson Honors Scholar: Environmental Studies, Creative Writing, and German, magna cum laude, June 2006

Wildland Firefighter Level 1 (S-130) Bristol, FL
Passed written test, but have not taken fitness test, June 2017

Wilderness First Responder Fort Collins, CO
Certified by the National Outdoor Leadership School's Wilderness Medicine Institute, May 2009-December 2017

RESEARCH PRESENTATIONS

Wiebush, M.S., N. Underwood, B.D. Inouye, and K. M. Robertson. Fire affects the community composition and abundance of flowers in an old growth longleaf pine forest, Ecological Society of America, Louisville, KY, August 2019

Wiebush, M.S., and A.L. Angert. The effects of periodicity in precipitation on C3 and C4 grasses in Colorado's shortgrass steppe. Front Range Student Ecology Symposium, Fort Collins, CO, February 2011

GRANTS AND AWARDS

Joan Mosenthal DeWind Award—\$3750, Xerxes Society, Spring 2019

Godfrey Endowment—\$1000, FSU Department of Biological Science, Fall 2018

Best Undergraduate Poster—Front Range Student Ecology Symposium, February 2011

TEACHING

Graduate Teaching Assistantships

Spring 2020	BSC3016	Eukaryotic Diversity
Fall 2019	BSC2011L	Biology 2 Lab
Spring 2019	BSC3402L	Introduction to Experimental Design
Fall 2018	BSC3402L	Introduction to Experimental Design
Summer 2018	BSC3402L	Introduction to Experimental Design
Spring 2018	BOT3015L	Introduction to Plant Biology
Fall 2018	BOT3015L	Introduction to Plant Biology

Undergraduate Research Mentoring

Rex Rutledge—Directed Individual Study Summer-Fall 2018

Determining pollinator effectiveness of insects visiting *Hibiscus aculeatus* in an old growth pine savanna

Andrew Ibarra—Directed Individual Study Spring 2018

Direct and indirect effects of light environment on *Callophrys iris*—an imperiled butterfly.

Other Teaching Experience

October-November 2015 Horticulture North Idaho Correctional Institute & Lewis-Clark State College

January-May 2015 Horticulture North Idaho Correctional Institute & Lewis-Clark
State College

POSITIONS HELD

Research Technician March 2016-August 2018
Underwood Lab, Florida State University Tallahassee, FL

Managed an NSF-funded field experiment testing associational effects in *Solanum carolinense* and *Solidago altissima*, supervised 5-8 undergraduate team members in the field, and entered and quality-checked data.

Biological Science Technician June 2015-September 2015
June 2014-October 2014

Rocky Mountain Network Inventory and Monitoring Estes Park, CO

Performed surveys of vegetation, soils, and water quality at wetland and upland sites in Rocky Mountain National Park, Great Sand Dunes Park and Preserve, and Florissant Fossil Beds National Monument, often in backcountry locations.

Greenhouse and Laboratory Technician February 2014-May 2014
Summit Plant Laboratories, Inc. Fort Collins, CO

Planted tissue cultures of potatoes, mint, and hops in greenhouse, and cultured plants in lab, and trained temporary employees in the greenhouse.

Research Assistant January 2010-February 2013
December 2013-February 2014

Angert Lab, Colorado State University Fort Collins, CO

Propagated plants and developed pilot experiments and protocols, researched and georeferenced herbarium records, and performed field work in CA, AZ, NM, WY and CO.

Wildlife Diversity Technician
Multispecies Baseline Initiative, Idaho Fish and Game
May 2013-September 2013
Sandpoint, ID
Conducted standardized surveys for gastropods, insects, and amphibians throughout the Idaho Panhandle, including field sites in remote backcountry locations and located on private land.

Timber Cruiser
Clearwater Forest Farms
June 2002 and August 2009
Weippe, ID and Clearwater, ID
Gathered data to determine forest health, plan restoration projects, and determine timber volume on parcels of private property.

SERVICE

Volunteer
Natural Resources Conservation Service
January 2015-May 2015
Grangeville, ID
Helped develop a guide to identify grasses common in north and central Idaho by their vegetative characteristics.

Volunteer Naturalist
Durango Nature Studies
September 2006-November 2008
Durango, CO
Taught K-8 students natural history, basic ecological concepts, and snow science in outdoor field trips.