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Article

Short-term effects of prescribed fires on riparian arthropods around wetlands in north central Florida

Jack Cole[1], Lindsey S. Reisinger[2], Coleson F. Wrege[2,3]
[1] Pine Crest High School, Fort Lauderdale, Florida
[2] Department of Fisheries and Aquatic Sciences, University of Florida, Gainesville, Florida
[3] Biology Department, Southern Nazarene University, Bethany, Oklahoma

SUMMARY

Prescribed fires are an essential land management tool used in ecosystems throughout the southeastern U.S. It is well-documented that fires impact terrestrial and sometimes adjacent aquatic ecosystems. Connecting these habitats is the riparian zone, a transitional area on the edge of water bodies characterized by high nutrient cycling, mixed vegetation, and moisture content that varies from the adjacent upland environments. Riparian zones are often important corridors for wildlife escaping fire, as their mixed vegetation protects from an adjacent burning terrestrial ecosystem. Spiders frequently create webs in riparian areas to hunt emerging aquatic prey and other terrestrial prey and are biological indicators of riparian food web health and productivity. In this study, we investigated how prescribed fires impact arthropods in riparian zones. We hypothesized that spider and arthropod prey abundances would increase in the riparian zone following prescribed fires. We used pan traps to sample riparian zone arthropods surrounding six wetlands in north central Florida two weeks before and two weeks and one month after burns. There was an initial decrease then substantial increase in springtail abundance and biomass surrounding burned wetlands. There was no evidence of an increase in the abundance of spiders following prescribed fires, with marginal evidence that spider biomass decreased one month after the prescribed burn, indicating that spiders were smaller surrounding burned wetlands. Our work provides a basis for a much larger investigation into the short-term effects of prescribed fire on riparian ecosystems.

INTRODUCTION

Wildfires are common disturbances that have complex ecological impacts. As a result of recent changes to our climate, including a drier near-surface atmosphere, a shift in typical precipitation patterns, and accelerated snowmelt (in part due to particulates that originate from fires), there is a general concern that wildfires are becoming more frequent and more severe (1). In fact, there has been an eightfold increase in total land area burned in the western United States since 1985, with wildfires affecting higher altitudes than before due to warming temperatures and impacting a greater amount of vegetation due to prolonged droughts that have substantially increased available surface fuel loads (1). Since 1983, there has been an average of ~70,000 wildfires per year in the United States (2). Fires often have widespread impacts, including changes to the biogeochemical and mechanical properties of the environment (3). As a result, wildfires can impose dangerous consequences on very large tracts of land with impacts ranging from days to decades (3).

A management tool used to help reduce the impacts of dangerous wildfires is prescribed fires (4). Prescribed fires are intentional burns of a specific plot of land under controlled conditions (4). There are numerous benefits of prescribed fires, including the removal of invasive species, improved nutrient mobilization, increased habitat for fire-dependent species, and decreased fuel-load buildup that could potentially spark future, more deadly crown wildfires, which scorch the tops of trees and often lead to high tree mortality (5). The differing effects of prescribed fires are primarily due to seasonality, weather, and prior burn history, which are all considered when burns are planned (5).

Existing studies have largely focused on the impact of prescribed fires on terrestrial (land-based) ecosystems, since fires are initiated on land (4, 5). However, these studies often fail to isolate the impacts of prescribed fires in the area adjacent to aquatic environments. The interaction between terrestrial and aquatic ecosystems is known as a terrestrial-aquatic linkage and comes in many forms, including food web interactions, nutrient cycling, and productivity (7, 8). Previous research has demonstrated that a better understanding of the terrestrial-aquatic linkage can lend greater insight into potential ecosystem responses to a disturbance (8).

The transitional region that connects upland terrestrial and adjacent aquatic habitats is called the riparian zone. Riparian zones are characterized by high biodiversity and productivity, with transitional vegetation densities and generally moist soil (9). Both terrestrial and aquatic organisms can take refuge in riparian zones during fires such as foxes, songbirds, and otters (10). Riparian zones can provide shelter for a wide range of organisms and help filter nutrients following burning (11). Since riparian zones are the site for many terrestrial-aquatic linkages, analyzing the effects of prescribed fires in these riparian areas can provide valuable information on how terrestrial-aquatic interactions among various biota are altered by prescribed fire (13).

Riparian zones of wetlands are ideal ecosystems for investigating aquatic-terrestrial linkages because wetlands are diverse aquatic ecosystems and are common in Florida (14). In addition, wetlands can be some of the most productive ecosystems, particularly for arthropods in and around them (12). Arthropods serve diverse roles, ranging from nutrient cycling, pollination, improving water quality, serving as predators and prey, and more (15). Araneae, or spiders, were a useful group to examine because of their dependence on the terrestrial habitat for residence and prey and the aquatic

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Figure 1. Riparian vegetation surrounding a burned wetland at Austin Cary Forest, Florida. Panoramic view of vegetation at 5 m facing the edge of the wetland one month after the burn.

habitat for emerging prey. Spiders often build webs or hunt from the ground in riparian zones to catch emerging insects from aquatic habitats, which can result in an increase in spider abundance when fire stimulates aquatic prey emergence (13, 16). Collembola, or springtails, are litter-dwelling/semi-aquatic arthropods, and fire can cause changes to their migrations and movements (17). Additionally, springtails are a consistent prey source for spiders in various environments (18).

In general, there is a knowledge gap regarding the short-term impacts (less than six-months since burn) of prescribed fires on terrestrial-aquatic arthropod linkages in the riparian zone (6). Many prior studies that have examined the effects of fire on terrestrial-aquatic linkages performed measurements years after the burns (6, 13, 17). By examining how prescribed fires impact arthropods (focusing on spiders and their prey [especially springtails]), land managers will be better informed about short-term impacts of prescribed fire to riparian zone food webs to inform management decisions (19).

We studied the arthropod communities in riparian zones surrounding wetlands subjected to prescribed fires in North Central Florida in the short-term (less than three months after the prescribed fire). We hypothesized that there would be an increase in spider abundance and biomass in the riparian zone following burns (at two weeks and one month). Previous research has indicated that arthropods in disturbed ecosystems have improved survival when there is more prey availability (20). We also hypothesized that springtail abundance in the riparian zone would decrease following burns and be associated with predation pressure from riparian predators, including spiders, and decreased vegetation cover in riparian zones, but that total prey abundance would increase following burns due to stimulation from the burn increasing emergence of aquatic insects from the wetland. We found no evidence for significant changes in the abundance of spiders across burn treatments in the two-week and one-month post-burn time periods and weak evidence for a slight but non-

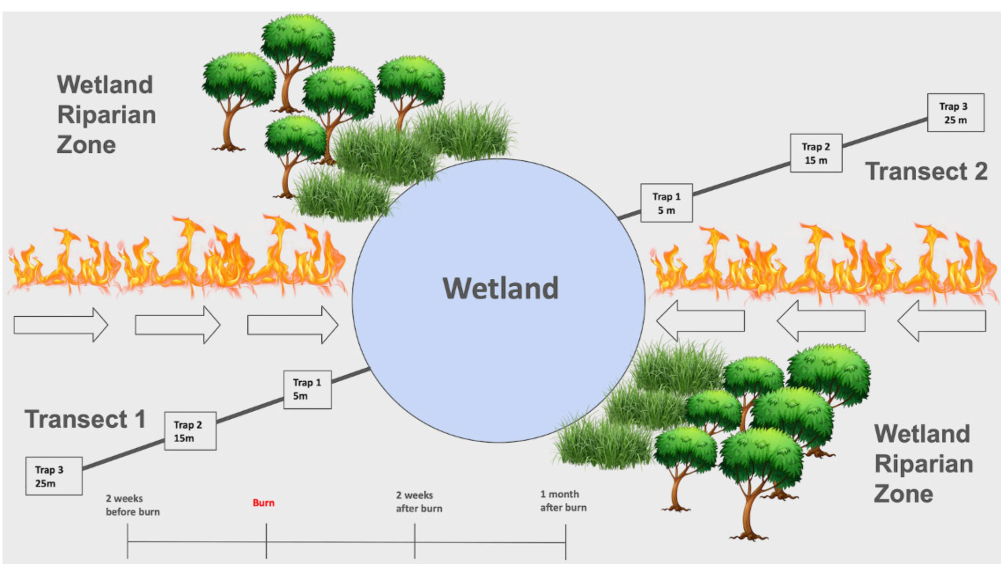

Figure 2. Schematic diagram of prescribed burn setup in each wetland at Austin Cary Forest, Florida. Each transect had traps at 5 m, 15 m, and 25 m from the edge of the wetland. We sampled two weeks before burning, two weeks after burning, and one month after burning. Representative riparian zone vegetation is also shown.

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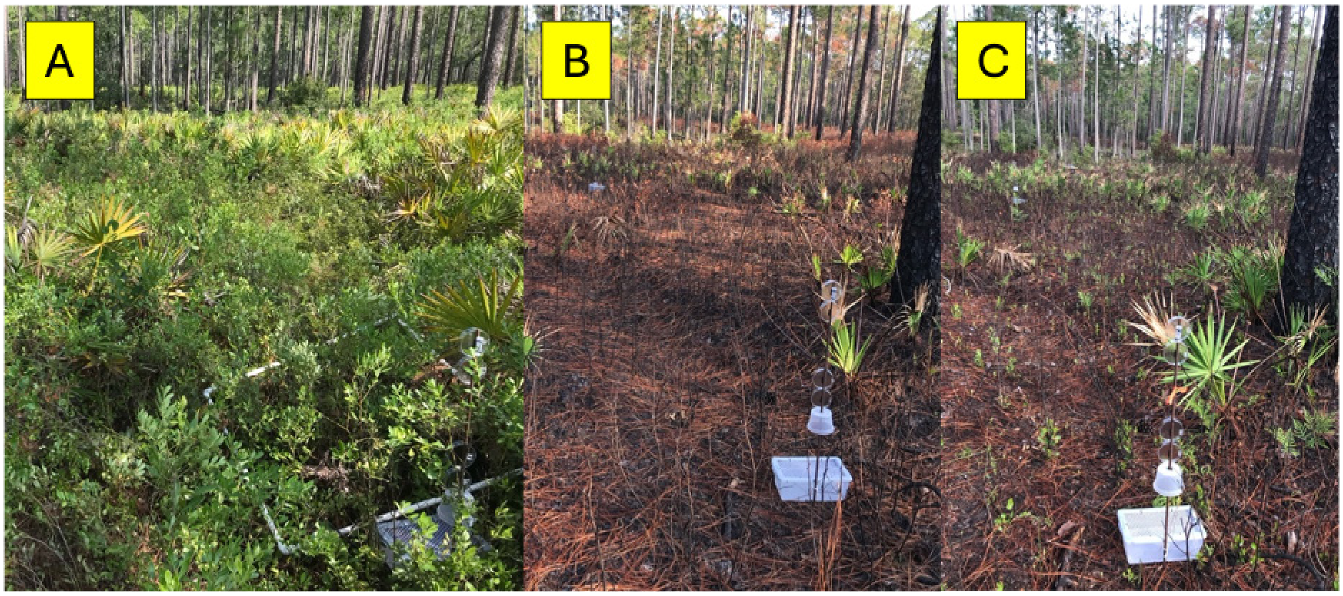

Figure 3. Riparian vegetation cover at Austin Cary Forest, Florida, at different time points. Riparian vegetation shown for the same 25 m transect facing the wetland at the following time periods: **A)** two weeks before burn, **B)** two weeks after burn, and **C)** one month after burn. Pan traps are seen in each image.

significant decrease in biomass of spiders in the one-month post-burn time period for the burned versus unburned riparian zones. Prey biomass did not change following burns, but prey abundance did. There was strong evidence for a statistically significant initial decrease two weeks after burning followed by a subsequent increase one month after burning in prey abundance overall, driven strongly by springtail abundances. The results indicate that spider abundances did not change post-burn, but that spider biomass decreased slightly. In addition, springtail abundances initially decreased (two weeks after burn), then increased at one month after burn.

RESULTS

We conducted this experiment with the goal of determining the short-term effects of prescribed fire on riparian arthropod abundances and biomass in north central Florida wetland riparian zones. We sampled the burned riparian zones of three wetlands and three unburned wetlands before and after prescribed fire to study the impacts of prescribed fire on arthropod abundances and biomass. We used three sets of pan traps (at 5 m, 15 m, and 25 m from the wetland edge), which are non-directional traps that can catch both flying and non-flying arthropods, along two transects perpendicular to each wetland to capture arthropods (**Figures 1, 2**). We sampled arthropods from the riparian zones before the burn, two weeks, and one month after prescribed burns to track arthropod abundance and biomass trends (**Figure 3**).

There was no evidence that spider abundance significantly changed between burned and unburned riparian zones of wetlands (χ^2 = 2.04, p = 0.153) across any time period ($\chi2$ = 0, p = 1.000) (**Figure 4**). Trap distance also did not explain any of the variation (χ^2 = 4.89, p = 0.087). Before the burns occurred, there was an average abundance of eight spiders in riparian zones of soon to be burned wetlands and seven spiders in riparian zones of unburned wetlands (**Figure 4**). Two weeks after burning, spider abundances averaged three in riparian zones of burned wetlands and four in riparian zones of unburned wetlands (**Figure 4**). One month after burning, spider abundances averaged two in riparian zones of burned wetlands and five in riparian zones of unburned wetlands (**Figure 4**).

There was a non-significant trend towards smaller spider biomass in burned riparian zones compared to unburned riparian zones of wetlands following prescribed burns (χ^2 = 3.52, p = 0.061) (**Figure 5**). There was no evidence for a significant difference in spider biomass based on time period (χ^2 = 0.003, p = 0.958) or the interaction between time period and burned versus unburned riparian zones (χ^2 = 0.66, p = 0.415) (**Figure 5**). Trap distance did not impact spider biomass (χ^2 = 3.08, p = 0.215). There was no evidence that spider biomass differed significantly between the burned and unburned wetlands in the two weeks after burning time period (p= 0.436) (**Figure 5**). In the one month after burning time period, there was a non-significant trend indicating that spider biomass decreased in burned riparian zones compared to those in unburned riparian zones (-0.715 mg, p = 0.062) (**Figure 5**).

In contrast, for prey abundance, there was a significant interaction between burned and unburned wetlands and time period since burn (χ^2 = 10.88, p = 0.001), as prey abundances were lower in burned than unburned riparian zones at two-weeks post-burn, and higher at one-month post-burn (**Figure 6**). Prey abundances were higher overall in burned than unburned wetlands following the burn (χ^2 = 5.68, p = 0.017), driven primarily by the higher abundances at one-month post-burn compared to two-months post-burn (χ^2 = 7.69, p = 0.006). Prey abundances did not differ significantly in burned vs unburned riparian zones at two-weeks post-burn (t-ratio

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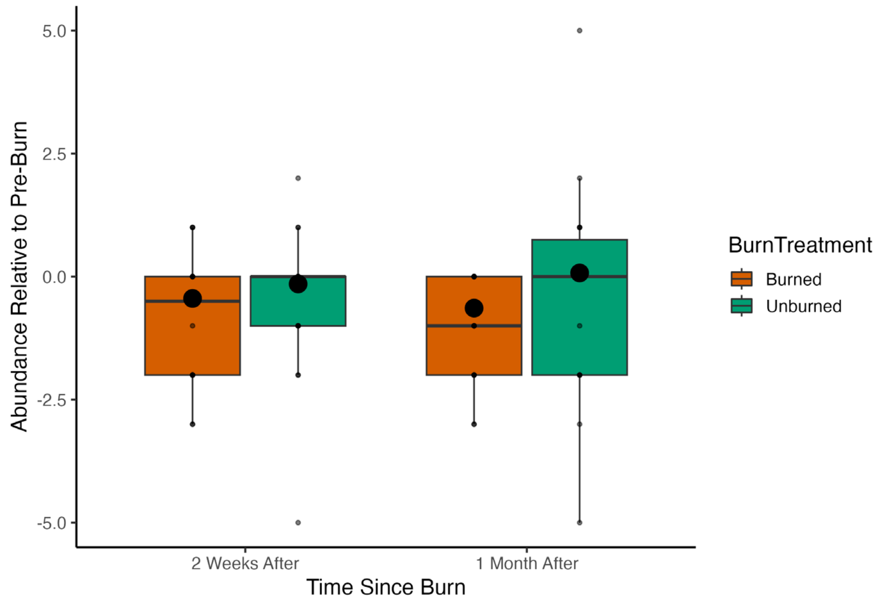

Figure 4. Spider abundances from burned and unburned wetland riparian zones. Boxplot of spider abundances relative to pre-burn abundances two weeks and one month after prescribed fires in burned and unburned riparian zones (n=6). We collected spiders using three sets of pan traps secured along two transects surrounding each wetland at the corresponding times. Type II Wald χ^2 tests determined there were no significant differences between burned and unburned wetlands (χ^2 = 2.04, p = 0.153), between two weeks or one month after burn (χ^2 = 0, p = 1.000), or the interaction between these variables (χ^2 = 0.23, p = 0.634). Tukey's Honestly Significant Difference (HSD) post-hoc tests were not conducted since no variables were significant.

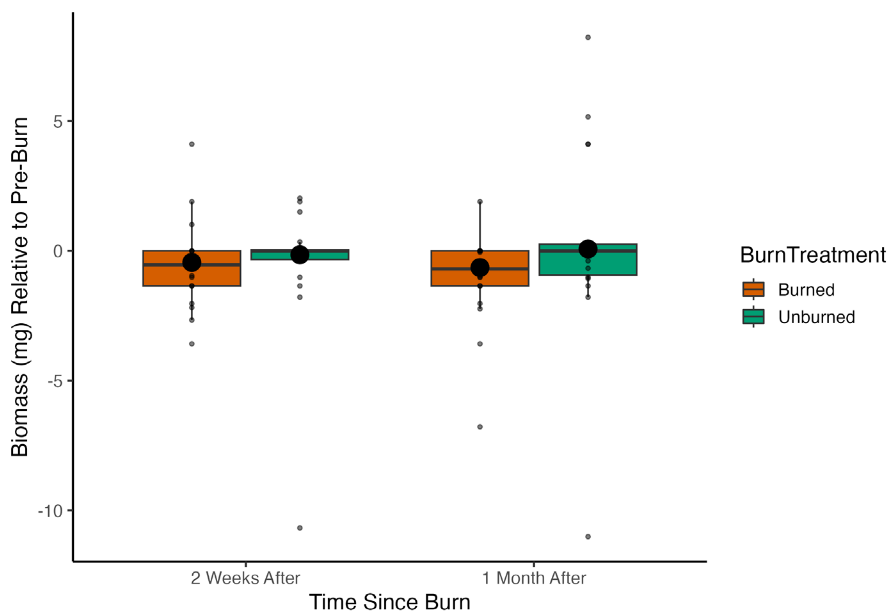

Figure 5. Spider biomass (mg) from burned and unburned wetland riparian zones. Boxplot of spider biomasses (mg) relative to pre-burn abundances two weeks and one month after prescribed fires in burned and unburned riparian zones (n=6). Biomass was calculated using length-mass regression values from the literature (26). We collected spiders using three sets of pan traps secured along two transects surrounding each wetland at the corresponding times. Type II Wald χ^2 tests determined there was a trend towards lower spider biomass in riparian zones of burned wetlands compared to unburned wetlands (χ^2 = 3.52, p = 0.061), but spider biomass did not differ between two weeks or one month after burn (χ^2 = 0.003, p = 0.958) or the interaction between these variables (χ^2 = 0.66, p = 0.415). Tukey's Honestly Significant Difference (HSD) post-hoc tests were not conducted since no variables were significant.

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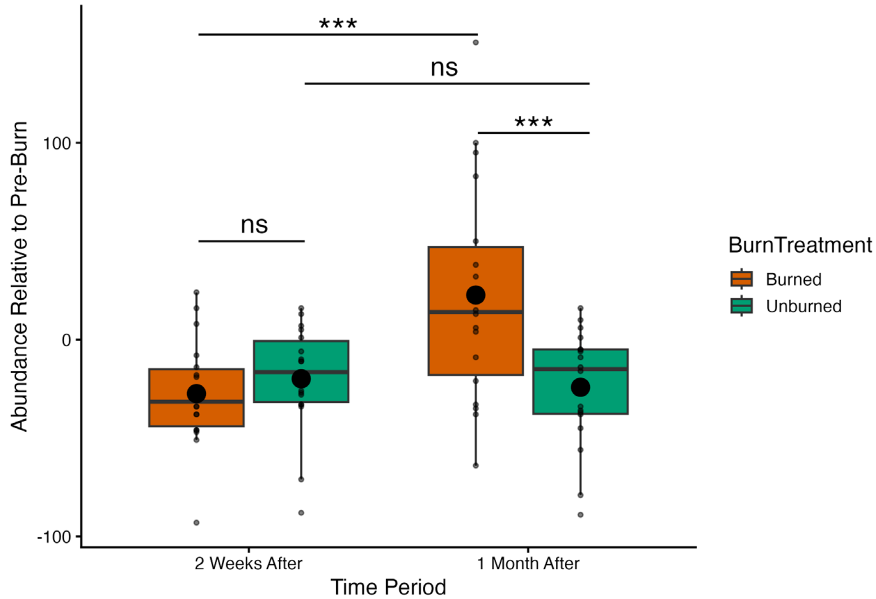

Figure 6. Prey (non-spider arthropods) abundances from burned and unburned wetland riparian zones. Boxplot of prey abundances relative to pre-burn abundances two weeks and one month after prescribed fires in burned and unburned riparian zones (n=6). We collected prey using three sets of pan traps secured along two transects surrounding each wetland at the corresponding times. Type II Wald χ^2 tests determined there was an interaction between whether the wetland was burned and time since burn (χ^2 = 10.88, p = 0.001), with lower prey abundances in burned riparian zones two weeks after burn but higher prey abundances in burned riparian zones one month after burn compared to riparian zones of unburned wetlands. There were more prey in general one month after burn compared to two weeks after burn (χ^2 = 7.69, p = 0.006) and more overall between riparian zones of burned than unburned wetlands (χ^2 = 5.68, p = 0.017). Tukey's Honestly Significant Difference (HSD) post-hoc tests were conducted to compare the estimated marginal means for the groups. Asterisks (*) denote statistically significant pairwise differences.

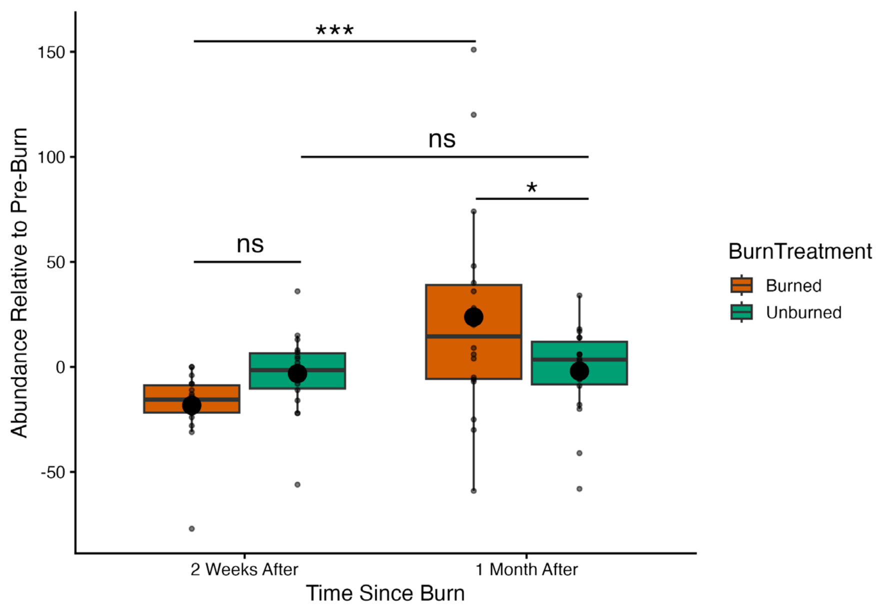

Figure 7. Springtail (Collembola: Isotomidae) abundances from burned and unburned wetland riparian zones. Boxplot of springtail abundances relative to pre-burn abundances two weeks and one month after prescribed fires in burned and unburned riparian zones (n=6). We collected springtails using three sets of pan traps secured along two transects surrounding each wetland at the corresponding times. Type II Wald χ^2 tests determined there was an interaction between whether the wetland was burned and time since burn (χ^2 = 10.28, p = 0.001), with lower springtail abundances in burned riparian zones two weeks after burn but higher springtail abundances in burned riparian zones one month after burn compared to riparian zones of unburned wetlands. There were more springtails in general one month after burn compared to two weeks after burn (χ^2 = 11.49, p = 0.0007) but no difference overall between riparian zones of burned and unburned wetlands (χ^2 = 0.44, p = 0.507). Tukey's Honestly Significant Difference (HSD) post-hoc tests were conducted to compare the estimated marginal means for the groups. Asterisks (*) denote statistically significant pairwise differences.

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= -0.65, p = 0.520) but did increase significantly (47 more prey) at one-month post-burn (t-ratio = 4.02, p = 0.0002). Furthermore, prey abundances did not differ significantly between two-weeks and one-month post-burn for unburned riparian zones (t-ratio = -0.37, p = 0.712) but did increase significantly (50 more prey) for burned riparian zones from two-weeks to one-month post-burn (t-ratio = 4.29, p = 0.0001) (**Figure 6**). Trap distance (5 m, 15 m, or 25 m from wetland edge) did not impact prey abundances (χ^2 = 4.70, p = 0.095). The biggest reason for changes in prey abundances were from springtails, particularly the family Isotomidae.

There was strong evidence that springtail (Isotomidae) abundances differed based on the interaction between burned versus unburned riparian zones and time since burn (χ^2 = 10.28, p = 0.001), as springtail abundances were lower in burned than unburned riparian zones at two-weeks post-burn, and higher at one-month post-burn (**Figure 7**). Before burning, there was no evidence for a significant difference between burned and unburned wetlands (p = 0.559), with an average abundance of 139 springtails in riparian zones of soon to be burned wetlands and 102 springtails in riparian zones of unburned wetlands (**Figure 7**). Two-weeks post-burn, springtail abundances decreased to an average of 29 in riparian zones of burned wetlands and 83 in riparian zones of unburned wetlands (**Figure 7**). One-month post-burn, springtail abundances increased to an average of 281 in riparian zones of burned wetlands and 90 in riparian zones of unburned wetlands (**Figure 7**). Springtail abundances were higher across burn treatment at one-month post-burn than two-weeks post- burn (χ^2 = 11.49, p = 0.0007), but this was driven by lower abundances in burned riparian zones at two-weeks post-burn and higher abundances at one-month post-burn. Springtail abundances did not differ significantly in burned vs unburned riparian zones at two-weeks post-burn (t-ratio = -1.47, p = 0.146) but did increase significantly (26 more springtails) at one-month post-burn (t-ratio = 2.51, p = 0.015). Furthermore, springtail abundances did not differ significantly between two-weeks and one-month post-burn for unburned riparian zones (t-ratio = 0.13, p = 0.898) but did increase significantly (42 more springtails) for burned riparian zones (t-ratio = 4.66, p < 0.0001). Springtail abundances did not differ significantly based on burn treatment (χ^2 = 0.44, p = 0.507). Trap distance had an impact on springtail abundances (χ^2 = 10.13, p = 0.006). Springtail abundances were higher for burned riparian zones one-month post-burn relative to two-weeks post-burn at 5 m (mean = 41, t-ratio = 2.65, p = 0.011), at 15 m (mean = 51, t-ratio = 3.27, p = 0.002), and at 25 m (mean = 34, t-ratio = 2.17, p = 0.034) per transect. There were no significant differences between trap distances for unburned riparian zones.

There was no evidence that prey biomass changed between burned and unburned wetland riparian zones (χ^2 = 0.44, p = 0.506) or between burning time periods (χ^2 = 0.34, p = 0.558). There was also no interaction between these variables (χ^2 = 0.53, p = 0.466), and trap distance (χ^2 = 3.23, p = 0.199) had no impact on prey biomass.

DISCUSSION

One-month post-burn springtail abundance likely reflected the stage of recovery of riparian zones following burning throughout this study. As springtail abundance decreased two weeks after the prescribed burn, it is likely that the riparian ecosystem was still recovering from the fire disturbance. However, the increase in springtail abundance one month after the burn suggests that prescribed fire can increase the abundance of some arthropods shortly (one month), but not immediately (two weeks) following burns, contributing to the recovery of the ecosystem. This demonstrates the prescribed fires were linked to an initial decrease, then strong increase of springtail abundance following burning between burned and unburned wetland riparian zones.

This recovery also suggests that there were localized conditions surrounding the wetlands that may have acted as refugia for springtails in the disturbed riparian ecosystem, as higher springtails were observed at 5 m and 15 m compared to 25 m from the wetland. Previous research has suggested that the conditions in the upper portions of the soil that springtails inhabit can dramatically change in the short-term following fire and become lethal (21). This study's findings of an increased abundance of springtails one month following prescribed burning supports the idea that the wetlands may have acted as a refugial buffer until conditions in the riparian ecosystem were suitable for springtail abundances to rebound (7, 10). Additionally, springtails could have taken advantage of the newly burned vegetation as a food source, allowing their population to increase, although further research is needed to determine the extent to which springtails consume burned organic matter from prescribed fires (22, 23). Taken together, this study suggests that the riparian ecosystem had a resurgence in recovery between two-weeks and one-month post burn. Continuous sampling would be needed to determine more specific points of ecosystem regrowth and recovery. More specifically, daily sampling would provide clearer data on changes in springtail populations over time. Additionally, monitoring other factors such as vegetation recovery and soil characteristics could help assess ecosystem health and riparian zone recovery.

Contrary to the hypothesis, there was no evidence of a significant increase in spider abundance or biomass in the riparian zone following prescribed burning of wetland riparian zones. Spider biomass had a slight, but nonsignificant decrease after burning, suggesting that the remaining spiders were marginally smaller. One possible explanation for why smaller spiders may have been able to survive more easily after the prescribed fires was through greater availability of very small prey (24). Additionally, the riparian zone was a much more barren and open landscape following burning, so it is possible that smaller spiders were better able to survive as a result of access to more numerous, small prey, and by avoiding becoming prey to larger predators (24). This may provide insight into the short-term dynamics that can lead to an overall increase in diversity or abundance of spiders following prescribed burns that has been documented in other studies (25, 26). To confirm this theory, researchers would need to analyze the diets of remaining spiders after burns and determine if there was a direct relationship between smaller spider diets and springtails.

This study suggested that the riparian zone food web showed signs of recovery following burning in the short term that extends beyond arthropods. Vegetation growth

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observed in the weeks following burning likely provided cover for various organisms, increasing their chances of survival. These observations may support the findings of previous studies that found increased energy flux in the riparian zone in the midterm following burning (6, 11, 13). To further support this inference, future researchers could establish camera traps or other methods to continuously monitor the activity of other riparian predators such as birds, bats, and lizards in the burned areas.

An interesting observation that requires further investigation was an apparent increase (via rough visual estimate) in the number of spiderwebs on the ground rather than suspended in the air in the post-burn landscape. Ground-dwelling spiders prey on different arthropods than those suspended in the air, so this would provide further food web insights (24). Quantifying this observation would involve visual surveys using quadrats or setting pitfall traps that are flush with the ground (27, 28). Pan traps, although on the ground, have entrances that are above ground level (~5"). Additionally, exceptionally large spiders (>20 mm) were prevented from entering the pan traps via mesh that also excluded vertebrates. Additionally, all data from this study are specific to late summer sampling and may vary for burns conducted in different seasons (5,17).

For land managers, the results of this study are helpful when considering the role of riparian arthropods following prescribed burning in north central Florida. First and foremost, these findings are beneficial because they assist land managers in understanding the short-term consequences of using prescribed fires on riparian arthropod abundances as well as ecosystem recovery following burning. This study can help land managers incorporate riparian arthropod food webs into their management strategies. Information about riparian predators like spiders and litter-dwelling/semi-aquatic arthropods like springtails is helpful for decisions that can affect land function. For land managers to fully grasp the complex effects of prescribed fires in the period after burning, it is always important to consider the timeline on which the affected ecosystem can begin recovery and return to stable functioning. The findings of this study, which suggested that the riparian zone was able to recover to a degree in the short term, provides valuable data to land managers as to when they might expect their land to experience regrowth and riparian food web recovery.

This study provides an important look into the effects of prescribed burns in the southeastern United States. We investigated an understudied effect of prescribed burns on riparian arthropods and gained information that landowners can use to make more educated management decisions regarding the use of prescribed fires and their impact on riparian zone arthropod food webs of wetlands in North Central Florida.

MATERIALS AND METHODS

Study location and time

We conducted this study at the University of Florida Austin Cary Forest in Gainesville, Florida. We sampled riparian zones of wetlands (cypress dome swamps) from early August to mid-September. To account for natural trends in changes to biota, we sampled unburned wetlands concurrently with burned wetlands throughout the study. We selected six wetlands (three recently burned, three unburned) with similar size, vegetation structure, water levels, and riparian zones and sampled two weeks before, two weeks after, and one month after burning. The burned riparian zones of wetlands were located within a single burn unit and were at the following coordinates: 29.7474°N, -82.2163°W; 29.7477°N, -82.2175°W; 29.7474°N, -82.2181°W. The unburned wetlands were located within two units that each were ~800m from the burned unit and had the following coordinates: 29.7402°N, -82.2182°W; 29.7533°N, -82.2072°W; 29.7549°N, -82.2091°W.

Pan traps

We constructed pan traps from Sterilite© 5.7 L bins (13 ⅝" x 8 ¼" x 4 ⅞") to sample arthropods both before and after prescribed fires. Each trap was covered with a 12" x 8" x 4" mesh lattice to exclude vertebrates. We arranged traps along two transects within the riparian zone at opposite sides of the wetlands (**Figure 2**). We secured traps to a stake at 5 m, 15 m, and 25 m from the edge of the wetland. We filled each pan trap with 850 mL of water containing one squirt of liquid detergent. We collected the arthropods in the traps three days after we set them and preserved them in 70% ethanol for later identification.

Burning

The land managers at Austin Cary State Forest used drip torches and fire lines to create a mild-moderate prescribed fire and followed all local laws and regulations. The burn was relatively homogeneous from the upland terrestrial environment through the riparian zone and to the edge of the wetland and was allowed to extinguish naturally after burning for less than an hour. Fire lines were used for full precautions to create a controlled burning environment.

Sample processing

We identified all arthropods under a dissecting microscope (Leica Microscope EZ4 Stereo Dissecting Microscope, 10447197) to order (Araneae; spiders) or family (Collembola, other prey organisms) using *Triplehorn and Johnson* (28). Lengths of the arthropods were measured with a grid to the nearest mm under the microscope to calculate biomass of the organisms (29, 30).

Data entry/analysis

We entered all data in the Excel data analysis program. We calculated the biomass numbers based on length-mass regressions from Sabo, et. al for spiders and Verslujis et. al for springtails and other prey organisms (29, 30). We analyzed the data using R Statistical Software version 2025.05.1+513 (31). We rearranged and prepared data for analysis using the "tidyverse" and "dplyr" packages (32, 33). We tested the data for potential transformations using "bestNormalize" and for the assumptions of normality using "DHARMa" (34, 35). We used generalized linear mixed effects models from the "glmmTMB" package to test between our dependent variables (abundance, biomass) based on the fixed factors and the interactions between burn treatment, time period, and trap distance (36). We used the function 'Anova' to conduct

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Type II Wald χ^2 tests and obtain p-values for all models using the "car" package (37). We then used Tukey *post-hoc* tests to conduct multiple comparisons if the null hypothesis was rejected for the dependent variables using "emmeans" (38). We made figures using "ggplot2" (39).

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