Effects of Prescribed Burns on Litter Decomposition and Microarthropod Communities in New Jersey Pinelands

Julia Defeo
Michael R. Gallagher
Katie Malcolm

Introduction

In the Northeastern United States, climate change, shifts in forest disturbance regimes, and associated shifts in forest processes are expected to continue to impact forest structure, composition, and diversity (Clark, Skowronski, and Gallagher 2015); however, changes in soil community dynamics and processes, especially those in the soil are not yet fully understood. Restoration of fire dependent ecosystems has been proposed as one solution for mitigating the negative impacts of these changes while reducing the wildfire risk, particularly in Northeastern forests where fire has been largely excluded for much of the past century (Forman and Boerner 1981, Fahey and Reiners 1981, Marschall et al. 2016). However, there is limited information on how such efforts may impact soils and their communities. In pine ecosystems, prescribed burning and wildfire management has provided strong evidence for restoring structure following long-term fire suppression that reduces forest health and resilience (Forman and Boerner 1981, Lee et al. 2019, Van Lear et al. 2005). Yet there is a lack of fundamental research to understand how fire may impact communities of micro-organisms, such as microarthropods, in forest soil and detritus layers that are critical for the forest nutrient cycles.

Climate change and forest management activities intended to mitigate climate change impacts or maintain healthy forests can have direct and indirect impacts on forest communities and their functions. For example, in forests from the

Appalachians to New England, landscape scale forest defoliation due to gypsy moth infestation caused a 20-40% increase in oak mortality (Clark, Skowronski, and Gallagher 2015). Subsequent shifts in ecosystem fluxes result from shifts in living forest structure, increased woody material at the forest floor, and increased ecosystem respiration which is attributed, at least in part, to increased microbial activity (Clark et al. 2018, Renninger et al. 2014, Lovett and Ruesink 1995). Likewise, the desiccation-resistant lone star tick, *Amblyomma americanum,* is undergoing a rapid northward and westward expansion of its range that corresponds to changing temperatures of the Eastern United States. Although, not considered a micro-arthropod, *A. americanum* occupies similar parts of the forest environment and may be an indicator of changes in other communities. Most importantly, broad-scale environmental shifts, related to climate change, likely have large impacts on micro-organisms.

Although shifts in forest structure are evident, some evidence exists for restoration of forest ecosystems in the New Jersey Pinelands using prescribed fire. The history of wildfire in this area of New Jersey predates its earliest settlers, and early fires were likely low in intensity (Forman 2012). As forests were thinned by settlers, however, fuel loads increased, and wildfires subsequently become more severe. These fires created space for dense oak understories to develop, thus crowding out pine seedlings. Prescribed burning in the upland forests of the NJ Pinelands has been found to prevent the successional effects that would favor certain oak species over the predominant pine species, pitch pine (*Pinus rigida* Mill.), which is known to be fire-resistant (Little 1946). In areas left unburned for several decades, dense understories of young oaks can be found. Low-intensity prescribed burns are used to reduce fuel loads in order to decrease the probability of large and destructive wildfires and modify forest biomass pools and their structure (Skowronski et al. 2011, Clark et al. 2009).

Little research has been performed in Northeastern forests on the effects of prescribed burning on the communities of soil microarthropods which inhabit the leaf litter, although evidence exists for the reduction of larger related arthropods, such as *A. americanum*, in burned habitat (Gleim et al. 2019, Gleim et al. 2014). Previous research has shown that understanding fire severity is key to predicting recovery of microarthropod communities. Generally, fire can be expected to reduce microarthropod abundances, and higher fire severities have been found to correlate with higher population recovery times (Malmstrom 2010). Mites and collembolan, as key examples of soil microarthropods, serve as necessary linkages in the soil ecosystem, and their ecological functions are imperative to soil health. After fungi decompose dead organic material, these organisms consume the fungal hyphae. Because microarthropods serve as the link between fungal detritovores that they eat and the predators that consume them, they are imperative in the cycling of nutrients found in decaying plant material (Coleman et al. 2007). In addition to being fungivores, oribatid mites are also known to be detritivores themselves; therefore, they also contribute to nutrient cycling directly by breaking down the leaf litter in which they reside. Interrupting this cycle by decreasing microarthropod populations could, in turn, slow or halt plant growth by decreasing nutrient availability (Coleman et al. 2007).

In order to contrast the potential effects of a low-intensity, dormant and growing season prescribed fire on soil microarthropods, this study has inventoried mite and collembolan populations at a series of prescribed fires in the New Jersey Pinelands. We compared morphospecies abundance pre- and post-burn, and evaluate richness and diversity of oribatid mites. This work is ongoing and this report serves as an intermediate step to document our approach and preliminary results from the dormant season portion of the study.

Methods

Site Description

This study took place within Franklin Parker Preserve, located within the 440,000 ha New Jersey Pinelands National Reserve (PNR). The PNR is comprised primarily of upland forest ecosystems, which are dominated by pine and oak species in the overstory and scrub oak (*Quercus marlandica Münchh* and *Q. ilicifolia Wangenh*) in the understory. Depending on succession and fire regime, PNR forests can be a) dominated by a mixture of oak species, b) dominated by Pitch Pine (*Pinus rigida)* forests or c) comprised of mixed oak and pine stands. *Pinus rigida* can be found throughout, even in oak-dominated ecosystems. Furthermore, soils in the New Jersey Pinelands are generally sandy, acidic, and nutrient-poor. Soils in the PNR are derived from the Kirkwood and Cohansey formations, and they can be characterized by dry oak leaves and pine needles within the upper two centimeters, followed by approximately twenty centimeters of loose gray sand, with an approximate pH of 4.7 (Forman 1979). Lower horizons are also sandy, with pH varying between 4.6 and 5.0 in the first 100 centimeters. These soils generally are well-drained with rapid permeability (Forman 1979). Fires are not expected to significantly decrease soil nutrients due to rapid vegetative regrowth, which prevents leaching of nutrients to groundwater or streams (Forman 1979). The Franklin Parker Preserve is a representative example of these characteristics and was largely sculpted by a destructive fire in 1954 and subsequent pitch pine forest community regeneration.

Experimental design

Nine 100m^2 plots were set up in a pine-dominated forest that had not burned since a wildfire in 1954. Three plots were burned during the dormant season, in April 2018, and three were burned during the growing season, in July 2018. Each burned plot was sampled for microarthropods one to two days prior to the burn, and one day after. To evaluate day-to-day variation, three control plots were also sampled before and after each burn. During each sampling event, three 20x20 cm 1mm mesh litter bags with approximately 5 grams of pine needle litter were collected from each plot and weighed. Microarthropods were extracted from each sample for one week in a modified Tullgren funnel, with gradually increasing heat, into an alcohol and glycerol mixture (Coleman et al. 2007, Akoijam et al. 2013). Larger arthropods, such as ticks and spiders, were discarded before extraction. The organisms collected were then identified to morpho-groups based on physical characteristics with a stereomicroscope. When possible, collembola were identified to family and mites to order.

In order to characterize productivity of soil organisms, soil respiration was measured in the field using a modified infra-red gas analyzer (IRGA; PP Systems Model EGM-3, V. 3.3), three times immediately before the fire and three times immediately after the fire. Soil respiration measurements were also taken monthly after each fire (n=3). A square attachment to the instrument was held over each litterbag in the field for 120 seconds. In order to quantify the effect of fire on soil habitat conditions, soil moisture and temperature were also measured fifteen times per sampling event using a Delta-T HHS Moisture Meter. Three 15cm soil cores were taken per plot before and after each fire to determine bulk density and loss-on-ignition.

Analysis

Simpson's biodiversity was calculated once per litterbag for each of the following microarthropod categories: all mites and collembolan, all collembolan, all mites, and all oribatid mites. Simpson's D values and morpho-group richness values were analyzed using two-way ANOVA. Tukey's Honest Significance Difference Test was performed on ANOVA results.

Results

Soil respiration (measured in grams CO_2 emitted per hour) was not found to be affected by the dormant season burn when compared to control plots (Table 1); treatment litterbags respired similarly to control litterbags immediately before the burn, immediately after the burn, and in May and July 2018. Furthermore, loss-on-ignition, soil moisture, and soil temperature were not affected by the dormant season burn.

Days Since Burn	Control (mean ± SD)	April Burn (mean ± SD)
-1	478.33 ± 9.87	469.89 ± 3.60
1	474.22 ± 10.60	466.67 ± 6.35
13	479.89 ± 13.12	479.11 ± 1.68
82	544.67 ± 12.65	525.78 ± 13.18

Table 1. Partial data set of soil respiration (gCO2 per m2 per hour) immediately before (- days) and after prescribed burns in April 2018. Soil respiration was not affected by the prescribed burns in April.

Approximately 3,960 mites and collembolan were counted from litterbags collected in April 2018. Mites totaled 1,654, comprising 41.8% of total mites and collembolan observed. 1,420 mites were part of the order *Oribatida*, representing 35.8% of total mites and collembolan, and 85.9% of all mites collected. Although collembolan were greater in number, comprising 58.23% of all mites and collembolan sampled, oribatid mites represent the single largest order observed. Approxiamtely 0.04% of organisms observed were neither mites, nor collembolan. These were identified when possible, and most often were found to be nematodes, insect larvae, or small spiders.

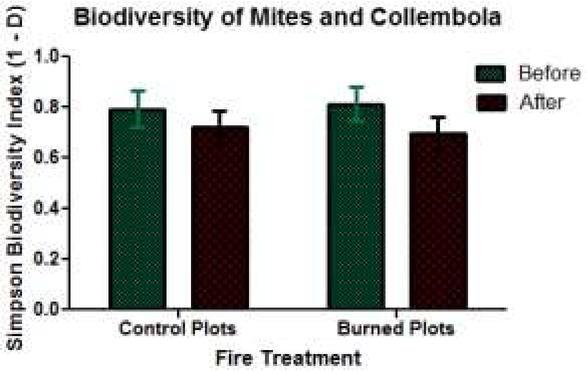

Figure 1: Simpson biodiversity of microarthropod communities before and after a low intensity prescribed burn in April 2018 (n=3). No significant difference.

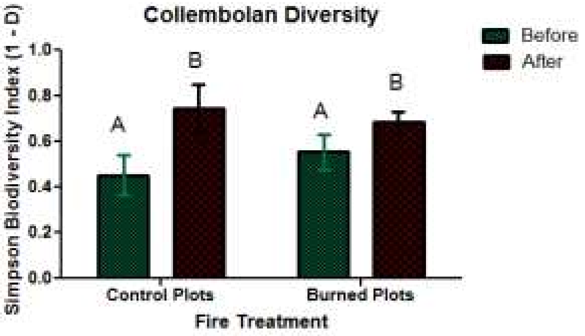

Figure 2: Simpson biodiversity of collembolan communities before and after a low intensity prescribed burn in April 2018 (n=3). Letters denote main effect results of two-way ANOVA (p<.05).

In burned plots, average oribatid richness dropped from 11 species before the burn to 4.11 species after the burn. Richness in control plots experienced a smaller decline that can be attributed to day-to-day variation, dropping from an average of 10.33 species before the burn to 7.22 species after. Average Simpson's diversity increased in control plots by 0.018; in burned plots, Simpson's diversity also increased, but by 0.206. When considering all mites and collembola, average species richness decreased from 23.44 species to 7.78 species in burned plots and from 20.89 species to 17.22 species in control plots. In control plots, average Simpson's diversity decreased by 0.038, while it increased in burned plots by 0.005.

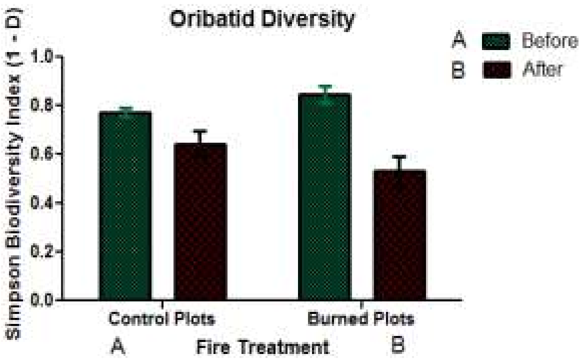

Figure 3: Oribatid diversity before and after a low intensity prescribed burn in April 2018 (n=3). Letters denote main effect results of two-way ANOVA (p<.05).

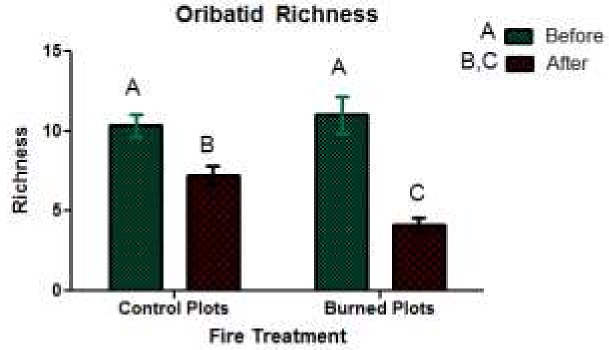

Figure 4: Oribatid richness before and after a low intensity prescribed burn in April 2018 (n=3). Letters denote main effect results of two-way ANOVA ($p<.05$). Similar patterns were observed with oribatid abundance.

No significant difference was observed in Simpson biodiversity across all mites and collembola before and after the April 2018 low intensity prescribed burn (Fig. 1) based on results of two-way ANOVA ($p<0.05$). Simpson diversity was found to increase in collembolan communities in both burned and control plots (Fig. 2), also based off of results of two-way ANOVA ($p<0.05$); however, richness and abundance of oribatid mites decreased after the burn both in control plots and in burned plots; the decrease was significantly larger in burned plots (Fig. 4) based of main effect results of two-way ANOVA ($p<0.05$). This trend is further reflected in oribatid diversity which decreased significantly in burned plots compared to control plots (Fig. 3), according to main effect results of two-way ANOVA ($p<0.05$).

Discussion

This study found nuanced changes in microarthropod diversity following a low-intensity, dormant season prescribed burn in the NJ Pinelands (Fig. 1). We found that oribatid mite communities decreased in diversity which was attributable to the burn (Figs. 5-6); while increased diversity of collembolan communities was attributable to normal day-to-day variation in collembolan movement (Fig. 2). A possible explanation for absence of fire effects in collembolan communities may lie in their morphology; their furcula or "springtail" means these organisms may have increased capacity to leave a disturbed habitat that is lacking in mite communities. Burn effects on oribatid communities are reflected in the overall diversity of all microarthropods. Furthermore, moisture and temperature varied by day, and there was no significant difference in loss-on-ignition (data not shown).

Because microarthropod communities play a critical role in soil nutrient cycling, any decrease in mite diversity, and especially in oribatid diversity, could have effects on nutrient availability through durations extending through the post-fire forest recovery phase or longer. Microarthropods are just one type of soil-inhabiting organism that may be impacted by fire, and the results shown here may indicate that similar patterns could occur with other soil organisms involved in nutrient cycling, such as fungi and larger arthropods. Alternatively, our results suggest that other arthropods that share habitat space with the microarthropods in our study and vector diseases that increasingly pose health risks to humans and wildlife (e.g. ticks), could also be impacted by prescribed burns. Additional research focused on impacts and recovery of various arthropod communities following fire could be helpful in guiding the use of fire to promote resilience of forest soil organisms as well as potentially mitigate the growing health risks of parasitic arthropods to humans and animals.

As climate change increases the expected frequency of wildfire and the prescribed burns used to manage these events, understanding the effect of fire on soil organisms will become key to preserving their community structure and function. Historically, prescribed burns in the New Jersey Pinelands have been performed during dormant seasons.

New legislation, the New Jersey Prescribed Burn Act of 2018, allows for multi-seasonal prescribed fire, including the growing season. Burns performed during growing seasons may impact soil communities differently than dormant season burns. Considering fire is a natural and critical disturbance that has shaped and maintained the Pinelands, it is also important to consider that there is a strong likelihood of mechanisms that function at the scales of individuals, populations, or communities that enable resilience of these organisms in the long run. However, these mechanisms have yet to be explored and may depend on complex spatial, temporal, and qualitative characteristics of fire occurrence on this landscape.

This study examined the effects of fire under a very limited set of conditions that only represent the low range of fire characteristics or effects that are present on the landscape, and support the potential for future studies to investigate effects more broadly. For instance, our study explored the effect of only low-intensity prescribed fire, but additional research is required to characterize the effects of moderate and high severity fire on microarthropod communities in the New Jersey Pinelands, which are likely to be impacted given our results. Likewise, the impacts of fire under different seasonal conditions and across more replicates of fires would be beneficial in understanding how fire may impact the dynamics of microorganism communities and function on this landscape. Further, our study was only focused on documenting fire effects for a short period following fire, and did not examine potential ecological mechanisms of community resilience or recovery, as the forest environment itself recovered to pre-fire conditions. A better mechanistic understanding in the Pinelands, however, would be beneficial to making broader inferences of how diversity may be conserved through repeated disturbances in other systems beyond the Pinelands. Further, additional research should investigate how fire may impact ticks and other forest parasites that negatively impact humans and wildlife and vector deadly and debilitating diseases.

Acknowledgements

The authors thank New Jersey Forest Fire Service Division Firewarden Michael Achey and Section Firewardens Benjamin Brick and Tom Gerber for their assistance in implementing the fire treatments, as well as Dylan Bell, Nicholas Soriano, Megan Rhone, Gary Coyler Jr. and Jannat Fareen for their help in their field, and John Dighton, Alexis Everland and Steve Schulze for their suggestions during the development of this report. We also thank the New Jersey Conservation Foundation for allowing this research at the Franklin Parker Preserve and Dr. Nicholas Skowronski of the USFS Northern Research Station for supporting this work through Joint Venture Agreement 18-JV-11242306.

Works Cited

Akoijam, R., B. Bhattacharyya, and L. Marangmei. 2014. "Tullgren Funnel - an Efficient Device for Extracting Soil Microarthropods." *Environment and Ecology* 32 (2): 474–76.

Clark, K., H. Renninger, N. Skowronski, M. Gallagher, and K. Schäfer. 2018. "Decadal-scale reduction in forest net ecosystem production following insect defoliation contrasts with short-term impacts of prescribed fires." *Forests* 9 (3):145.

Clark, K.L, N. Skowronski, J. Hom, M. Duveneck, Y. Pan, S. Van Tuyl, J. Cole, M. Patterson, and S. Maurer. 2009. "Decision support tools to improve the effectiveness of hazardous fuel reduction treatments in the New Jersey Pine Barrens." *International journal of wildland fire* 18 (3):268-277.
Clark, K.L., N. Skowronski, and M. Gallagher. 2015. "Fire Management and Carbon Sequestration in Pine Barren Forests." *Journal of Sustainable Forestry* 34 (1-2):125-146.

Coleman, D.C., D. A. Crossley, and P.F. Hendrix. *Fundamentals of Soil Ecology*. 2nd ed. Amsterdam: Elsevier/Academic Press, 2007.

Fahey, T.J., and W.A Reiners. 1981. "Fire in the forests of Maine and New Hampshire." *Bulletin of the Torrey Botanical Club*:362-373.

Forman, R.T.T. 2012. *Pine Barrens: Ecosystem and Landscape*: Elsevier.

Forman, R.T.T., and R.E. Boerner. 1981. "Fire frequency and the pine barrens of New Jersey." *Bulletin of the Torrey Botanical Club*:34-50.

Forman, R.T.T., ed. *Pine Barrens: Ecosystem and Landscape*. New York, NY: Academic Press, 1979.

Gleim, E.R., L.M. Conner, R.D. Berghaus, M.L Levin, G.E. Zemtsova, and M.J. Yabsley. 2014. "The phenology of ticks and the effects of long-term prescribed burning on tick population dynamics in southwestern Georgia and northwestern Florida." *PloS one* 9 (11):e112174.

Gleim, E.R., G.E. Zemtsova, R.D. Berghaus, M.L. Levin, M. Conner, and M.J. Yabsley. 2019. "Frequent Prescribed Fires Can Reduce Risk of Tick-borne Diseases." *Scientific reports* 9 (1):1-10.

Lee, C., G.R. Robinson, I.P. Robinson, and H. Lee. 2019. "Regeneration of pitch pine (Pinus rigida) stands inhibited by fire suppression in Albany Pine Bush Preserve, New York." *Journal of forestry research* 30 (1):233-242.

Little, S. 1946. *The effects of forest fires on the stand history of New Jersey's pine region*: US Department of Agriculture, Forest Service, Northeastern Forest Experiment Station.

Lovett, G.M., and A.E. Ruesink. 1995. "Carbon and nitrogen mineralization from decomposing gypsy moth frass." *Oecologia* 104 (2):133-138.

Malmstrom, A. 2010. “The Importance of Measuring Fire Severity—Evidence from Microarthropod Studies.” *Forest Ecology and Management* 260 (1): 62–70.

Marschall, J.M., M.C. Stambaugh, B.C. Jones, R.P. Guyette, P.H. Brose, and D.C. Dey. 2016. "Fire regimes of remnant pitch pine communities in the Ridge and Valley region of central Pennsylvania, USA." *Forests* 7 (10):224.

Renninger, H.J., N. Carlo, K.L. Clark, and K.V.R. Schäfer. 2014. "Modeling respiration from snags and coarse woody debris before and after an invasive gypsy moth disturbance." *Journal of Geophysical Research: Biogeosciences* 119 (4):630-644.

Skowronski, N.S., K.L. Clark, M. Duveneck, and J. Hom. 2011. "Three-dimensional canopy fuel loading predicted using upward and downward sensing LiDAR systems." *Remote Sensing of Environment* 115 (2):703-714. doi: 10.1016/j.rse.2010.10.012.

Van Lear, D.H., W.D. Carroll, P.R. Kapeluck, and R. Johnson. 2005. "History and restoration of the longleaf pine-grassland ecosystem: implications for species at risk." *Forest ecology and Management* 211 (1-2):150-165.