# EFFECTS OF FINE WOODY DEBRIS ON ARTHROPOD COMMUNITIES IN THE NJ PINELANDS

By

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ABSTRACT OF THESIS

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Climate change is modifying weather patterns, including the frequency and intensity of storms. The ecological consequences of these storms have primarily been studied for warm weather storms, such as hurricanes. During the winter of 2017-18, New Jersey experienced an increase in snowstorms. These storms caused significant tree damage, mostly consisting of broken branches and limbs. For the NJ Pinelands, this produced an atypical environment. The increased fine woody debris (FWD) altered the forest floor, increasing its habitat complexity. We tested the hypothesis that a forest floor with increased FWD would result in increased ground dwelling arthropod abundance and diversity, with potential shifts in composition. We conducted a field experiment in the NJ Pinelands with varying levels of FWD (removal, control, & addition treatments). Carnivores were ~50-60% less abundant in removal plots than in control and addition plots, respectively. Carnivores also had significantly different composition in addition plots compared to all other plots, with Staphylinid beetles and spiders contributing the most to differences among plots. Similarly, ant species composition was significantly shifted in addition plots compared to other plots and ant diversity was 56% higher in addition plots than it was in control plots. Prenolepis imparis, Tapinoma sessile, and Crematogaster lineolata contributed the most to differences among plots. In contrast, detritivores had significantly higher abundance in plots with FWD removed than in control and addition plots. Detritivore composition was also most distinct in removal plots with Collembola contributing the most to differences among plots. These changes in arthropod communities in the NJ Pinelands could lead to altered ecosystem services they provide, including soil turnover, decomposition and seed dispersal. The results found in this study broadly implicate the effect of climate change on the NJ Pinelands Reserve.

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## Introduction

Climate change is a global driver of change, which includes changes in temperature, precipitation patterns and extreme weather events. It has also led to an increase in heavier precipitation (US EPA 2016) and specifically, in the northern and eastern US, an increase in winter storm intensity (Kunkel et al. 2013). We are beginning to understand that not only can climate change affect the frequency of these weather events, but also their intensity. Francis and Skific (2015) suggest an increase in the intensity of snowstorms in the Northeast and Midwest is due to rapid Arctic warming and its effects on weather patterns. For example, during cold seasons in the northern hemisphere, both storm frequency and intensity have increased (Vose et al. 2014). The increasing intensity of storms results in an increase in storm damage, which includes broken stems and branches of trees. The addition of this fine woody debris may lead to changes in habitat complexity. Storm damage has the potential to alter ecosystems, yet its effects are understudied.

Storms with high winds or heavy precipitation can cause damage to trees such as broken branches, crowns, and snapped trunks. Ice storms can lead to the bending and snapping of twigs and the breakage of mature stems (Dale et al., 2001). The addition of twigs and stems on the forest floor leads to microhabitats and this heterogeneity can increase insect diversity and abundance by creating differences in food availability and habitat conditions (Bouget and Duelli 2004). Nitterus and Gunnarsson (2006) found the addition of slash in a temperate forest in Sweden increased ground beetle abundance. They suggested that an increase in habitat complexity may produce refuge from larger predators. Ulyshen and Hanula (2009) found an overall increase in litter-dwelling arthropods near coarse woody debris (>10 cm diameter) in loblolly pine forests of the Southeastern United States. However, it is still unclear how fine woody debris (0.5-10 cm diameter) would affect these communities due to the lack of studies performed in temperate forests on the addition of fine woody debris.

Winter storms in the Northeastern United States have recently become more intense. According to the NOAA, in 2018, the Northeast received four back to back nor'easter winter storms during the month of March and three smaller snowstorms earlier in the season, with an approximate total of 34 inches of snow fall. This is in comparison of approximately 30-40 inches during the entire 2014-2015 winter season, 12-20 inches during the 2015-2016 winter season and less than 4 inches during the 2016-2017 winter season. During each season, with the exception of 2016-2017, there was a major snowstorm resulting in at least 12 inches of snow (Kunkel et al. 2013).

The NJ Pinelands is a temperate forest which is recognized as a National Reserve with over one million acres of protected land. A majority of the area contains soil, which developed from the Cohansey geologic formation. This soil is sandy with medium to coarse grains, with a pH of approximately 3.5-4. The Kirkwood-Cohansey aquifer contains 17.7 trillion gallons of water in the outer coastal regions of the Pinelands, which provides residents living in the area their drinking water (NJ Pinelands Commission 2015).

The characteristics of the soil in the NJ Pinelands influences which species survive in that environment. The species living in the NJ Pinelands are adapted to its sandy soil which cannot hold a substantial amount of water or nutrients and has low pH. These features can make the NJ Pinelands uninhabitable for species common in other parts of the region. Uniquely, species living in the oak/pine upland forests in this area have evolved to survive and even thrive to fire disturbance. While seemingly destructive, there are benefits to wildfire disturbances in this ecosystem (Thomas et al. 2010). Some plants require fire to reproduce including the shortleaf pine (Pinus echinata), whose serotinous cones only open with high heat. Additionally, fire management teams utilize prescribed burns to simulate the historically frequent natural fires to reduce fuel loads, resulting in little to no leaf litter.

Fires are a common occurrence in the NJ Pinelands. This leaves the forest floor relatively free of natural debris. The addition of woody debris from stronger winter storms can provide an increase in habitat complexity. A more complex habitat may lead to increases in refuge from predators and nesting sites for reproduction. The changes made by fine woody debris may therefore lead to changes in arthropod communities.

With 1.2 million species, arthropods are the most numerically dominant animal group on Earth. They are essential to most ecosystems because they perform a diverse range of ecological functions including ecosystem engineering, pollination, seed dispersal, and aiding in decomposition (Crossley 1976). Despite their importance ecologically, we are just beginning to understand the magnitude of the effects of climate change on these communities, especially the impact of increasing winter storm activity.

Most arthropods play important roles in food webs and trophic interactions. Trophic feeding guilds, groups of arthropods that exploit specific feeding resources, contribute to these dynamics. These guilds shape arthropod communities through bottom-up or top-down effects, with predators at the top and omnivores, herbivores and detritivores at the bottom. Trophic feeding guilds play an integral role in shaping arthropod communities yet we have a poor understanding of how fine-scale habitat complexity affects their population growth (Dominik et al., 2018).

Ants are particularly important to many aspects of almost every habitat on the planet. They are the dominant invertebrate group in a majority of areas and are highly abundant and diverse (Wilson and Holldobler 1990). Ants play an important role in ecosystem processes with their ability to aerate soil, cycle nutrients and aid in decomposition. Both Majer (1983) and Andersen et al. (2004) suggest ants may be good candidates for use as bio-indicators due to several characteristics, including high abundance and species richness, their ability to occupy higher trophic levels and sensitivity to environmental change.

Ants perform a number of ecosystem processes in the NJ Pinelands. With the acidity of the soil, decomposition is naturally slowed, but ants aid in this process by tunneling and nesting in dead organic material. Ants also perform bioturbation through tunneling. This aerates and turns over soil, oxygenating and moving nutrients to the surface, which provides a more suitable condition for plants (Folgarait, 1998). Several species of Viola in the Pinelands, including the New Jersey state flower Viola sororia, utilize ants as seed dispersers (Beattie and Lyons 1975). Ants are attracted to the fatty attachment on the seeds, called an elaisome, and disperse them by bringing them to their nests to be consumed (Beattie 1985).

In this study, we addressed the following questions: (1) how do arthropods generally, and trophic guilds specifically, respond to an increase in fine woody debris in the NJ Pinelands and (2) how do ant species respond to an increase in fine woody debris in the NJ Pinelands?

Based on the connections between FWD and the arthropod driven food web of the forest floor, we expect to see an overall increase in abundance and diversity of all arthropods, including ants, in response to the increase of FWD. Also, we predict a shift in community composition for all arthropods, including ants.

# Materials and Methods

## Study Site Description

This study was conducted within the New Jersey Pinelands Reserve, a nationally protected reserve with over 1 million acres, located in southern New Jersey. The study site area is dominated by a mix of pitch pine (Pinus rigida), short leaf pine (Pinus echinata) and with an understory of ericaceous shrubs (Gaylussacia baccata and Vaccinium sp.) and scrub oak (Quercus ilicifolia). During the experiment, monthly mean temperatures ranged from 24.48°C (±1.64) °C) to 29.57°C (±0.99 °C) and precipitation ranged from 8.56cm to 14.73cm.

## Site Selection

In May 2018, we visited ~10 sites that had confirmed observations of increased fine woody debris (FWD; M. Gallagher, personal observations) after stronger-than-usual winter storms (Jan-March 2018). At each site, we assessed the amount of FWD, the distance to paved roads, and the distance between sites. Based on these observations, we selected three sites that were separated by at least 10 km (Figure 1).

Within each site, we first established a buffer zone of 30m from paved roads. We then followed established trails (when present) and identified 4 patches of 14 x 4m. Each patch was at least 30m from established trails at least 30m from other study patches. We then divided the patch into 3 separate plots that We treated as an experimental block. All experimental blocks had at least 1cm of leaf litter covering at least 60% of the ground. To determine leaf litter cover, we placed string grids (1x1m) across the forest floor and recorded the number of grids with at least 50% of the ground covered by leaf litter. The plots were 4 x 4m and separated from each other by 1m (Figure 2).

Sampling

We sampled the plots monthly from May-September 2018. To sample for litter-dwelling arthropods, we collected approximately 1L of leaf litter to soil level within each plot between 9-10am. We used the Winkler sifting/extraction method (Bestelmeyer et al., 2000). Briefly, this method entails collecting leaf litter and FWD and putting it into a sifter which separates larger detritus. The remaining sample is placed into a 4mm mesh inlet sack which is then placed into a Winkler sack. A specimen collection cup filled with 95% ethanol is attached to the bottom of the Winkler sack. The apparatus is left for 72 hours to allow for migration of invertebrates to the collection cup. We identified arthropods using Daly et al., 1998. We identified arthropods to a taxonomic resolution in which it allowed us to assign them to a trophic guild. We identified ants to species using Ellison et al. (2012).

Data Analyses

Overall diversity

We first constructed taxa by abundance matrices for arthropod orders, families, trophic feeding guilds, and ant species. Next, we used Primer-E v7.0.13 to calculate Shannon's diversity index. To examine the relationship between these diversity values and my experimental treatments, We used a one-way, repeated measures analysis of variance (ANOVA) using OriginPro 2019 v 9.6.0.172. Prior to conducting these analyses, we used Mauchly's W test to assess the sphericity of the variances across all time points. We used the Greenhouse-Geisser correction when the assumption of sphericity was violated.  When the ANOVAR was significant, we conducted post-hoc Tukey HSD tests to determine which treatment levels significantly differed. We used 0.05 as the α for these tests.

Composition

We examined composition of arthropod communities for all arthropod groups (above) using a non-metric multidimensional scaling (NMDS) ordination in Primer-E v7.0.13. To correct for distortions caused by zeros in the matrix, we added 1 as a dummy variable for all groups. We then created a Bray-Curtis resemblance matrix for abundance by plot. We used this dissimilarity matrix to construct an NMDS plot using 100 restarts and a Type We Kruskal fit scheme. The 2-dimensional stress for all the NMDS ordinations never exceeded 0.25. To find the similarity percentage (SIMPER) of individuals, we used a one-way design using the Bray-Curtis resemblance matrix with a 70% cut-off.

To assess the relationship between abundance and treatment, We conducted a permutated multivariate analysis of variance PERMANOVA with treatment as a fixed factor, unrestricted permutation of raw data with 9999 permutations and Type IIWe sums of squares. When it was significant, We conducted post-hoc pair-wise PERMANOVA test to identify which treatment groups differed significantly from one another.

## Results

### Overall arthropod abundance, diversity, & composition

Across all treatments, we collected a total of 2,713 arthropods from 13 orders. Of these, 8.9% (223) were carnivores, 5.8% (148) were herbivores, and 47.1% (1844) were detritivores. Ants were the only omnivores in the study plots and they represented 22.5% (498) of all arthropods. There were 18 species of ants (Table 1).

The FWD treatments (addition & removal) did not influence overall abundance (ANOVAR, F=1.39, P=0.25), diversity (ANOVAR, F=1.19, P=0.303), or composition (PERMANOVA, F=1.29, P=0.23) of arthropod communities in the study plots. There were also no significant differences between control plots and either type of treatment plots in terms of overall abundance or diversity (ANOVAR, P=0.24, P=0.31, respectively).

### Abundance & diversity within trophic groups

There were stronger responses to the FWD treatments within trophic groups, but only for abundance. Carnivores were significantly less abundant in removal plots than either control or addition plots (ANOVAR: F=27.47, P=1.58E-9; Tukey HSD, P=0. 7.08E-8 & 0.04, respectively; Figure 3). Specifically, carnivores were ~62% and ~51% more abundant in addition and control plots compared to removal plots, respectively.

Detritivores were significantly more abundant removal plots than in either addition or controls plots (ANOVAR: F=4.19, P=0.02; Tukey HSD, P=0.02; Figure 3). Specifically, detritivores were ~35% & ~54% more abundant in removal control plots compared to addition and control plots, respectively.

## Abundance & diversity within ants

In contrast to other arthropods, the addition of FWD caused a stronger response with ant diversity than abundance. Ant diversity was significantly higher with the addition of FWD in addition plots than it was in the control plots (ANOVAR: F=3.89, P=0.02; Tukey HSD, P=0.04; Figure 4). Specifically, ant diversity was ~56% higher in addition plots compared to control plots. Ant diversity in removal plots did not differ from the ant diversity in either addition or control plots (Tukey HSD, P=0.05 & 0.99, respectively). There were no significant differences in ant abundances in response to any treatment (ANOVAR, F=3.89, P=0.89; Figure 3).

## Composition within trophic groups

There were significant shifts in composition in response to the FWD treatments for all trophic groups except herbivores (PERMANOVA, P=0.78).

Carnivores responded most strongly to the FWD addition treatment (PERMANOVA, F=4.647, P=0.002). Carnivore composition was significantly different in addition plots than in either control or removal plots (Pairwise PERMANOVA, P=0.047, 0.001; Figure 5). Spiders (Araneae), Rove Beetles (Staphylinidae), and Pseudoscorpions (Pseudoscorpiones) contributed the most to differences between addition plots and both control and removal plots. Spiders and Pseudoscorpions were 240% and 36% more abundant in addition plots than in control plots, while Rove Beetles were 27% less abundant in addition plots than in control plots. When comparing addition and removal plots, spiders, rove beetles and pseudoscorpions all were more abundant in addition than removal plots, with ~410%, ~140% and ~67% increases (Table 2).

Detritivore composition also varied significantly in response to the FWD treatments (PERMANOVA, F=2.609, P=0.027; Figure 6) with the addition and removal plots differing significantly (PERMANOVA, P=0.008). Poduromorpha and Entomobryomorpha (both Collembola families) contributed the most to compositional changes for detritivores. Poduromorpha contributed ~46% to differences between addition and removal plots and were ~16% more less abundant in addition plots than they were in removal plots. Similarly, Entomobryomorpha, which contributed to ~36% of differences between addition and removal plots, were ~86% less abundant in addition plots than they were in removal plots (Table 3).

Composition within ant communities

Ant composition shifted in addition plots compared to control and removal plots, which were not different from one another (PERMANOVA, P=0.042, 0.009 & 0.19, Figure 7). Prenolepis imparis contributed ~27% to the compositional shifts between addition and control plots. The abundance for P. imparis increased ~102% when FWD was added. Tapinoma sessile and Crematogaster lineolata, which contributed ~15% and ~12% to the compositional changes between addition and control plots, were ~28% and ~38% less abundant when FWD was added.  (Table 4). The top three species contributing to differences among addition and removal plots were all more abundant in addition plots; P. imparis were responsible for ~28% differences between addition and removal plots and had 554% higher abundances in addition plots than in removal plots. While less extreme, C. lineolata and Myrmecina americana were ~18 and 14% more abundant with the addition of FWD. They were responsible for ~14 and 10% of differences among addition and removal plots (Table 4).

# Discussion

## Summary

We experimentally evaluated the influence of fine woody debris (FWD) on local arthropod community structure. We expected that arthropods would benefit from the initial influx of FWD resources that is associated with increasing intensities of winter storms as a result of climate change. Instead, we found that responses to varying abundances of FWD depended strongly on trophic feeding guild identity. Herbivores were unresponsive to these changes, while carnivores, detritivores, and ants all had shifts in composition, diversity, and/or abundance in response to my experimental manipulations.

## Effects of FWD on overall composition, diversity, & abundance were not significant

My prediction of an increase in abundance and diversity was based on the idea that more complex habitats have a positive effect on abundance and/or diversity, as shown in the broader literature (Gardner et al., 1995; MacArthur and MacArthur, 1961; Tews et al., 2004). However, we did not find any responses to FWD treatments in terms of overall composition, abundance, or diversity. This could have been due to the short duration of the experiment. There may not have been enough time for arthropods to utilize additional FWD as a resource. Also, nutrient dynamics caused by decomposition have yet to occur and arthropod communities may be more strongly influenced by the addition of FWD after decomposition has begun. Decomposition will make FWD more palatable over time. This process creates a mixture of substrates within a resource which allows for different soil arthropods to persist (Castro and Wise, 2009).

## Results of FWD manipulation on carnivores

My results indicated a positive effect of FWD additions on abundance within the carnivore group. This could be explained by the increased number of Staphylinidae (rove beetles) in the addition plots. Several studies have shown beetle abundance having a positive correlation with increased habitat complexity (Jacobs et al., 2007; Klepzig et al., 2012; Lassau et al., 2005). We also saw an increase in spider abundance in addition plots which has also been shown in previous studies (Bultman and Uetz, 1982; Schmidt and Rypstra, 2010). The differing vertical distribution spiders utilize for their foraging strategies could explain the increase in abundance with increased habitat complexity. For example, one study found that addition of FWD increased the abundance of web builders because of web attachment points (Castro and Wise, 2009). When examining compositional changes in response to increased FWD, we found carnivore assemblages differed in addition plots compared to the control and removal plots. Lassau et al., (2005) found a similar pattern when looking at Staphylinidae in high complexity habitats. A future study to further elucidate these results could include an FWD manipulation with additional collection methods including net sweeping to ensure web-building spiders are included and pit-fall trapping. Also, identifying these carnivores to species could allow us to better explain trophic patterns of carnivore communities by allowing us to place them in more specific functional groups, i.e. generalists or specialists.

Results of FWD manipulation on detritivores

Detritivore abundance responded significantly and positively to FWD removal. This is contrary to other studies which found that increased habitat complexity provided refuge from prey (Humphries et al., 2011; Warfe and Barmuta, 2004). The reduction of detritivores in the addition plots may be a result of the increase in carnivore presence in those plots. Previous work has shown that an increase in refuge stabilizes predator-prey interactions (Berryman et al., 2006). Further studies may be needed to better understand these responses. For example, a longer-term study may provide more time for these interactions to occur and be captured.

Results of FWD manipulation on ants

Ant communities differed in response to the addition of FWD

Ant diversity increased and their composition also shifted in plots with the addition of FWD. Ants are often used as bioindicators to detect changes in environments. Ants are sensitive to environmental disturbance and their community wide responses to disturbance are well studied (Andersen and Majer, 2004; Majer, 1983; Van Schagen, 1986). This is one possible reason We saw a shift in ant composition and increase in diversity with the disturbance of added FWD. Also, increased FWD leads to increased habitat complexity, which can lead to more nesting sites, areas of refuge and microhabitats. These shifts could have an effect on ecosystem services that ants provide in the NJ Pinelands. For example, a reduction or disappearance of seed dispersing ants could potentially reduce seed fitness for myrmecochorous plants, particularly the native Viola (Connell, 1971; Janzen, 1970).

Results of FWD manipulation on herbivores

There were no significant responses to either treatment in terms of herbivore abundance, diversity or composition. There is a possibility of a sampling bias against plant inhabiting herbivores. The Winkler sampling method is used for collecting leaf litter arthropods and may be why there was a low abundance and diversity of herbivores.

This is compared to studies that found herbivores as the most abundant trophic group (Simao et al., 2010).

## Conclusions

Climate change is altering ecosystems all around the world. Many studies have been conducted to see how these changes are affecting ecosystems and the animal communities within them. One region with little information on how climate change is affecting it, is the NJ Pinelands. Climate change is altering weather patterns, including increasing the frequency and intensity of winter storms. In the NJ Pinelands, these storms have created an influx of fine woody debris and this increase in FWD is changing the structure and complexity of the forest floor. Over short time scales, we found that carnivores, detritivores and ants were most affected by an influx of FWD in the NJ Pinelands. These groups play integral roles in food webs and ecosystem services. Carnivores especially play an important role in food webs and variations in their communities could have detrimental top-down effects on other trophic group abundances, diversity and composition. Specifically, increased diversity can lead to increased competition. Increased competition could lead to competitive exclusion, niche differentiation or even local extinction (Thébault and Loreau, 2015), leading to cascading effects in the food web. Species that are adapted to live in the NJ Pinelands may be driven out by new species in response to additional FWD. This may be detrimental to the ecosystem services that these adapted species provide by reducing, changing or removing these services. Ants in particular provide important ecosystem services in the NJ Pinelands such as soil turnover and seed dispersal. The changes in their diversity and composition may have a negative effect on plant survival in the NJ Pinelands.

Future work should include an assessment of FWD's influence on arthropod communities on a longer time scale. This longer time scale could allow us to how increased FWD is altering nutrient dynamics and its effect arthropod communities. Additionally, we should also look at how the addition of FWD affects other organisms in the NJ Pinelands such as plants and fungi.

Broadly, we sought to find climate change's effect on arthropods in the NJ Pinelands. My results indicate that there may be shifts in arthood communities as a result of increased FWD from increasingly intense and frequent snow storms from climate change in the NJ Pinelands. This potentially could result in the decrease or loss of the ecosystem services arthropods provide.

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