Effects of Ecological Restoration on the Leaf-Litter Arthropod Community

BY

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THESIS

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This dissertation is dedicated to friends, family, teachers, and students near and far: Without your support, patience, and understanding, I would not have been able to study and teach what I love. As a teacher and student, I would also like to also dedicate this dissertation to SFC. Ronald Tanner Wood, and SPC. Ashley Sietsema, you taught me how to be a good leader and a good follower, but most importantly how to be a good person. I owe you my stripes both on my army uniform and on my academic regalia.

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CONTRIBUTION OF AUTHORS

Chapter 2 describes a study done on 28 sites part of the Chicago Wilderness Land Management Research Program. Collaborators from other research institutions and forest preserve districts surveyed the sites and produced vegetation summaries and categorized the sites before the start of this study.

Chapter 5 describes a study performed at UIC where we assessed the nutrient leaching of leaf litter and the food choice preferences of terrestrial isopods. This was a collaborative project with one of my undergraduate students (Allison Brackley, UIC class of 2015), where I produced the experimental design and justification, and she conducted the experiment as part of her undergraduate research project. Allison helped draft the first version of this manuscript as well as compiled the data for analysis.

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SUMMARY

Current ecological restoration and management programs in forests of the Chicago metropolitan region focus on the removal and control of invasive plant species as a high priority. Additional efforts, such as seeding and selective cutting and burning, aim to alter the composition of herbaceous vegetation and canopy species, with the goal of managing the plant communities. Leaf-litter arthropods are a source of high biodiversity, and as key members of the detrital food web, facilitate the decomposition of organic matter into simple compounds, thereby affecting nutrient cycling between above- and below-ground structures of the plant community. Changes in the plant community caused by both invasive plant species and land management techniques have the potential to alter the detrital community by modifying both the diversity and structure of the leaf litter. However, it is still unclear how restoration and management practices have altered the leaf-litter arthropod community.

This dissertation research examines how the forest leaf-litter arthropod community responds to changing leaf-litter conditions influenced by restoration and management efforts. I investigated how land management and invasive plant leaf litter have impacted the arthropod community at three different scales. At the regional level, I studied how the management history of 28 woodland sites in 4 adjacent counties has affected the leaf litter and leaf-litter arthropod community structure. At the site and microhabitat scale, I researched the colonization and consumption patterns of arthropods on native and invasive litter monocultures and mixed litter treatments.

This research examines the current knowledge of how land management and invasive plant species impact the arthropod community with the goal of helping decision makers explore ways to incorporate the arthropod community into restoration goals, understand mixed-litter

effects on litter disappearance rates, and provide key biodiversity data for current and future long-term research.

The overall objective of this dissertation is to advance our existing body of knowledge of woodland restoration through four research projects. The first (Chapter 2) is a study to examine how the detritus-based arthropod community responds to woodland restoration history and individual leaf litter characteristics at 28 sites in northeastern Illinois; the second (Chapter 3) I focused on determining if an introduced litter type from an invasive shrub, European Buckthorn (*Rhamnus cathartica)*, impacts the arthropod leaf-litter colonization rate in a field experiment. In the third study (Chapter 4), I investigate how an invasive plant species targeted in woodland restoration efforts, and used in chapter 3, influences the consumption rates of major detritivores in a mixed-litter mesocosm study. Lastly (Chapter 5), I examined how direct contact with the leaf litter of the invasive plant used in chapter 3 and 4 influences the palatability of native canopy species in a cafeteria-style food choice experiment. Finally (Chapter 6), I coalesce the findings of the research projects into a general discussion and future research directions.

LIST OF ABBREVIATIONS

Bio-Env	**Ranked test for biological-environmental relationships**
BO	**Burr Oak (*Quercus macrocarpa*)**
BT	**European buckthorn (*Rhamnus cathartica*)**
C	**Carbon**
(C)	**Isopod consumption rate**
C:N ratio	**Carbon to nitrogen ratio**
CAP	**Canonical Analysis of Principal coordinates**
CR	**Consumption Rate of isopods**
distLM	**Distance-based linear model**
FWD	**Fine Woody Debris**
H	**Shagbark hickory (*Carya ovate*)**
LL:FWD	**Ratio of Leaf Litter to Fine Woody Debris**
M	**Sugar maple (*Acer saccharum*)**
N	**Nitrogen**
PCO	**Principle Component Ordination**
PERMANOVA	**Permutational multivariate analysis of variance**
PERMDISP	**Permutational test of homogeneity of dispersion**
PVC	**Polyvinyl chloride**
RO	**Red oak (*Quercus rubra*)**
WO	**White oak (*Quercus alba*)**
WRV	**Water Retention Value**

CHAPTER 1: AN INTRODUCTION TO THE INTERACTION BETWEEN WOODLAND MANAGEMENT HISTORY AND THE LEAF-LITTER ARTHROPOD COMMUNITY

1.1. Introduction

1.1.1 Restoration of the vegetation community and its impact on the arthropod community

Ecological restoration efforts have primarily focused on managing the plant community to increase biodiversity and habitat availability for both floral and faunal components of systems (Herath et al. 2009, Riggins et al. 2009). These efforts often ignore the impact restoration, and management practices have on the leaf-litter arthropod community, a key player in nutrient cycling (Lattin 1993, Hättenschwiler and Gasser 2005), a source of high biodiversity, and a prey source for many vertebrate and invertebrate predators on the forest floor.

Changes in plant community composition due to restoration efforts have the capacity to indirectly influence the arthropod community by altering leaf-litter input in both quantity and quality to the forest floor (Hättenschwiler and Gasser 2005). Understanding the multiple interactions between land management, plant communities, leaf litter and the arthropod community can help us understand how the arthropod community can be used as a response variable to current restoration efforts as illustrated in [Figure 1. (1.1)].

Ecological restoration aims to re-establish ecosystem structure and function to a similar state to what existed before disturbance. Although restoration goals may evolve with time and added empirical evidence, including restoring a site to a known historical community or a new community structure valued by stakeholders, the main objective to increase diversity and ecosystem function often remains the same. In the Chicago Wilderness region, the greatest disturbances to woodland sites are those caused by invasive species and habitat loss. Invasive species have been shown to have the capacity of altering both community assemblages and ecosystem processes (Frappier et al. 2003, Ashton et al. 2005, Mayer et al. 2005, Heneghan et al. 2006, Szlavecz et al. 2006). This has made invasive species prime targets for removal in many restoration efforts.

Restoration of the vegetation community, including the physical removal of invasives, has been documented to have a positive impact on the above- and below-ground arthropod community. This impact includes an increase in arthropod diversity with an increase in vegetation diversity (Longcore 2003, Gratton and Denno 2005, Gerber et al. 2008, van Hengstum et al. 2013). These changes to the terrestrial arthropod community due to restoration have been shown to track in a trajectory leading to the characteristics of non-disturbed reference sites (Gratton and Denno 2005, Majer et al. 2007). Re-establishment of native vegetation in areas previously dominated and altered by introduced plants has at times resulted in the rapid recovery of arthropod assemblages associated with restored habitat characteristics such as live and dead plant biomass (Gratton and Denno 2005).

The return of litter-arthropod assemblages due to restoration is influenced by management protocols. The use of prescribed burning as a restoration tool, for example, has been shown to have short-term negative, but long-term positive effects on the arthropod community (York 2000, Coleman and Rieske 2006). These long-term benefits to the arthropods may only be apparent after several years of restoration (Coleman and Rieske 2006) and may have resulted from increased habitat and nutrient availability. Changes to the vegetation community as a result of management may alter the rate, timing, or composition of leaf-litter inputs to the forest floor, which in turn can shift patterns of species dominance within the detrital system. Sites with increased age of restoration have been found to have higher understory plant diversity and cover, and higher litter mass (Larkin et al. 2014), which in turn may increase litter-arthropod habitat availability (Hättenschwiler et al. 2005).

1.1.2. Litter influences on the arthropod community

Leaf litter is a representation of the plant community above it, and its suitability as arthropod habitat is influenced by individual characteristics that each litter type contributes. Physically complex layers at different decomposition stages provide food and habitat for decomposers, detritivores and predators alike. Litter is characteristically complex, with its complexity compounded by the diversity of leaf-litter species, moisture retention capabilities and its structural heterogeneity (Uetz 1979, Gartner and Cardon 2004, Hättenschwiler et al. 2005). Litter can absorb and retain moisture and in doing so produces microclimates suitable for arthropods susceptible to desiccation (Antunes et al. 2008). Endophagous mites, for example, help increase microhabitat for other litter arthropods by producing open spaces within the litter, and by doing so increasing moisture-holding capacity, which facilitates decomposition (Gartner and Cardon 2004). In addition, increased depth of litter helps minimize temperature fluctuations, and litter depth has been documented to be influential on the spider community by Bultman and Uetz (1982). The leaf-litter depth and its combined attributes are the most important factors determining litter-arthropod diversity and abundance (Bultman and Uetz 1984, Hansen 2000, Wagner et al. 2003, Lassau et al. 2005).

Suitability of litter as a habitat and the rate at which it decomposes are highly influenced by litter diversity and abiotic factors. The speed at which litter is consumed by arthropod detritivores is greatly influenced by nutrient level within the litter (Hedde et al. 2007, Abelho and Molles 2009, Vos et al. 2011) and the moisture retention capability (Levings and Windsor 1984). Nutrient availability in the leaf litter is governed by litter species and has also been shown to alter litter decomposition rates (Moore et al. 1988, Sayer 2005, Illig et al. 2008). Characteristics including leaf toughness, nitrogen, lignin and polyphenol concentrations, as well as C: N ratio can influence decomposition rates by altering the rate of microbial activity (Hättenschwiler et al. 2005). The degree and type of influence individual litter characteristics have on the arthropod community can be species-specific; they have been studied as both individual litter species effects or mixed-litter effects (Hansen 2000).

Given the impact and pace human activities have had on local natural areas, it is essential to understand how to efficiently and quickly sample and identify highly diverse, and abundant, arthropods at an appropriate taxonomic resolution. The use of arthropods can be justified as both indicators of ecosystem health (Naeem et al. 1994, Lavelle et al. 2006, Majer et al. 2007), and management practices (York 2000, Abbott et al. 2003, Coleman and Rieske 2006, Pétillon et al. 2008, Arnan et al. 2009). Their utility as ecological research tools depends upon the taxa used and the taxonomic resolution to which they are identified, both of which may be system specific. This research work will address the influence of ecological restoration and its effect on the arthropod community by helping understand how ecological restoration and the arthropod community are intertwined between management, restoration, leaf litter and the leaf-litter arthropods [Figure 1. (1.1)]. I will also address the problem of scale, and examine how the scale of management categories can influence our ecological conclusions, by focusing on studies that use regional, site, and food patch scale in its investigations [Figure 2. (1.2)].

1.1.3. The problem of conceptual scale

One challenge to understanding how restoration of the vegetation affects the leaf-litter arthropod community has to do with the problem of dealing with different spatial, temporal and taxonomic scales; and with impacts of restoration history as well as possible underlying mechanisms. I have addressed the challenges of scale by relying on studies that use different regional, site and food-patch scales; and studies that examine the impact on the entire arthropod community after many years of restoration to short-term studies on the colonization and feeding behavior of particular arthropod detritivores [Figure 2. (1.2)].

One: At the regional scale, (Chapter 2) I assessed the effects of restoration history on the leaf-litter arthropod community across 28 sites in four adjacent counties in northeastern Illinois. Because arthropod community composition is defined by the density of each taxon, I assessed how the way we as researchers calculate density can help explain density at three increasing site scales. I transformed density data into three distinct data frames, allowing me to interpret how management categories may influence the arthropod community at increasing site scales, including 0.05 m^2 litter sample, 4 m^2 subplot, and the 1-hectare site scale. I used the raw arthropod abundances (*N*) as a starting data frame to represent abundance per 0.05 m^2 sample area. The raw data was then coupled with the grams of litter found in each litter sample allowing me to calculate the number of arthropods per gram of leaf litter collected (*N/g*). Lastly, I used the percent litter cover calculated at each subplot to extrapolate the abundance of arthropods to the entire1 ha site (*N/ha* cover).

In addition to the scale of arthropod density in Chapter 2, I also investigated how we identify and categorise the full spectrum of 28 restoration sites part of this dissertation. I assess how my sites can be identified to three or two management categories depending on how one assesses the criteria for each category. I evaluate the conclusions produced by categorizing 28 research sites into three or two pooled management categories, and if they differ in the conclusions, they produce. This information was also compared to a previous study that used pitfall traps and arthropod activity-density in 22 of the 28 sites (McCary et al. 2015).

Two: At the site scale (Chapter 3), I focus on investigating how different leaf litter treatments in the form of litter cages influence the arthropod colonization rates at these sites. I assessed the activity density found in three sites that range in restoration history, and produce conclusions about how the three sites produce overall unique arthropod communities, and how these communities are influenced by litter patch treatments.

Three: At habitat and food patch scale (Chapter 4, and 5), I assess how one of the main invasive species targeted in restoration efforts in our research sites influences mixed leaf litter decomposition patterns and consumption rates using two lab experiments. The first is a mesocosm experiment to assess if an introduced invasive shrub litter type increases the overall consumption rate of a common litter detritivore. At the food patch scale, I investigate if nutrient leaching from the same invasive shrub influences decomposition by influencing the food preference of the same detritivore in a cafeteria-style food-choice experiment.

With the use of these three research objectives I hope to better understand how ecological restoration influences the arthropod community not only at the site scale but down to the small food patch scale, and understand how changes in community structure at the site scale may be a reflection of changes in microhabitat food patches preferences.

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1. FIGURES

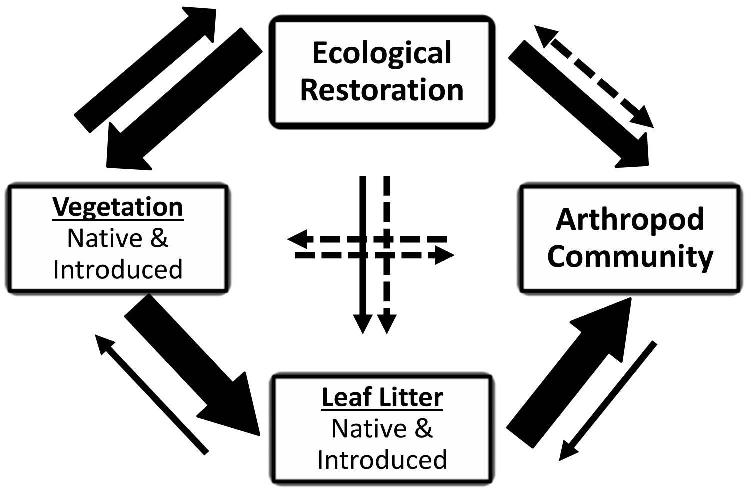

Figure 1. (1.1). The conceptual framework of direct effects (solid arrow →), and indirect effects (dashed arrow ⇢), between ecological restoration, vegetation, leaf litter and the arthropod community. The hypothesized proportional influence is represented in the thickness of the arrows.

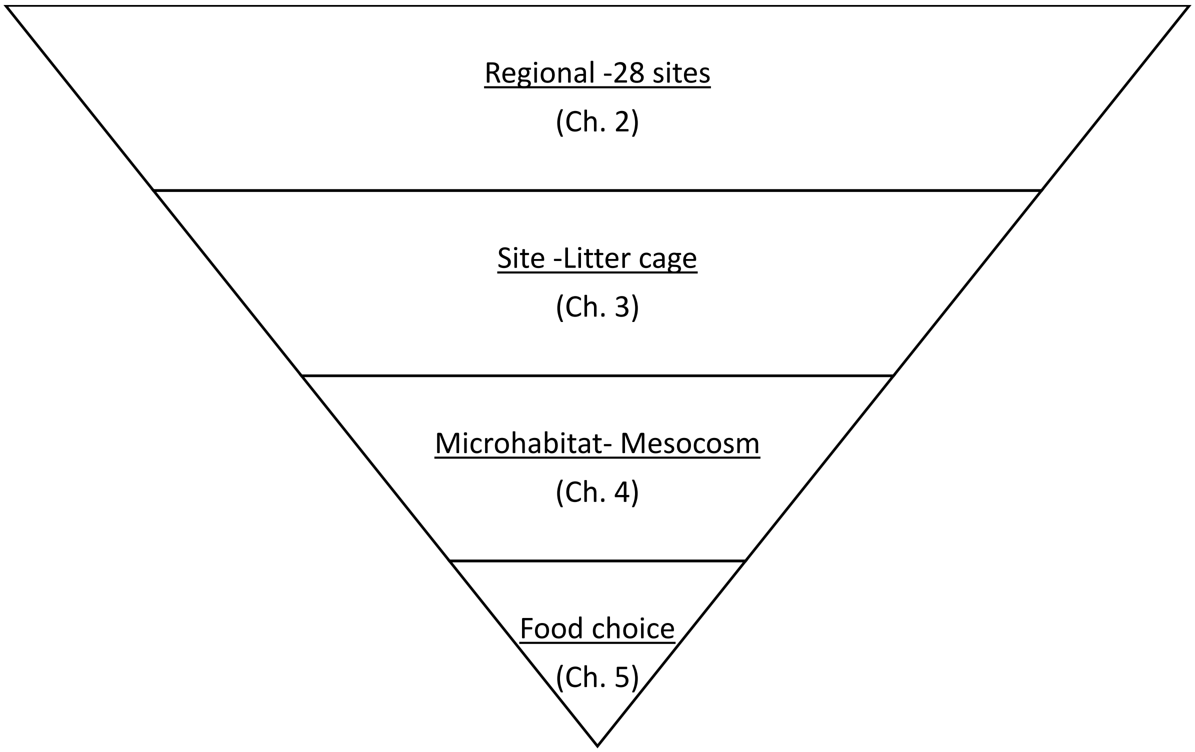

Figure 2. (1.2). The scale of the conceptual framework of this dissertation research. Each chapter addresses how woodland restoration influences the arthropod community — at a large regional scale in Chapter 2, where 28 sites at four counties were used to address a question; at the site scale in Chapter 3 where I used three sites and 27 litter cages to address litter colonization rates; at the microhabitat scale Chapter 4 where I used 198 mesocosms to study effects of litter types and mixture on decomposition; down to the food patch scale for my food-choice experiment in Chapter 5.

CHAPTER 2: EFFECTS OF WOODLAND RESTORATION AND MANAGEMENT ON THE LEAF-LITTER ARTHROPOD COMMUNITY

2. Abstract

The effects of land management history and restoration efforts on the abundance and diversity of forest leaf-litter arthropods have seldom been investigated. Woodland restoration efforts have primarily focused on plant communities, while often ignoring the detrital arthropod members of this system. In this study, I investigate the influence of woodland restoration efforts on the leaf litter arthropods community by sampling 28 one-hectare sites which are part of the Chicago Wilderness Land Management Research Program. Land managers have grouped these sites into three categories based on existing conditions. Control sites (*n=5*) are unmanaged, never restored sites considered to be in a degraded state by land managers and often invaded by invasive species. Managed-INT (*n=17*) sites are in the intermediate stages of restoration (3-21 years of restoration) and are currently actively managed. Managed-REF (*n=6*), are restored, managed sites that represent restoration goals for land managers. Management efforts focused primarily on removing European buckthorn and other invasive plants followed by application of techniques to restore native plant diversity. The sites were sampled for 1-2 years in both spring and summer with most sites being sampled for 2 full years using a Berlese-funnel apparatus to extract arthropods from 0.05 m^2 litter grabs. Arthropods were sorted to 36 taxonomic groups. Permutational analysis of variance (PERMANOVA) and subsequent canonical analysis of principal coordinates (CAP) revealed that the arthropod community structure varied between the three management categories, with the difference between categories being more prominent in the summer sampling season. Univariate analysis of leaf-litter characteristics showed litter weight and percent litter cover were lowest in the Control, compared to Managed sites. The

knowledge gained from this study may assist land managers in predicting impacts of land management approaches on a major subsystem of the forest ecosystem by informing them of the impact of land management history on the litter arthropod community.

2. Keywords: Arthropods, Leaf-litter, Community Structure, Conservation Management, Ecological Restoration, Invasive Plants, Soil nutrients.

2.1. Introduction

2.1.1 Woodland restoration in the Chicago metropolitan area

As part of the Chicago Wilderness Land Management Research Program (from now on CWLMRP), this study seeks to understand the success of habitat restoration efforts in restoring community structure and ecosystem functioning. A greater understanding of the success and effectiveness of management is essential information for land managers and stewards alike. CWLPRP has designated more than 100 one-hectare plots of woodlands, savannas, and prairies that have been undergoing restoration for different numbers of years, including some which have not been managed at all. Goals of the program are to uncover current patterns that reflect past restoration history and establish baseline conditions for research on changes to the sites in the future. The one-hectare sites are distributed within four adjacent counties around the Chicago metropolitan area.

A previous study conducted on 22 of the same sites used pitfall traps and activity density to assess the impact of restoration upon the epigeic (ground-active) arthropod community. This study found Control sites had nearly twice as many invasive detritivorous isopods as the Managed-REF sites (McCary et al. 2015), and Managed-REF sites had four times as many native fungivorous springtails (Collembola) as Control sites. These change in arthropod activity-density due to management history may be reflective of leaf litter conditions within the sites, with Control maintaining a higher activity density of the epigeic detritivorous isopod due to reduced litter layer. The absence or sparse distribution of litter within these sites may help explain the higher activity density of isopods, which may need to forage more to find suitable litter patches.

Studying the arthropod community as the response variables, and using the litter compositional weights of each sample as a cofactor, will allow me not only to look at management categories but also key litter characteristics influencing the arthropod community. Previous studies have shown site variables to impact the arthropod community including vegetation, coarse woody debris, and soil moisture (Bultman and DeWitt 2008, Castro and Wise 2009, Martay et al. 2012).

This study aims to expand on existing knowledge from these sites and investigate the link between management history, leaf-litter characteristics and the arthropod community.

2.1.2 Objectives

The objectives of this study were to 1) study how the detritus-based arthropod community responds to woodland restoration; 2) determine if restoration influences leaf-litter characteristics; 3) determine which changes in leaf-litter characteristics can explain changes to the arthropod community.

2.2. Methods

2.2.1 Site selection

Local land managers have placed the CWLMRP sites into one of three categories, representing management history and the manager's perception of site quality (McCary et al.

2015). Sites have been identified as Control, Managed-INT, and Managed-REF. In total, I used 28 woodland sites representing the range of three management-history categories. Control sites (*n=5*) were unmanaged, never-restored sites considered to be in a degraded state by land managers that were invaded by non-native plant species such as European buckthorn. Managed-INT (*n=17*) sites were in the intermediary stages of restoration (3-21 years of restoration) as judged by land managers, and are currently being managed. Managed-REF (*n=6*) were restored sites that managers identified as representing management goals with respect to restoration of the vegetation. Managed-REF sites are still under active management and usually haven't been managed much longer than Managed-INT sites (11-21 years of restoration). Managed-REF sites have varying vegetation composition and management time frames but are considered particularly successful restoration efforts [Table 1. (2.1)].

Twenty-four sites were sampled during the first sampling event in the summer of 2009 (Control *n=5*, Managed-INT *n=15*, Managed-REF *n=2*), and were subsequently sampled during the spring and summer of the following year, 2010. In the spring of 2011, four additional Managed-REF sites were added to the CWLMRP, bringing the total number of sites sampled to 28. At the end of the summer of 2011, twenty-eight sites had been sampled at least once in spring and summer, with most sites being sampled twice in both spring and summer [Table 2. (2.2)].

2.2.2 Arthropod Sampling

Six 4-m^2 subplots were randomly selected at each site by walking a distance of 5-40 m from the center (identified by GPS coordinates and a pre-placed stake), in one of 6 preselected directions between 1-360° indicated by a compass direction [Figure 2. (2.1)]. At the designated subplot, the percent litter cover was calculated and recorded. In each sampled subplot, the ground area with the most noticeable amount of litter cover was selected and a 25-cm diameter litter-grab sample was taken, sampling in the bare ground was avoided. A round metal waste can with a base diameter of 25cm was used for litter isolation and removal. The can's bottom was cut off, and the bottom rim was filed down making a sharp edge all around the base. The waste can was placed on the leaf litter and pressed down, cutting and isolating the litter layer. The high walls of the waste can prevented large, fast-moving arthropods from escaping. The litter was removed down to the mineral A-horizon of the soil layer or until a solid layer was encountered, including the humus layer if encountered. Each litter sample was labeled and placed in a bag and transported to the lab to begin arthropod extraction the same day.

Litter-grab samples were placed in a Berlese funnel, and the temperature was slowly increased over three days. The Berlese funnels were constructed from Behrens^{tm} galvanized tractor funnels with a 26-cm diameter top rim, 12-cm depth, and a 17-cm funnel length [Figure 4.(2.2)]. A modified clamp light fixture was secured on top of the funnel with a 40w bulb to produce heat and light gradient within the funnel. The Berlese funnel causes the arthropods to escape the warm top leaf litter and be funneled down to a preserving jar at the bottom. A metal screen was secured in the middle of the funnel to prevent detritus from falling into the preserving agent jar at the bottom of the funnel. After extraction, arthropods were preserved in 70% ethanol, identified and counted for each litter grab.

Thirty-six taxonomic groups were selected as leaf-litter representative taxa which included fungivores, detritivores, predators, and generalist omnivores. These included beetles, spiders, isopods, Collembola, Chilopoda, Diplopoda, and Hymenoptera. Together these taxa represent leaf litter-dwelling arthropods that have been used in past studies to investigate both ecological restoration and leaf-litter qualities (Andersen et al. 2002, Pearce and Venier 2006, Pohl et al. 2007, Steffen and Draney 2009, Magrini et al. 2011). Arthropods were sorted and identified to varying taxonomic resolution with some taxa being identified to order and others to family. The taxonomic resolution was guided by the diversity and ease of identification for each taxonomic group. Due to their diverse ecological roles at the family level, Collembola, spiders, and beetles were identified to family. All samples were sorted "blindly" (i.e., the person doing the sorting and identification of animals did not know the identity of the sample) to eliminate biases. All identified and unidentified non-target taxa have been archived for potential future study at the University of Illinois at Chicago's Martinez insect teaching collection or as voucher specimens deposited at the Field Museum of Natural History.

Managed sites were continually managed during this study. At times when a site or part of a site was burned as a restoration technique, measures were taken to sample both the burned and adjacent unburned areas. Two Managed-REF sites received prescribed burning treatments during this study and both types of areas were sampled accordingly. This allowed me to investigate how prescribed burn management efforts influenced the arthropod community and enabled me to compare changes in leaf-litter characteristics as a result of burning.

2.2.3 Leaf-litter characteristics

After arthropod extraction, the litter sample was dried and separated into its components, each of which was weighed. Components included: total litter weight (total detritus), leaf litter alone (LL), fine woody debris (FWD), seeds and acorns, and remaining inorganic material. The ratio of leaf litter to FWD within each litter weight was also calculated and used in the analysis (from now on LL: FWD ratio). In the same manner that carbon and nitrogen ratios have been used in other detrital and soil studies, I suggest LL: FWD ratio may be an informative value for examining how structure of the arthropod leaf-litter community may be related to physical characteristics of the litter.

2.2.5 Statistical analyses

2.2.5.1 Multivariate statistical analyses: Effects of restoration and land-management history on the leaf-litter arthropod community

To study the influences of management categories on arthropod community structure, multivariate statistical approaches were used to assess differences related to management history, site environmental factors, seasonality and year. Furthermore, I assessed how these categories influenced arthropod community at three distinct spatial scales: 0.05-m^2 litter sample, 4-m^2 subplot, and 1-ha site. First, I used the raw arthropod abundances (*N*) to represent density per 0.05-m^2 sample area. The raw data was then coupled with the grams of litter found in each litter sample allowing me to calculate density as the number of arthropods per gram of leaf litter (*N/g*). Lastly, I used the percent litter cover calculated at each subplot to extrapolate the density of litter-dwelling abundance of arthropods as abundance per hectare site (*N/ha*).

The three different measures of density were fourth-root transformed, and a community distance matrix was calculated for each density measurement using Gowers S19 (excluding double zeros) dissimilarity matrix. Gowers S19 was used in order reduce the undefined characteristics of two samples that lack many species in common (Clarke and Gorley 2006). Unlike Gowers S15, which gives a coefficient value of 1 to double zeros, S19 gives the coefficient a value of 0 for double zeros in a sample. Differences in arthropod community structure (i.e., differences between samples in relative abundances of taxa) between management categories were tested with permutational multivariate analysis of variance (PERMANOVA: 10,000 permutation of the entire dataset; Type III SS) performed on the community distance matrix using the statistical software PRIMER V6. (Anderson et al. 2008). A permutational multivariate analysis of dispersion (PERMDISP) was also run to test for differences between management categories in the dispersion of arthropod assemblages within each category (Anderson et al. 2008). PERMDISP is used to compare the distances from observations to their group centroid (similar to the measure of variance), which allows for the comparison of heterogeneity of communities between categories. To test for interactions between management category, year and season, a three-factor PERMANOVA was performed using management category, season and year as fixed factors.

To visualize which arthropod taxa were likely causing changes in the multivariate cloud of points (community structure), I used a vector overlay on the Canonical Analysis of Principal Coordinates (CAP) ordinations, constrained by management category. The purpose of a CAP is to find statistical axes through multivariate clouds of points that best discriminate among groups. Vector overlays on CAPs were used to interpret the influence of particular arthropod taxa which produce the separation of communities according to management category. When vector overlays on CAPs where produced, they represent Partial Correlation $r > 0.4$ for vector overlays; the circle represents $r = 1$.

The initial analysis was first conducted on the 24 sites that were sampled for two full years in both spring and summer seasons. If the initial three-factor PERMANOVA indicated no significant interactions among management category and year, the two sampling years would be pooled together for each site for each summer and spring sample. If no interaction between management category and season was found, spring and summer samples would also be pooled together. The addition of four new Management-REF sites at the end of the 2011 year resulted in an additional analysis that incorporated the increased number of Management-REF sites.

Because the additional four Management-REF sites were only sampled once for each season, this provided me with the opportunity to study how the additional 4 Management-REF sites would alter the conclusion based on the original 24 sites. This was accomplished by analyzing the 24 and 28 site data frames separately for each season, and pooled across season and year. This analysis allowed me to investigate how the addition of four new Management-REF sites alters the conclusion of the original PERMANOVA results and in their locations in ordination space.

All sites had been identified by land managers to fall within one of three managed categories (Control, Managed-INT, Managed-REF). Managed-REF are sites that are managed but represent restoration goals. Because Managed-REF sites also include current restoration activity I investigated how pooling the two management categories would influence the overall conclusions. I assess how the arthropod community responds to management categories at the 3-management category scale (Control, Managed-INT, Managed-REF), and at the 2-management category scale (Control, Managed-ALL). The new pooled management category of Managed-ALL reclassifies Managed-INT and Managed-REF as being in a current state of restoration efforts and compares this with the Control sites.

2.2.5.3 Multivariate statistical analyses: Arthropod community relationship to litter environmental factors

I tested whether the variation in the arthropod community distance matrix was related to leaf-litter characteristics using distance-based linear modeling (distLM) (Legendre and Anderson 1999, McArdle and Anderson 2001) and a ranked test for biological-environmental relationships (Bio-Env). DistLM models the variation in the multivariate distance matrix with one or more predictor variables. The model uses the arthropod distance matrix as a linear function of explanatory variables. The Bio-Env test finds combinations of explanatory variables of leaf-litter characteristics that results in a distance matrix that has the strongest ranked relationship with the arthropod response matrix, using Euclidean distance. Prior to running the distLM test the leaf-litter variables were normalized by subtracting the mean and dividing by the standard deviation for each variable (Clarke and Gorley 2006). The statistical significance of distLM terms was determined using 10,000 permutations.

2.2.5.2 Influence of management history on leaf-litter structure and characteristics

Univariate statistical approaches were used to study the influence of management categories on leaf-litter characteristics. This analysis used 106 leaf litter samples from all collection periods to investigate how leaf litter characteristic are influenced by management category [Table 2. (2.2)]. Litter components including total litter weight, leaf litter weight, percent leaf litter cover and LL: FWD ratio were used to look for relationships between land management category and leaf-litter components. ANOVAs, boxplots, and plot of means graphs, were conducted with the R statistical, language (R.Development.Core.Team 2016).

2.3. Results

2.3.1 Arthropod abundance and frequency

A total of 39,765 leaf litter arthropods was collected and identified to 36 taxonomic groups. I removed any taxonomic group that was represented by fewer than ten individuals in the entire study. The remaining arthropods were dominated by springtails (Collembola)

(26,575), ants (5,213), isopods (2,156), spiders (2,141), and beetles (1,664), [Table 3. (2.3)]. The relative abundance of Collembola families and all other taxa are illustrated in [Figures 5. (2.3) and 6. (2.4)].

2.3.2 Influence of data frame manipulation on ecological conclusions (N, N/g, N/ha).

An initial parallel analysis of the three arthropod density data frames revealed similar patterns in the effect of management categories and seasonal variation on the arthropod community at the three increasing site scales (*N*, *N/g*, *N/ha*). A three-factor PERMANOVA found no interactions between management and year or season between the first sampled 24 sites for all three data frame manipulations [Table 4. (2.4)]. After pooling all spring and summer samples together for each site, data showed the effects of management and seasonal variation to be influential on the arthropod community, but no interaction between management and season was found in any of the three new pooled datasets. All datasets demonstrated an influence of seasonality, with summer season being more influential on the arthropod community than the spring.

After pooling all samples together across year and season for each data frame, parallel analysis of the 24-site data frame and the 28-site data frame for each density scale found the 28 sites to persistently produce more visible separation between the three management categories, compared to the original 24 sites [Table 4. (2.4)]. Canonical Analysis of Principle Coordinate (CAP) ordinations revealed that the additional four Managed-REF sites did separate together in ordination space in the 28-site analysis [Figure 7. (2.5)]. The vector overlay with a partial correlation of r > 0.4, revealed that several of the spider families and a few Collembola families might be driving the separation between the Management-REF and the other management categories. Spider families including the Salticidae, Lycosidae, and Theridiidae for the (*N*) density analysis, Gnaphosidae in the (*N/g*) density, and Linyphiidae and Tetragnathidae in the (*N/ha*) density.

The *N/ha* data frame was selected to best represent the arthropod community at a large one-hectare site scale and was thus chosen for further multivariate and univariate analysis. This density measure was selected because it couples the raw density of arthropods in a sample and the leaf litter percent cover found at each subplot. In the selection of where to take litter samples, I choose not to sample in bare ground, but only sampled in areas where litter was found. The *N/ha* multiplies the raw *N*, with the percent cover at each subplot, producing a more accurate representation of the arthropod density on the entire plot.

2.3.3 Effects of management history on arthropod communities at the large site scale (N/ha data frame)

The initial three-factor PERMANOVA of the 24 sites sampled over two years found no interactions between management and year nor season between the first sampled 24 sites (Management x Season x Year: Pseudo $F_{2,95} = 0.753$, $P = 0.869$), (Management x Season: PERMANOVA, Pseudo $F_{2,95} = 1.044$, $P = 0.391$, Management x Year: Pseudo $F_{2,95} = 0.922$, $P = 0.604$). Because no interaction was found, arthropod abundances were averaged across year and season for the initial 24 sites. Because arthropod density was averaged across year and season, the four new Management-REF sites were also averaged across season and aggregated to the 24 sites dataset and analyzed in parallel. This resulted in an initial analysis of the 24 and 28 sites respectively. The 24 sites PERMANOVA found no difference between management categories in the 24-site analysis, but a marginal difference in the 28 sites analysis. (PERMANOVA, Pseudo $F_{2,23} = 1.049$, $P = 0.385$, PERMANOVA, Pseudo $F_{2,27} = 1.360$, $P = 0.068$). The CAP analysis does show a good separation between all three categories, with the new Managed-REF sites aggregating close to each other in the ordination [Figure 8. (2.6)]. The same analysis was run with the management categories (C, Managed-INT, Managed-REF) pooled into two categories, Control and Managed-ALL, with no difference in management category being found [Table 4. (2.4)].

The arthropod community composition did differ between the three management categories before seasonal aggregation, (PERMANOVA, Pseudo $F_{2,95} = 1.5955$, $P = 0.014$), and after (PERMANOVA, Pseudo $F_{2,55} = 1.64$, $P = 0.010$). The post aggregation two-factor PERMANOVA using Management and Season as fixed factors did not find an interaction between the two ($P = 0.106$), but did find managed category and season to be influential on the arthropod assemblages ($P < 0.01$).

A CAP analysis for the 24 and 28 site data frames separated by season (Spring and Summer) shows that the separation of management categories in the 28-site ordination was more prominent in the summer CAP analysis than the spring [Figure 9. (2.7)], a pattern that was seen in several other PERMANOVA tests for the two other data frames (*N*), and (*N/g*) [Table 4. (2.4)].

A distance-based test for homogeneity of multivariate dispersions (PERMDISP) analysis on the 28 sites data frame, using both spring and summer, revealed lower average distance from centroids in Managed-INT (21.11 ± 0.59), than either Managed REF (24.78 ± 1.25) or Control (21.99 ± 0.85), PERMDISP $F_{2,55} = 4.689$, $P = 0.03$. Managed-INT arthropod assemblages appear to be less variable compared to Managed-REF and Control sites.

The data was then analyzed separately by season using permutation pair-wise comparison of the arthropod community. For the spring season, I found no difference in any management category, [Table 9 (2. APPENDIX T.1)]. Only a marginal difference was detected when comparing Control and Managed-INT (*P*=0.087). The pair-wise comparison of the summer dataset showed a clear influence on the arthropod community between Control and Managed-INT (*P* =0.030), Managed-INT and Managed-REF (*P* =0.008) and Control and Managed-REF (*P* =0.029), a pattern that was seen in all three site scales (*N*, *N/g*, and *N/ha*) [Table 9 (2. APPENDIX T.1)].

2.3.4 Effects of prescribed burning on the arthropod community

I found no evidence for an effect of burning treatment on the arthropod community composition. The arthropod community matrix of the two sites with burning events was analyzed separately as burned and unburned samples (2 sites x 2 burning treatments x 2 seasons = 8 samples). A 2 factorial PERMANOVA using burning and season as fixed factors found no interactions between management and season, but did find season to be more influential in interpreting the data than burning treatment alone; burning $F_{1,7}$=1.167 *P* =0.349, season $F_{1,7}$=2.11 *P=0.042*, [APPENDIX Figure 14. (2-A1), 15. (2-A2)]. Although no change in arthropod composition was found between the burning treatments, a 30% decrease of total arthropod abundance was found in the burned sites (1,670) compared to the unburned adjacent sites (2,352), [Table 5. (2.5)].

2.3.5 Effects of management history on leaf litter characteristics (Univariate analysis)

Analysis of the leaf litter characteristics revealed overall similar patterns of change with trends from Control sites to Managed-REF sites. I analyzed 106 litter samples from all 28 sites collected in both spring and summer for all sites [Table 2. (2.2)]. Percent litter cover was not found to be influenced by either management history (*P*= 0.291) or season (*P*=0.279). Analyzing the Control sites alone, I found only a marginal difference in percent cover between spring and summer (P = 0.10), [Figure 10. (2.8)]. However, the percent change in litter cover between spring and summer was largest in the Control (Control: -12.7%, Managed-INT: -2.8% and Managed-REF: -2.7%). Total litter weight, % cover, and leaf litter were not found to be influenced by management history or seasonality within my samples. Fine woody debris was found to be influenced by the three management categories, ANOVA $F_{2,102}$ = 3.426, P = 0.0363 with the Control sites having a larger amount and decreasing downwards toward the Managed-REF sites [Figure 11. (2.9)]. The LL:FWD ratio was also found to increase with management history $F_{2,102}$ = 3.871, P = 0.024 [Figure 12 (2.10)].

The two sites that received prescribed burning treatments during this study were analyzed separately, and changes in leaf litter composition due to the burning events were found. This included a decrease in percent cover, litter weight, and LL: FWD ratio in burned sites compared to unburned adjacent sites. In addition, I found increases in FWD weight in burned sites. (all $P<0.05$) [Figure 13. (2.11). and Table 6. (2.6)].

2.3.6 Effects of leaf litter characteristics on arthropod abundances (Multivariate analysis)

The Bio-Env test suggests several potential combinations of leaf-litter characteristics helpful in postulating mechanisms underlying the correlation of management category with difference in arthropod community structure. The top three had a range between r = 0.35 and r = 0.40, and all combinations included the LL: FWD ratio as a component [Table 7. (2.7)]. DistLM revealed a relationship between several individual litter characteristics and the variation in arthropod community structure assemblages [Table 8. (2.8)]; in total, the leaf litter characteristics explain 21% of the variation in the arthropod assemblages, with total litter weight (all detritus together), explaining the highest percent variation (8%), followed by % cover (4%) and leaf litter alone (3%).

2.4. Discussion

2.4.1 Discussion of data frame manipulation (N, N/g, N/ha)

The initial analysis of the dataset revealed similar overall pattern of conclusions at all 3 data-frame scales. The original hypothesis that the arthropod community may respond to restoration timeframes differently at the litter grab scale (*N*), the numbers per gram of litter (*N/g*), or the overall abundance as a representative of the percent litter cover found at the subplot (*N/ha*), was not supported. This may be a reflection of the arthropod abundance being linked to the grams of detritus found for each sample, and the linkage between the grams of litter and the % litter cover found at each subplot.

The parallel analysis of the 24 and 28 data frames for all three site scales produced a similar pattern in the CAP ordination [Figure 7. (2.5)]. A clear difference between management categories was found using the 28 sites dataset, but not in the 24 site data frame. This may be a result of more Managed-REF sites replicates available to make a more clear distinction between management categories based on the arthropod community. At the 24 site data frame, Managed-REF is only represented by two site replicates, whereas in the 28 sites this is represented by six total Managed-REF sites. This increase of Managed-REF sites could have helped define the arthropod community composition in the Managed-REF sites and created a better differentiation between the categories in multivariate space.

The 28 site ordination with the four new Managed-REF site, suggested the Managed-REF sites were influenced by several Collembola and spider families, both of which are highly influenced by nutrient and habitat heterogeneity. Studies have shown sites previously dominated and altered by introduced plants have at times resulted in the rapid recovery of arthropod assemblages associated with restored habitat characteristics such as live and dead plant biomass (Gratton and Denno 2005). In addition, increased litter depth, which often is associated with restored sites, can help minimize temperature fluctuations, which have been documented to be influential on the spider community by Bultman and Uetz (1982). The increased abundance of Collembola and spiders in this initial analysis may reflect the fact that Management-REF sites may produce a better litter habitat for both fungivorous Collembola and predatory spiders. In addition, an increase in Collembola abundance can result in an increase in spiders, one of the Collembola's main predators.

Although no difference in the conclusion between the three data frames was found, I used the (*N/ha)* data frame as being the best representative of the three which included the arthropod abundance in each litter grab coupled with the % litter cover of the subplot. The (*N/ha)* data frame was used for further analysis of the arthropod assemblage.

2.4.2 Discussion on findings using the (N/ha) litter data frame

The PERMANOVA analysis found the season to be influential on the arthropod composition in many of my analyses, [Table 4. (2.4)]. Because samples were often pooled together if no interaction between management category and season or year was found, I found it appropriate to average all sites across years for each season producing 28 spring and 28 summer samples to better interpret the community composition found in the first set of CAP orientation [Figure 8. (2.6)], which pooled all sites across year and season.

When looking at the entire 28 site dataset, I found an influence of seasonality on the arthropod assemblages. When analyzing the data by season, I found an effect of treatment only in the summer season, and no effect of treatment in spring. The CAP analysis for the 28 sites divided by season [Figure 9. (2.7)], does reveal that this change in community composition between management categories may be more pronounced in the summer season. The CAP overlay identified Carabidae, Coleoptera larvae and several spider families as the driving force of the Managed-REF ordination pattern. Spider families including the Linyphiidae, Theridiidae Corinnidae, and Gnaphosidae were identified as influential taxa in the ordination. This suggests that those taxa are highly influenced by management categories and this influence may be intensified during the late summer season when the litter layer decreases and suitable litter patches become scarcer.

Percent litter cover at all three management categories was always higher in the spring than in the summer [Figure 10. (2.8)]. The lower % litter cover in the summer may explain how this increasingly scarce resource may have a greater impact on the arthropod community in the summer season, compared to the spring. As the summer growing season continues each year, the amount of litter cover decreases as a result of normal litter decomposition of the previous fall litter input. Studies have found that patchiness variation in litter use by arthropods can be based on litter moisture, which can alter arthropod distribution during the dry season (Levings and Windsor 1984). Because arthropods are susceptible to desiccation, this may be one of the driving forces altering the arthropod community composition between our management categories.

Although the analysis of the burned sites was opportunistic, because I did not coordinate with land managers to stop burning or alter their site management regiment, I did seize the opportunity to compare the arthropod community and seasonality between the burned and non-burned patches of our research sites. The findings that seasonality was more influential on the arthropod assemblages than burning treatment was unexpected. This may be a reflection of the short-term impact of burning across the season. I found a 30% decrease in total arthropod in the burned sites, but the assemblage of arthropod was more influenced by seasonality rather and the burning treatment.

The permutational test of homogeneity of dispersion (PERMIDISP) revealed Management-INT arthropod assemblages to be slightly less variable compared to Management-REF and Control. The larger variance in both these categories perhaps reflects more variable communities found in both, which for the Control sites may reflect a combination of both native and invasive arthropod taxa found in disturbed sites. The Management-REF site showed the largest variance which can be reflective of the diverse native communities that now exist in those sites. The low variance in Management-INT sites may be explained by these sites receiving similar management techniques such as brush cutting and litter burning which may produce a less viable community in the first few years of restoration. Recently applied restoration efforts like burning and brush cutting may lower variability in its existing arthropod assemblages, compared to a degraded site. Control sites may have remnants of its native community with the addition of new arthropod assemblages that have an affinity to the disturbance of the site. Although Control had a slightly larger variance than Management-INT, the Control arthropod assemblage was represented by an overall smaller average abundance per sample [Table 3. (2.3)].

2.4.3 Effect of management history on leaf litter characteristics

Although I found no effect of management history on % litter, the marginal difference observed between spring and summer in the control site is suggestive. The findings that Control sites had the largest % cover change (-12.7%) between spring and summer is in line with other studies which suggest that sites with buckthorn invasion may have an increased litter disappearance rate due to higher earthworm density, higher N content in the soil and higher soil moisture (Heneghan et al. 2007, Knight et al. 2007, Madritch and Lindroth 2009). A previous study on the same sites found Control sites had twice as many non-native isopods (detritivores) compared to Managed-REF sites (McCary et al. 2015). This increase in isopod activity density may be a contributing factor for the altered leaf litter changes in Control sites. All of the sites categorized as Control have moderate to severe buckthorn invasion [Table 1. (2.2)].

Control sites had the largest amount of FWD, which may be an artifact of a higher rate of leaf litter decomposition due to the nitrogen-rich buckthorn litter present. Because FWD takes longer to decompose compared to leaf litter, it is not surprising that sites with suggested higher decomposition rates may produce a detritus with a higher proportion of FWD to litter alone. I did find LL: FWD ratio increased with management category, this is a reflection how management can successfully influence this key litter trait, [Figure 12. (2.10), and Table 7 (2.7)].

2.4.4 Relation between leaf litter characteristics and arthropod community structure as revealed by Bio-ENV Test

Bio-ENV test is an exploratory method to identify which explanatory variables correlate to the arthropod dissimilarity matrix. My data showed leaf-litter characteristics were able to explain 20.75% of arthropod ordination. Total litter amount was the most significant single model variable, explaining 8.26% of the variation. Total litter represents all detritus found within a sample this includes leaf litter, FWD, humus, and seeds. It is important to note that total litter was the best model variable to explain the arthropod ordination, which was a better indicator of the arthropod community than % cover [Table 7. (2.7)].

Both the Bio-ENV test and the distance-based linear model found LL: FWD ratio to be highly influential on the arthropod assemblage [Table 7. (2.7) Table 8. (2.8)]. I suggest the use of this ratio as an informative gauge of leaf-litter quality. A decrease in LL: FWD was found in the degraded Control sites, which I believe is a representation of the higher litter disappearance rate due to altered decomposition rates in these sites caused by invasive buckthorn. As restoration progresses in converting degraded sites in to Managed-INT or Managed-REF sites, we see pattern of increased LL:FWD ratios [Figure 12. (2.10)].

2.4.5 Future directions

My findings suggest that woodland restoration and management, which aim primarily at increasing native-plant diversity and removal of introduced plant species, can also restructure the leaf litter layer and leaf litter arthropod community within. In this study, I found a general increase in litter weight, and litter heterogeneity with increased restoration timeframes. Collembola and spider families emerged as key members of the detrital community to be highly influenced by both seasonality and management category.

Several studies have shown how woodland management efforts have had a positive impact in restoring degraded vegetation community. This study proposes the addition of the leaf litter arthropod community as a response variable to woodland restoration efforts. In addition, I also suggest the addition of leaf-litter layer components as restoration response variables. Coupling the leaf-litter layer and the leaf-litter arthropod communities can help land managers better assess a key driving force between the above and below ground community composition in their sites.

2. Acknowledgements

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2. FIGURES

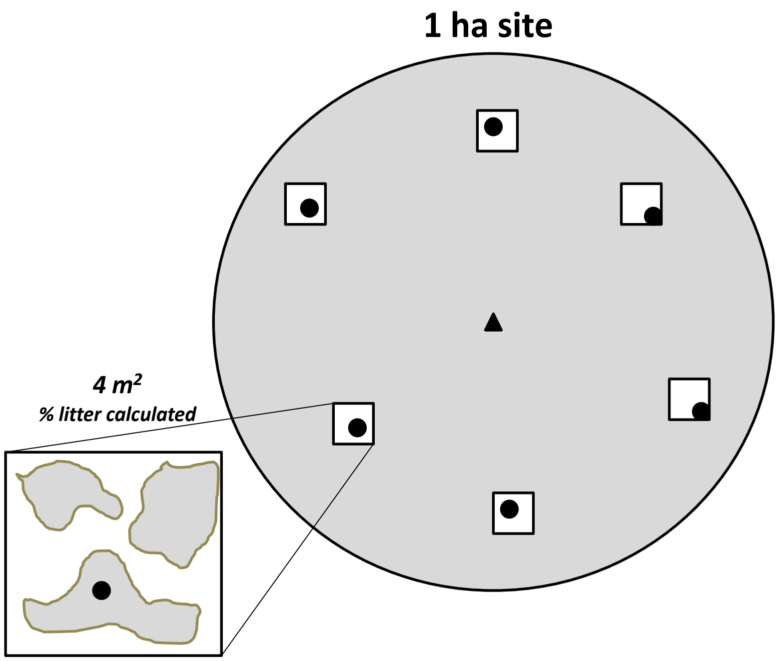


Figure 3. (2.1). Schematic diagram of the distribution of sample sub-plots for each one-hectare site. The percent leaf-litter cover was calculated from each $4m^2$ sub-plot, represented by the white squares ☐; the gray represents visible litter layer within the sub-plot. The $0.05m^2$ litter grabs (n=6), represented by solid circles (●), were taken from the area in the sub-plot that appeared to have the deepest litter layer.

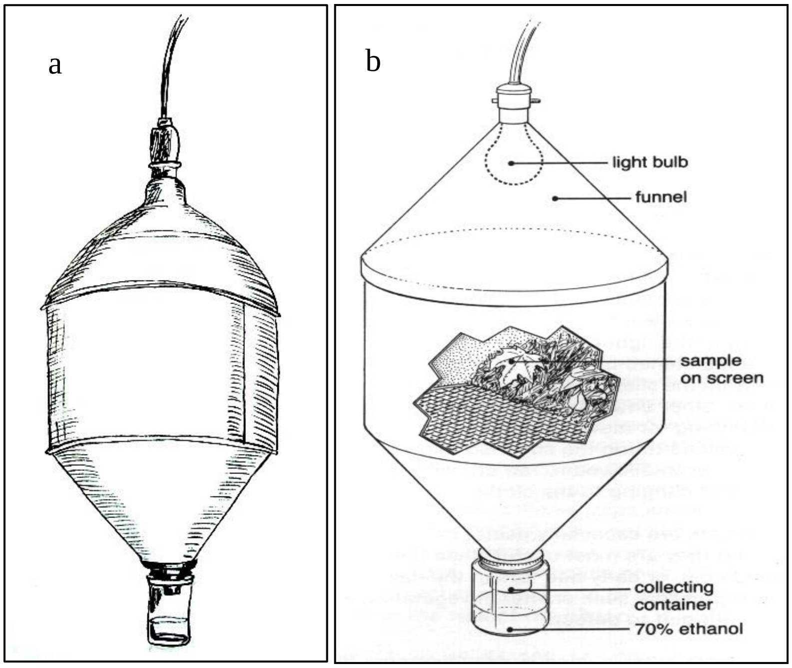


Figure 4. (2.2). Design of the 72 Berlese funnels created to extract arthropods from leaf litter. A collected litter grab was placed in the funnel, and a modified clamp light fixture with a 40w bulb created a heat gradient. The arthropods would move to the bottom of the funnel and fall into a glass jar with 70% ethanol. Illustration 3a. is the rendition of the outside of the Berlese funnel (by Kathlene Powers), figure 3b. is the inside of the funnel illustrating the mesh wire and litter. (USDA.gov).

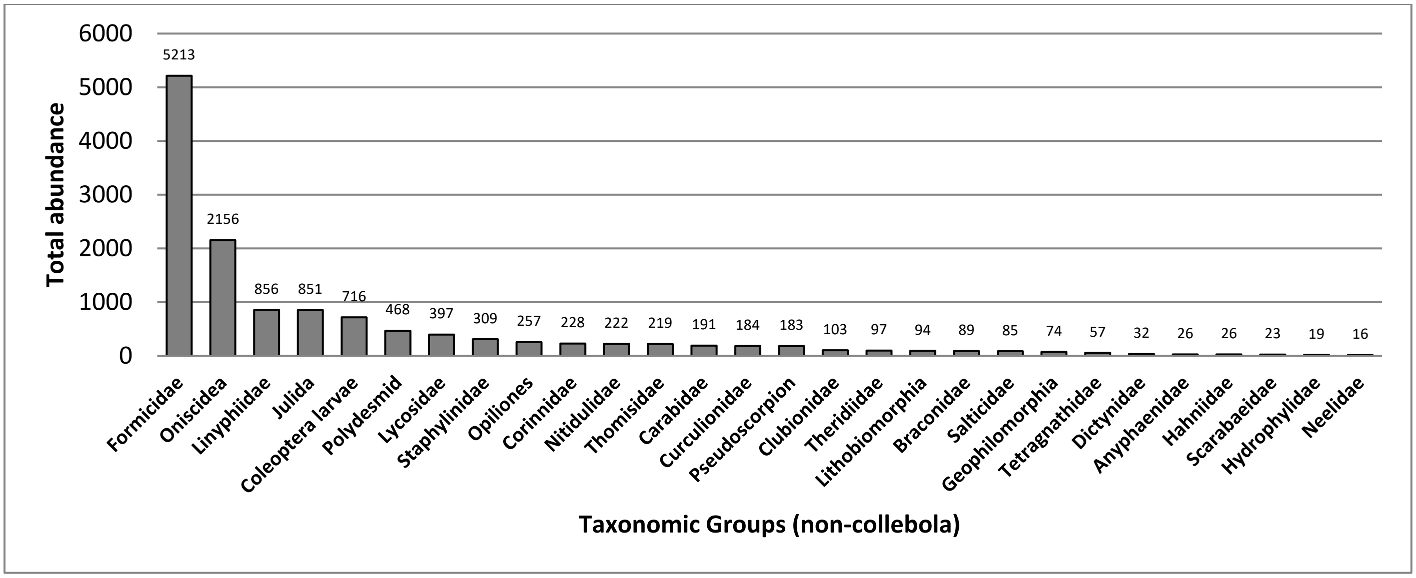


Figure 5. (2.3). Relative abundance of arthropods sampled, excluding the most abundant seven families of Collembolas (see Figure 6. (2.4.)).

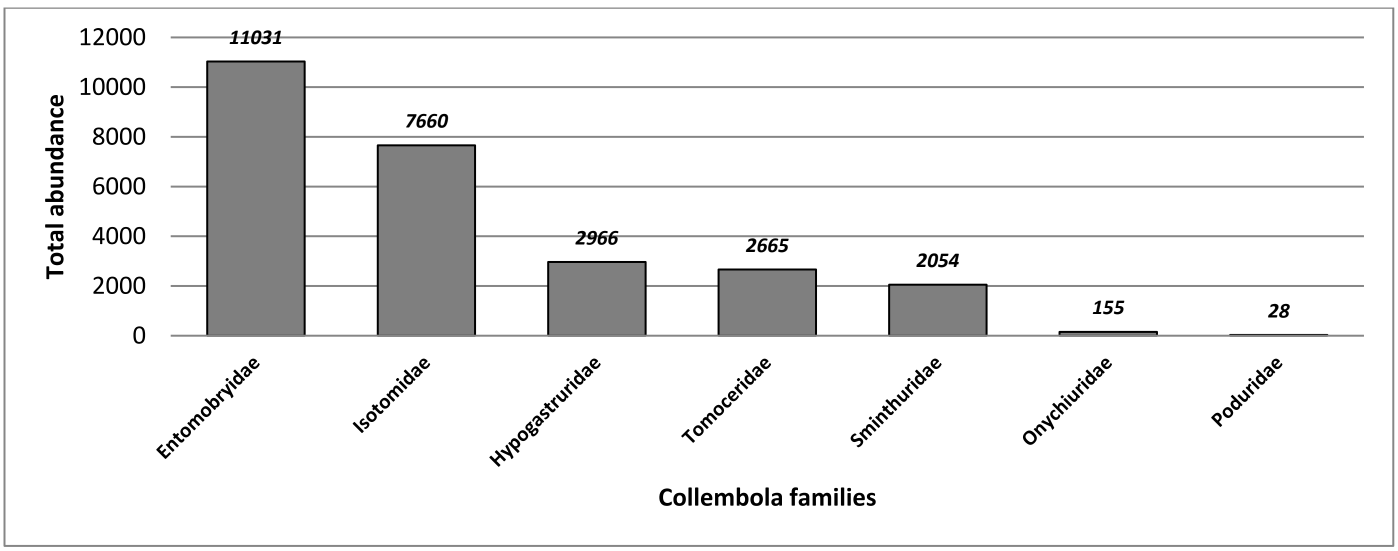
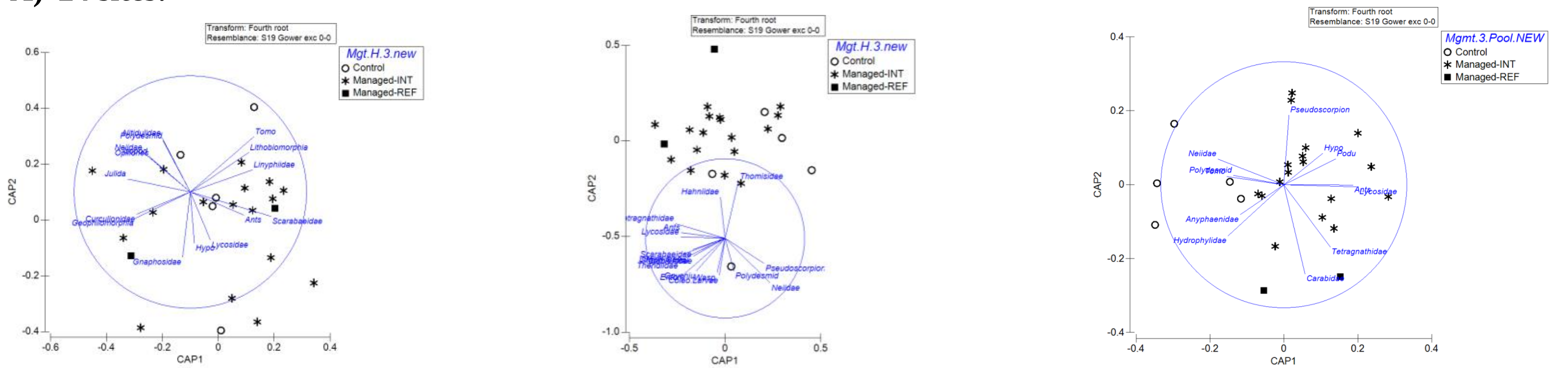


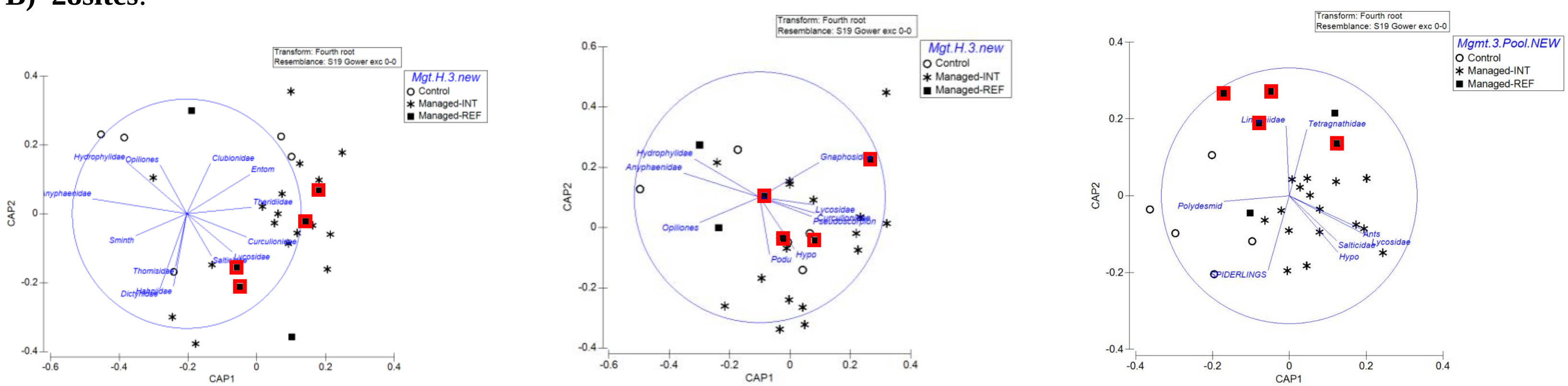
Figure 6. (2.4). Relative abundance of the seven most abundant Collembola families sampled in this study.

A) 24 sites:



N *P(perm)= 0.243* ***N/g*** *P(perm)= 0.0779* ***N/ha*** *P(perm)= 0.385*

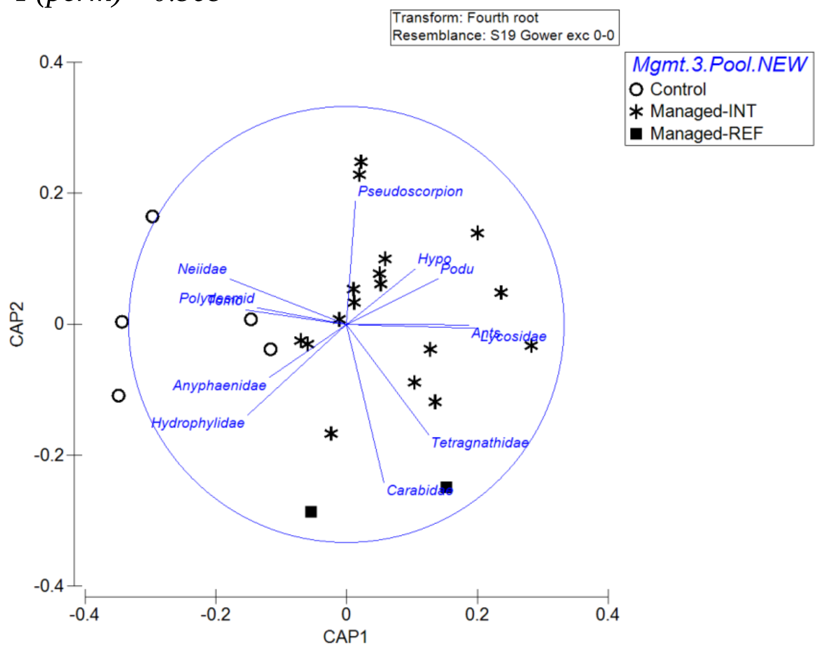
B) 28sites:



N *P(perm)=* ***0.049*** ***N/g*** *P(perm)=* ***0.015*** ***N/ha*** *P(perm)= 0.068*

Figure 7. (2.5). Canonical Analysis of Principal Coordinates (CAP), for arthropod taxonomic groups constrained by management category (Partial Correlation r > 0.4 for Vector overlay), the circle represents r = 1. Each site is represented by one ordination point averaged across year and season for the original 24 sites (A), and the same ordination test with the additional 4 Managed-REF sites averaged a crossed year and season. Red squares (■) represent the additional four reference sites. CAP ordinations are illustrated for all three data manipulation test; abundance (*N*), abundance per gram of litter (*N/g*), and abundance per hectare (*N/ha*). *P(perm)* = permutational *P*-value, with bold being < 0.05.

***A)* 24 sites**, *P(perm)= 0.385*



B) 28 sites, ***P(perm)= 0.068****

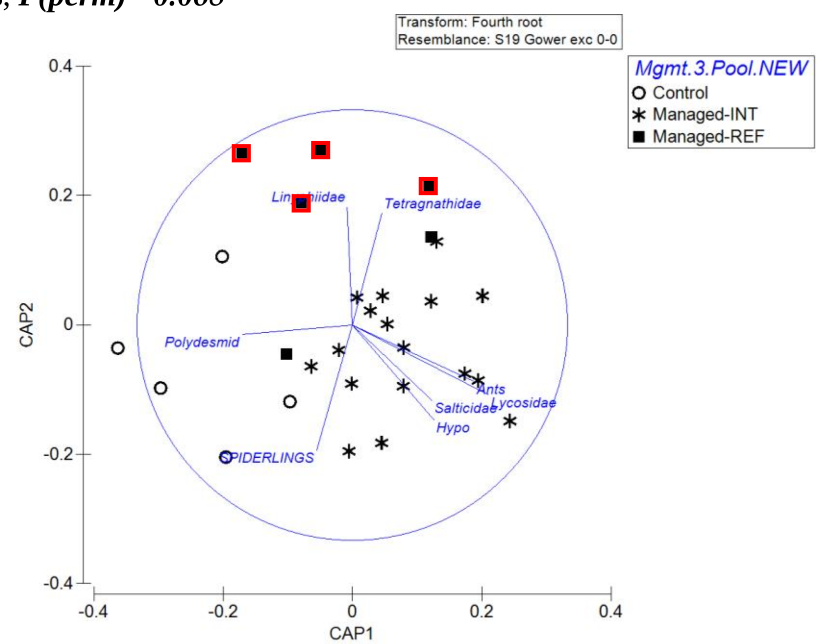
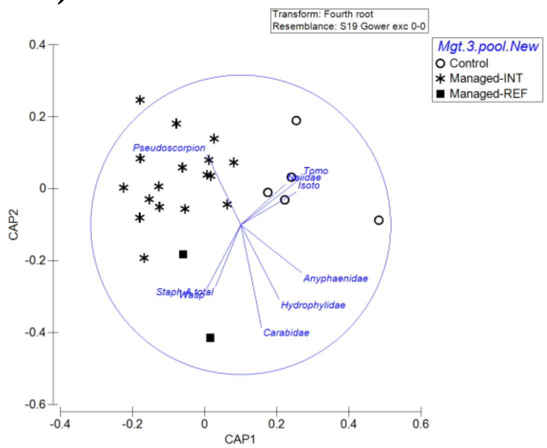
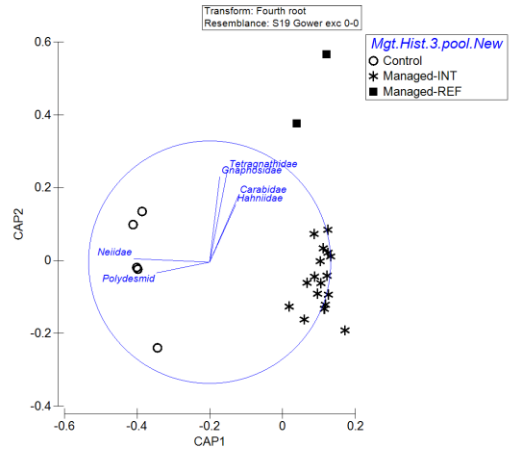


Figure 8. (2.6). Canonical Analysis of Principal Coordinates (CAP), for arthropod taxonomic groups constrained by management category (Partial Correlation r > 0.4 for Vector overlay), the circle represents r = 1. Each site is represented by one ordination point averaged across year and season for the original 24 sites (A), and the same ordination test with the additional 4 Managed-REF sites averaged a crossed year and season. Red squares (■) represent the additional 4 Managed-Ref sites. Ordinations illustrate used the abundance per leaf litter percent cover data (*N/ha*), *P(perm)* = permutational *P*-value.

A) 24 sites

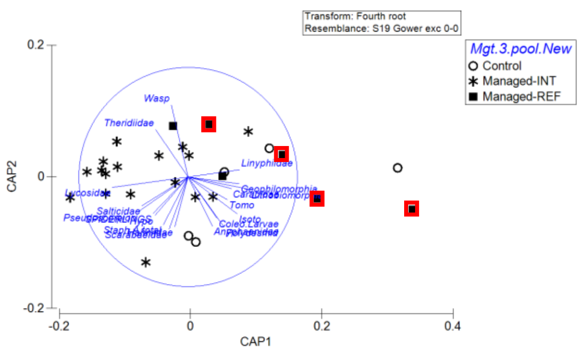


Spr *P(perm)*= 0.270

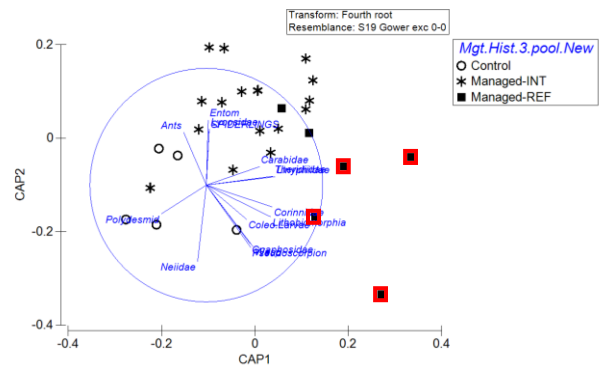


Sum, *P(perm)*= 0.342

B) 28 sites



Spr, *P(perm)*= 0.217



Sum, *P(perm)*= **0.038***

Figure 9. (2.7). Canonical Analysis of Principal Coordinates (CAP), for arthropod taxonomic groups constrained by management category (Partial Correlation r > 0.4 for Vector overlay), the circle represents r = 1. Each site is represented by one ordination point averaged across year, ordination for spring (Spr) and summer (Sum) are illustrated for the original 24 sites (A), and the same ordination test with the additional 4 Managed-REF sites averaged a crossed year. Red squares (■) represent the additional 4 Managed-Ref sites. Ordinations illustrate used the abundance per leaf litter percent cover data (*N/ha*), *P(perm)* = permutational *P*-value.

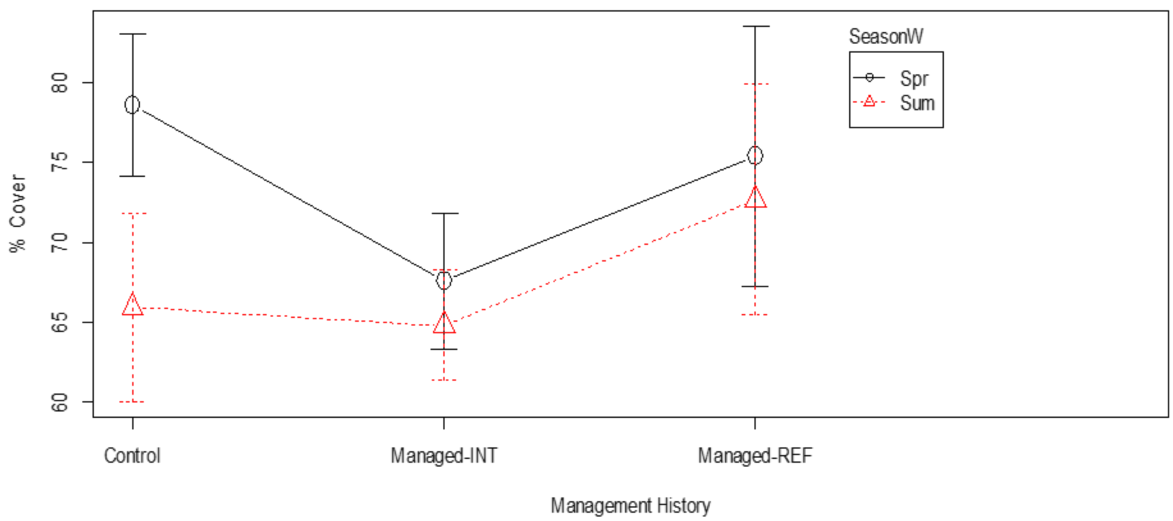


Figure 10. (2.8). The plot of mean graph, with percent litter cover, found in each of the three site management categories. Data is illustrated by season, Sum = Summer and Spr = Spring, whiskers = standard error. Percent litter cover was not found to be influenced by either management history (*P= 0.291*) nor season (*P=0.279*).

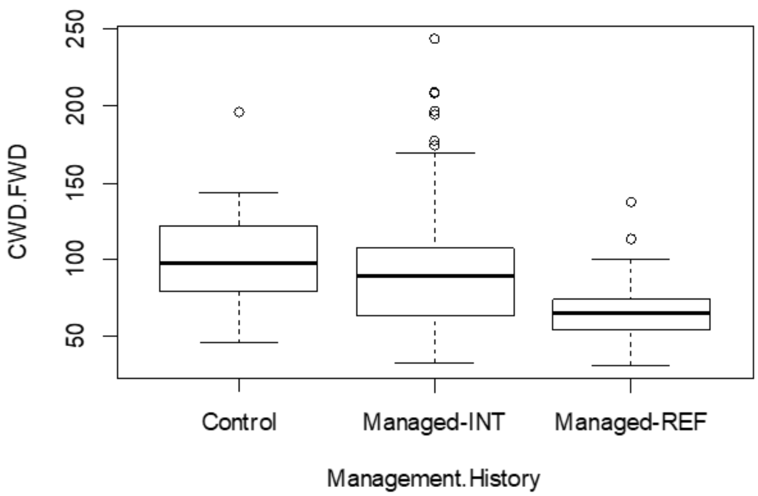


Figure 11. (2.9). Influence of management categories on fine woody debris (FWD) weight in grams, illustrated as a box plot. The boxplot's horizontal line shows the median FWD weight in grams. The bottom and top of the box show the 25th and 75th percentiles respectively. The whiskers on the boxplot show the range, with outliers illustrated in open circles.

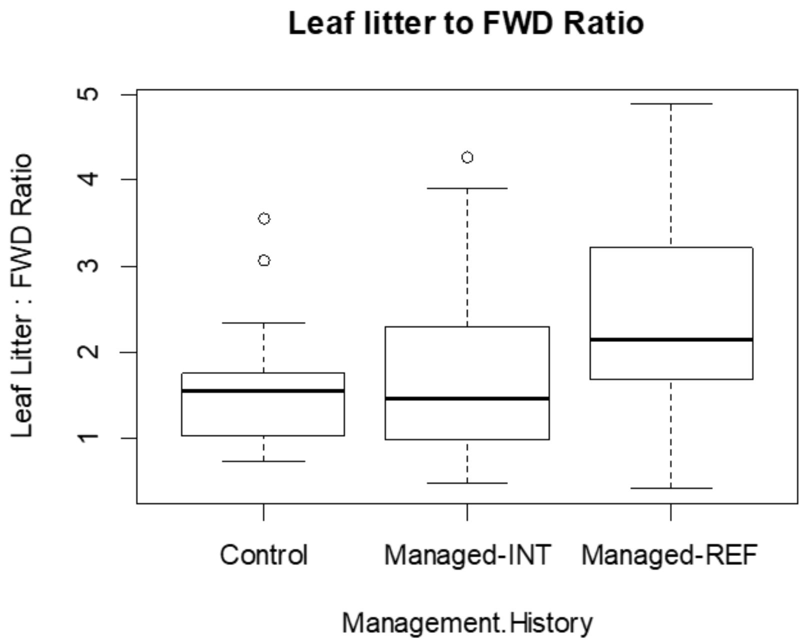


Figure 12. (2.10). Influence of management categories on leaf litter to fine woody debris ratio (LL: FWD), illustrated by season, Sum = Summer and Spr = Spring, whiskers = standard error. The ratio is illustrated as a box plot. The boxplot's horizontal line shows the median and the bottom and top of the box show the 25th and 75th percentiles respectively. The whiskers show the range, with outliers illustrated in open circles.

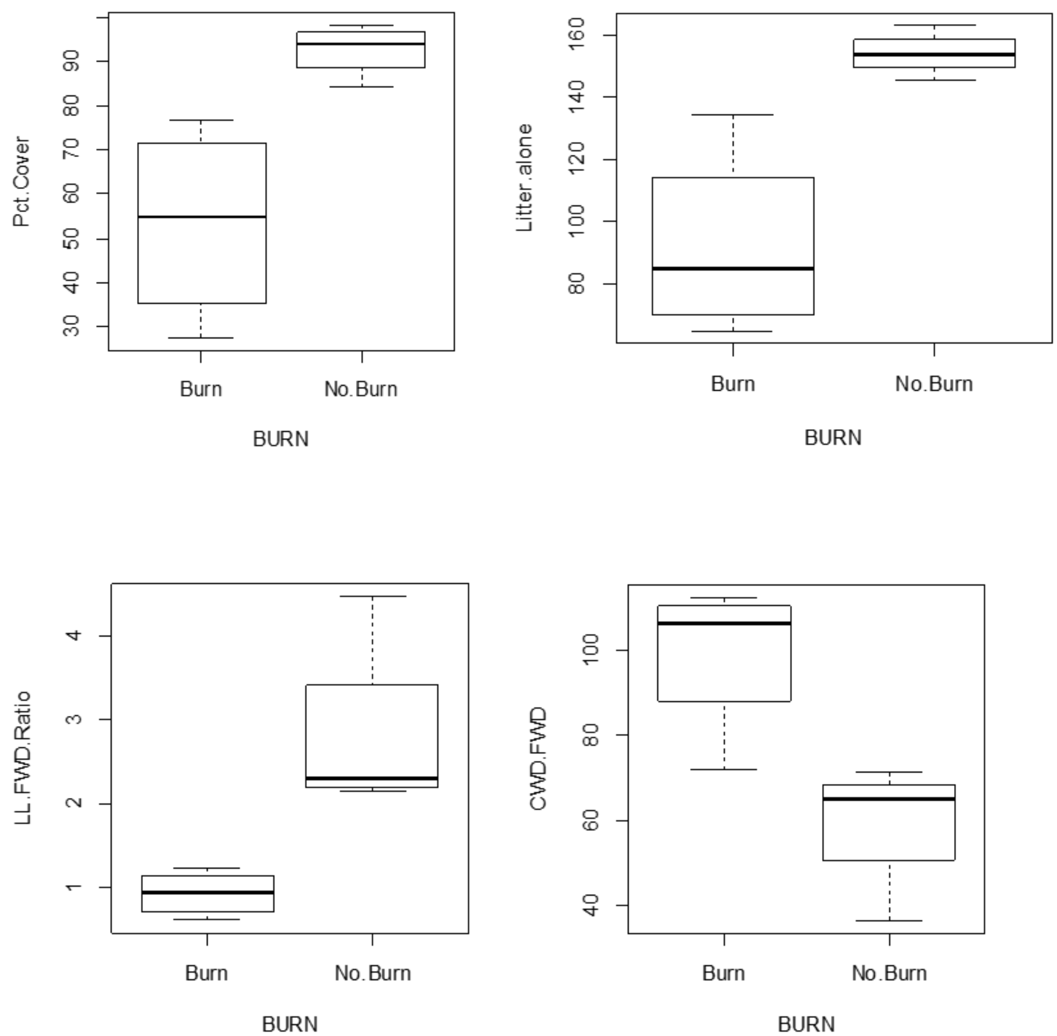


Figure 13. (2.11). Boxplot of the influence of prescribed burning on litter characteristics including; Percent over (Pct.cover), Litter weight (Litter.alone), leaf litter to fine woody debris ratio (LL: FWD.Ratio) and fine woody debris weight (g) (CWD.FWD). The boxplot's horizontal line shows the median and the bottom and top of the box show the 25th and 75th percentiles respectively. The whiskers show the range, with outliers illustrated in open circles.

2. TABLES

Table 1. (2.1). List of the 28 sites sampled including management category, names, location, soil texture, and vegetation summary. Modified from McCary et al. (2015).

	Site	Coordinates	Soil texture	Vegetation summary
Control (n=5)				
	Old School 1	42. 16'32.31"N 87.55'36.02"W	Clay Loam	Mature *Quercus rubra* (red oak) and *Quercus alba* (white oak) canopy. *Rhamnus cathartica* (buckthorn) is present but not dense. Other shrubs include *Crataegus* spp. (hawthorn), *Carya* spp. (hickory), and *Ulmus americana* (elm). Herbaceous layer of mostly buckthorn seedlings, hickory, and *Lonicera* spp. (honeysuckle). Minimal detritus present
	WFG Northgate Woods	41°43'27.49"N 87°58'56.01"W	Silty Clay Loam	Canopy of some mature hickory, red and white oak Shrub layer is very dense, which is dominated by buckthorn and honeysuckle. There appears to also be an early invasion of *Fraxinus* spp. (ash). There is very little leaf litter present
	WFG South Central	41°41'47.57"N 87°58'31.12"W	Clay Loam	Red oak-dominated canopy. Some buckthorn and elm – not too heavily invaded though. Herbaceous layer of ash seedlings, buckthorn seedlings, *Polygonum* spp. (knotweed) and sparse weeds.Detritus and fallen oak branches present
	WM Highlake Savanna	41°52'32.75"N 88°10'17.93"W	Clay Loam	White oak, *Prunus* spp. (cherry), and some red oak canopy. Very heavy buckthorn invasion, with *Rosa* spp. (multiflora rose) and honeysuckle also present in the shrub layer. Some weedy species in the herbaceous level. There is a fair amount of detritus present
	GP Sladkey East	42° 25' 50.9"N 88°18' 6.8"W	Clay Loam	Invaded by honeysuckle and buckthorn. Mature *Quercus macrocarpa* (Burr oak) canopy. Old walkway with herbaceous layer. No herbs in invaded area. Little leaf litter present

Managed-INT (n=17)				
	Ethel Woods 1	42. 27'27.28"N 87.59'54.82"W	Silty Clay Loam	White oak and *Carya ovata* (Sharkbark hickory) canopy. Shrub layer mostly ovate saplings. Herbaceous layer covered with rose, *Solidago* spp. (goldenrod), *Ageratina altissima*, *Aster* spp., and *Rudbeckia* spp. A good amount of detritus present
	Ethel Woods 2	42.27'22.4"N 87.59"34.62"W	Silty Clay Loam	White oak and Sharkbark hickory canopy. Shrub layer is mostly hickory saplings. Herbaceous layer covered with goldenrod, rose, *Ageratina altissima*, *Aster* spp., and *Rudbeckia* spp. Detritus present Mature burr oak canopy with a lot of invasive
	GP DeCarlo	42°24'49.39"N 88°19'40.43"W	Clay Loam	Mature burr oak canopy with a lot of invasive shrubs. Rose, buckthorn, *Populus* spp. (cottonwood), honeysuckle all abundant. Small amount of detritus is present
	West DuPage Woods	41°52'14.10"N 88°11'20.36"W	Silty Clay Loam	White oak canopy with some cherry. Shrub layer also includes buckthorn and a lot of rose. Buckthorn seedlings, goldenrod, and *Aster* spp. make up the herbaceous layer. Not much detritus
	WFG Cemetery Ridge	41°41'57.41"N 87°59'5.89"W	Silty Clay Loam	Canopy of burr oak, younger red and white oak, and ash. Minimal amount of shrubs. Solid herbaceous layer: goldenrod, *Carex* spp., and *Aster* spp. A good amount of litter cover
	MacArthur Woods	42.14'42.38"N 87.55'39.54"W	Silty Clay Loam	Mature white oak canopy. *Tilia* spp. and *Acer* spp. (maple) shrub layer. Good herbaceous layer with lots of young knotweed. Minimal detritus, some dead buckthorn stems
	Old School 2	42.16'16.53"N 87.55'13.7"W	Silty Clay	Mature red and white oak canopy. Buckthorn is present but is not dense. Other shrubs include hawthorn, hickory, and elm. No herbaceous layer but numerous buckthorn, hickory, and honeysuckle seedlings. Not much detritus
	GP Sladkey West	42°25'50.62"N 88°18'11.44"W	Clay Loam	Canopy of Shagbark hickory, bur oak with a large herbaceous cover, some buckthorn, honeysuckle and rose found (Authors's input)
	GP Weidrich	42° 24' 56.7"N 88°19' 21.5"W	Loam	Mature burr oak canopy. Invaded by honeysuckle and buckthorn. Old walkway with herbaceous layer. No herbs in invaded area. Some remaining dead tree stumps left

			behind from management activities This site has a lot of topography with a burr oak, white oak, and some hickory canopy. *Cornus* spp. (dogwood) shrubs. Some early invasion by buckthorn. Thick herbaceous layer and a fair amount of detritus
WFG Old Glen Woods	41°42'59.63"N 87°57'35.35"W	Silty Clay Loam	Canopy of burr, white, and red oak. Good mature tree cover. Shrubs of hickory, cherry, buckthorn (sparse but mature.) A lot of rose and grasses make up the herbaceous layer. Good amount of detritus present
WFG Poverty Savanna	41°41'26.29"N 87°59'39.57"W	Silty Clay Loam	Red and white oak, hickory, *Juglans nigra* (walnut) canopy. Minimal amount of shrubs. Thick herbaceous layer of goldenrod, rose, and *Aster* spp. A fair amount of leaf litter
WFG Rocky Glen	41°42'6.57"N 87°57'55.97"W	Clay Loam	Hickory, maple, and elm-dominated canopy. Honeysuckle and some buckthorn make up a dense shrubby layer. Herbaceous layer is barely present
Maple woods	41° 47'27.59"N 88°1'28.50"W	Silty Clay Loam	Maple dominant canopy with a few Red Oaks present. Shrub layer of maples, some honeysuckle, elm, ash, and pockets of buckthorn. Herbaceous layer minimal. Some Oak regeneration. Wild ginger and garlic mustard present.
Elm Road	42°12'52.02"N 87°54'49.52"W	Silt Loam	Mature red & white Oak canopy. Elm, Hickory, Cherry thick understory. Other vegetation: Geum, Polygonum, Tickweed, Toxicodendron radicans, Asters, Solidago. Some new buckthorn.
Middlefork W1	42°14'55.36"N 87°53'4.77"W	Clay Loam	Mature swamp white oaks, some red oak, shrubs look like they were managed with a sepi w/ remaining mulch on ground. Lots of raspberry. Stake is located in shrubby area - possibly reinvasion?
Pleasant Valley	42°14'18.70"N 88°27'15.22"W	Silt Loam	Very open canopy with mature oaks (white, black and burr) as well as shagbark hickory. Thick herbaceous layer with thick leaf litter present. (Cristian's Input)
Grassy Lake	42°12'28.65"N 88°10'21.52"W	Silt Loam	Mature burr oak, hickory, and elm. Minimal shrub layer. Solidago present. Minimal invasion by *Rhamnus cathartica* except for a few invation pockets under gaps in the canopy.

Managed-REF (n=6)				
	Fischer Woods	41°56'04.5"N 87°57'36.4"W	Silty Clay Loam	Dominated by a *Quercus velutina* (black oak) canopy (a full and mature canopy), with rose, hickory, elm, *Ostrya virginiana*, and *Tilia Americana* present. The understory is open, with many herbaceous plants. A fair amount of oak litter present
	Housier's Grove	41°58'43"N 88°11'33"W	Silty Clay Loam	Dominated by white oak, rose, and *Prunus serotina*. Diverse understory with many herbaceous species. Mature canopy and a dense leaf-litter layer
	Meacham Grove	41°57'50.10"N 88°5'10.30"W	Silty Clay Loam	Canopy, which is full and mature, is dominated by *Acer saccharum* (sugar maple), *Tilia americana*, and *Ostrya virginiana*. No shrub layer, understory very open. Moderate amount of leaf litter present
	Middlefork W3	42°15'10.65"N 87°53'10.96"W	Clay Loam	Very open canopy with mature oaks (namely white oak) with a lot of high-quality herbaceous species in understory. No or very little leaf litter
	Ryerson	42°10'51.24"N 87°54'35.73"W	Silty Clay Loam	Mature and full white oak canopy. Shrub layer of sugar maple and cherry. Herbaceous layer is almost non-existent –only some seedlings of sugar maple, cherry, and ash. Extremely dense leaf-litter layer (most dense layer of all sites), mainly consisting of white oak litter
	Paw Paw	41°43'08.3" N 87°53'02.6 W	Silt Loam	Dense canopy made up of red and white oaks. Very thick layer of leaf litter (Authors input from images)

Table 2. (2.2). Total number of sites sampled for each management category and the times each was sampled. Each period represents one summer and one spring. The addition of four restoration sites in the spring of period two is also included (+ 4). The summation of total number sampled for the spring and summer, including litter samples collected at all sites, is listed.

Management Category	Period #1		Period #2		Period #3	Total in Spring	Total in Summer
	Summer 2009	Spring 2010	Summer 2010	Spring 2011	Summer 2011		
Control	5	5	5	5		5	5
Managed-INT	17	17	17	17		17	17
Managed-REF	2	2	2	2 (+4)	2 (+4)	6	6
Total Sites	24	24	24	24 (+4)	2 (+4)	28	28
Litter samples	24	24	24	28	6		

Table 3. (2.3). The mean and total abundance of leaf litter arthropods sampled in this study. Taxa are represented by management category of each site. Taxa are listed in alphabetical order within its class or order and are labeled into functional groups.

			Mean invertebrates at sites			Total
			Control	Managed-INT	Managed-REF	
Class/Order	Family	Functional Group	Mean, *n*=5	Mean, *n*=17	Mean, *n*=6*	
Araneae						
	Anyphaenidae	Predator	0.70	0.12	0.11	26
	Clubionidae	Predator	0.20	1.18	0.11	103
	Corinnidae	Predator	1.45	1.85	3.44	228
	Dictynidae	Predator	0.20	0.32	0.33	32
	Gnaphosidae	Predator	0.20	0.10	0.22	15
	Hahniidae	Predator	0.00	0.28	0.39	26
	Linyphiidae	Predator	6.15	7.29	9.56	856
	Lycosidae	Predator	1.20	4.44	3.50	397
	Salticidae	Predator	0.15	1.07	0.50	85
	Tetragnathidae	Predator	0.15	0.35	1.50	57
	Theridiidae	Predator	0.30	0.91	1.28	97
	Thomisidae	Predator	0.05	0.04	0.00	219
Collembola						
	Entomobryidae	Fungivore	55.30	103.94	106.39	11031
	Hypogastruridae	Fungivore	22.15	32.03	16.17	2966
	Isotomidae	Fungivore	83.95	63.59	78.22	7660
	Onychiuridae	Fungivore	0.65	1.99	0.28	155
	Poduridae	Fungivore	0.00	0.41	0.00	28
	Sminthuridae	Fungivore	19.20	19.53	18.33	2054
	Tomoceridae	Fungivore	37.00	21.28	23.78	2665
	Neelidae	Fungivore	0.50	0.06	0.11	16
Coleoptera						
	Carabidae	Predator	1.60	1.35	3.56	191

	Curculionidae	Herbivore	1.10	2.06	1.22	184
	Hydrophylidae	Predator	0.50	0.01	0.44	19
	Nitidulidae	Herbivore	2.05	2.10	1.83	222
	Scarabaeidae	Herbivore	0.15	0.25	0.17	23
	Staphylinidae	Predator	2.40	3.09	2.39	309
	Coleoptera larvae	Multi-functional	6.25	5.26	11.94	716
Chilopoda						
	Lithobiomorphia	Predator	0.65	0.82	1.33	94
	Geophilomorphia	Predator	0.70	0.62	0.94	74
Diplopoda						
	Julida	Detritivore	8.15	7.41	9.89	851
	Polydesmid	Detritivore	8.55	3.37	3.78	468
Opiliones						
	Opiliones	Predator	2.20	2.59	1.83	257
Hymenoptera						
	Formicidae	Omnivore	24.15	61.35	25.67	5213
	Braconidae	Predator	0.40	0.62	2.28	89
Isopoda						
	Oniscidea	Detritivore	17.35	21.59	17.17	2156
Pseudoscorpiones						
	Pseudoscorpion	Predator	1.00	1.37	3.61	183
					Total:	39,765

Table 4 (2.4). Results of the permutational analysis of variance (PERMANOVA) used to assess the arthropod response to Management category (Mgt), season (Se) and year (Ye). Control (C), Management-INT (Mgt-I), and Management-REF (Mgt-Ref). Data were analyzed using three data manipulations including raw abundance (*N*), abundance per gram of leaf litter (*N/g*), and abundance per hectare (*N/ha*). Data was first analyzed with the first 24 sites over 2 years and 2 seasons, (24 x 2 x 2 = 96 samples); data were then averaged across years for each season for the first 24 sites, Spr(24), Sum(24). The additional 4 sites of year two were added and also averaged across for each season Spr(28), Sum(28). I averaged all sites across year and season for both the 24 sites (total = 24) and 28 sites (total = 28). The permutational results for each management categories are also given for the 3 management categories (C, Mgt-I, Mgt-Ref), and 2 management categories pooled (C, Managed). All PERMANOVAs used 10,000 permutations and used Gowers S19 (excluding double zeros) distance measure, (*df*) = degrees of freedom *P(perm*) = permutational ***P* value**.

	96n		**Spr(24)**		**Sum(24)**		**Spr(28)**		**Sum(28)**		**Total(24)**		**Total(28)**	
PERMANOVA test	*df*	*P(perm)*	*df*	*P(perm)*	*df*	*P(perm)*	*df*	*P(perm)*	*df*	*P(perm)*	*df*	*P(perm)*	*df*	*P(perm)*
N														
Management 3 (C, Mgt-I, Mgt-Ref)	2	**0.005**	2	0.249	2	0.251	2	0.131	2	**0.001**	2	0.243	2	**0.049**
Season	1	**0.039**												
Year	1	**0.000**												
Mgt * Se	2	0.594												
Mgt * Ye	2	0.498												
Se * Ye	1	**0.006**												
Mgt * Se * Ye	2	0.734												
Res	84		21		21		2		2		21		25	
Total	95		23		23		25		25		23		27	
Management 2 (C, Managed)	1	**0.001**	1	0.076	1	**0.019**	1	0.394	1	**0.008**	1	**0.045**	1	**0.053**
Season	1	**0.040**												
Year	1	**0.000**												
Mgt * Se	1	0.965												
Mgt * Ye	1	0.439												
Se * Ye	1	**0.003**												
Mgt * Se * Ye	1	0.516												
Res	88		22		22		1		1		22		26	
Total	95		23		23		26		26		23		27	

	96n		Spr(24)		Sum(24)		Spr(28)		Sum(28)		Total(24)		Total(28)	
PERMANOVA test	*df*	*P(perm)*	*df*	*P(perm)*	*df*	*P(perm)*	*df*	*P(perm)*	*df*	*P(perm)*	*df*	*P(perm)*	*df*	*P(perm)*
N/g														
Management 3 (C, Mgt-I, Mgt-Ref)	2	**0.008**	2	0.292	2	0.487	2	**0.012**	2	**0.004**	2	0.0779	2	**0.015**
Season	1	**0.000**												
Year	1	**0.000**												
Mgt * Se	2	0.749												
Mgt * Ye	2	0.787												
Se * Ye	1	**0.004**												
Mgt * Se * Ye	2	0.855												
Res	84		21		**21**		2		2		21		25	
Total	95		23		23		25		25		23		27	
Management 2 (C, Managed)	1	**0.001**	1	0.090	1	0.055	1	0.548	1	**0.030**	1	**0.049**	1	0.078
Season	1	**0.000**												
Year	1	**0.000**												
Mgt * Se	1	0.980												
Mgt * Ye	1	0.715												
Se * Ye	1	**0.001**												
Mgt * Se * Ye	1	0.602												
Res	88		22		22		1		1		22		26	
Total	95		23		23		26		26		23		27	
N/ha														
Management 3 (C, Mgt-I, Mgt-Ref)	2	**0.014**	2	0.270	2	0.342	2	0.217	2	**0.002**	2	0.385	2	0.068
Season	1	**0.000**												
Year	1	0.093												
Mgt * Se	2	0.391												
Mgt * Ye	2	0.604												
Se * Ye	1	**0.008**												
Mgt * Se * Ye	2	0.869												
Res	84		21		21		25		25		21		25	
Total	95		23		23		27		27		23		27	

	96n		Spr(24)		Sum(24)		Spr(28)		Sum(28)		Total(24)		Total(28)	
PERMANOVA test	*df*	*P(perm)*	*df*	*P(perm)*	*df*	*P(perm)*	*df*	*P(perm)*	*df*	*P(perm)*	*df*	*P(perm)*	*df*	*P(perm)*
Management 2 (C, Managed)	1	**0.005**	1	0.104	1	**0.053**	1	0.478	1	**0.038**	1	0.113	1	0.213
Season	1	0.116												
Year	1	**0.000**												
Mgt * Se	1	0.865												
Mgt * Ye	1	0.380												
Se * Ye	1	**0.005**												
Mgt * Se * Ye	1	0.796												
Res	88		22		22		26		26		22		26	
Total	95		23		23		27		27		23		27	

Table 5. (2.5). Total and mean leaf litter arthropod abundance at burned and adjacent unburned sites.

			Total invertebrates at sites					
			Burn			No Burn		
			Spring	Summer	Site Avg.	Spring	Summer	Site Avg.
Class/Order	Family	Functional Group	*n*=2	*n*=2	*n*=4	*n*=2	*n*=2	*n*=4
Araneae								
	Anyphaenidae	Predator	0.0	0.0	0.0	0.0	0.0	0.0
	Clubionidae	Predator	0.0	1.0	1.0	0.0	1.0	1.0
	Corinnidae	Predator	2.0	11.0	13.0	2.0	7.0	9.0
	Dictynidae	Predator	1.0	0.0	1.0	2.0	2.0	4.0
	Gnaphosidae	Predator	0.0	0.0	0.0	0.0	0.0	0.0
	Hahniidae	Predator	0.0	1.0	1.0	0.0	2.0	2.0
	Linyphiidae	Predator	36.0	26.0	62.0	23.0	48.0	71.0
	Lycosidae	Predator	6.0	4.0	10.0	0.0	1.0	1.0
	Salticidae	Predator	0.0	0.0	0.0	0.0	1.0	1.0
	Tetragnathidae	Predator	0.0	0.0	0.0	0.0	1.0	1.0
	Theridiidae	Predator	3.0	3.0	6.0	4.0	1.0	5.0
	Thomisidae	Predator	0.0	0.0	0.0	0.0	0.0	0.0
Collembola								
	Entomobryidae	Fungivore	756.0	125.0	881.0	825.0	196.0	1021.0
	Hypogastruridae	Fungivore	17.0	10.0	27.0	17.0	62.0	79.0
	Isotomidae	Fungivore	318.0	29.0	347.0	574.0	29.0	603.0
	Onychiuridae	Fungivore	0.0	0.0	0.0	0.0	0.0	0.0
	Poduridae	Fungivore	0.0	0.0	0.0	0.0	0.0	0.0
	Sminthuridae	Fungivore	42.0	1.0	43.0	21.0	11.0	32.0
	Tomoceridae	Fungivore	4.0	28.0	32.0	144.0	41.0	185.0
	Neelidae	Fungivore	0.0	0.0	0.0	1.0	0.0	1.0
Coleoptera								
	Carabidae	Predator	7.0	4.0	11.0	9.0	3.0	12.0

	Curculionidae	Herbivore	3.0	0.0	3.0	7.0	0.0	7.0
	Hydrophylidae	Predator	0.0	0.0	0.0	0.0	0.0	0.0
	Nitidulidae	Herbivore	0.0	5.0	5.0	0.0	6.0	6.0
	Scarabaeidae	Herbivore	0.0	0.0	0.0	2.0	0.0	2.0
	Staphylinidae	Predator	1.0	7.0	8.0	1.0	5.0	6.0
	Coleoptera larvae		29.0	2.0	31.0	28.0	17.0	45.0
Chilopoda								
	Lithobiomorphia	Predator	1.0	1.0	2.0	1.0	3.0	4.0
	Geophilomorphia	Predator	3.0	0.0	3.0	4.0	0.0	4.0
Diplopoda								
	Julida	Detritivore	13.0	5.0	18.0	9.0	5.0	14.0
	Polydesmid	Detritivore	0.0	2.0	2.0	16.0	27.0	43.0
Opiliones								
	Opiliones	Predator	1.0	2.0	3.0	4.0	1.0	5.0
Hymenoptera								
	Formicidae	Omnivore	94.0	8.0	102.0	50.0	36.0	86.0
	Braconidae	Predator	2.0	6.0	8.0	0.0	1.0	1.0
Isopoda								
	Oniscidea	Detritivore	23.0	19.0	42.0	22.0	65.0	87.0
Pseudoscorpiones								
	Pseudoscorpion	Predator	2.0	6.0	8.0	3.0	11.0	14.0
		TOTAL:	1364.0	306.0	1670.0	1769.0	583.0	2352.0

Table 6. (2.6). Average leaf litter characteristics for sites that had prescribed burning during this study. Characteristics include percent litter cover (% Litter Cover), leaf litter weight, fine woody debris weight (FWD), and leaf litter to fine woody debris ratio (LL: FWD ratio), all weights in grams (g).

	Burn			No Burn		
	Spring *n*=2	Summer *n*=2	Site Avg. *n*=4	Spring *n*=2	Summer *n*=2	Site Avg. *n*=4
% Litter Cover	52.1%	55.0%	53.5%	91.3%	94.1%	92.7%
Leaf Litter (g)	79.4	104.9	92.2	158.6	149.5	154.0
FWD (g)	108.4	90.5	99.4	50.9	68.2	59.5
LL: FWD ratio	165.3	16.7	181.9	79.3	36.7	116.0

Table 7. (2.7). Results of Bio-Env analysis showing the best leaf-litter environmental variables predicting the abundances of litter arthropod community. The abbreviations of the variables are as follows: Percent litter cover at site (% cover), Leaf litter alone (Litter), Fine woody debris (FWD), ratio of leaf litter and fine woody debris: (LL: FWD), weight of both leaf litter and identifiable humus (Litter + humus).

Best potential models	*Sample statistic*	*Significance level*
% Cover + Litter + LL:FWD	**0.402**	**0.01%**
% Cover + LL:FWD	**0.392**	
Litter + LL:FWD	**0.353**	
% Cover + Litter + FWD + LL:FWD	0.341	
% Cover + Litter + (Litter + humus) + LL:FWD	0.338	
% Cover + (Litter + humus) + LL:FWD	0.337	
LL:FWD	0.336	
Total weight + % Cover + Litter + LL:FWD	0.336	

Table 8. (2.8). Results of the Distance-Based linear model (Marginal tests) of leaf litter characteristics and their correlation to arthropod assemblages. The abbreviations of the variables are as follows: Total weight of all detritus collected (Total litter), percent litter cover at site (%cover), Leaf litter alone (Leaf litter), Seeds, Fine woody debris (FWD), leaf litter to fine woody debris ratio: (LL:FWD), weight of both leaf litter and identifiable humus (Litter + humus).

Model Variable	*SS(trace)*	*Pseudo-F*	*P-value*	*Prop.*	*% Variation explained*	*Cumulative % Variation explained*
Total litter	864.94	1.6219	**0.0363**	0.0292	8.26	8.26
% Cover	2204.3	4.3349	**0.0001**	0.0743	3.75	12.01
Leaf litter	1591.8	3.0621	**0.0001**	0.0537	3.08	15.09
Seeds	660.18	1.2292	0.2071	0.0223	1.89	16.98
FWD	636.57	1.1843	0.2452	0.0215	1.75	18.72
Litter + humus	1266.2	2.4078	**0.0006**	0.0427	1.27	19.99
LL:FWD	1286.4	2.4481	**0.0011**	0.0434	0.75	20.75

2. APPENDIX

A.1 APPENDIX figures and table

Table 9. (2.APPENDIX.T.1). Results of the permutational analysis of variance, modified from [Table 4. (2.4)]. Table has all PERMANOVA results including Pairwise test conducted on the 28 spring and summer data frames.

	96n		Spr(24)		Sum(24)		Spr(28)		Sum(28)		Total (24)		Total(28)		Pairwise test	Spr(28)		Sum(28)	
	df	*P(perm)*	*df*	*P(perm)*	*df*	*P(perm)*	*df*	*P(perm)*	*df*	*P(perm)*	*df*	*P(perm)*	*df*	*P(perm)*		*df*	*P(perm)*	*df*	*P(perm)*
N											***N***				***N***				
Management 3 (C, Mgt-I, Mgt-Ref)	2	**0.005**	2	0.249	2	0.251	2	0.131	2	**0.001**	2	0.243	2	**0.049**	Control, Managed-INT	20	0.062	20	**0.011**
Season	1	**0.039**													Managed-INT, Managed-REF	21	0.090	21	**0.016**
Year	1	**0.000**													Control, Managed-REF	9	0.987	9	**0.010**
Mgt * Se	2	0.594																	
Mgt * Ye	2	0.498																	
Se * Ye	1	**0.006**																	
Mgt * Se * Ye	2	0.734																	
Res	84		21		21		2		2		21		25						
Total	95		23		23		25		25		23		27						
Management 2 (C, Managed)	1	**0.001**	1	0.076	1	**0.019**	1	0.394	1	**0.008**	1	**0.045**	1	**0.053**	Control, Managed-ALL	26	0.385	26	**0.008**
Season	1	**0.040**																	
Year	1	**0.000**																	
Mgt * Se	1	0.965																	
Mgt * Ye	1	0.439																	
Se * Ye	1	**0.003**																	
Mgt * Se * Ye	1	0.516																	
Res	88		22		22		1		1		22		26						
Total	95		23		23		26		26		23		27						
N/g											***N/g***				***N/g***				
Management 3 (C, Mgt-I, Mgt-Ref)	2	**0.008**	2	0.292	2	0.487	2	**0.012**	2	**0.004**	2	0.0779	2	**0.015**	Control, Managed-INT	20	0.091	20	**0.046**
Season	1	**0.000**													Managed-INT, Managed-REF	21	**0.002**	21	**0.022**
Year	1	**0.000**													Control, Managed-REF	9	0.851	9	**0.002**
Mgt * Se	2	0.749																	
Mgt * Ye	2	0.787																	
Se * Ye	1	**0.004**																	
Mgt * Se * Ye	2	0.855																	
Res	84		21		**21**		2		2		21		25						
Total	95		23		23		25		25		23		27						

Management 2 (C, Managed)	1	**0.001**	1	0.090	1	0.055	1	0.548	1	**0.030**	1	**0.049**	1	0.078	Control, Managed-ALL	26	0.537	26	**0.029**
Season	1	**0.000**																	
Year	1	**0.000**																	
Mgt * Se	1	0.980																	
Mgt * Ye	1	0.715																	
Se * Ye	1	**0.001**																	
Mgt * Se * Ye	1	0.602																	
Res	88		22		22		1		1		22		26						
Total	95		23		23		26		26		23		27						
N/ha											*N/ha*				***N/ha***				
Management 3 (C, Mgt-I, Mgt-Ref)	2	**0.014**	2	0.270	2	0.342	2	0.217	2	**0.002**	2	0.385	2	0.068	Control, Managed-INT	20	0.087	20	**0.030**
Season	1	**0.000**													Managed-INT, Managed-REF	21	0.125	21	**0.008**
Year	1	0.093													Control, Managed-REF	9	0.982	9	**0.029**
Mgt * Se	2	0.391																	
Mgt * Ye	2	0.604																	
Se * Ye	1	**0.008**																	
Mgt * Se * Ye	2	0.869																	
Res	84		21		21		25		25		21		25						
Total	95		23		23		27		27		23		27						
Management 2 (C, Managed)	1	**0.005**	1	0.104	1	**0.053**	1	0.478	1	**0.038**	1	0.113	1	0.213	Control, Managed-ALL	26	0.488	26	**0.037**
Season	1	0.116																	
Year	1	**0.000**																	
Mgt * Se	1	0.865																	
Mgt * Ye	1	0.380																	
Se * Ye	1	**0.005**																	
Mgt * Se * Ye	1	0.796																	
Res	88		22		22		26		26		22		26						
Total	95		23		23		27		27		23		27						

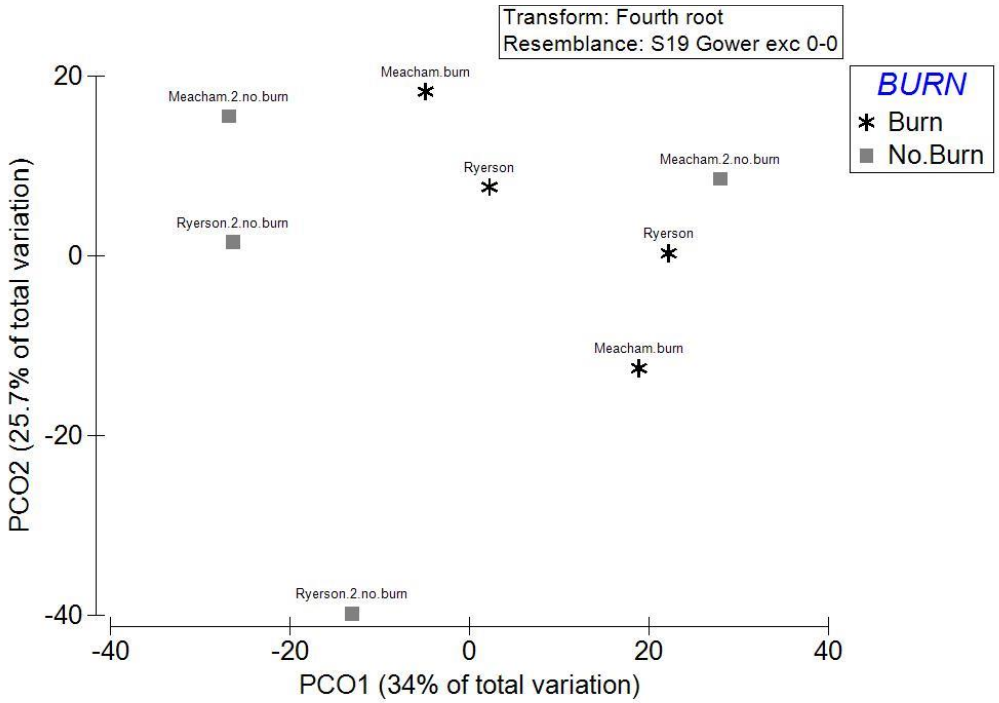


Figure 14.(2-A1). Canonical Analysis of Principal Coordinates CAP, for arthropod assemblages in Burned and No Burn sites.

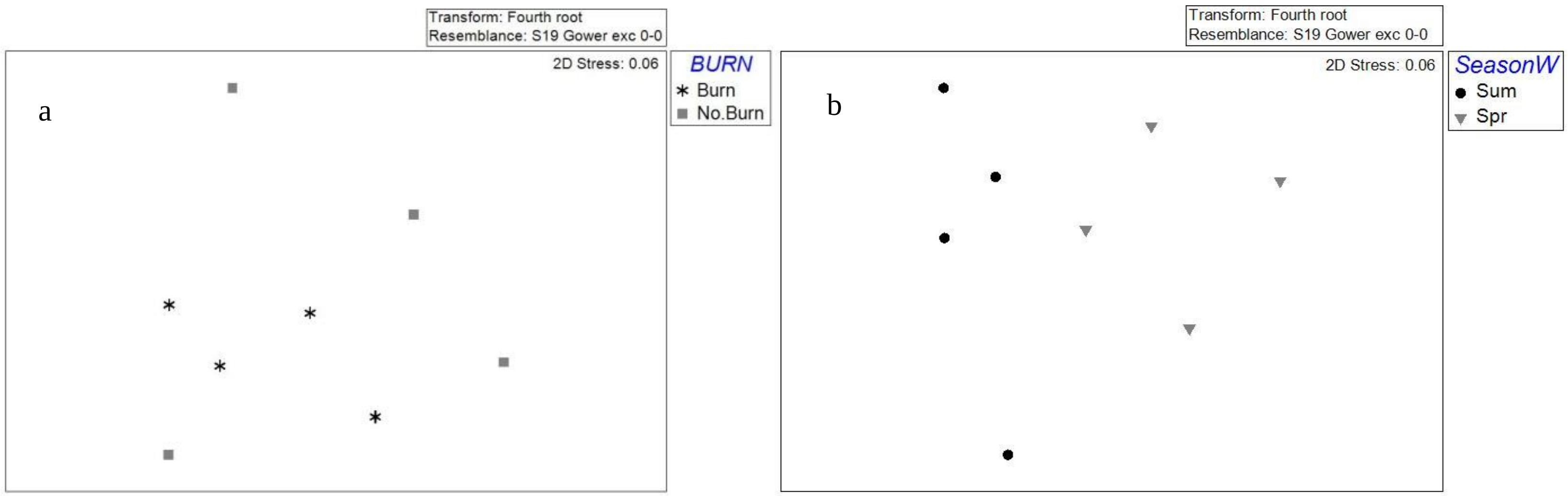


Figure 15. (2-A2). Non-metric multidimensional scaling (nMDS) plot is showing arthropod community assemblages at the Burned and No Burn sites. Labeled by (a) burning treatment (b) season.

CHAPTER 3: IMPACT OF THE INVASIVE EXOTIC SHRUB *RHAMNUS CATHARTICA* ON COLONIZATION RATES OF LEAF LITTER ARTHROPODS: A FIELD EXPERIMENT

Abstract

Leaf litter of invasive exotic species can have an impact on the community of litter-dwelling arthropods by changing the structural heterogeneity, nutrient quality and moisture levels of the leaf-litter layer. To investigate the possible impact of the invasive exotic shrub European Buckthorn (*Rhamnus cathartica)* on leaf-litter arthropods, I measured colonization rates of experimental litter patches consisting of either monocultures or mixed-litter treatments. The litter patch was a modified litter cage that contained a pitfall trap to gauge activity-density as a representation of colonization rate. I used monocultures of European buckthorn (*Rhamnus cathartica*) and white oak (*Quercus alba*), and mixtures of four native litter species [red oak (*Quercus rubra)*, shagbark hickory (*Carya ovata)*, sugar maple (*Acer saccharum)*, and white oak (*Quercus alba)*] as well as a mixture of all five litter types at litter patch treatments. This study found litter cages with a buckthorn monoculture to be the most-colonized litter treatment, with a persistent activity density of fungivorous Collembola, detritivorous isopods, and beetles for the duration of the 10-week study. Collembola was found to be the dominant group driving the colonization rate. This study's findings suggest that Collembola and isopods along with the diverse predatory beetle family (Staphylinidae) prefer to colonize high-nutrient litter of the invasive European buckthorn in preference to the leaf litter of native canopy species. The findings also suggest that increased litter diversity may help dampen the impact of buckthorn on the rates of colonization of leaf-litter by arthropods.

Keywords: Isopod, Woodlice, Functional diversity, Leaf litter decomposition, Leaf litter mixing effects, Macrodetritivores, Nutrients, Ecosystem function, Decomposition, Biodiversity, Mesocosm. Plant diversity, Invasive species, Ecological restoration, Food choice.

3.1. Introduction

Leaf litter arthropods are considered to play a very important role in litter decomposition and nutrient cycling within the detrital system (Wardle et al. 2004, Hättenschwiler et al. 2005, Meyer Iii et al. 2011). Detritivoreous arthropods assist in litter decomposition by fragmenting the litter when consuming it, increasing the surface area and facilitating the entrance of the saprophytic microbial community. Naturally occurring mixed litter is characteristically complex, with its complexity influenced by the diversity of leaf-litter species, moisture retention capabilities and its structural heterogeneity (Uetz 1979, Gartner and Cardon 2004, Hättenschwiler et al. 2005).

Suitability of leaf litter as a habitat for arthropods and the rate at which it decomposes are highly influenced by litter diversity and abiotic factors. The speed at which arthropod detritivores consume litter is greatly influenced by nutrient level within the litter (Hedde et al. 2007, Abelho and Molles 2009, Vos et al. 2011) and its moisture retention capability (Levings and Windsor 1984). As decomposition progresses, polyphenol content is leached out and the C: N ratio decreases, increasing the palatability of the litter to detritivores (Rushton and Hassall 1983, Zimmer 2002).

The decomposer community is suggested to show little adaptation to a recurrent input of unique litter types but instead can respond quickly to changes in overall litter quality (Makkonen et al. 2012). Due to decomposers having metabolic flexibility, they are not suggested to specialize in particular litter types, but can respond quickly to changes in litter quality. Changes in qualities such as N content and C: N ratio can have a large impact on how decomposers community look for and find litter patches to inhabit and consume. Previous studies have investigated the influence invertebrates had on leaf litter disappearance by physical restriction to detritus with mesh of a particular size (Wise and Schaefer 1994, Bokhorst and Wardle 2013), chemical deterrents (Seastedt and Crossley Jr 1980, Heneghan et al. 1999), or removal from study plots by hand (Lawrence and Wise 2000, 2004). Previous studies have used litter bags to assess the effects of arthropods have on forest litter colonization and consumption rate (Seastedt and Crossley Jr 1980, Wise and Schaefer 1994, Tiegs et al. 2008). In this study, I used litter cages to assess if the changes in arthropod assemblages and differences in functional groups seen in Chapter 2 may be explained by changing colonization rates of the leaf litter patches due to its nutrient value or habitat heterogeneity.

In this study, I carried out an experiment to evaluate the effects of leaf litter patches as both monoculture and mixed litter on the colonization rates of leaf litter arthropods in northeastern Illinois. I assessed if leaf litter from the invasive European buckthorn (*Rhamnus cathartica*) can change colonization rates of litter patches at three restoration sites that range in restoration history and plant community structure. I hypothesized (1) that leaf litter from buckthorn would have a high colonization rate but a quick decline in a boom-bust population dynamic; (2) that mixed litter with 4 or more litter types would have a higher colonization rate due to its nutrient and habitat complexity compared to a monoculture; (3) an increased colonization rate in mixed-litter treatments when buckthorn is part of the mixture.

3.1.2 Objectives/Key Questions

The objectives of this study were to determine: **1)** Does mixed litter produce a more hospitable habitat for marodetritivores compared to monocultures? **2)** Does the habitat complexity of individual monocultures influence the colonization rates of arthropods? **3)** Does the introduction of invasive European buckthorn to mixed litter increase its colonization rate by the arthropod community? **4)** Is there a change in the community succession in the arthropod community as the litter types progress in decomposition?

3.2. Methods

3.2.1 Site Selection

Three forest preserves, part of the Chicago Wilderness Land Management Research Program (CWLMRP), were chosen as study sites. They represent a variety of management history and plant community structure in northeastern Illinois. The CWLMRP has established over 105 one-ha plots which are used by both land managers and ecologist to assess the change on these long-term restoration plots. The selected sites include one degraded site with no management and which has a high density of invasive shrubs (Control), an early restoration site (Managed-INT) which has been under management for 14 years, and a reference site which has been deemed a restoration goal by local land managers (Managed-REF), [Table 10. (3.1)]. The sites are located within 10 km of each other and are part of the Lake County Forest Preserve District. At each site, nine randomly selected sub-plots were chosen by walking 5-30 meters from the center of the one-ha plot, at a randomly pre-selected direction (1-360 ° from north) [Figure 16. (3.1)]. At the chosen sub-plot, the leaf litter was cleared to expose the soil, the litter cage was installed, and the leaf litter was returned to the edge of the litter cage after pitfall activation.

3.2.2 Litter cage design

Litter cages were constructed from galvanized hardware cloth with a mesh opening of 0.5 inches /1.27cm. The mesh opening was large enough to allow macroarthropods to enter the litter cage and keep the leaf litter in place. The litter cages measured 30 x 30 x 15cm and were held in place by galvanized metal spikes [Figure 17. (3.2)].

3.2.2 Leaf litter species and treatments

Freshly senescent leaves of both native canopy and the introduced litter type were collected in the fall of the previous year. Four common native canopy species and one invasive shrub leaf-litter species were selected as identifiable representatives of canopy litter species and an introduced species. Litter species included white oak (*Quercus alba*), sugar maple (*Acer saccharum*), shagbark hickory (*Carya ovate*), red oak (*Quercus rubra*) and the introduced European buckthorn (*Rhamnus cathartica*). After collection, leaves were oven dried and stored until the start of the experiment the following summer. The leaf litter was used to produce several litter mixtures as both monoculture or mixed-litter samples. Using the average litter weight found in a previous study (Chapter 2), it was calculated that 45 g of litter would be needed to produce a naturally occurring litter weight inside the cage. The same total litter weight was used in each litter treatment [Table 11. (3.2)].

Litter cages were given one of 4 litter treatments equaling 45g of litter each: 1) buckthorn monoculture; 2) white oak monoculture; 3) mixture of the four native litter types, and 4) mixture of the four native litter types and buckthorn. A large amount of buckthorn litter was collected for this study, which allowed me to replicate the buckthorn litter treatment three times. All other treatments were replicated twice at each site, for a total of 9 litter cages per sites. In total 27 litter cages where installed (3+2+2+2 cages x 3 sites = 27). Each litter cage was placed in one of nine randomly selected sub-plots at each site.

3.2.2 Arthropod colonization and sampling

Pitfall traps were used to assess the arthropod activity density and colonization rate at each litter treatment over time (Southwood and Henderson 2009). The pitfall trap was constructed from a 50-ml plastic centrifuge vial with a 2.5cm diameter opening and was placed with the lip of the vial flush to the ground. A rubber stopper was placed in the opening of the vial before activation of the pitfall trap to reduce potential effect of soil disturbance on capture. Each pitfall trap was activated to collect arthropods by removing the lid and adding 25 mL of 50:50 propylene glycol (as a preserving agent) and 70% ethanol (killing agent), with a single drop of liquid detergent to break the liquid surface tension. Traps were activated for five trap days at four time intervals spanning 10 weeks. The litter cages and pitfall traps were installed one day before the start of the first collection event to reduce soil disturbance around the pitfall trap. The traps were activated for five trap days on the first day of the study to obtain initial conditions. The traps were then reactivated at weeks 2, 6, and 10 for 5 trap days each. At each collection event, the trap was carefully removed and replaced with a sealed empty vial until the next collection event. Each time the trap was reactivated, the seal on the empty vial would be removed, and the trap would be activated by adding the 50:50 propylene glycol and ethanol solution and leaving it unsealed for 5 days. A total of 108 pitfall-trap samples were collected, representing 27 cage samples over 4 time intervals (27 x 4 = 108), [Table 12. (3.3)]. Any samples damaged by non-invertebrate wildlife (raccoons or deer) were excluded from the analysis.

3.2.3 Arthropod sorting

All sampled arthropods were sorted and identified to 47 taxonomic groups from 8 arthropod classes, which included 25 orders. Arthropods were sorted and identified to varying taxonomic resolution with some taxa being identified to order and others to family. The taxonomic resolution was guided by the diversity and ease of identification for each taxonomic group. Due to their diverse ecological roles at the family level, Collembola, spiders, and beetles were identified to family. All samples were sorted "blindly" (i.e., person doing the sorting and identification of animals did not know the identity of the sample) to eliminate biases. The sorted material was counted for each individual pitfall. All identified and unidentified non-target taxa have been archived for potential future study at the University of Illinois at Chicago's Martinez insect teaching collection

3.2.4 Statistical analysis, Multivariate statistics.

Differences in arthropod community structure (i.e., differences between samples in activity density of taxa) between treatments were tested with permutational multivariate analysis of variance performed on the community distance matrix using the statistical software PRIMER V6 (PERMANOVA:10,000 permutations of the entire dataset; Type III SS), (Anderson et al. 2008). Site, litter treatment and collection period were analyzed as fixed factors using Gowers S19 (excluding double zeros) dissimilarity matrix calculated on the fouth-root transformed data. Gowers S19 was used in order reduce the undefined characteristics of two samples that lack many species in common (Clarke and Gorley 2006). Unlike Gowers S15, which gives a coefficient value of 1 to double zeros, S19 gives the coefficient a value of 0 for double zeros in a sample.

To visualize which taxa were likely causing changes in community structure in response to the treatments, I used vector overlays on Canonical Analysis of Principal Coordinates (CAP) ordination constrained by site, time or treatment. The vector reflects a correlation coefficient of an arthropod taxon with the two axes; vectors with $r > 0.4$ are shown.

3.2.5 Statistical analysis, Univariate statistics.

Univariate statistical approaches were used to study the influence of site, litter treatment and collection period on the abundance of individual arthropod taxa. ANOVAs, boxplot, and plot-of-means graphs were conducted with the R statistical, computational language (R.Development.Core.Team 2016).

3.3. Results

3.3.1 Overall abundance patterns (no statistical analysis)

A total of 3,202 arthropods was collected and identified to 47 arthropod taxonomic groupings. Two other invertebrates, Gastropoda and Lumbricidae, where also frequently collected and counted [Table 13. (3.4)]. The fungivorous Collembola represented the most abundant group with 56% of total arthropods collected, and is represented by 6 families; the second most abundant group were the beetles with 20%, followed by the spiders with 9% of total arthropod abundance. The single most abundant individual taxon of the 47 targeted groups was the Collembola family Entomobryidae, which made up 28% of total arthropods collected. When divided into sites used in this study, the Management-REF site had the lowest overall arthropod abundance, followed by the Control site. The Management-INT site had the highest overall arthropod abundance with 46% of total arthropods collected.

After adjusting for the extra buckthorn monoculture cage, the buckthorn monoculture represented the most colonized litter treatment, with 39% of total arthropod collected [Table 13. (3.4)]. This was driven by the large numbers of Collembola which represented 65% of total arthropods collected in that treatment. The Oak monoculture was the next treatment with overall high abundance with 22% total arthropods, followed by Mix-All including buckthorn 21%, followed by 18% in the Mix without buckthorn. The buckthorn monoculture treatment had the overall highest mean colonization for Collembola, Coleoptera, and Isopod.

When broken down to the collection periods and the colonization rates by arthropods to the litter cage treatments, the overall pattern of colonization was similar. I found an overall increase from the start, to the highest colonization point for most major taxa in the second collection period, week 2, followed by an overall decrease in arthropod abundance for week 6 and 10. The only exception to this was the buckthorn monoculture, which showed an overall continuous higher rate of colonization for Collembola, isopods, and beetles, which are driving taxa in total arthropod numbers in the buckthorn treatment [Figure 18. (3.3), Table 13. (3.4)]

3.3.2 Effect of treatments on the structure of the colonizing arthropod community

To assess how the arthropod community structure responded to litter treatment at the four collection periods, a three-factor PERMANOVA was used and found no interactions between treatment and site nor collection period (Treatment x Site: PERMANOVA, Pseudo $F_{6,105}$ = 1.1174, P = 0.1889, Treatment x Period: Pseudo $F_{6,105}$ = 1.0645, P = 0.2713). The arthropod community composition did differ between sites (PERMANOVA, Pseudo $F_{2,105}$ = 7.1696, P = 0.0001) [Figure 19. (3.4)], and period (PERMANOVA, Pseudo $F_{4,105}$ = 4.9864, P = 0.0001

[Figure 20. (3.5)], and litter treatments (PERMANOVA, Pseudo $F_{3,105}$ = 1.6859, P = 0.0009) [Figure 21. (3.6)].

I assessed how the arthropod community colonization of litter treatments changed over time by plotting the ordination using Canonical analysis of principal coordinates (CAP) for litter treatment over time [Figure 22. (3.7)]. The PERMANOVA results show a difference in the assemblages of arthropod colonizing the litter treatments at the start and at week 6, but no significant difference between the assemblages in week 4 and 10.

The CAP vector overlay analysis indicates that buckthorn monoculture treatment was characterized by different arthropod taxa. The ordination illustrates a shift in community composition in arthropod colonization over time. The CAP showed that buckthorn monocultures were often associated with isopods and several Collembola families like Hypogastruridae at the start, and Tomoceridae, Hypogastruridae, and Isotomidae at 6 weeks [Figure 22. (3.7)].

3.3.3 Univariate analyses

I found that total Collembola responded to the litter treatment [ANOVA $F_{3,102}$ = 4.336, P = 0.0064] [Figure 18. (3.3)], with the buckthorn monoculture exhibiting the higher colonization activity density over time. This pattern was also found in the Coleoptera ANOVA $F_{3,102}$ = 2.812, P = 0.0431, and in particular the predatory family Staphylinidae, ANOVA $F_{3,102}$ = 2.682, P = 0.0507. When assessing the total arthropod abundance for each treatment over time, the buckthorn monoculture showed a consistently high activity density at week 2, 6, and 10 [Figure 18. (3.3)]. This was in part driven by the Collembola families which had a high activity density which was driving this total arthropod colonization rate [Figure 23. (3.8), Figure 24. (3.9)].

3.4. Discussion

3.4.1 Influence of litter treatment over time; a multivariate and univariate approach

The buckthorn monoculture had the higher overall colonization rate over the 10-week duration of this study. White oak had a high initial colonization rate at week 2 but this was not maintained over time [Figure 18. (3.3)]. When added to the native mix of 4 litter types, the buckthorn litter produced a small but non-significant increase in the arthropod colonization rate [Table 13. (3.4)]. This finding suggests that increased litter diversity may counter the impact invasive litter monocultures have on arthropod colonization activity dentistry.

The higher rate of colonization of buckthorn was expected, but the long-term and persistent colonization rate was not. Previous studies have suggested that the introduction of nutrient-rich litter may produce a boom-bust economy, where abundance increases rapidly only to produce a population crash after resources are exhausted (Hansen 2000). This boom-bust dynamic does seem to be expressed in non-Collembola arthropods, including the spiders and many Coleoptera families. For these groups the highest overall abundance in the litter cage colonization was in the second week, followed by a decline by week 10. This boom-bust economy has been shown to play a role in the detrital system as well in predator-prey dynamics (Hansen 2000, Steffen and Draney 2009, Price et al. 2011).

A previous study found collembola, in particular, the entomobryid family, to be negatively correlated with invasive plant cover (McCary et al. 2015). Although I did not calculate invasive plant cover, my finding does suggest an increase in collembola activity density, including Entomobryidae, in invasive plant litter patches. My results suggest increased invasive litter cover should have a positive impact on the abundance of Collembola found an opposite pattern as McCary has found. My study does only span 10 weeks during the summer, McCary's conclusions may be a long-term impact of invasive litter cover instead of a short-term colonization rate dynamics like those presented here.

This study found a high and persistent activity dentistry for both isopods and Collembola in the buckthorn monoculture litter patch. This data also showed a surprising negative correlation between isopod and Collembola activity density across litter treatments. A decrease in collembola in the presence of isopod activity density was seen in all 4 litter treatment [Figure 25. (3.10)]. Isopods are detritivores but are also opportunistic consumers of insects, and this negative correlation may be a reflection of Collembola fleeing behavior near Isopods.

A previous study which used these and 19 other sites found sites identified as Control had 2x the Isopod activity-abundance as the Managed-REF sites (McCary et al. 2015). This pattern is supported in this study with the abundance of the introduced isopods within the Control site having 55% of total isopods found in this study. The Control site also showed a higher abundance of slugs and earthworms, both of which are introduced (Jass and Klausmeier 2000, Pinceel et al. 2005, Heneghan et al. 2007). The decrease of Collembola in the presence of isopods across our litter patches may help explain how McCary and colleagues found both the isopods and the entomobryidae collembola to be indicators of degraded and Managed-REF sites respectively. A high rate of isopod activity density may have altered the collembola activity density in degraded Control sites, and the lack of isopods in the Manage-REF sites would suggest an increase in Collembola activity density in those sites.

3.4.3 How is colonization critical in understanding novel litter species effects?

Novel liter types introduced by invasive species have been documented to either retard or accelerate decomposition (Moore et al. 2004). This change in decomposition rate is driven by both habitat and litter chemico-physical conditions. Buckthorn has been shown to have a higher nitrogen content than some native canopy tree species (Heneghan et al. 2002), and because nitrogen can accelerate decomposition (Poulette and Arthur 2012, David 2014), via microbial or arthropod food choice, it can lead to an increased decomposition rate in newly invaded habitats.

My results show that buckthorn can increase colonization of leaf litter in monoculture litter patches. This increase, which is driven by the fungivorous collembola, may represent an increase of fungal community activity in buckthorn litter. This increase in arthropod colonization and possible increased fungal community may accelerate litter decomposition in mixed litter that includes buckthorn. Although final litter weight was not calculated, and therefore litter disappearance was not measured, I did observe buckthorn monoculture litter patches to show a higher litter disappearance rate compared to all other litter treatment. Litter patches of the two non-buckthorn treatments showed a persistent litter layer for the duration of this study, while the buckthorn monoculture looked to have been reduced to small litter particles which adhered to the bare soil.

3.4.4 Is the fungal community driving colonization rate? Alternatively, is it habitat heterogeneity?

Although I did not test for fungal community activity in this study, the introduction of a high nitrogen novel litter type such as buckthorn has the ability to drive the microbial community. Previous studies have found a decrease in microbial activity after the removal of buckthorn in a system (Madritch and Lindroth 2009). This change was attributed to the decrease of the nutrient-rich litter input. These changes in microbial and detritivore communities may be limited if a heterogeneous litter layer existed.

Heterogeneity within litter types is not suggested to have had a significant impact on the colonization rate of our litter cage treatment. Both the 4-native litter mixture and the 5 litter mixtures that included buckthorn had a lower than expected total colonization rate compared to the buckthorn and oak monocultures.

The increased and long-term colonization rate in buckthorn litter is suggested to be due to a consistent fungal community produced by the nutrient-rich litter types. I suggest this is the driving force for a long-term rate of colonization by the fungivorous collembola and may explain the same pattern in detritivorous isopods and some predatory beetles. The increase in isopod colonization of buckthorn litter suggests isopods may have an attraction to consume buckthorn litter more than native litter canopy types. The observed increase of predatory Staphylinidae beetles may be due to the presence of collembola prey, but this pattern was not observed in other predatory beetles such as Carabidae.

More investigation is needed in to the impact invasive litter patches, like those presented in this study, have on the ground arthropod community. As buckthorn disperses to new uninvaded areas a better understating of the mechanisms of how it alters both the ground arthropod community as well as any changes to normal nutrient cycling deserves more investigation.

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3. FIGURES

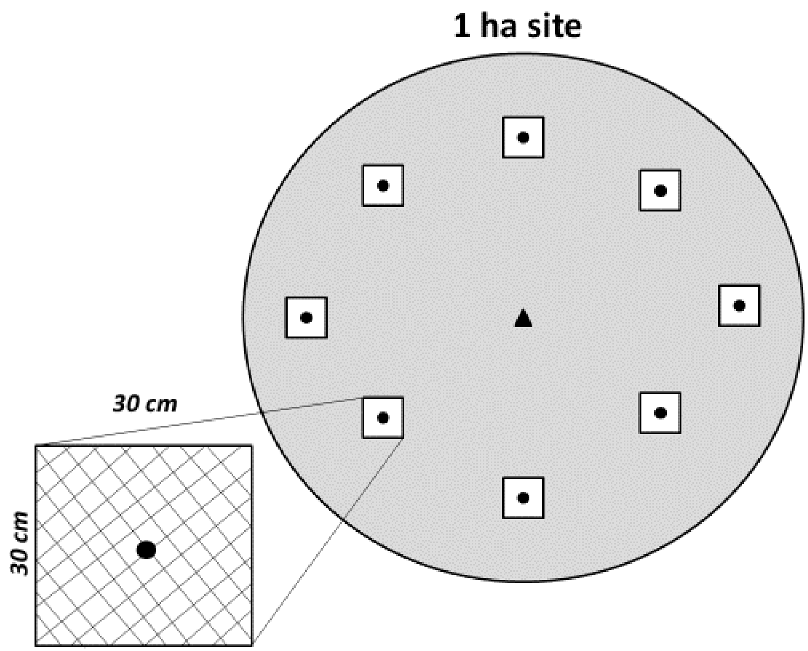


Figure 16. (3.1). Litter cage distribution per site (not to size). Each litter cage was randomly distributed in the site.

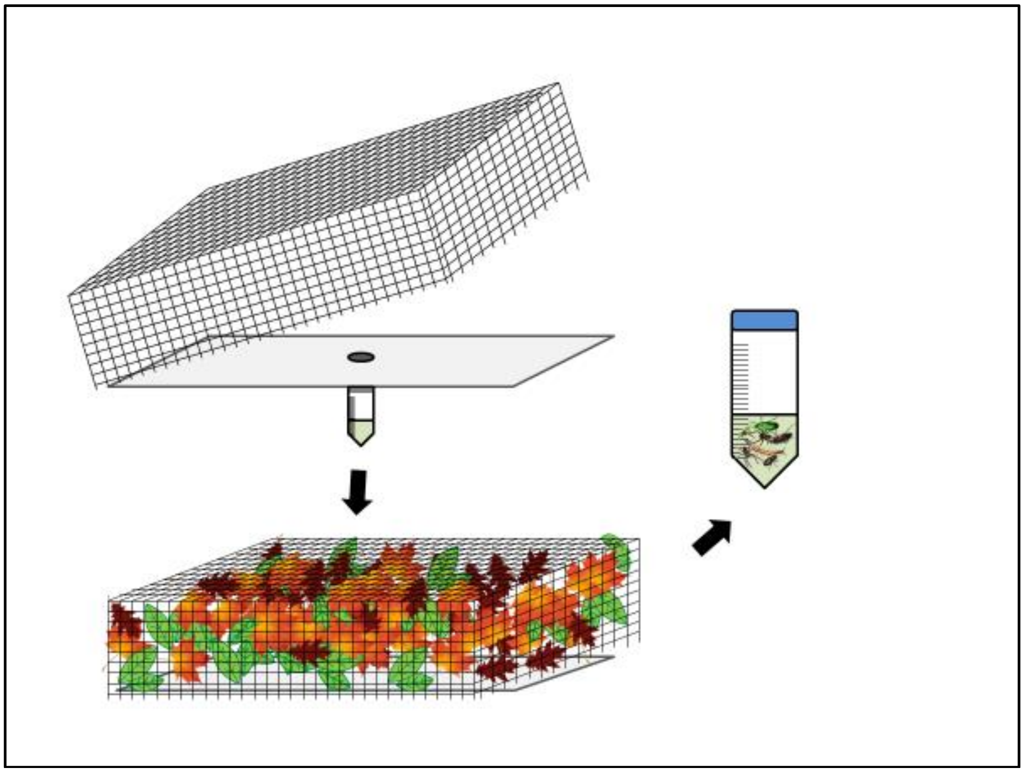


Figure 17. (3.2). Litter cage design using a centrifuge pitfall trap vials to calculate colonization activity-density of each cage treatment. Pitfall traps were activated for 5 trap days during 4-time intervals; Start, 2 weeks, 6 weeks and 10 weeks.

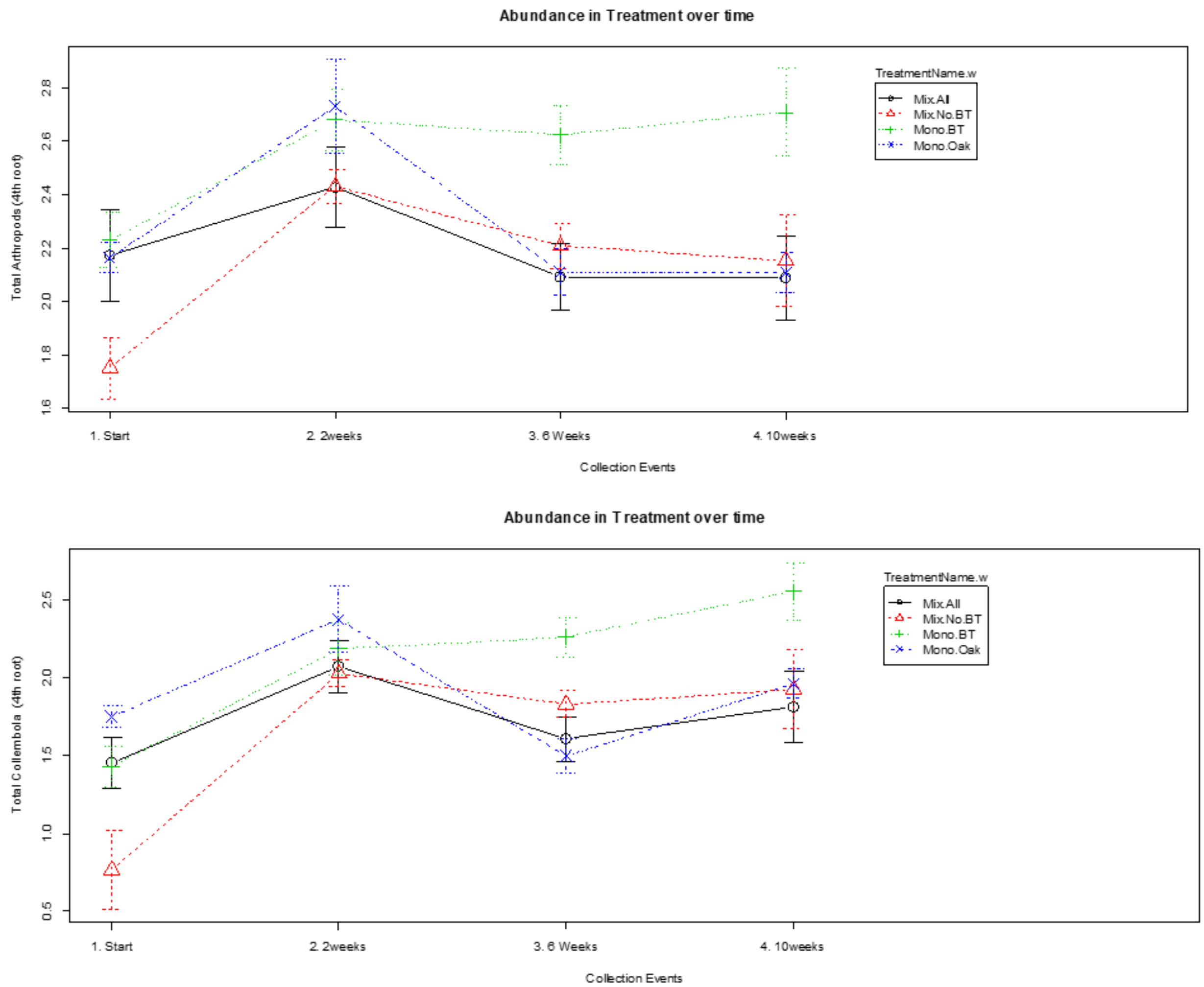


Figure 18. (3.3). The plot of mean total arthropod and Collembola activity-density found in each of the four litter cage treatments across the four collection periods (4^{th} root transformed). Mix All= 5 litter species including buckthorn, Mix.no.BT= 4 native litter species excluding buckthorn, Mono.BT= Monoculture of buckthorn litter, Mono.Oak = Monoculture of White Oak.

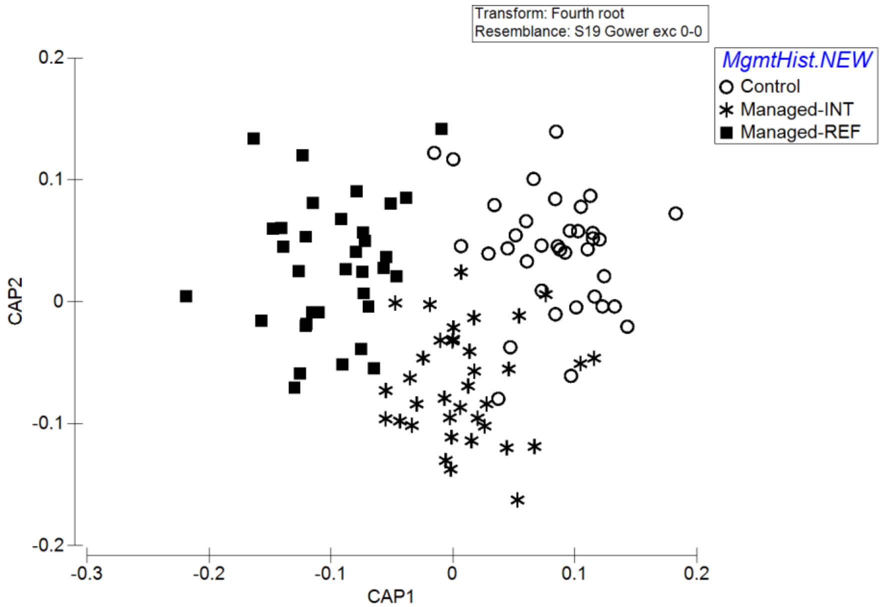


Figure 19. (3.4). Canonical Analysis of Principal Coordinates (CAP), for arthropod taxonomic groups constrained by site management category.

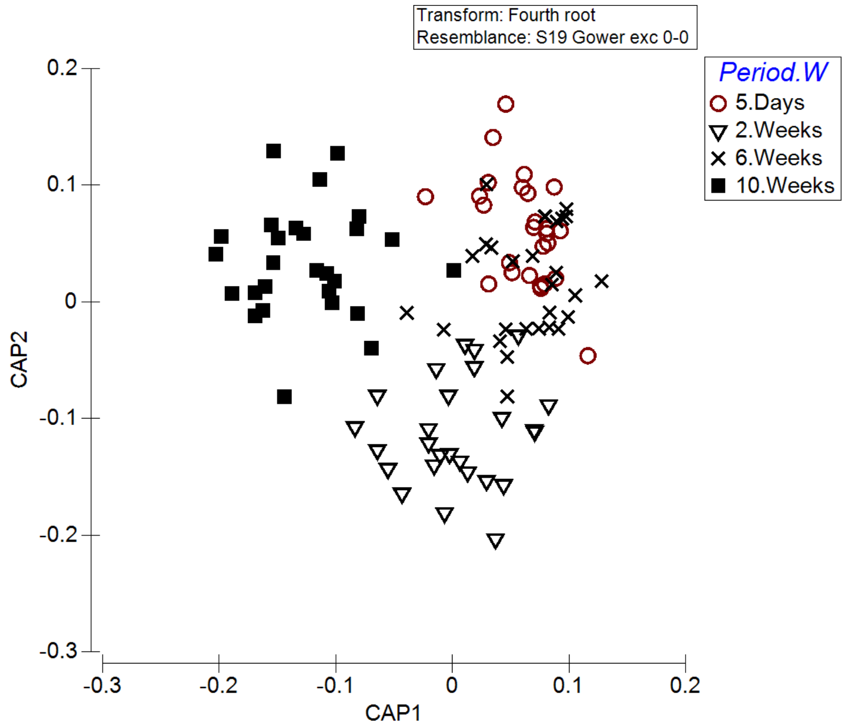


Figure 20. (3.5). Canonical Analysis of Principal Coordinates (CAP), for arthropod taxonomic groups constrained by collection period.

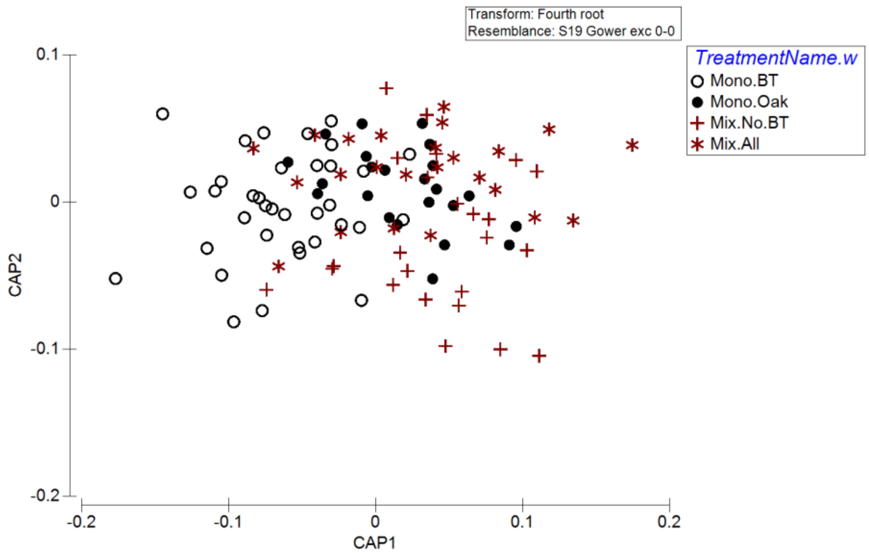
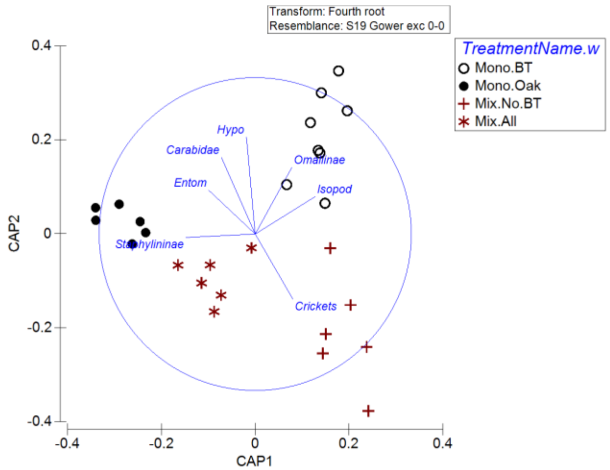
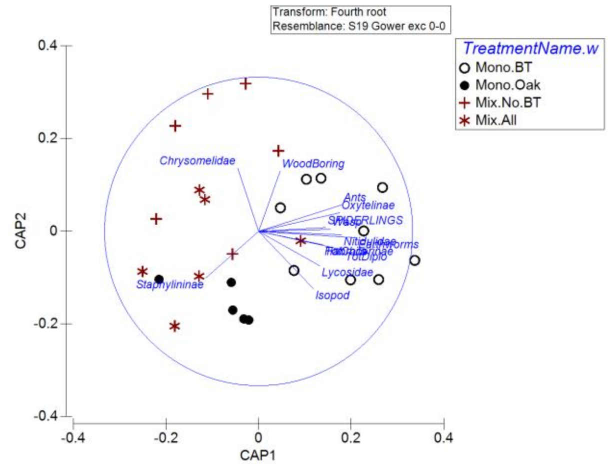


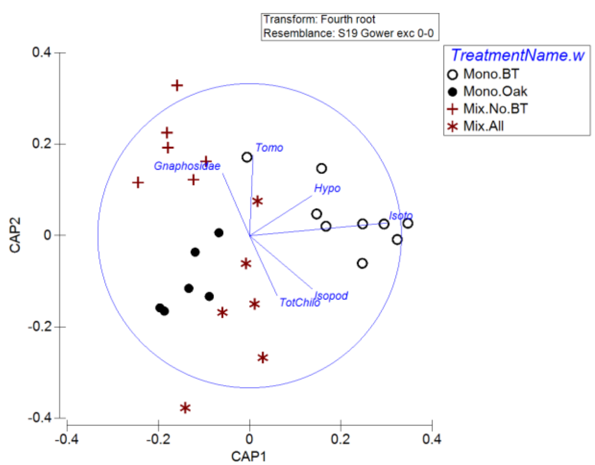
Figure 21. (3.6). Canonical Analysis of Principal Coordinates (CAP), for arthropod taxonomic groups constrained by litter cage treatment. Each symbol of the ordination plot represents one litter cage treatment. Mono.BT= Buckthorn monoculture, Mono.Oak= White Oak monoculture, Mix.no.BT= Mixture of the 4 native litter types, Mix.All= Mixture of the 4 native litter types including buckthorn.



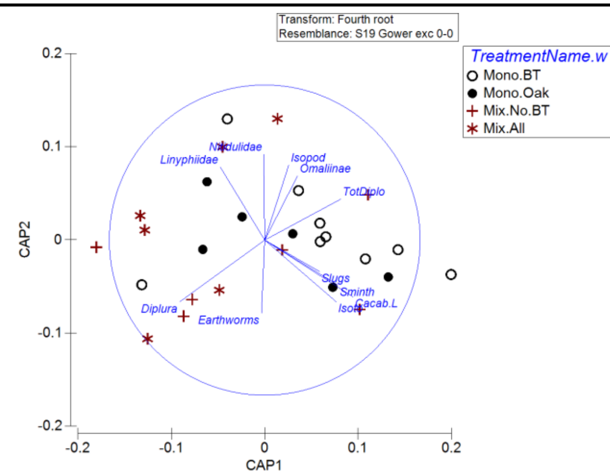
Start (day 5): *P(perm)*= **0.0472***



2 weeks: *P(perm)*= 0.3596



6 weeks: P*(perm)*= **0.0301***



10 weeks: *P(perm)*= 0.5642

Figure 22. (3.7). Canonical Analysis of Principal Coordinates (CAP), for arthropod taxonomic groups (Partial Correlation r > 0.4 for Vector overlay), the circle represents r=1. Ordinations represent all collection periods including; Start, 2 weeks, 6 weeks, and 10 weeks from the installation of the litter cages. *P(perm)* = permutational ***P* value**.

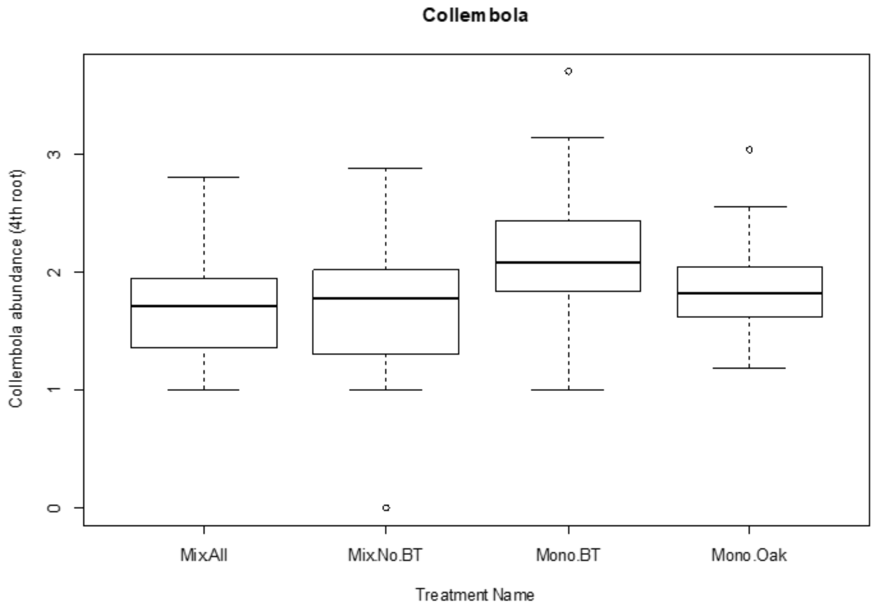


Figure 23. (3.8). The plot of mean and a box plot of Collembola activity density found at each of the four litter cage treatments (4th root transformed). Mix All= 5 litter species including buckthorn, Mix.no.BT= 4 native litter species excluding buckthorn, Mono.BT= Monoculture of buckthorn litter, Mono.Oak = Monoculture of White Oak.

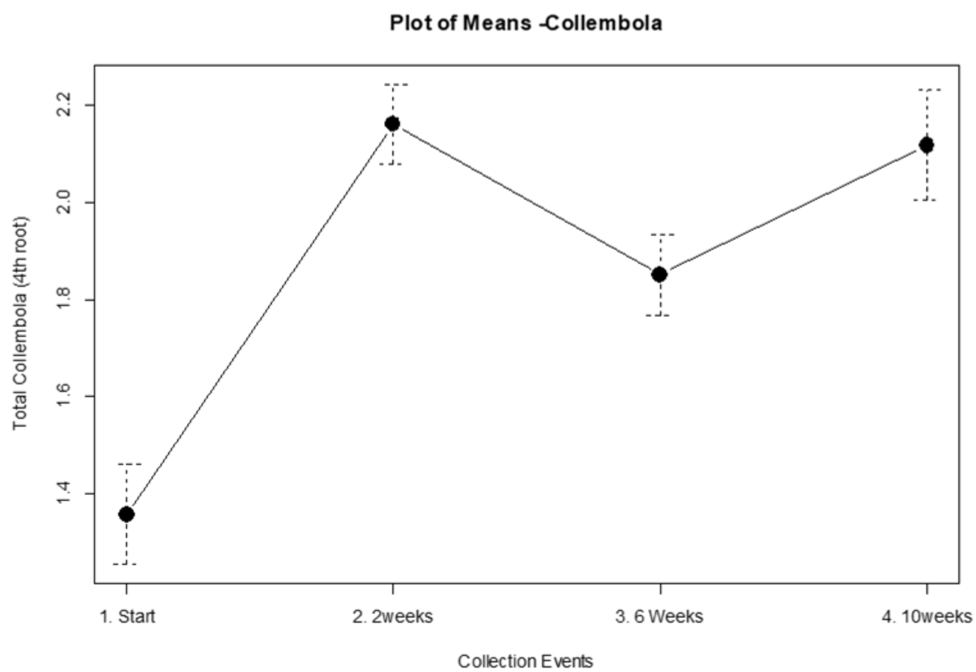


Figure 24. (3.9). The plot of mean Collembola activity-density found in each of the four collection periods (4th root transformed), whiskers = SE.

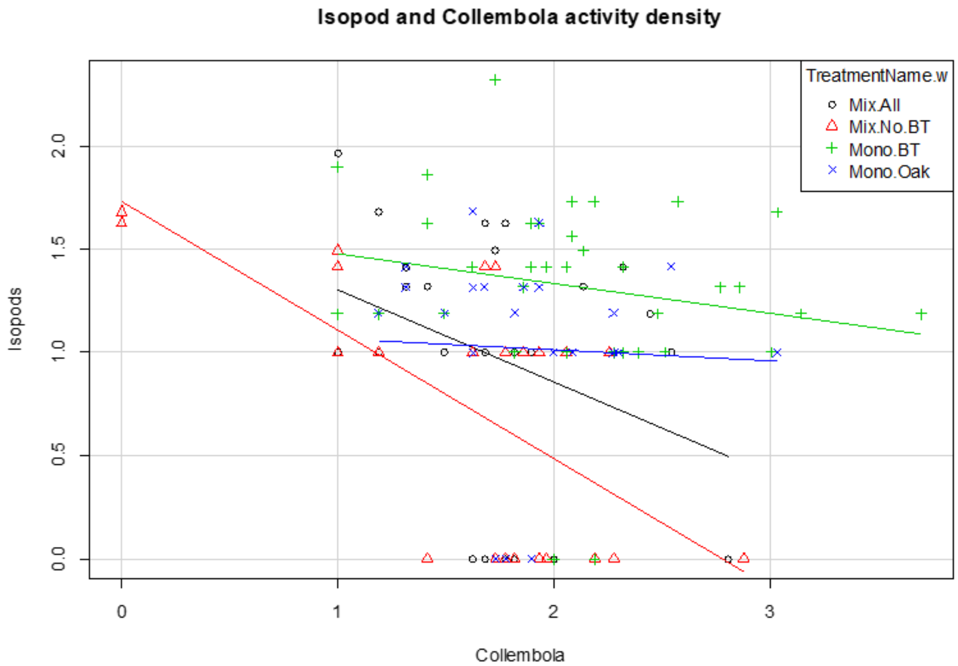


Figure 25. (3.10). Relationship between activity-density of Isopod and Collembola for all litter treatments. Activity-density was 4th root transformed, $r^2 = 0.029$, $F_{1,104} = 3.131$, $P = 0.08$.

3. TABLES

Table 10. (3.1). Characteristics of study sites; *Control*, *Managed-INT*, and *Managed-REF* sites.

Site	Coordinates	Years managed	Soil texture	Vegetation summary
Control				
Old School	42. 16'32.31"N 87.55'36.02"W	0	Clay Loam	Mature *Quercus rubra* (red oak) and *Quercus alba* (white oak) canopy. Rhamnus *cathartica* (buckthorn) is present but not dense. Other shrubs include *Crataegus* spp. (hawthorn), *Carya* spp. (hickory), and *Ulmus americana* (elm). Herbaceous layer of mostly buckthorn seedlings, hickory, and *Lonicera* spp. (honeysuckle). Minimal detritus present.
Managed-INT				
Old School	42.16'16.53"N 87.55'13.7"W	14	Loam Silty Clay	Mature red and white oak canopy. Buckthorn is present but is not dense. Other shrubs include hawthorn, hickory, and elm. No herbaceous layer but numerous buckthorn, hickory, and honeysuckle seedlings. Not much detritus.
Managed-REF				
Ryerson	42°10'51.24"N 87°54'35.73"W	12	Silty Clay Loam	Mature and full white oak canopy. Shrub layer of sugar maple and cherry. Herbaceous layer is almost non-existent –only some seedlings of sugar maple, cherry, and ash. Extremely dense leaf-litter layer (most dense layer of all sites), mainly consisting of white oak litter.

Table 11. (3.2). Component species of litter treatment as 45g monoculture, 11.5 g four native litter species mix, and the four native litter species mix with the addition of Buckthorn.

Litter species	Monocultures	Native mix	Native mix + Buckthorn
Buckthorn (*Rhamnus cathartica*)	45g		9g
White Oak (*Quercus alba*)	45g	11.5g	9g
Sugar maple (*Acer saccharum*)		11.5g	9g
Red Oak (*Quercus rubra*)		11.5g	9g
Shagbark (*Carya ovata*)		11.5g	9g

Table 12. (3.3). The design of the litter-cage experiment, including four collection events and the litter cage treatments.

Litter cage treatments	Collection Events			
	START Event 1	Week 2 Event 2	Week 6 Event 3	Week 10 Event 4
Monoculture Native - (White oak)	2	2	2	2
Monoculture Introduced - (Buckthorn)	3	3	3	3
Mixed Native - (4 natives)	2	2	2	2
Mixed Native +Introduced -(4 natives + Buckthorn)	2	2	2	2
Number of sites	3	3	3	3
Litter cage per site	9	9	9	9
Total	27	27	27	24

Table 13. (3.4). Total activity-density of invertebrate taxa by management category and Treatment. Mono.Oak= Monoculture of White Oak, Mono.BT = monoculture of Buckthorn, Mix.all= Mixture of 4 native litter types with the addition of Buckthorn. Mix.no.BT= 4 native leaf litter types.

			Total invertebrates at sites			Total invertebrates per treatment				Total
			Control	Managed-INT	Managed-REF	Treat 1	Treat 2	Treat 3	Treat 4	
Class/Order	Family	Functional Group				Mono.Oak	Mix.All	Mono.BT	Mix.no.BT	
Araneae										
	Agelenidae	Predator	1	0	0	1	0	0	0	**1**
	Amaurobiidae	Predator	1	0	1	1	0	0	1	**2**
	Corinnidae	Predator	0	0	3	0	0	2	1	**3**
	Dictynidae	Predator	0	0	1	0	0	1	0	**1**
	Gnaphosidae	Predator	0	0	2	1	0	0	1	**2**
	Hahniidae	Predator	0	0	2	0	1	0	1	**2**
	Linyphiidae	Predator	74	38	14	28	34	34	30	**126**
	Lycosidae	Predator	75	52	11	18	70	36	14	**138**
	Thomisidae	Predator	2	2	7	3	1	5	2	**11**
	Uloboridae	Predator	0	0	1	0	1	0	0	**1**
	Spiderlings	Predator	3	3	2	2	0	4	2	**8**
Collembola										
	Entomobryidae	Fungivore	316	523	42	247	175	319	140	**881**
	Tomoceridae	Fungivore	3	71	57	44	29	22	36	**131**
	Isotomidae	Fungivore	40	110	49	24	29	114	32	**199**
	Hypogastruridae	Fungivore	9	14	121	10	8	107	19	**144**
	Sminthuridae	Fungivore	69	263	105	62	81	207	87	**437**
	Onychiuridae	Fungivore	1	0	0	1	0	0	0	**1**
Coleoptera										
	Carabidae	Predator	11	203	176	141	49	145	55	**390**
	Chrysomelidae	Predator	0	0	2	0	1	0	1	**2**
	Curculionidae	Herbivore	0	1	0	0	1	0	0	**1**
	Mordellidae	Herbivore	0	1	0	0	0	1	0	**1**

	Nitidulidae	Detritivore	11	5	22	6	3	21	8	**38**
	Scolytinae	Herbivore	3	0	3	1	2	2	1	**6**
	Coccinellidae	Predator	0	0	2	0	0	1	1	**2**
	Staphylinidae									
	Aleocharinae	Predator	7	8	1	2	3	5	6	**16**
	Paederinae	Predator	0	0	1	0	0	0	1	**1**
	Ptiliidae	Predator	3	0	1	0	3	1	0	**4**
	Staphylininae	Predator	6	3	5	4	5	1	4	**14**
	Tachiporinae	Predator	1	1	1	0	1	2	0	**3**
	Oxytelinae	Predator	21	3	0	1	1	19	3	**24**
	Habrocerinae	Predator	2	0	0	0	0	2	0	**2**
	Omaliinae	Predator	0	2	16	0	1	14	3	**18**
	Staphylinidae Larvae	Predator	1	1	7	0	8	0	1	**9**
	Carabidae Larvae	Predator	2	6	3	2	1	4	4	**11**
	Other Coleoptera Larvae	Multi-functional	13	4	5	4	5	4	9	**22**
Chilopoda										
	Lithobiomorphia	Predator	5	3	0	1	4	3	0	**8**
Diplopoda										
	Julida	Detritivore	6	5	12	3	4	11	5	**23**
	Polydesmid	Detritivore	5	0	6	0	1	6	4	**11**
Opiliones										
	Opiliones	Predator	1	1	1	1	1	1	0	**3**
Hymenoptera										
	Formicidae	Omnivore	38	69	17	28	29	32	35	**124**
	Braconidae	Predator	11	9	4	1	4	15	4	**24**
Isopoda										
	Oniscidea	Detritivore	137	42	69	52	68	88	40	**248**
Orthoptera										
	Gryllidae	Detritivore	1	14	4	5	5	3	6	**19**
Pseudoscorpiones										
	Pseudoscorpion	Predator	2	0	2	1	1	1	1	**4**
Diplura										
	Diplura	Omnivore	55	30	1	21	28	11	26	**86**
Non Arthropods										
Gastropoda										

Haplotaxida	Gastropoda (Slug)	Detritivore	28	2	4	6	9	8	11	**34**
	Lumbricidae (Worms)	Detritivore	8	4	2	1	6	3	4	**14**
	Total Arthropods		**938**	**1487**	**778**	**717**	**659**	**1243**	**584**	**3202**
	Total Invertebrates									**3250**

CHAPTER 4: IMPACT OF LEAF LITTER OF THE INVASIVE EXOTIC SHRUB *RHAMNUS CATHARTICA* ON FEEDING PREFERENCES OF A DETRITIVOROUS ARTHROPOD AND CONSEQUENCES FOR RATES OF DISAPPEARANCE OF LITTER OF NATIVE CANOPY SPECIES: A MESOCOSM EXPERIMENT

4. Abstract

The introduction of novel leaf litter types from invasive species into the forest floor has been documented to either increase or decrease the rate of disappearance of litter of native canopy species. In woodlands of the Chicago region, isopods are among the most abundant detritivorous arthropods. They can be particularly abundant in areas invaded by the exotic shrub *Rhamnus cathartica* (European buckthorn). In this study, I documented the feeding preferences of the common terrestrial isopod *Trachelipus rathkii* (Isopoda: Oniscidea: Trachelipodidae) for several canopy species and nutrient-rich leaves of invasive buckthorn. A mesocosm experiment was constructed to study how this common isopod influenced the disappearance rate of native and introduced litter types in both monocultures and mixed-litter treatments. This study used 198 mesocosms with eleven litter-mixture (including single-species) treatments. The presence of buckthorn in a 1:1 mixture with native canopy litter increased the overall consumption rate compared to the single canopy species treatment. This effect of buckthorn on overall disappearance rate decreased with an increase in the diversity of the mixed-litter treatments. Mixed-litter effects on isopod consumption rates were found to be non-additive, and antagonistic when compared to single species dynamics, suggesting that buckthorn litter may alter the isopod's overall consumption rate less than would be expected in comparison to native-litter monocultures. These findings may help explain increased litter loss found in degraded sites invaded by buckthorn, which past studies have also attributed to higher isopod activity-densities.

4. Keywords: Isopod, Woodlice, Functional diversity, Leaf litter decomposition, Leaf litter mixing effects, Macrodetritivores, Nutrients, Ecosystem function, Biodiversity, Mesocosm, Plant diversity, Invasive species, Ecological restoration.

4.1. Introduction

4.1.1Mixed leaf litter effects

The ability of invasive plant species to disrupt native community structure via direct competition or altering soil nutrient dynamics have been key factors which have made them a designated target in many local management efforts (Heneghan et al. 2006a, Knight et al. 2007, Iannone et al. 2015). Leaf litter is a representation of the plant community above it, and the introduction of novel litter types due to recent plant invasion can alter normal leaf-litter decomposition dynamics (Gartner and Cardon 2004, Ashton et al. 2005). These mixed-litter effects on decomposition can be classified into one of three interactions; *antagonistic* interaction with slower decomposition rates relative to what is expected based on single-species dynamics, *synergistic* with an accelerated rate of decomposition, and *neutral* with no net effect (Zimmer et al. 2005, Poulette and Arthur 2012).

Fast decomposing litter has been documented to accelerate the decomposition rates of neighboring litter via nutrient leaching (Xiang and Bauhus 2007), and increased arthropod colonization (Pereira et al. 1998). These mixed-litter effects have been suggested to be driven by litter species identity, composition, and species chemo-physical characteristics (Hansen 2000, Hättenschwiler and Gasser 2005, Wardle et al. 2006). High nutrient content and higher water retention capabilities are examples of such chemo-physical characteristics that litter species contribute to mixed litter. This altered decomposition rate may be facilitated by detrital arthropod communities. Leaf litter fauna have been shown to relocate nutrients within the soil by consuming, transporting and defecating microbial propagules as they forage (Lussenhop and Wicklow 1984).

The decomposer community is suggested to show little adaptation to a recurrent input of a particular litter type but instead can respond quickly to changes in litter quality (Makkonen et al. 2012). During litter decomposition, polyphenol content is leached out and the C: N ratio decreases, increasing the palatability of the litter to detritivores (Rushton and Hassall 1983a, Zimmer 2002). Isopods are an active and abundant detritivore, and this increase in palatability may help explain altered disappearance rates of leaf litter where isopods are common (McCary et al. 2015). Researchers have shown that litter of the invasive shrub *Rhamnus cathartica* (European buckthorn: hereafter buckthorn) is rapidly consumed by introduced earthworms (Heneghan et al. 2006b), and has been hypothesized to have a synergistic effect on disappearance rate on native litter types due to its high nutrient content (Heneghan et al. 2002). Buckthorn produces leaf litter high in nitrogen content which in other litter species has led to higher consumption rates by isopods (Zimmer 2002, Vos et al. 2013). It is still unclear what role the feeding preferences of arthropod macrodetritivors play in the suggested altered decomposition rates, and if they play any role in the hypothesized synergistic effects in mixed litter.

Buckthorn was used as a model to study how the leaf litter of an invasive exotic shrub influences the decomposition dynamics of native canopy litter. A synergistic effect may be due in part to increased colonization and consumption of litter mixed with buckthorn, leading to the rapid consumption of introduced litter followed by a shift to nutrient-poor litter after the exotic resource has been depleted. In addition, synergistic effects could also be due as well to direct leaching of nutrients from buckthorn on to native litter types (Chapter 5).

Mixed-litter effects on the abundance and diversity of decomposers, when they occur, are likely to be of secondary and generally minor significance when compared to effects of litter species identity and composition (Wardle et al. 2006). Leaf-litter characteristics may also produce contrasting effects on different components of the arthropod community, with structural heterogeneity being important to particular taxa such as generalist predators (Uetz 1979, Bultman and Uetz 1984), and nutrient composition being important to detritivores (Dudgeon et al. 1990, Abelho and Molles 2009). Research studies on the effects of leaf-litter characteristics, whether as a single influential factor or a combination of factors, on target taxa have been conducted with a range of arthropod groups, including Coleoptera, Collembola, spiders, and mites (Uetz 1979, Chen and Wise 1999, Hansen 2000, Rieske and Buss 2001).

In general, leaf litter is a nutrient-poor food source. This constraint may increase selective pressures on arthropod detritivores to consume nutrient-rich litter types with high nitrogen content and low C: N ratio (David et al. 2001). As litter starts the decomposition process, polyphenol content is leached out and the C: N ratio decreases. This may increase the palatability of the litter to isopods later in the decomposition process (Rushton and Hassall 1983b, Zimmer 2002).

Here I present a mesocosm study to examine how a dominant detritivore reacts to litter monocultures, mixed native litter, and litter mixtures with an invasive nutrient-rich litter type. I test how different mixtures alter the consumption rate which may help interpret mixed-litter disappearance patterns as antagonistic, synergistic or neutral.

4.1.2 Objectives

This study aimed to examine how dominant macrodetritivores in local woodlands impact the litter disappearance rate of native and introduced litter in both monocultures and mixed culture using a mesocosm experiment. In this study, my goals were to answer two basic questions: **A)** Do macrodetritivores consume buckthorn litter at a higher rate than native litter types? **B)** Does the presence of nutrient-rich buckthorn litter create a synergistic effect on the litter consumption of native litter species?

4.2. Methods

*4.2.1 Model macrodetritivore (*Trachelipus rathkii*)*

In northeastern Illinois, the macrodetritivore isopod *Trachelipus rathkii* was found to be the most abundant and frequently encountered isopod in recent woodland restorations studies, author's unpublished data (Chapter 2.) and McCary et al. (2015). This isopod was found to be common in those study sites as well as having been identified as a common isopod species in the Midwest by previous authors (Hatchett 1947, Jass et al. 2001). Live isopods were collected and identified in the field, and a colony of approximately 3,000 was established at the laboratory. Isopods were collected from the same research sites as described in Chapters 2 and 3. After collection, isopods were housed in five 10-gallon glass aquariums and fed a mixture of bark, mixed leaf litter, and potatoes. Due to this isopod's ease of care and dominance as a detritivore in local woodlands, it was chosen as a model detritivore to explore its feeding preferences in relation to native litter types and the introduced litter species.

4.2.2 Leaf litter species

The study utilized buckthorn litter and litter of four native tree species that ranged in N, C: N ratio and lignin concentration. Freshly senescent leaves were collected in the fall of 2013 from local woodlands in northeastern Illinois and were oven dried and stored until used. The isopods were exposed to different litter treatments, including mixed and monocultures, and a combination of four native and one invasive leaf-litter species common in several forest sites in the region [Table 14. (4.1)]. Litter species were white oak *Quercus alba*, red oak *Quercus rubra*, shagbark hickory *Carya ovata*, sugar maple *Acer saccharum,* and the introduced European buckthorn *Rhamnus cathartica*.

4.2.3 Mesocosm design and experimental treatments

Mesocosms were constructed of 10-cm diameter x 15-cm high cylindrical polyvinyl chloride pipes (PVC). The mesocosms were closed with a 210-µm mesh screen bottom and a plastic mesh cover made from 500 µm mesh [Figure 26. (4.1)]. The mesocosms were randomly placed in plastic trays, six mesocosms per tray [Figure 26. (4.1)]. Each mesocosm contained a 4-cm layer of sieved, homogenized and defaunated forest soil. Each microcosm contained 10g of leaf litter treatment that was placed on top of the soil and added as either one species monoculture (10g each), a mix of 2 species (5g each), 4-native mix (2.5g each) or 5 species mixed treatment with (2g each) [Table 14. (4.1)]. In total, 11 unique litter treatments were used with 5 monocultures, 4 unique 2-species combinations, and a 4 and 5-species mixture treatment. Each of the 11 litter treatments was exposed to five isopods (~ 0.5g) or a no isopods (control) treatment. All mesocosms were placed in an environmental chamber with controlled humidity, temperature, and a 12:12 dark-light ratio. This study ran for 6 weeks, with 4 replicates of the treatments with isopods and 2 replicates of each no-isopod treatment being destructively harvested at three time intervals; 2, 4, and 6 weeks after the start of the experiment. Thus, there were 198 mesocosms: 132 with isopods (11 x 4 x 3), and 66 with no isopods (11 x 2 x 3)

4.2.4 Calculation of isopod consumption rate

The isopod leaf-litter consumption rate for each litter treatment was calculated according to the formula of David (1998):

$$C = \frac{Wi - WiD - Wf}{\sqrt{(1-D)}} \qquad \text{Eq. (1)}$$

C = Consumed litter,
Wi = Initial dry weight of litter,
Wf = Final dry weight of litter,
D = Proportion of weight loss in control without isopods:

$$D = \frac{Wi - Wf}{Wi} \qquad \text{Eq. (2)}$$

The total equation for consumption rate is:

$$C = \frac{Wi - Wi\,(\frac{Wi-Wf}{Wi}) - Wf}{\sqrt{1-(\frac{Wi-Wf}{Wi})}} \qquad \text{Eq. (3)}$$

This equation considers the natural microbial litter loss that is present in any biotic environment (Control) and subtracts the litter loss when isopods are present, to isolate the litter loss attributed to the isopods alone.

4.2.5 Leaf litter mixing effects

The relative mass loss due to leaf-litter consumption by isopods was further examined to understand if the changes in consumption rates in mixture treatments were higher or lower than expected. The presence of a leaf-litter mixing effect was tested with an adaptive version of Loreau and Hectors's (2001) additive partition methods as described in Vos et al. (2011) as follows:

$$\Delta Y = \text{O-E} \qquad \text{Eq. (4)}$$

In this equation, *net effect* (ΔY) is the difference between the observed mass loss of a litter mixture (O) and its expected mass loss (E). The expected mass loss is the average mass loss of individual component species in their respective monocultures. This net effect has also been referred to as the net diversity effect. If the net effect deviates from zero, non-additive leaf litter diversity effects are suggested to have occurred. Non-additive effects are driven by leaf litter species interactions with each other, whereas additive effects are controlled by individual leaf-litter species characteristics that are independent of the presence of other litter species. A detection of a positive or negative net effect can suggest a larger than expected influence of an individual component litter species. I assessed net effects for the two species mixtures (native + buckthorn), the four native litter types alone (Native 4 mix), as well as the addition of buckthorn to the native 4 mixture (Native 4 + European buckthorn).

4.2.6 Leaf litter water retention value

The water retention value of the five litter species was calculated to investigate if the consumption rate was related to the water retention of each litter species. Six trial batches of each litter species were submerged in a 21 °C water bath for one hour, then patted down with a paper towel until superficially dried, and immediately weighed. Leaves were then placed in a paper bag and oven dried at 50°C for 48 hours. After the leaves had been dried, they were reweighed. The water retention value was then calculated as:

$$WRV = \left(\frac{Ww - Dw}{Ww}\right) \text{ x } 100 \qquad \text{Eq. (5)}$$

WRV= Water retention value
Ww = Wet weight
Dw = Dry weight

The water retention value helps to evaluate the results of the study, as leaves that retain more water should be easier for both microbes and macrodetritovores to feed on.

4.2.7 Statistical analysis

Univariate statistical approaches were used to study the influence of mixed, and monoculture treatments on the consumption rate by the model isopod. ANOVAs, boxplot, and plot of means graphs and were conducted with the R statistical, computational language (R.Development.Core.Team 2016).

4.3. Results

4.3.1 Water Retention Values for leaf litter species.

Buckthorn was found to have the greatest WRV with a mean of 75.8, sd = 1.8 and red oak was the litter species with the smallest mean WRV of 46.8, sd = 4.7 [Figure 27. (4.2)], ANOVA $F_{5,30} = 103.3$, $P < 0.05$ [Table 15. (4.2)].

4.3.2 Isopod consumption rate in monoculture and two species litter mixture

An ANOVA test for differences in the three harvesting periods found no difference in the consumption rates. Therefore I aggregated all three collection periods together. I first assessed if the addition of buckthorn litter to native litter influenced the consumption of isopods. The consumption rates of the four native canopy species monocultures were compared to the 1:1 mixture of buckthorn and each of the four native litter types. I found an overall increase in consumption rate when buckthorn was part of the mixed litter treatment. Native litter types on average exhibited a consumption rate of 15.44 ± 2.91, and the addition of buckthorn increased this to 28.29 ± 4.36. In the 1:1 mixture, isopods were found to exhibit an overall higher consumption rate, compared to the native monocultures. ANOVA $F_{1,94} = 287.6$, $P = 0.05$ [Figure 28. (4.3)]. This pattern was observed in all 1:1 mixtures [Figure 29. (4.4)].

4.3.2 Results of introduction of buckthorn on four species mixtures

I furthered assessed if the addition of buckthorn litter to four native litter influenced the overall rate of consumption by isopods. The consumption rate of the four-native litter type was compared to the five-species mixture of native and buckthorn litter. I found a minor increase in consumption rate when buckthorn was present in the mixture, with the four-native litter mixture on average exhibiting a consumption rate of 15.93 ± 1.37, and the addition of buckthorn increasing that to 20.37 ± 3.35, this increase was not found to be significant ($P = 0.09$) [Figure 30. (4.5)].

When assessing the consumption rate on buckthorn monocultures against native litter monocultures as well as native four species mixtures and the effect of adding buckthorn, I found buckthorn to increases the overall consumption rates more in the 1:1 species mixtures. This change in isopod consumption rate is diminished by the increase in the diversity of native litter types in the mixture [Figure 30. (4.5)].

The increase in overall consumption rate when buckthorn was added could simply have been due to the fact that isopods consume buckthorn at a faster rate. Given the fact that buckthorn is consumed at a much faster rate than any of the monocultures, it is not surprising that the overall consumption rate of a 1:1 mixture is higher than the native monoculture (and lower than buckthorn by itself). Thus, I next determined if the effect of buckthorn on overall consumption rate was *additive* or *synergistic*.

4.3.3 Mixed litter effects ΔY = O-E

An analysis of the net diversity effect on the isopod consumption rate revealed a high deviation from expected as interpreted by a deviation from zero. The four native litter mixture had the lowest net diversity effect with 0.48 ± 0.11, followed by the mixture of all native litter types including the buckthorn -4.88 ± 1.31. The 1:1 mixture of native and buckthorn litter had the largest net diversity effect of -12.87 ± 3.86 [Figure 31. (4.6)], revealing an antagonistic net effect. An analysis revealed significant difference between the mixed litter treatments ANOVA $F_{2, 15} = 7.927$, $P = 0.005$.

4.4 Discussion

4.4.1 Influence of chemo-physical characteristics on isopod consumption rates

Leaf litter and its chemico-physical traits have been shown to affect the consumption by detritivores, by either accelerating or retarding disappearance rates (Zimmer et al. 2005, Vos et al. 2011, Jabiol and Chauvet 2013, Vos et al. 2013). The physical characteristic of water retention of leaf litter can have a high impact on the rate of consumption by detritivore. This impact can be achieved by promoting microbial and microarthropod activity which may be susceptible to desiccation.

Previous experiments have shown microarthropods to move to litter patches with higher litter moisture content (Levings and Windsor 1984). My results show a high correlation between WRV and isopod consumption rates, with litter with high WRV also exhibiting a high consumption rate. The water retention pattern mirrors that of the isopod consumption pattern in the leaf litter monocultures. I found buckthorn to have both the highest WRV and highest isopod consumption rate. In addition, the two oak species I examined (white oak, red oak) also showed the lowest isopod consumption rate, [Figure 29. (4.4), and WRV values Figure 27. (4.2)]. This correlation may help explain results in Chapter 3, if arthropods seek litter with higher water-retaining characteristics.

4.4.2 Why is the consumption rate of isopods significant?

Isopods, as part of the decomposer community, have been suggested to show little adaptation to the recurring input of unique litter types but instead can respond quickly to changes in litter quality (Makkonen et al. 2012). Previous studies have altered the nutrient content of litter to investigate altered palatability, or to investigate what chemico-physical conditions drive palatability in isopods with varying conclusions (Dudgeon et al. 1990, David et al. 2001). What is known about isopods is that the assimilation efficiency is low (Zimmer 2002). This low assimilation efficiency has been documented to change rates of consumption when nutrient poor litter is encountered (Rushton and Hassall 1983b, Dudgeon et al. 1990).

My results support previous findings of isopods changing consumption rates depending on the chemico-physical value of a novel litter. When averaged across all native litter types, native litter was consumed at a lower rate than buckthorn. My results take into account natural litter loss in the mesocosm due to microbial activity in the no-isopod Control and isolate the change in litter amount due only to the consumption rate of the isopods in the mesocosm.

4.4.3 Net Diversity Effects on Mixed Litter (ΔY = O-E)

The CI (approx. 2x SE) of the net diversity effect for the four native species broadly overlapped zero. Thus, mixing canopy species produced no antagonistic nor synergistic effect on litter decomposition. Within the mixed-litter treatments, non-additive effects occurred only in the mixed litter treatments that included buckthorn. Unexpectedly, the impact of buckthorn was *antagonistic*, as its presence decreased overall consumption rate from what would be expected from the additive-effects model. Or alternatively, and most likely, because isopods consumed monocultures of buckthorn at much higher rates than native-species monocultures, the presence of the native species impeded the consumption of buckthorn by isopods.

If buckthorn is the preferred litter type, isopods will find it harder to find and consume it if buckthorn becomes a smaller and smaller proportion of the litter habitat. It is also possible that the chemical and physical properties of native litter have short-term but cumulative negative effects on rates of ingestion and digestion (Wood et al. 2012, David 2014).

Although an introduced species, *Trachelipus rathkii* has become a dominant detritivore found in the Midwest. It will be interesting to see whether this altered consumption rate is also exhibited by other native detritivores. Millipedes, which occupy a similar functional role in the detrital system, may be a suitable candidate for a future study.

Global biodiversity is in a sharp decline due in part by the loss of habitat and the introduction of invasive species. Therefore, understanding the mechanisms by which biodiversity alters nutrient cycling and ecosystem function requires more attention. The introduction of European buckthorn likely influences leaf-litter decomposition dynamics. It is clear that if buckthorn accelerates overall decomposition of the litter, it is not due to its effect on the feeding behavior of isopods, a common macrodetritivore. My results indicate that buckthorn decreases the overall consumption rate of the litter mixture from what would be expected if isopods were consuming litter species at rates independent of the presence of native species. Thus, alternative explanations, that do not involve isopods, will have to be found for why the leaf-litter layer appears to be disappear more rapidly in areas where buckthorn has invaded.

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4. FIGURES

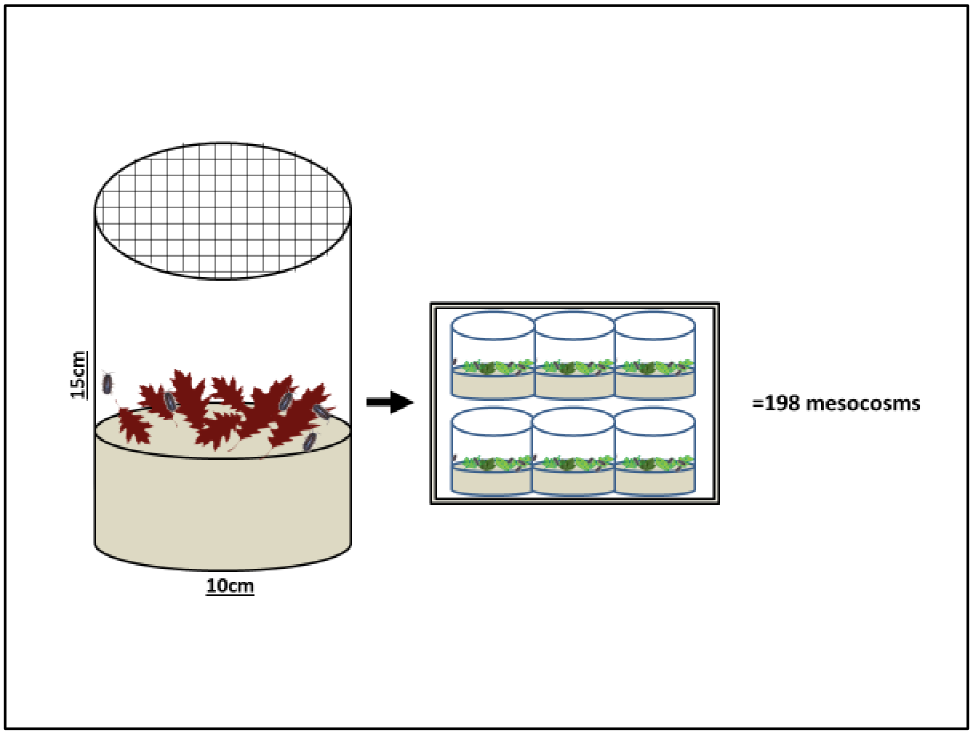

Figure 26. (4.1). Mesocosm design. Each mesocosm was given 10g of litter for each litter treatment and randomly placed in 33 trays. 11 litter treatments x 3 harvesting events x 6 replicates each = 198 total mesocosms used. The 6 replicates represented 4 mesocosms with isopods, and 2 without isopods (control).

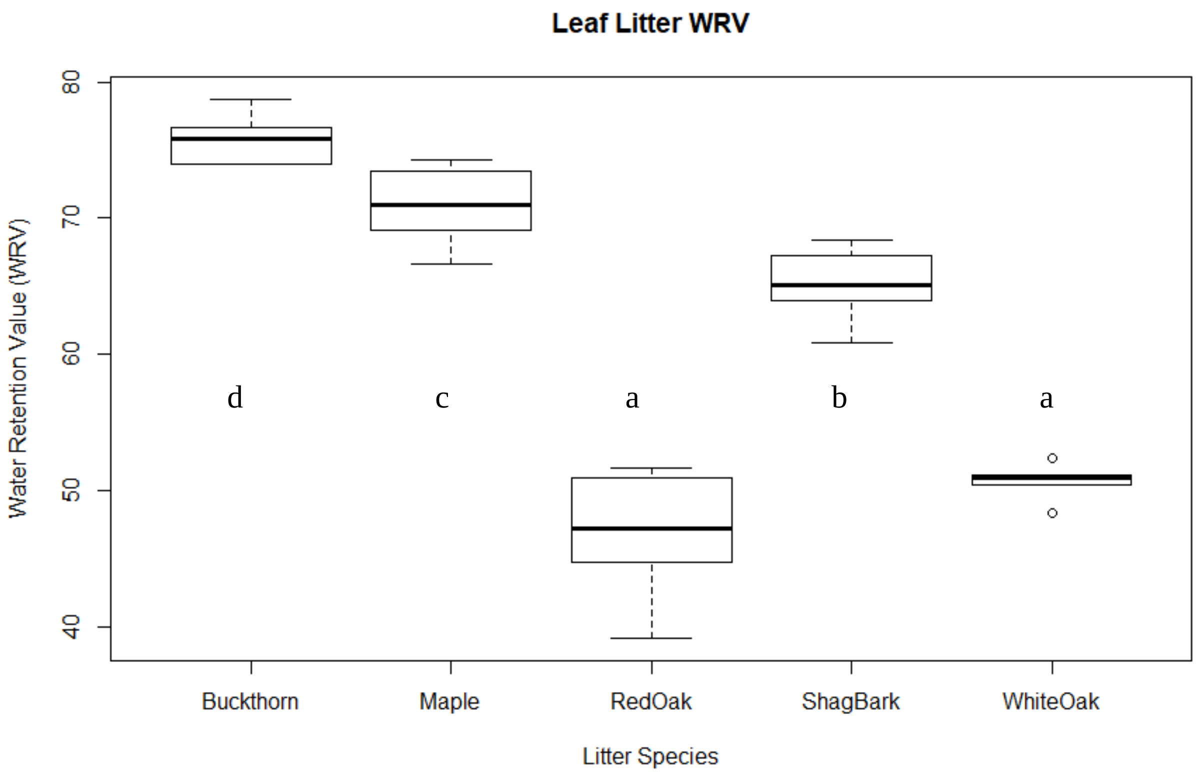

Figure 27. (4.2). Box plot of the Water Retention Value of each litter species used in this study. Boxplots display medians, bounded by the first and third quartiles, with outliers as single dots ANOVA $F_{4,25} = 114.6$, $P < 0.05$. The letters a, b, c, d correspond to a post hoc statistical test. Different letters indicate a significant difference (ANOVA) between the litter treatments, n=6 samples each.

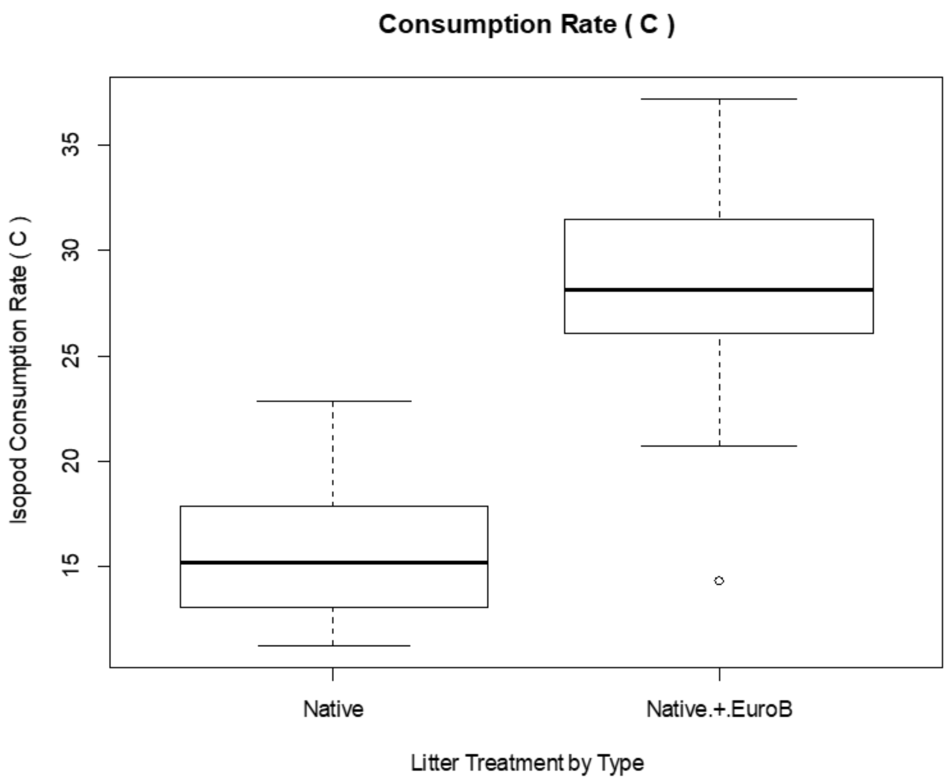

Figure 28. (4.3). Box plot of the consumption rate (C) of isopods on native litter monocultures (Native) and the 1:1 native and buckthorn litter mixtures (Native + EuroB). The consumption rate is the corrected % of litter consumed by isopods using Equation 3. All litter treatments start as a 10g of litter, and isopod mixtures. Boxplots display medians, bounded by the first and third quartiles, with outliers as single dots ANOVA $F_{1,94} = 287.6$, $P < 0.05$.

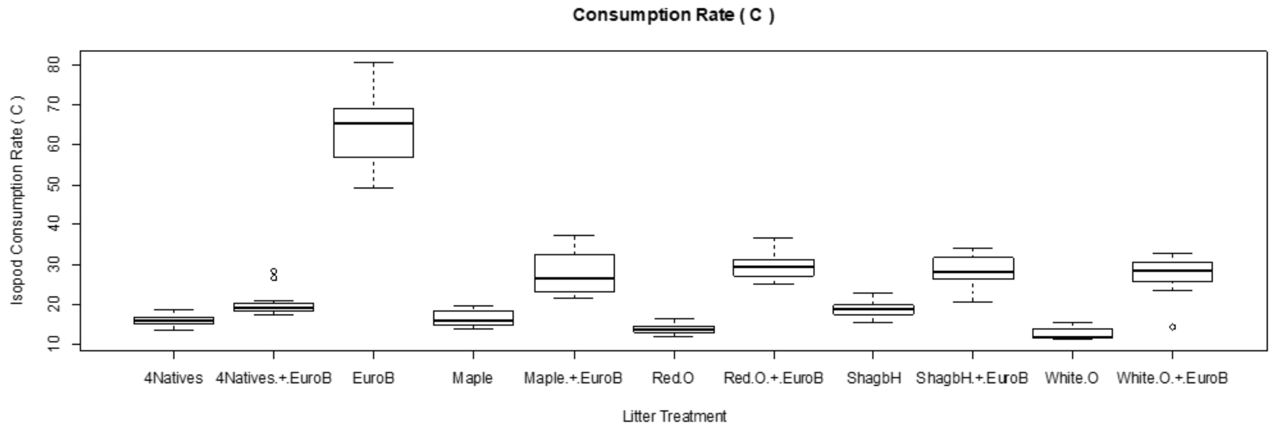

Figure 29. (4.4). Box plot of the isopod consumption rate (C) for all leaf litter treatments, including 4 Native mix = consumption rate of 4 native litter species, 4 Native + EuroB is the mixture of the four native types and buckthorn, EuroB = Buckthorn monoculture, and each of the four litter types monocultures and the 1:1 litter mixture of native and buckthorn.

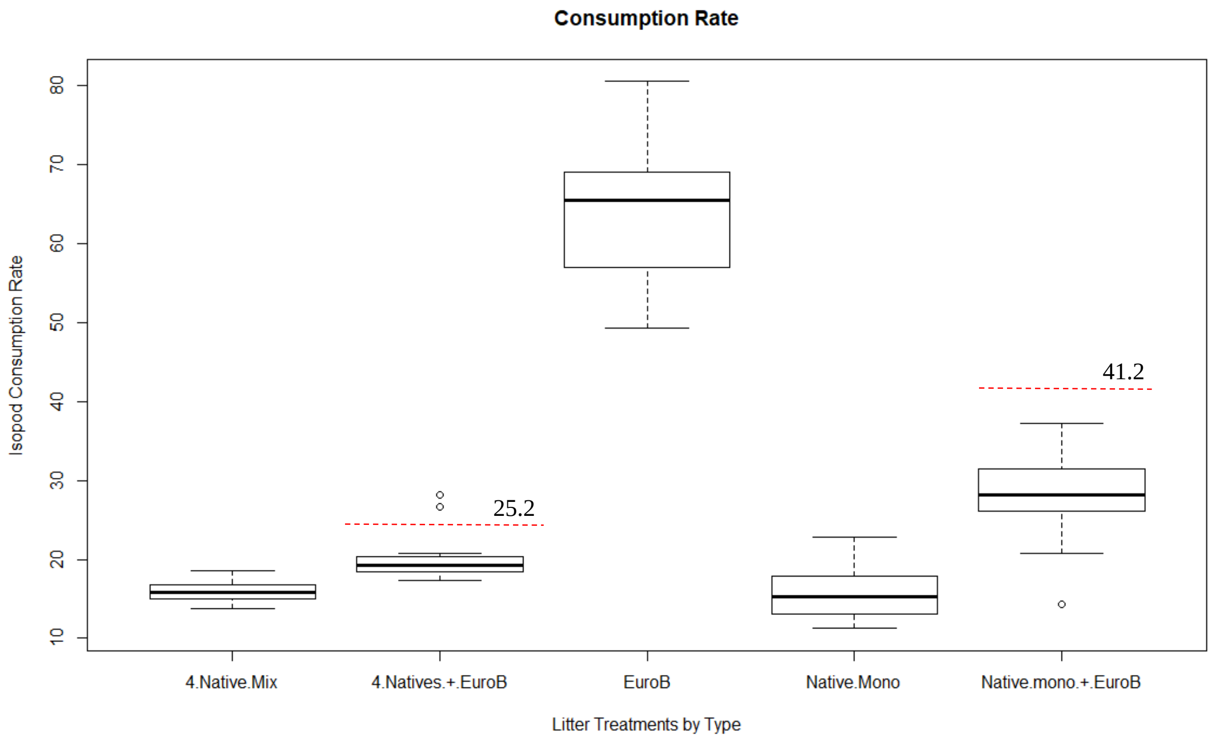

Figure 30. (4.5). Box plot of the consumption rate (C) summary of isopods on a leaf litter treatment, including 4 Native mix = consumption rate of 4 native litter species, 4 Native + EuroB is the mixture of the four native types and buckthorn, EuroB = Buckthorn monoculture, Native Mono = all native litter monocultures, Native Mono + EuroB = 1:1 litter mixture of native and buckthorn. The dotted lines (- - - -) indicate expected consumption rates based on the single-species dynamic model.

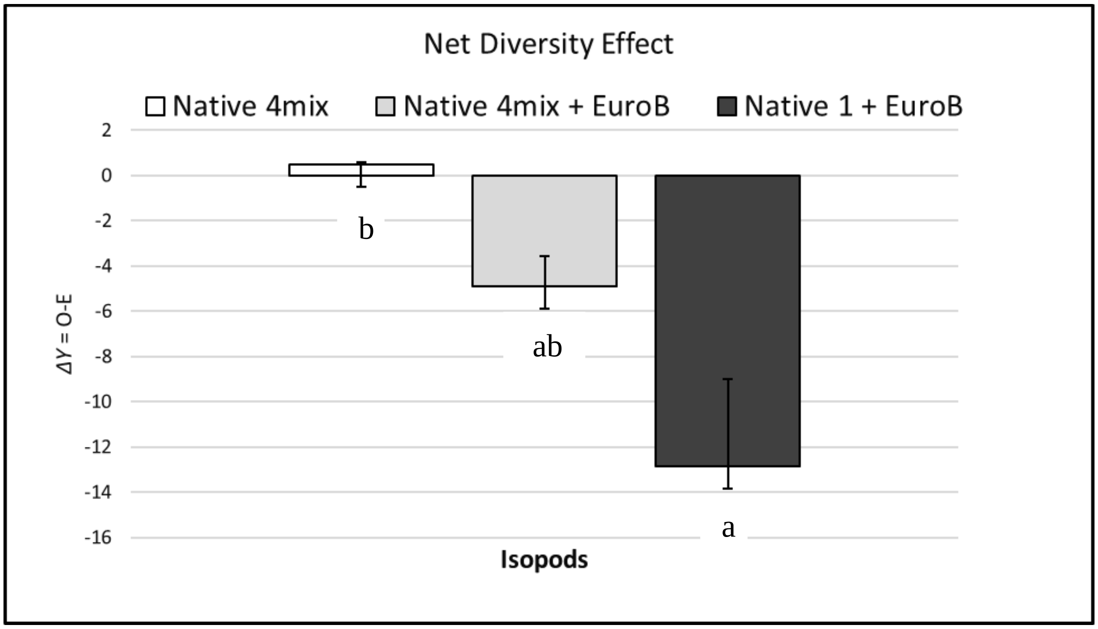

Figure 31. (4.6). Net diversity effects on isopod consumption rates (mean ± SE). Mixed litter treatments are broken down into the four native litter types (Native 4mix, *n=3*), the mixture of all four natives and buckthorn (Native 4mix +EuroB, *n=3*), and the 1:1 mixture of the 4 native litter types with buckthorn (*n=12*). Different letters correspond to a post hoc statistical tests and indicate significant differences between litter treatments, ANOVA $F_{2, 15} = 7.927$, $P = 0.0045$

4. TABLES

Table 14. (4.1). Isopod and leaf litter treatments, including the break down of mixture of dried litter used in each treatment

	Treatments	*Replicates*		
Isopods	Control: No isopod	2	2	2
	Isopod: *Trachelipus rathkii*	4	4	4
Monocultures	White oak, *Quercus alba*	1		
	Red oak, *Quercus rubra*	1		
	Shagbark hickory, *Carya ovata*	1		
	Sugar maple *Acer, saccharum*	1		
	European buckthorn, *Rhamnus cathartica*	1		
2 Species Mix	White oak, + European buckthorn		1	
	Red oak, + European buckthorn		1	
	Shagb1ark hickory, + European buckthorn		1	
	Sugar maple, + European buckthorn		1	
4 Species Mix	White oak, Red oak, Shagbark hickory, Sugar maple			1
5 Species Mix	White oak, Red oak, Shagbark hickory, Sugar maple + European buckthorn			1
Total		11	10	8

Table 15. (4.2). Leaf litter Water Retention Value (WRV) for all litter species.

Litter species	Litter type	Mean	SD	Trials
European buckthorn, *Rhamnus cathartica*	Introduced	75.83	1.84	6
Sugar maple, *Acer saccharum*	Native	70.90	2.82	6
Red oak, *Quercus rubra*	Native	46.78	4.66	6
Shagbark hickory, *Carya ovata*	Native	65.10	2.65	6
White oak, *Quercus alba*	Native	50.69	1.34	6

4. APENDIX

A.1 APPENDIX figures and table

Figure 32. (4.A1). A picture illustration of a mesocosm, randomly placed mesocosms in trays, and their random placement in the environmental chamber. Mesocosms are separated by the three destructive harvesting-collection events.

CHAPTER 5: NUTRIENT LEACHING BY THE INVASIVE SHRUB *RHAMNUS CATHARTICA* INFLUENCES LEAF LITTER CONSUMPTION PATTERNS OF MACRODETRTITIVORES: A FOOD CHOICE EXPERIMENT

5. ABSTRACT

Invasion by exotic plant species continues to be a local concern in the woodlands of the Midwest. Work continues to better understand these introduced species and how they influence leaf-litter diversity and arthropod composition. Yet, little is known about how many introduced plant species, whose leaf litter can differ substantially in nutrients from litter of native species, impacts litter disappearance by modifying detritivore consumption rates. I assessed how leaching of materials from leaf litter of the invasive shrub European buckthorn (*Rhamnus cathartica*) changes the palatability of native litter types to macrodetritivores. This study was a cafeteria-style food-choice experiment involving five native leaf litter types and the common detritivorous isopod *Trachelipus rathkii* (Crustacea: Isopoda: Oniscidea). This study found a direct effect of buckthorn leaf-litter contact with native leaf litter on the latter's palatability to isopods. Isopods on average increased the consumption of native litter that had buckthorn contact by 7.0%, compared to litter that did not have buckthorn contact. My findings show that direct contact with conspecific litter can also increase the palatability to isopods by 2%. These findings suggest buckthorn, through direct contact and nutrient leaching, can alter the leaf-litter decomposition rate by altering the palatability of native leaf litter to macrodetritivores.

5. Keywords: Isopod, Woodlice, Functional diversity, Leaf litter decomposition, Leaf litter mixing effects, Macrodetritivores, Nutrient leaching, Plant diversity, Invasive species, Ecological restoration, Food choice, Cafeteria style study

5.1. INTRODUCTION

5.1.1 Nutrient leaching and choice experiments

Detritivorous isopods, along with other macrodetritivores, are capable of feeding on a large variety of detritus, including leaves, fine woody debris, as well as carrion. The preference of which detritus is consumed are dictated by the palatability and the energy assimilation rate from the detritus. Some litter types are not palatable as either fresh or freshly senescent leaf due to secondary compounds. During leaf litter decomposition, polyphenol content is leached out and the C: N ratio decreases, increasing the palatability of the litter to detritivores (Rushton and Hassall 1983, Zimmer 2002). Leaves that exhibit a high microbial activity and nutrient leaching capability have been documented to be preferred by some detritivores. Feeding on leaves by Collembola, for example, has been shown to increase leaching of ammonium, nitrate, and calcium from the leaf litter (Ineson et al. 1982). Fungal colonization may differ between plant litter types and has been observed to increase after polyphenol concentration decreased (Pieper and Weigmann 2008).

5.1.2 Habitat and food choice in detritivores

The decomposer community is suggested to show little adaptation to a recurrent input of a unique litter type, but instead have been shown to respond quickly to changes in litter quality (Makkonen et al. 2012). If Makkonen is correct, then nutrient-rich litter from an introduced invasive plant may incur a quick response from decomposers in the mixed litter and may help explain higher rates of litter decomposition in locally invaded sites found in previous research (Heneghan et al. 2007, Knight et al. 2007)

In this study, an investigation was made into the influence of microbial activity, and nutrient leaching on food choice of a common detritivore. I assessed how nutrient leaching and leaf-litter conditioning may influence detritivore food choice. I used leaves that were conditioned in soil trays to facilitate the incubation of microbes, primarily saprophytic fungi. Studies have used the incubation of microbial communities in the past to study how it plays a role in decomposition (Sulkava et al. 2001). I used leaf litter conditioned by leachates from buckthorn litter to determine how conditioning may influence detritivore food preferences. Although fugal abundance was not measured in this study, the presence of fungal hyphae during conditioning, can help justify the assumption of increased microbial activity during conditioning.

5.1.3 Objectives

The objective of this study was to explore how nutrient leaching from buckthorn litter to a litter of native species may alter litter consumption by an abundant macrodetritivore.

5.2. METHODS

*5.2.1 Model macrodetritivore (*Trachelipus rathkii*) and leaf litter species*

The isopod *Trachelipus rathkii,* which was used in Chapter 4, was utilized in this study as a representative of a common detritivore in northeastern Illinois. Five native canopy tree species and one invasive shrub leaf-litter species common in the Midwest were selected for this study: white oak (*Quercus alba)* red oak (*Quercus rubra)* burr oak (*Quercus macrocarpa)* shagbark hickory

(*Carya ovata)* sugar maple (*Acer saccharum),* and the invasive shrub European buckthorn (*Rhamnus cathartica)*. Freshly senescent leaves of each species were collected in the fall, oven dried and used as needed.

5.2.2 Leaf litter conditioning

The soil used was collected from three field study sites used in Chapter 4. The soil was defaunated and homogenized by sifting through a fine sieve and removing any visible plant or animal material; it was allowed to dry until used. The soil was not oven dried in order to retain any saprophytic microbial community propagules that may facilitate nutrient leaching, mimicking the microbial conditions documented in woodlands. If an invertebrate was encountered during the experiment's conditioning phase, it was removed.

To standardize the shape of the diverse leave morphs used, whole leaves were cut into 2-cm diameter discs using a cork borer. Discs were cut out of the inside of the leaf while avoiding leaf edges. To simulate natural nutrient leaching from precipitation and microbial activity, the leaf litter discs were conditioned by allowing nutrient leaching and leaf litter weathering from one leaf to another in a controlled environment before the start of the food choice experiment.

To condition the leaves, litter discs were randomly placed in five conditioning soil-lined trays, [Figure 33. (5.1)]. Each disc was allowed to condition in the trays in one of three treatments: 1) alone as a single disc laying on the defaunated soil, 2) a litter disc under a conspecific disc laying directly above it, or 3) a litter disc directly under a buckthorn litter disc, [Figure 34. (5.2) and Figure 35. (5.3)]. There were 360 conditioned discs used: twenty-four replicates of each of the three-disc treatment for each of the five native litter species (5 x 3 x 24 = 360). Conditioning was used to simulate natural nutrient leaching caused by microbial activity, and soluble organic and non-organic molecule transfer between disc due to precipitation. The leaching process was facilitated by the addition of moisture to the conditioning trays.

After the litter discs were randomly placed in the trays, the samples were moistened every 2-4 days with approximately 45 milliliters of water per tray, enough for water droplets to form on the top of each disc. An indirect mist device was used so as not to disturb the placement of the samples. Each sample had been oven dried for 48 hours and then weighed before starting the leaf conditioning, it was weighed again at the end of the conditioning period.

To account for nutrient leaching over time, three time intervals of litter conditioning were used. All litter conditioning started at the same time, and three groups of all conditioning types were collected at three time intervals: three weeks, four weeks and five weeks from the onset of the conditioning.

5.2.3 Food choice experimental design

I constructed 120 feeding chambers from 100mm x 15mm petri dishes; each chamber floor was lined with Whatman filter paper. All three pre-treated leaf-disc treatments were placed inside each chamber and arranged uniformly. A small amount of water was added to the middle of the chamber to maintain a level of humidity that would prevent the isopods from dying of desiccation and to partially rehydrate the litter discs.

Before the start of the food choice experiment, the isopods were starved for 24 hours. Only intermolt individuals from 0.02 – 0.04 grams were used. Leaf disc samples were placed over the moist filter paper. The isopods were allowed to forage within the chamber for 48hrs. All feeding chambers were placed in a 12hr;12hr light-dark time rotation environmental room with an ambient temperature of 21°C. After the food choice experiment had concluded, the isopods were removed from the chamber and the litter discs were removed from the feeding tray, oven dried and reweighed. Results were calculated as % litter loss due to the conditioning phase of this experiment, the isopod food choice phase, and the total litter loss due to both.

5.3. RESULTS

5.3.1 Results of litter mass changed due to conditioning and food choice

Initial and final weights (including % mass change) were calculated for the leaf litter conditioning, isopod feeding chamber trials and the overall change due to conditioning and isopod feeding [presented in Table 16. (5.1)]. When assessing the time frame of leaf disc conditioning, I found no interaction between time and treatment. Because no interaction between time frame and mass loss was observed, the three time frames were aggregated together, and treatments were assessed without time as a factor.

An overall pattern of litter loss emerged, N < N/N < N/B pattern, where (N) is native litter alone with the lowest litter loss, (N/N) is native litter under a conspecific, and (N/B) native litter under buckthorn with the highest litter loss rate. Litter conditioning had a similar impact on % litter loss for all treatments, with conditioning producing a range from 14.17-15.51% litter loss across treatments in the conditioning phase; this change was not found to be significant, ANOVA $F_{2, 338} = 0.407$, $P = 0.666$.

The overall pattern N < N/N < N/B was also apparent in the isopod food choice part of this study, where conditioning under buckthorn caused an additional 5.2% litter loss on native litter discs compared to discs that were conditioned under conspecifics. An overall 7% increase in isopod consumption was seen for litter discs conditioned under buckthorn, compared to conditioning alone [Table 16. (5.1)].

5.4. DISCUSSION

5.4.1 Nutrient Leaching and conditioning

Although I did not measure fungal community activity, our results do support previous findings of fungal community colonization and litter loss to be dictated in magnitude by the litter-species identity (Hättenschwiler et al. 2005, Makkonen et al. 2012). The average % mass loss for all three-litter treatments was 14.7% during the conditioning phase [Table 16. (5.1)]. The overall similar % change in conditioning between our three treatments suggest that the % litter loss due to isopods is driven by small changes in the chemical composition in the litter. These changes may be attributable to changes in fungal mass or concentration of ammonia, nitrate or polyphenols within the litter.

5.4.2 Food Choice

In this study I used a straightforward and common method to test for food preference of detritivore. This cafeteria-style study design has been employed in previous research to investigate detritivore food choice using different litter types (Abelho and Molles 2009).

The exhibited increase of consumption of native litter types, and its increase if conditioned under buckthorn suggest that this increase is due to nutrient leaching. Not only do I present evidence that buckthorn litter and its physical contact with native litter types alters isopod food choice, but I also demonstrate that the physical contact of native litter and its conspecific litter will also produce a change in the palatability of that litter. The increased palatability for all treatments with direct contact to other litter types may be due to increased water retention in the space between disks. This increased moisture within the litter may have increased the microbial activity in these treatments. The overall increase of palatability of the conspecific litter types was close to 2% ; replacing the conspecific litter with buckthorn increased that by 5.2%.

5.4.3 Synergistic influence?

Studies have found that decomposition of leaf litter may be driven by dominant species and not complementary interactions between litter species (Treplin et al. 2013). Others have suggested a complementary, sometimes termed "synergistic," effect on decomposition. In a review of mixed-litter studies, authors found 67% of all mixtures tested in litter decomposition experiments to show a non-additive mass loss, with synergistic responses having a greater occurrence than antagonistic responses (Gartner and Cardon 2004). Here I show that buckthorn litter is driving an increase in palatability of native litter types. I also show that interactions with conspecific litter types can increase the palatability of litter by 1 to 2% on average [Table 16. (5.1)].

Although not a significant difference is shown between treatment in the conditioning phases of this study, I do see a very small but suggestive change of 1.34% mean increase in litter loss due to microbial community activity in the buckthorn treated litter compared to conditioning alone, a pattern that is also seen in the isopod feeding choice. Fungal activity was observed during the conditioning phase of this experiment, with hypha being visible within the first 24 hours. It was also noted that litter treatments with the buckthorn discs were colonized by visible hyphae at the start of conditions [Figure 30. (5.2)].

This study provides support of how non-additive effects of litter mixtures might impact leaf-litter decomposition. This data showed how buckthorn litter can change leaf-litter decompositions dynamics by altering native leaf litter palatability when under direct contact with buckthorn. The added palatability of native litter types in the presence of buckthorn contradicts the results in Chapter 4. The increased palatability of native litter due to nutrient leaching can help me understand the non-additive antagonistic results found in Chapter 5.

In this chapter I see a direct influence on leaf litter consumption patterns by a detritivore, whereas in Chapter 4 I investigated the overall litter loss in mixed litter. My contradictory results between Chapter 4 and Chapter 5 may stem from the complexity of the interaction between native and introduced species. This chapter suggesting more work is needed to better understand how buckthorn is influencing the decomposition mechanisms in areas of invasion.

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5. FIGURES:

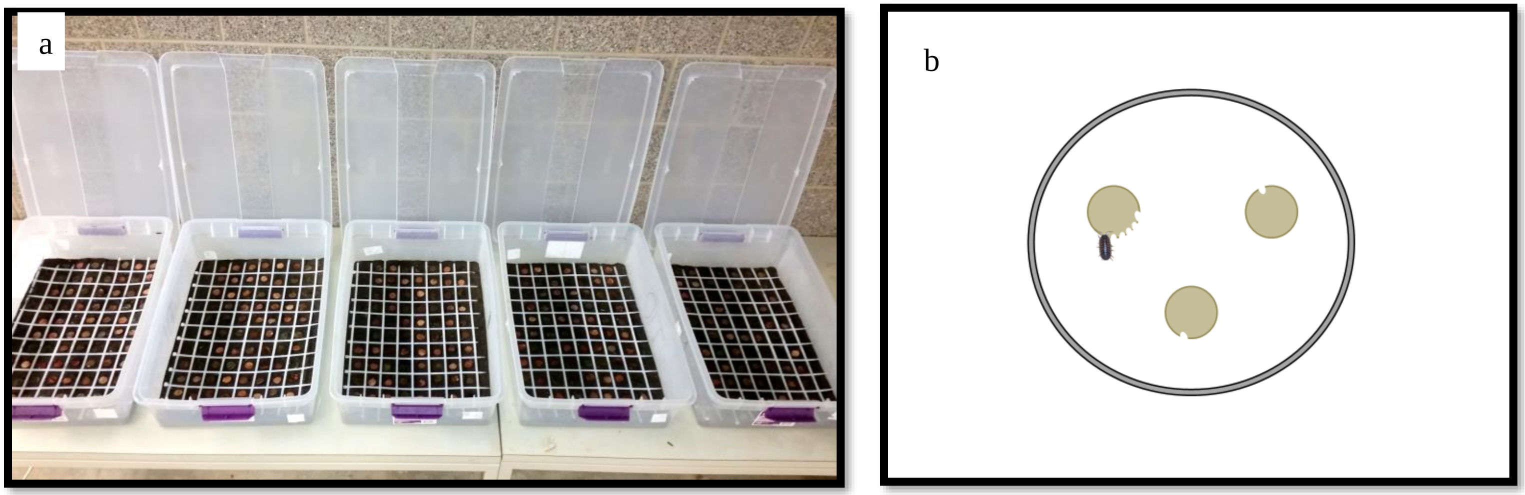

Figure 33. (5.1). Illustration of litter-conditioning trays and food-choice chamber. a) Leaf litter disc conditioning trays. Each litter disc was randomly arranged in one of five trays. Trays had a bed of defaunated sifted soil from three research sites. The soil was sieved and homogenized before use; 2 inches of soil was used as bedding in each tray. The plastic grid was used to identify the leaf litter discs, treatment and time interval used. b) Diagram of food choice feeding chamber showing the arrangement of the 3 discs of conditioned litter.

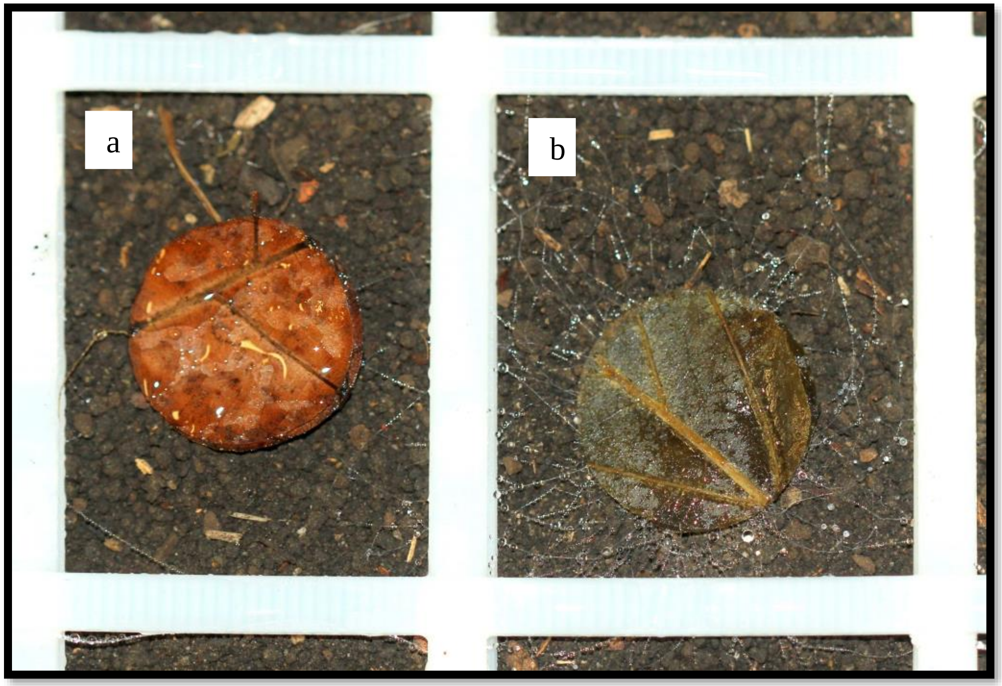

Figure 34. (5.2). Illustration of litter conditioning trays and the increased fungal hyphal activity after 24hrs from the start of the conditioning phase. a) Red Oak, b) Buckthorn.

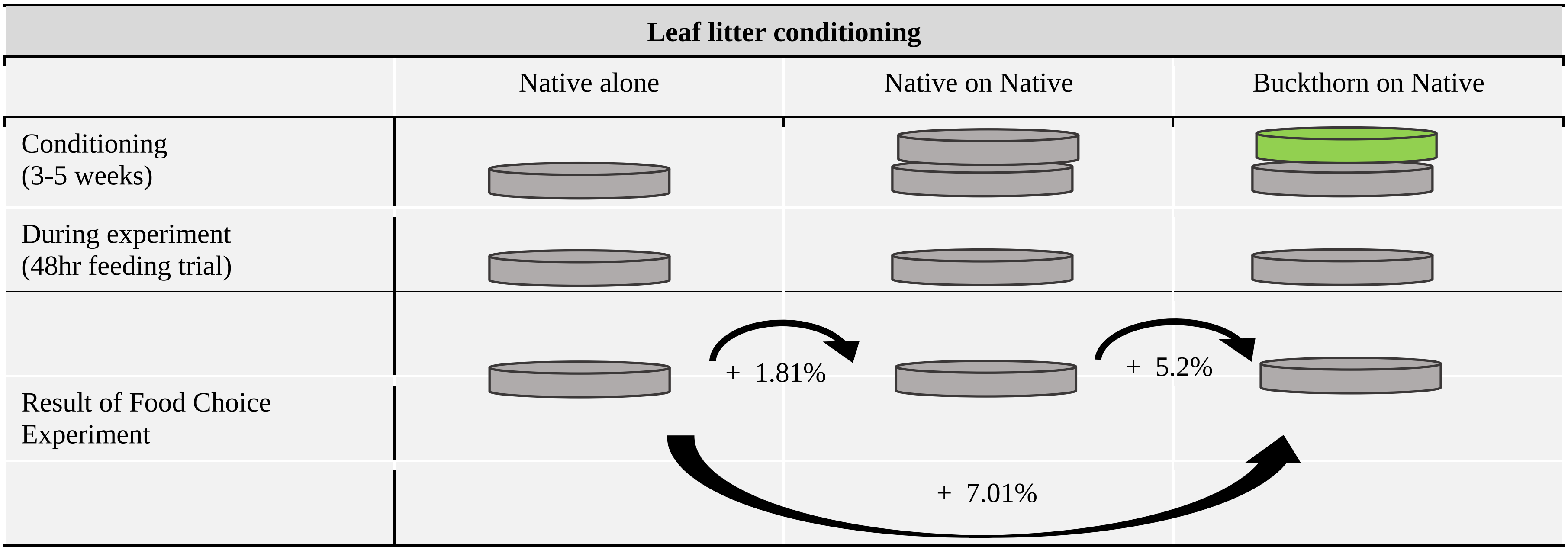

Figure 35. (5.3). Illustrated results of the impact of litter conditioning on native, native-on-native and buckthorn-on-native litter. With percent increased consumption rates.

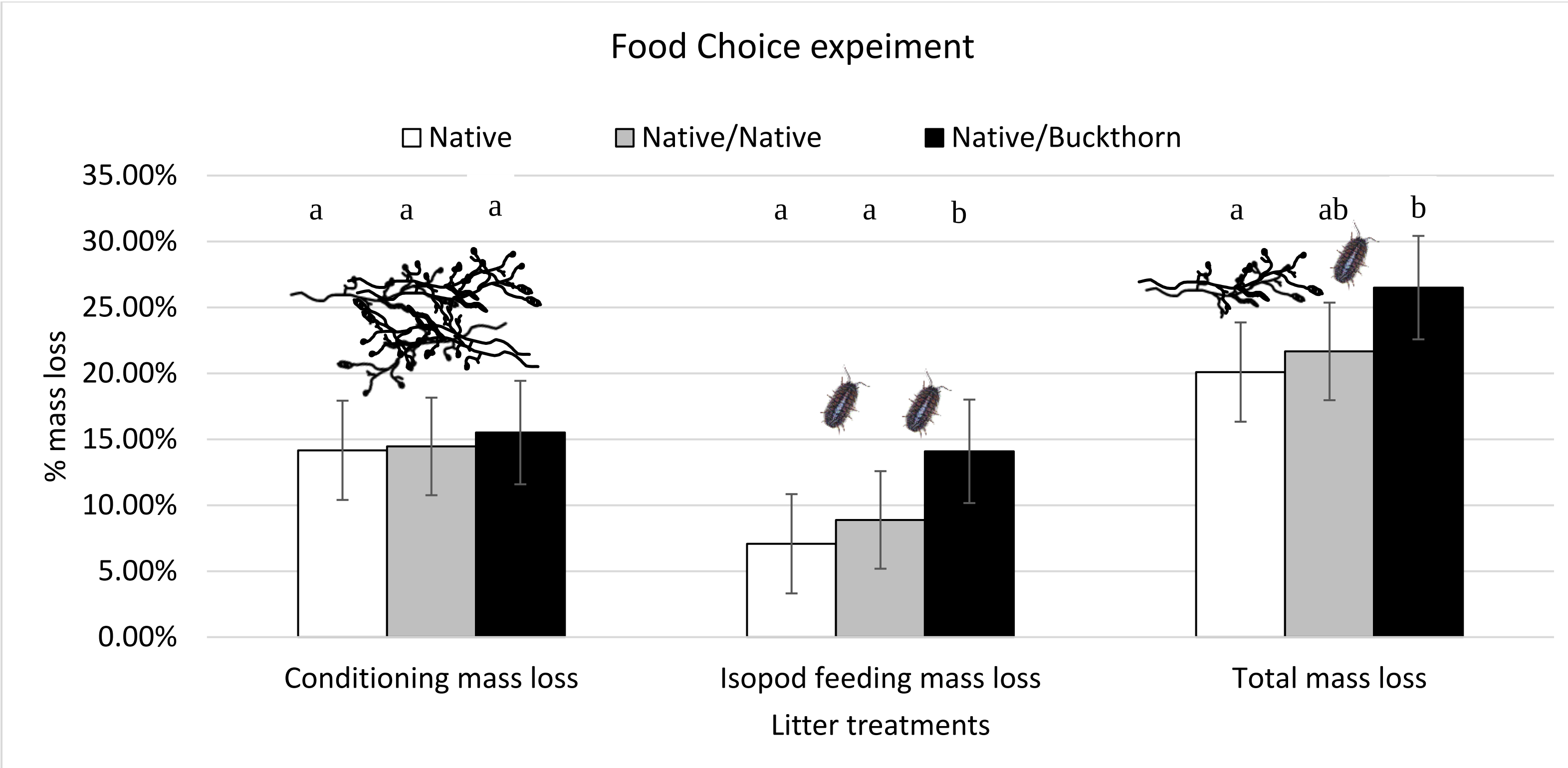

Figure 36. (5.4). Litter mass loss (as a percentage of dry litter removed from disc) due to leaf litter conditioning, isopod food choice and total mass loss across the study (mean ± SE). Different letters correspond to a post hoc statistical test and indicate significant differences between treatments (P< 0.05 a ANOVA). Native (n = 113), Native on Native (n=114), Native and Buckthorn (n=114). Conditioning: ANOVA $F_{2, 338} = 0.407$, $P = 0.666$, Isopod: ANOVA $F_{2, 330} = 5.346$, $P = 0.005$, Total Mass loss: ANOVA $F_{2, 338} = 3.932$, $P = 0.021$.

5. TABLES:

Table 16. (5.1). Results of litter loss due to Conditioning, isopod food choice, Total % change. Data is presented as the % mass loss for each treatment (N=Native *n=113*, N/N= Native on Native *n=115*, N/BT= Native under Buckthron *n=115*). Results are also listed by litter species used to produce the three treatments, they include (BO= Bur Oak, H= Hickory, M= Maple, RO= Read Oak, WO=White Oak. BT= Buckthorn).

		Conditioning					***Isopod Food choice***				***Total % change***		
Treatment	***Litter Species***	***Initial (g)***	***Final (g)***	***(g) lost***	***%.Change***	***SE***	***Post Isopod (g)***	***Post Isopod (g) loss***	***Post Isopod % loss***	***SE***	***Final (g)***	***Final % loss***	***SE***
N	BO	0.0251	0.0239	0.0012	-4.46%	1.35%	0.0228	0.0011	-4.49%	0.80%	0.0023	-8.78%	1.42%
N/N	BO/BO	0.0240	0.0230	0.0010	-4.22%	1.83%	0.0219	0.0011	-5.28%	0.99%	0.0021	-9.27%	1.93%
N/BT	BO/BT	0.0243	0.0226	0.0017	-7.22%	0.94%	0.0215	0.0011	-4.82%	1.03%	0.0028	-11.68%	1.39%
N	H	0.0141	0.0109	0.0033	-21.84%	2.18%	0.0095	0.0018	-11.32%	2.41%	0.0047	-30.03%	2.82%
N/BT	H/BT	0.0171	0.0131	0.0040	-23.46%	2.27%	0.0115	0.0017	-14.01%	5.90%	0.0057	-32.94%	2.29%
N/N	H/H	0.0139	0.0105	0.0034	-24.60%	1.99%	0.0094	0.0011	-10.52%	2.24%	0.0045	-32.60%	2.44%
N	M	0.0079	0.0065	0.0014	-16.57%	3.38%	0.0057	0.0008	-12.86%	5.00%	0.0022	-28.05%	5.17%
N/BT	M/BT	0.0091	0.0073	0.0018	-19.97%	2.51%	0.0054	0.0022	-32.13%	8.23%	0.0040	-44.11%	6.45%
N/N	M/M	0.0086	0.0069	0.0018	-22.10%	3.23%	0.0058	0.0010	-16.20%	4.68%	0.0028	-34.21%	4.26%
N	RO	0.0234	0.0186	0.0049	-20.44%	1.71%	0.0177	0.0009	-5.00%	0.82%	0.0058	-24.51%	1.62%
N/BT	RO/BT	0.0213	0.0167	0.0046	-21.98%	2.51%	0.0160	0.0015	-7.76%	1.40%	0.0061	-27.75%	2.57%
N/N	RO/RO	0.0224	0.0190	0.0034	-14.81%	1.77%	0.0179	0.0012	-6.84%	1.32%	0.0046	-20.54%	2.13%
N	WO	0.0260	0.0239	0.0021	-8.08%	1.08%	0.0237	0.0014	-1.84%	0.71%	0.0035	-9.73%	1.11%
N/BT	WO/BT	0.0314	0.0295	0.0033	-6.74%	1.46%	0.0280	0.0015	-5.16%	0.82%	0.0047	-11.49%	1.75%
N/N	WO/WO	0.0293	0.0272	0.0034	-6.67%	1.46%	0.0260	0.0011	-4.51%	0.75%	0.0045	-10.89%	1.51%

	Conditioning			***Isopod Food choice***			***Total % change***		
		mean	***SE***		***mean***	***SE***		***mean***	***SE***
Native	N	14.17%	1.09%	N	7.08%	1.16%	N	20.10%	1.47%
Native/Native	N/N	14.46%	1.09%	N/N	8.89%	1.43%	N/N	21.67%	1.62%
Native/Buckthorn	N/BT	15.51%	1.05%	N/BT	14.09%	1.44%	N/BT	26.50%	1.61%

CHAPTER 6: CONCLUSION, RECOMENDATIONS AND FUTURE DIRECTIONS

6.1 Introduction

This chapter will serve as a synopsis of significant findings in this dissertation, as well as how this information can be used in management efforts and citizen-scientist efforts, as well as introducing future research directions and directions the author will take.

6.2 Major Conclusions for Each Chapter

6.2.2 Conclusions: Chapter 2, 100 sites project

In this chapter, I found management history category is very influential on the leaf-litter arthropod community, and this is driven by how sites differ in leaf-litter characteristics and seasonality. Much work has been done to improve the knowledge of the impact of management of the invasive shrub buckthorn, and what influence this has on the arthropod community. I addressed this problem using different scales but found comparable results in all three site-scales used (*N, N/g, N/ha*). My suggestion of using LL: FWD as a measure of litter quality was supported by my Bio-Env analysis, which showed this ratio be a good predictor of the abundance of the leaf litter arthropod community.

Because leaf litter is a representation of the litter input from the above vegetation community, it is highly influenced by the diversity of the plant community that produces it. If novel litter such as that produced by buckthorn becomes a dominant litter input, this can alter nutrient cycling and habitat suitability for leaf litter arthropods. Sites with degraded status (Control) showed the lowest overall abundance of arthropods.

This chapter spurred the following chapters in trying to understand how invasive litter types can influence the arthropod community by altering the diversity of litter types and how this influences both colonization rates, consumption rates, and food choice.

The recommendations to land managers from this chapter include increased assessment of leaf litter characteristics within research sites. Gauging leaf litter conditions between sites can help interpret how restoration efforts impact the leaf litter and the leaf-litter arthropod community. When surveying restoration efforts at these sites, sampling both at the start and the end of the summer can better assess how restoration efforts are impacting the detrital arthropod community. Studies like that produced in chapter 2 could produce added information of diversity differences and changes over time if a higher taxonomic resolution were used. Although it requires an elevated level of time investment, the production of species lists that can be attributed to individual sites is a tangible product of studies like this. Species lists not only can be used in assessing the diversity of the site but can be used in 20, 30 or 50 years to assess how individual species change ranges, become locally extinct or can identify the timeframe a new invasive species establish at the site.

The next step for this chapter's data will be to analyze how the identification to species influences the conclusions presented in chapter 2. To date, I have identified four taxonomic groups to species, including: ants (26 spp), isopods (7 spp), spiders (79 spp), and beetles (203 spp). This data represents 66 families, 215 genera and 315 species to use in a new analysis.

6.2.3 Conclusions: Chapter 3, Litter cage

Litter-cage treatment had an overall influence on colonization rates by arthropods; buckthorn monoculture had higher colonization rate by Collembola, a major detritivore and very abundant taxon found in this study. The elevated level of arthropod colonization was visible at the start of the experiment and peaked at week 2, with a lowering of colonization in week 6 and week 10 to earlier levels, except for buckthorn. Buckthorn litter patches had a consistent rate of colonization across the 10 weeks. In addition to arthropods, both slugs and worms were found in high abundance in the Control site, suggesting that these invasive invertebrates may be characteristic of degraded sites.

The recommendation to land managers from this chapter is that to decrease the impact buckthorn has on arthropod colonization activity density, managers must strive to produce a diverse litter layer within restoration sites. The data produced both in this chapter, Chapter 4, and Chapter 5 address the impact buckthorn has on mechanisms of decomposition. These patterns can serve to inform land managers on how their decisions can better target the negative influences of this invasive species.

6.2.4 Conclusions: Chapter 4, Mesocosm

The detritivorous isopod *Trachelipus rathkii,* exhibited a small mean increase in overall consumption rate in mixed native litter compared to monoculture of native litter. The isopods also exhibited a large rate of consumption on monocultures of buckthorn litter. When given litter treatment with buckthorn added both as single native litter type or a mixture of 4 native litter types, a mean increase in overall consumption rate was found although the overall net diversity effect of mixing the litter with buckthorn was *antagonistic*, i.e. the overall consumption rate was less than predicted by an additive model. As isopods are offered mixtures with increased litter diversity that includes buckthorn, they exhibit a lower overall consumption rate.

The overall high consumption rate of buckthorn monoculture, and the lower than expected rate when in a mixed litter, may be due in part to isopod altering their feeding choice in mixed litter. The most probable cause of this pattern may be due to isopods consuming monocultures of buckthorn at a much higher rate than native-species monocultures, and the presence of the native species impeding the consumption of buckthorn by isopods.

6.2.5 Conclusions: Chapter 5, Food choice

In this chapter, I address the question of whether isopods exhibit an increased consumption rate of native litter species due to nutrient leaching between buckthorn and native litter types. I found litter conditioning impacted all litter types equally, with most litter types losing 14% of mass due to microbial activity during the conditioning stage of this experiment. The five native litter types responded differently when conditioned alone, with a conspecific litter, and with the buckthorn on top. Individual litter responded differently but showed a similar overall pattern of mass loss due to isopod consumption preferences with N < N/N < B/N. Results suggest that nutrient leaching does influence detritivore consumption rates for all 5 native litter types. These findings adds knowledge to the debate about mixed litter effects being synergistic or antagonistic in the presence of buckthorn.

In this dissertation and in other studies that have used the same sites, researchers have found isopods to be more abundant in degraded sites, and this may be due to their affinity to consume buckthorn litter at a higher rate. It would be informative to assess if native macrodetritivores exhibit similar feeding preferences, and if their relative abundances differ between degraded and restored sites.

VITA

José-Cristian Martínez

EDUCATION

Ph.D. *(Candidate)* The University of Illinois at Chicago, Dept. of Biological Sciences, Chicago, IL.
Dissertation: *Effects of ecological restoration on the leaf-litter arthropod community*
Advisor: Dr. David H. Wise

B.S. 2007 Biology, University of Illinois at Chicago (UIC)

TEACHING and RESEARCH OVERVIEW

My Ph.D. research focuses on woodland restoration efforts and how such efforts and time frames impact the leaf-litter insect community. I have chosen to take a dual approach in my research, incorporating both taxonomic and ecological approaches to answer community-level questions. This dual approach will facilitate answering key ecological questions while answering some long-ignored distribution changes of local insects which may reflect anthropogenic pressures.

I incorporate this research into my teaching philosophy and style. It has lent itself well to being integrated into to both the classroom and in one-on-one mentoring of students at all academic levels. As an entomologist, I use my >15,000 specimens strong insect teaching collection to illustrate key branches of biology such as Evolution, ecology, genetics, behavioral biology, developmental biology, and medical entomology.

I've taught a diverse population of traditional students and working adults with a wide variety of educational, racial and ethnic backgrounds. I personally develop the objectives, syllabus and course outlines to include learning objectives and outcome.

TEACHING INTEREST: General Biology* Anatomy and Physiology* Ecology and Evolution* Animal Behavior

RESEARCH INTERESTS: Insect Ecology * Invasive Species *Leaf Litter* Arthropod Diversity* Community Ecology

TEACHING EXPERIENCE

Instructor:

Department of Biology and Institute of Environmental Sustainability.
Loyola University Chicago, 2017-.

Co-Instructor:

Animal Behavior Lab BIOS 336

I co-taught a course on animal behavior, in this class we combined group discussions, critical evaluations of published research, as well as conducted interactive laboratory exercises to teach the students methodology and behavioral analysis. The University of Illinois at Chicago of Illinois at Chicago, 2014.

Combat Life Savers Course

Iraqi Army Soldiers and Emergency Medical Technician-Basic (EMT-B) refresher course for U.S. Army Soldiers, Kirkuk Iraq, 2005.

Graduate Teaching Assistant: Dept. of Biological Sciences, the University of Illinois at Chicago. I taught the lab and discussion sections of the following courses.

Animal Behavior Lab	BIOS 336	(1 semester)
Vertebrate Embryology	BIOS 325	(2 semesters)
Comparative Vertebrate Anatomy and Physiology	BIOS 272	(6 semesters)
Animal Behavior	BIOS 236	(1 semester)
Life Evolving	BIOS 104	(1 semester)
Population and Community Ecology	BIOS 101	(2 semesters)
Biology of Cells and Organisms	BIOS 100	(1 semester)
The Biological World (for non-bio majors)	NATS 103	(1 semester)

Course Development and Improvements:

Animal Behavior Lab BIOS 336

Developed and wrote invertebrate behavior labs, helped structure and wrote the syllabus as well as helped developed the protocols for invertebrate behavior labs.

Comparative Vertebrate Anatomy and Physiology BIOS 272

Identified and implemented dissection protocol improvements, and helped update exams as well as supervised new graduate teaching assistants.

Guest Lecturer:

The Biological World, the University of IL at Chicago. NATS 103

Workshops:

I taught two workshops at the University of Illinois Campus-Wide Teaching Assistant Orientation (2014). Workshop titles: Teaching in a Lab Setting, and Classroom Time Management

MENTORING EXPERIENCE

Student and Volunteer Mentoring (>25 total)

My research program has involved more than 19 undergrads, plus 6 high school students and 3 educators as research interns, providing each an opportunity to experience the breadth of scientific approaches in insect ecology. Some mentees have co-authored oral, and poster presentation at scientific conferences and some have assisted with fieldwork.

'STEM: Teach and Learn Research Mentoring', Bradley University and the University of Illinois at Chicago.

I participated as the science mentor for HS science teachers in a program which provided a foundation in inquiry-based scientific research opportunities to teachers.

Amani Abdur-Rahma: Hyde Park Academy High School and Bradley University

Project: "Impact of the invasive exotic shrub *Rhamnus cathartica* on detritivore arthropod feeding preferences and mixed-liter decomposition" (Summer 2014).

Independent research projects / Undergraduate thesis:

1. **Hanoa Pua'a Freitas:** Impact of tropical woodland restoration on the leaf litter ground beetle community (Coleoptera: Carabidae) at Las Cruces Biological Station. Costa Rica. (Summer 2015).
2. **Ulualepapa Sepulona "Sepu" Faleali'i:** Influence of tropical woodland restoration on the leaf-litter arthropod activity density at Las Cruces Biological Station. Costa Rica. (Summer 2015).
3. **Allison Brackley:** Impact of the invasive exotic shrub *Rhamnus cathartica* on leaf litter nutrient leaching and detritivore arthropod feeding preferences (Fall 2014-Spring 2015).
4. **Irfan Patel:** Researching and implementation of data management software to keep ecological and taxonomic information in past, current and future entomological research (Spring 2013).
5. **Curt Martini:** Using soil and vegetation data to analyze arthropod community dynamics in woodland restoration sites (Fall 2012-Spring 2013).
6. **Francis Antony:** Effects of woodland management history and leaf litter characteristics on the diversity and composition of terrestrial Isopods (Summer 2011-Fall 2012).
   The student won the 2013 Elmer Hadley Award for undergraduate research in ecology, evolution, or conservation biology.
7. **Bianca Rad:** Effects of organic litter structure on the abundances of spiders, Collembola, and Isopoda (Fall 2011).

Independent Study students BIOS 391

1. Kassandra Sandoval (Spring 2015)
2. Irfan Patel (Fall 2012)
3. Grace Seuffert (Fall 2012)

Undergraduate assistants and volunteers

1. Daniel Alamo (Spring 2012)
2. Sam Zagone (Summer 2011)
3. Miranda Guilbo (Summer 2010-Spring 2011)
4. Shannon Simmons (Summer 2010-Fall 2010)
5. Dhingra Akshay (Summer 2010)
6. Ryshona M. Odeneal (Summer 2010)
7. Priya Bhuva (Fall 2010)
8. Nicole Hok (Fall 2009-Spring 2011)
9. N. Cedar Smith (Fall 2009-Summer 2010)
10. Ashley Morra (Fall 2009)

High School student mentoring

1. Imtiaz García (Summer 2010)
2. Angelica Arroyo (Summer 2011)
3. Spiders In Space (team of 4) (Summer 2012-Summer 2013)

Adult lab volunteer

1. John Balaban (Summer 2011-Present)
2. Emily Hanson (Summer 2012-Fall 2012)

RESEARCH EXPERIENCE

2015- Tropical Woodland Restoration with NAPIRE (Native American and Pacific Islander Research Experience). Las Cruces Tropical Biological Station, Costa Rica.Tropical field instructor and mentor for undergraduate students conducting insect ecology research at Las Cruces Biological Station.

2013 Field Assistant. Los Tuxtlas Tropical Biological Station, Veracruz Mexico.
Tropical field assistant for Dr. Hank Howe conducting small mammal survey at woodland restoration sites. In addition, I helped curate the station's Staphylinidae beetle collection and collected insect specimens to expand UIC's insect teaching collection.

2009-11'Research Assistant. Dept of Biological Sciences, the University of Illinois at Chicago.
Developed arthropod sampling, sorting and identification protocols for the Chicago Wilderness' Land Management Research Program. Dr. David H. Wise and Dr. Liam Heneghan Co PI's.

2007-08'Field Museum of Natural History
Identified and curated staphylinid and other Coleopteran fauna collected in Iraq during a yearlong deployment. The goal of this work was to update the species catalog of staphylinid beetles in Iraq.

2003-04'University of Illinois at Chicago, and Field Museum of Natural History
Undergraduate research project: Behavioral interactions of myrmecophile Staphylinidae beetles and their ant hosts. Researched the interactions between inquilines and their ant hosts, and the development of myrmecomorphic and non-myrmecomorphic morphologies due to selective host behavior. Under the guidance of Dr. Margaret Thayer at the Field Museum.

INVITED PRESENTATIONS and SEMINARS

Martínez J-C. 2015. May I have this dance? Use of spider courtship behavior in ecology and its application in education. Invited speaker for UIC's Biology Colloquium. The University of Illinois at Chicago, Chicago, IL.

Martínez J-C. 2014. Chicago Wilderness Arthropod Monitoring Programs: Past, Present, and Future. Chicago Wilderness, Aquatic Task Force and US Army Corps of Engineers, Chicago, IL.

Martínez J-C. 2013. The poor man's tropical rainforest: Using the leaf-litter arthropod community to study the effect of woodland management efforts and in science outreach. Conservation and Science Lecture Series. Lincoln Park Zoo, Chicago, IL.

Martínez J-C. 2013. An Inordinate Fondness for Beetles, Spiders and More: A glimpse into entomological research at UIC. Invited speaker for UIC's Biology Colloquium. The University of Illinois at Chicago, Chicago, IL.

Martínez J-C. 2013. Leaf-litter decomposition and the arthropod community. *The Dirt on Soil Science*, Dept. of Liberal Arts. The School of the Art Institute of Chicago, Chicago, IL.

PUBLICATIONS and PRESENTATIONS

PAPERS

McCary M.A., Martínez J-C., Umek L., Heneghan L, and Wise D. H. .2015. Impacts of woodland restoration and management on the community of surface-active arthropods. *Biological Conservation*. 190: 154-166

PAPERS in PREP (data collection is complete):

Martínez J-C., and D.H. Wise. (*in prep*). Woodland management history and its effects on leaf litter and the leaf-litter arthropod community: *Ecological Applications*.

Martínez J-C., A. Bracklery, D.H. Wise. (*in prep)* Impact of the invasive exotic shrub Rhamnus cathartica on leaf litter nutrient leaching and detritivore arthropod feeding preferences: *Functional Ecology*

Martínez J-C., D.H. Wise. (*in prep).* Influence of taxonomic resolution on ecological conclusions in Chicago Wilderness restoration efforts. *Insect Conservation and Diversity.*

Martínez J-C., F. Antony, and D.H. Wise. (*in prep*). Effects of woodland management history and leaf litter characteristics on the diversity and composition of terrestrial Isopods (Isopoda: Oniscidea): *The Great Lakes* Entomologist **

Cordeiro, N.J., Karimuribo E., Keyyu J., Lonsdorf E., Martínez J-C., Murdoch K., Nash A., Feldheim K., Thayer M.K., Wentz-Hunter K. (*in prep).* Oppositely skewed sex ratios in host and symbiont of an African insect-rodent mutualism: *The American Naturalist*

Martínez J-C., Pua'a-Freitas H., Faleali'i U. (*in prep*). A comparison of rapid arthropod sampling methods using pitfall traps and berlese funnels, from leaf-litter arthropods in a neotropical premontane wet forest: *Biotropica* **

NON-PEER REVIEWED PAPERS

Pua'a-Freitas, H., Martínez J-C.,2015. Tropical Woodland Restoration and its Influence of the Leaf Litter Arthropod Community at Las Cruces Biological Station. *Native American and Pacific Islander Research Experience 2015 Course Book. Organization for Tropical Studies.* **

PRESENTATIONS*:*

Oral Presentation:

Martínez J-C. 2015. Insects, Spiders, and Mites, Oh My: An Introduction to Entomology and its Use in Restoration and Educational Efforts in Chicago Wilderness. Presentation at the 2015 Wild Things Conference, Chicago, IL.

Martínez J-C. 2013. Land management history and its effects on leaf-litter and the ground arthropod c ommunity structure: the role of taxonomic resolution in long-term ecological projects. Presentation at the 5th World Conference on Ecological Restoration, Madison, WI.

Martínez J-C. 2013. An Inordinate Fondness for Beetles, Spiders and More: A glimpse into insect biodiversity in the Chicago Wilderness area. Invited speaker for "EARTH DAY: A Celebration of Chicago's Biodiversity: How Many Species in Our Region?" Public Panel Discussion, DePaul University, Chicago, IL.

Martínez J-C. 2013. Land management history and its influence on the abundance and diversity of forest leaf-litter arthropods. Presentation at the 2013 Wild Things Conference, Chicago, IL.

Martínez J-C. 2012. Woodland management history and its effect on the abundance and diversity of forest leaf-litter arthropods. Presentation at the 2012 Annual Meeting, Entomological Society of America Meeting, Knoxville, TN.

Martínez J-C. 2012. Effects of land management history on the abundance and diversity of forest leaf-litter arthropods. Presentation at the 2012 Congress, Chicago Wilderness, Chicago, IL.

Martínez J-C. 2010. Effects of land management history on the abundance and diversity of forest leaf-litter arthropods. Presentation at the 2010 Annual Meeting, Entomological Society of America Meeting, San Diego, CA.

Poster Presentations

Pua'a-Freitas, H., Martínez J-C.,2015. Tropical Woodland Restoration and its Influence of the Leaf-Litter Arthropod Community at Las Cruces Biological Station. Poster presented at the 2015 Annual Meeting, SACNES: Society for Advancement of Chicanos/Hispanics and Native Americans in Science. Washington DC. **

Martínez J-C., Wise D.H, Berrios E., McDowell C., 2013. Charlotte goes to space: Student scientists study spider egg-sac development and cannibalism in weeks of weightlessness. Poster presented at the 2013 Annual Meeting, Entomological Society of America, Austin, TX. ††

Martínez J-C. and Antony F. 2012. Effects of woodland management history and leaf litter characteristics on the diversity and composition of terrestrial Isopods. Poster presented at the 2012 Annual Meeting, Entomological Society of America, Knoxville, TN. **

M. K. Thayer and Martínez J-C. 2008. Beetle-Bits 101: Imaging Staphyliniformia and Scarabaeiformia in the Beetle Tree of Life Project. Poster presented at the 2008 International Congress of Entomology meeting (ICE), in Durban, South Africa.

M. K. Thayer and Martínez J-C. 2007. Beetle-Bits 101: Imaging Staphyliniformia and Scarabaeiformia for the Beetle Tree of Life project. Poster presented at the 2007 Annual Meeting, Entomological Society of America(ESA), San Diego, CA.

** Co-authorship with undergraduate students.
†† Co-authorship with high school teachers as part of a science outreach projects.

GRANTS, FELLOWSHIPS and SCHOLARSHIPS

2017 Diversifying Higher Education Faculty in Illinois (DFI) Fellowship. Illinois Board of Higher Education, Springfield, IL. ($15,000)

2015 College of Liberal Arts and Science: Diversifying Higher Education Faculty in Illinois (DFI) at UIC Fellowship. The University of Illinois at Chicago, Chicago, IL. ($6,500)

2015 Elmer Hadley Graduate Research Award in Ecology and Evolution. Dept. of Biological Science, the University of Illinois at Chicago, Chicago, IL. ($1,700)

2014 Abraham Lincoln Graduate Fellowship. The University of Illinois at Chicago, Chicago, IL. ($15,000)

2014 Diversifying Higher Education Faculty in Illinois (DFI) Fellowship. Illinois Board of Higher Education, Springfield, IL. ($10,000)

2014 Elmer Hadley Graduate Research Award in Ecology and Evolution. Dept. of Biological Science, the University of Illinois at Chicago, Chicago, IL. ($1,500)

2012 Abraham Lincoln Graduate Fellowship. The university of Illinois at Chicago, Chicago, IL. ($20,600)
2011 Martin Luther King, Jr. Graduate Fellowship. Administered through the Office of Special Scholarship and Programs University of Illinois at Chicago, Chicago, IL. ($5,000)

FUNDING for MENTORING and INDEPENDENT TEACHING

2014 Bradley University STEM Teach and Learn Program. Center for STEM Education, Bradley University, Peoria IL. ($3,600 stipend for student, $500 supplies)
2013 Undergraduate mentoring funding. Dept. of Biological Science, the University of Illinois at Chicago, Chicago, IL. ($3,080)
2013 Managing and curation of UIC's Insect teaching Collection. Dept. of Biological Science, the University of Illinois at Chicago, Chicago, IL. ($4,742)

AWARD for ACADEMIC ACHIEVEMENT

2017 Graduate Teaching Award in Vertebrate Embryology. Department of Biological Sciences, the University of Illinois at Chicago
2014 Research Mentoring Award. Graduate College, the University of Illinois at Chicago, Chicago, IL. ($2,000)
2014 Images of Research. 3rd Place Winner. The University of Illinois at Chicago, Chicago, IL. ($200)
2013 Excellence in Undergraduate Mentoring Award. University-wide award for excellence in undergraduate student mentoring. Sponsored by the Office of the Vice Provost for Undergraduate Affairs, the Honors College, and the Graduate College, the University of Illinois at Chicago. ($750)

SCIENCE OUTREACH

Charlotte goes to space!

Participated as the scientific mentor for Unity Junior High School students as they developed and executed an experiment to send spider egg-sacs to the International Space Station as part of NASA's Student Spaceflight Experiment Program. With the objective of studying the egg sac survival, development, and spiderling cannibalism in microgravity. (May 2012-July 2013). Featured on UIC News October 31, 2012.
Students presented a talk and poster at a conference at the National Air and Space Museum in Washington DC. July 3rd, 2013

Guest speaker for science outreach programs at local grammar and high schools, with the goal of exposing predominantly minority students to minority professionals in science. Students learn about my work in entomology and the importance of the arthropod community through a lecture and show-and-tell of an insect collection.

-St. Ignatius College Prep, Chicago IL: "Intro to Entomological Research at UIC and Comparative Vertebrate Anatomy" October 20, 2012.

-UNO Octavio Paz Charter school, Chicago IL: "Entomology, how I caught the 'bug'" April 25, 2012

-WISE Lab host for the Morton Freshmen Center, Cicero IL: "Introduction to Insect Ecology" November 10, 2011.

-J. Sterling Morton East High School, Cicero IL: “Llaves del éxito, College readiness series” November 16, 2011.

-Foreman High School, Chicago IL: ASM Science Squad: Ambassadors for Urban Wilderness, November 30, 2011.

-Cicero East Grammar School, Cicero IL: “The 21st century” afterschool program initiative, guest science speaker, January 2011.

-Unity Junior High School, Cicero IL: “Big Dreams presentation” April 2010.

-J. Sterling Morton East High School, Cicero IL: “BLAST” Building Leadership and Success Together-lecture series, guest science speaker, April 2010.

ACADEMIC SERVICE

Departmental:

2012 Graduate student member on search committee for Assistant Professor Position in Microbial Ecology

2012- Graduate student chaperone and field instructor for the undergraduate Biology Colloquium club weeklong field trips:

Mammoth Caves, Kentucky	May 2015.
Hancock Biological Station, Kentucky	May 2014.
Kellogg Biological Station, Michigan	May 2013.
Reis Biological Station, Missouri	May 2012.

University:

2012- Graduate student mentor for new incoming STEM graduate students, Graduate College UIC.

Workshop panel member:	"Teaching Assistant Orientation"	August 2014.
Orientation panel member:	"Straight Talk"	August 2012.
Workshop panel member:	"PASSAGE Scholars Program"	June 2013.
Discussion leader:	"Field Museum STEM"	June 2013.

2014 Graduate student volunteer for UIC's Emergency Medical Technician class practical exams.

PROFESIONAL SOCIETIES

Entomological Society of America	2005-Present
The Coleopterist Society	2007-present
Society for Advancement of Chicanos and Native Americans in Science	2015-present

FEATURED NEWS ARTICLES

2012 Flood, Brian. "Spiders in Space: UIC biologist help young scientist' project", UIC mentors helped eighth-graders from a Cicero high school send the *Diplostyla concolor* spider into space earlier this month." *UIC News*. October 31, 2012.

2005 Dougherty, Kevin. "GI bitten by bug to catalog Iraq beetles: Soldier/entomologist using time downrange to collect specimens." *Stars and Stripes*. May 17, 2005.

MUSEUM CURATORIAL EXPERIENCE

***Collections Manager**: The University of Illinois at Chicago's Insect Teaching Collection:*

2012- Collections Manager for UIC's teaching insect collection. (9,609 pinned insects, from >600 local species)

Personal:

2009- Manage and maintains a diverse personal insect and spider collection, as both teaching and reference collection for ecological studies. (>70,000 arthropods both pinned and in alcohol)

WORK EXPERIENCE

2012- Army Corps of Engineers, Insect Survey Consultant.
Responsibilities: Conducted insect surveys at several forests preserve sites using no-kill methods to current community composition of ground arthropods. Written surveys were produced assessing the baseline species richness and composition between different sites pre-restoration and management treatment.

2006-'08 Field Museum of Natural History, Intern Division of Insects, Chicago Illinois.
Responsibilities: Specimen preparation and disarticulation for the Beetle Tree of Life web project. The work involved imaging whole and disarticulated specimens of 32 exemplar taxa in the series Staphyliniformia and 16 in Scarabaeiformia to document 600+ morphological characters of adults, larvae, and pupae. Developing and documenting procedures for imaging techniques. Applying working knowledge of the Microptics imaging system and SEM techniques to achieve high-quality images. Sorting of bulk samples and identifying target taxa (Coleoptera: Staphylinidae).

MILITARY SERVICE

1999- 2008 United States Army, National Guard Medical Healthcare Sergeant, North Riverside Illinois.
Responsibilities: (NCOIC) The sergeant in charge of a platoon-size element, in command of 55 medical personnel soldiers.

- -Operation Iraqi Freedom Aug 2004-Dec 2005.
- -Awarded Army Combat Medic Badge and Army Achievement Medal.
- -Warrior Leadership Course 2007, Ft. McCoy WI.
- -Healthcare Specialist (Combat Medic) course 2000, Ft. Sam Huston TX.

Key Teaching Courses taken:

Foundations of College Teaching GC 593, UIC 2014

Workshops:

Undergraduate Mentoring Workshop, Organization for Tropical Studies, San Jose Costa Rica 2015

SKILLS

Languages: Spanish: High fluency and proficiency, both verbal and written.
Bioinformatics: R, Primer-E
Educational Software: Sakai, Blackboard