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Effects of the Manipulation of Aboveground Plant Diversity in Restoration Management on the Diversity of Belowground Arthropod Assemblage

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EFFECTS OF THE MANIPULATION OF ABOVEGROUND PLANT DIVERSITY IN RESTORATION MANAGEMENT ON THE DIVERSITY OF BELOWGROUND ARTHROPOD ASSEMBLAGE

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ABSTRACT

A missing element in restoring belowground soil systems to a relatively healthy state may lie in promoting microarthropod diversity. By contributing to healthy nutrient cycling and assisting in the breakdown of leaf litter a diverse microarthropod population helps improve the overall soil quality. My study evaluated how current restoration practices aimed at maintaining aboveground diversity affects belowground microarthropod populations. I examined how the aboveground manipulation of plant diversity in restoration management practices affects the hyperdiverse assemblage of belowground arthropod communities. Additionally, I examined the relationship between soil nutrient content and microarthropod diversity. This study was conducted within the boundaries of Chicago Wilderness from sites with four different management treatments, ranging from unmanaged (W0) to highly managed (W3). 3 soil cores measuring 5 x 5 centimeters were taken from each site and microarthropods were extracted in a Berlese funnel. Abundance and species diversity were assessed. The microarthropod species data showed that while 12 common species were found at over 70% of the sites, 32 species were present at less than 30% of the sites. Of these 32 rare species, 15 were unique to only 1 site. Further analysis of the common mites revealed specific associations between those 12 common species. My results showed that restoration management had no significant effect on microarthropod diversity. Plant root simulator (PRS) probes were used on each site providing data on fifteen soil nutrients. There was significant explanatory value to the soil nutrient data, especially nitrogen, phosphorus, and zinc. As these nutrients increased in the soil, microarthropod diversity also increased. Knowledge of these nutrients offers a simple set of tools for evaluating the relationship between soil quality of a specific site and belowground diversity. I concluded that restoration management aimed at plant diversity was largely ineffective in determining microarthropod diversity; nevertheless, the relationship between soil nutrients available and microarthropod diversity may have implications for management. Understanding relationships such as these are instrumental in the development of new restoration management tools.

INTRODUCTION

Defining Restoration Practices in Soil Ecosystems

Biodiversity within urban habitats must be conserved in order to meet global restoration goals. Restoration ecology is the study and application of methods that revitalize and re-establish degraded, damaged, or destroyed ecosystems and habitats in the environment through strong human involvement. **"**Ecological restoration is human-facilitated improvement of a degraded ecosystem, which may be initiated from any point along a continuum from slight to severe ecosystem degradation" (Baer et al. 2010). Different kinds of ecosystem restoration include revegetation, habitat enhancement, remediation, and mitigation (Vaughn et al. 2010). Revegetation is the development of vegetation in areas where it has been formerly lost; the key objective is erosion control (Vaughn et al. 2010). Habitat enhancement is the practice of improving the suitability of a location that is the habitat for a certain desired species, often once native species. Remediation is enhancing an existing environment, or constructing a new environment, with the intention of replacing an environment that has deteriorated or been destroyed. Mitigation is legally mandated remediation to combat the loss of a protected species or ecosystem (Vaughn et al. 2010). In the past, many of these ecological restoration management practices have lacked a strong research foundation due to plant-oriented community ecology management strategies that disregard ecosystem-orientated and soil-based ecology (Heneghan et al. 2006). Consequently, there is a need to develop the relationship between the researcher and the practitioner for long-term restoration goals to be met. In fact, one of the major problems within restoration practices concerns whether or not restoration benefits more than just plants. It remains unclear if restoration is effective in promoting long-term change (Baer et al. 2010).

The leading cause of biodiversity loss in the world is habitat destruction. The second often overlooked cause is the presence of invasive species. The goals of restoration practices in invaded ecosystems include soil stabilization, re-establishment of biological diversity, and efficient nutrient cycling, all of which are characteristics of a pristine ecosystem (Baer et al. 2010). Ecological restoration practices have traditionally focused on sustaining or increasing plant diversity while disregarding soil biota and the ecosystem as a whole. A healthy soil system is one of the first steps toward restoring a plant ecosystem to the status of thriving.

Without proper restoration of the entire ecosystem, absent or rare native plant species will have a difficult time permanently re-introducing themselves into an ecosystem. The absence of native plant species can have a detrimental effect on litter quality, root distribution, water-use, fire cycles, and spatial heterogeneity of resources in the ecosystem (Baer et al. 2010). Regardless of the effort the management practitioner puts forth to maintain the topsoil in a diversity-deficient environment, the lack of an associated healthy native plant community can inflict long-term damages on the spatial organization of the restored soil and ecosystem structure.

Soil quality is the ability of soil to maintain plant and animal efficiency, improve or uphold air and water quality, and sustain human health and the natural environment (Heneghan et al. 2008b). Soil health is increasingly sensitive to the amount of soil biodiversity present and due to this practitioners must adhere to a “soil first” approach to restoration management. Soil ecology encompasses both soil science and organismal biology. The further degraded the environment, the more restoration of the physical environment will be needed to restore species composition and ecological functions to the original system state. Two examples of physical changes to a soil system are implementing tillage practices and applying fertilizers. Soil organisms, such as microarthropods, power soil nutrient dynamics and can therefore affect plant community growth and diversity (Caruso et al. 2007). A disturbed ecosystem is characterized by a patchy scattering of arthropods in the soil (Caruso et al. 2007). Often, this disturbed ecosystem is controlled by one commonly distributed, opportunistic arthropod species (Caruso et al. 2007). Furthermore, sensitive arthropod species in a disturbed ecosystem frequently start to exhibit low population levels; complete loss of the arthropod species to the area is a concern.

Conservation management directed at promoting the survival of native species often involves controlling invasive species. Species invasion mostly occurs in environments that are exceedingly patchy in vegetation structure, nutrient laden, and unburned (Heneghan et al. 2008a). The successful management of invasive species can be enhanced by incorporating soil ecological knowledge (SEK) into conservation management plans (Heneghan et al. 2008b). Methodological approaches have been incomplete in the past, failing to integrate knowledge of soil nutrient levels into restoration practices. SEK is the summation of all the physical, chemical, and biological elements of a soil system as viewed from an ecological perspective (Heneghan et al. 2008b). SEK can be used to direct restoration practice to include soil as part of the ecosystem. For example, SEK tries to incorporate both organismal and ecosystem processes, both of which affect patterns in the distribution, abundance, and composition of species in the soil (Heneghan et al. 2008b). Without knowing exactly how soil assemblages and ecosystem processes have been altered, restoring a habitat to its healthy state is exceedingly difficult. Currently there is inadequate information on the ways in which degradation and anthropogenic effects have changed soils in ecosystems. Soil ecosystems need to be monitored with SEK before and during invasive species establishment in order to fully restore an environment. The importance of soil microbial populations and soil physico-chemical properties to an ecosystem is an issue that soil restoration biologists don't yet completely understand (Baer et al. 2010).

Invasive Species Management within Degraded Ecosystems

The intrusion of invasive species into an ecosystem is regarded as a major challenge for both land practitioners and researchers. Once invasive species establish themselves, they are nearly impossible to permanently eradicate due to changes they cause to the entire environment. If an introduced species can persist in an ecosystem, this ecosystem is said to be invasible (Burke and Grime 1996). Potential barriers for an invasive species establishing itself in a community include competition from native species, parasitism and predation deaths, and lack of mates or mutualists (Crawley 1986).

Invasive species in the soil can have long lasting destructive consequences in the Chicago Wilderness region. Instead of simply removing the species in question there is a great need for the incorporation of SEK to successfully improve a soil system. So why is this SEK methodology different from similar approaches? Basically, this method doesn't look at soil factors in isolation nor does it divide aboveground from belowground ecosystem processes. Instead, for a newly restored ecosystem to function well it is imperative to integrate all of the soil's chemical, physical, and biological processes. Without this, there is little chance of ensuring long-term survival of the newly restored native plant species (Heneghan et al. 2006). When the starting properties of an ecosystem's soil nutrients are poor there may be a need to assemble a soil system from scratch. This method is called the aggrading approach. This approach allows for new ecosystems to be restored on raw mineral wastes where there is no existing biota (Perrow and Davy 2002). Some examples of raw mineral wastes include china clay wastes, calcareous rocks, and oil shale.

The Role of Soil Organisms in Soil Health

Soil organisms have major effects on the restoration process and play a large role in the rehabilitation stage of restoration. Microarthropods are tiny invertebrates between 0.2-10 mm in length (Loranger et al. 1998). They are in the phylum *Arthropoda* and the most recognized members of the microarthropod assemblage are mites (*Acari*) and springtails (*Collembola*) (Elsas et al. 1997). Most microarthropods live in the upper soil layers, the O, A, and E Horizons *(SSDS* 1993*)*. The O Horizon is the outermost surface layer with large quantities of organic matter in differing steps of decomposition (*SSDS* 1993). The A Horizon is the "topsoil" with a layer of dark decomposed organic matter called "humus" (*SSDS* 1993). Humus refers to organic matter that has reached a point of stability, where it will not be broken down anymore, and could possibly remain the same for centuries if conditions do not change (*SSDS* 1993). Most biological activity occurs in the A Horizon (*SSDS* 1993). The “E” in E Horizon stands for “eluviated” because this layer has been substantially leached of its mineral or organic content, leaving behind a pale layer mostly compiled of silicates (*SSDS* 1993). When it comes to maintaining a healthy soil system, the ecosystem’s soil microarthropod community is important for nutrient cycling through plant and root grazing as well as the pulverization of leaf litter; pulverization is the reduction of leaves, or similar substances, to fine particles (Caruso et al. 2007). Plant and root grazing encourages microbial growth on leaves while the pulverization of leaf litter enlarges the surface region for microbial action (Caruso et al. 2007). Soil structure with adequate dark organic material formation is reliant on microarthropod establishment. When microarthropods are established, their movement within the layers of the soil, release of nutrients, and fecal pellets contribute to soil health (Caruso et al. 2007). As a result of all of these factors, soil microarthropods play a significant role in the functioning and healthiness of an ecosystem’s soil.

Microarthropods are essential to decomposition in the soil, which is necessary for the release and recycle of nutrient elements, like phosphorus and nitrogen. Decomposition occurs through the fragmentation of detritus by microarthropods and other soil biota in addition to the chemical alteration of the substrate (Reichle 1977). Microarthropod grazing works to “control” the rate of decomposition so that a more linear release of nutrients happens during the growing period (Reichle 1977). This controlled, continuous release offers countless benefits for plant uptake of nutrients (Reichle 1977).

The interactions between fungi, bacteria, and arthropods in the soil are essential to numerous soil processes such as efficient decomposition and the ability of the zone that surrounds the root of plants, called a rhizosphere, to function (Lussenhop 1992). In the rhizosphere, microarthropods interact with three different groups of microorganisms that include saprophytic and pathogenic bacteria, vesicular-arbuscular mycorrhizal (VAM), and ectomycorrhizal (ECM) fungi (Lussenhop 1992). Microarthropods, bacteria, and fungi population levels are most dense around plant roots (Lussenhop 1992). One of the reasons that this occurs is because microarthropods carry fungal and bacterial inoculum to the roots, increasing root density (Lussenhop 1992). Microarthropods influence fungal abundance and distribution by selectively grazing and dispersing fungal propagules or spores (Lussenhop 1992). Selective grazing by a microarthropod puts mineral nutrients into the soil, diminishes fungal competition, promotes bacterial growth, and scatters the fungal propagules (Lussenhop 1992).

When considering that microarthropod diversity is often highest around plant roots, the importance of mycorrhizae has become a major focus of modern restoration practices (Heneghan et al. 2008b). How important mycorrhizal fungi are to a particular ecosystem depends upon how reliant the dominant and rare plant species are on the mycorrhizae (Heneghan et al. 2008b). If a dominant plant species is entirely dependent on mycorrhizae in their roots to survive then their existence will be required to restore the ecosystem (Heneghan et al. 2008b). With rare plant species, inoculating the roots of the specific plants with mycorrhizae may be necessary to reach the preferred structure of the community (Heneghan et al. 2008b). In order to successfully add mycorrhizae to a community, knowledge of connections between aboveground and belowground individuals, community structure, and ecosystem processes are all essential (Heneghan et al. 2008b).

The species diversity that can exist in any given area is largely dependent on the size of that habitat, its distance from bases of immediate migration, and the natural age of the terrain (Hooper et al. 2000). While the state of the soil and the fauna it contains has a major impact on plant species diversity aboveground, the reverse relationship can be present as well. Plant species diversity aboveground can have an effect on what microarthropods survive in the soil by impacting the amount and variety of food resources present; the healthiness of these food resources affect litter quality and composition. It has been found that the quality and composition of the soil in Ponderosa Pine Forests can be affected by the presence of woody biomass in the soil and this material can assist in native plant reestablishment (Korb and Gideon 2007).

In regard to the dependence of arthropod diversity on plant diversity, studies have revealed that adding more types of plants is essential to increasing arthropod diversity (Siemann et al. 1998). However, research has also shown that the structural or architectural diversity of plants in a region may be another central factor for increasing and maintaining arthropod diversity (Siemann et al. 1998). Hansen (2000) tested whether local microarthropod diversity is determined by the heterogeneity of their litter habitat or whether microarthropod species composition is determined by litter composition. He found that there is a significant positive relationship between arthropod diversity and variety in plant litter (Hansen 2000). Enlarging plant species diversity and plant functional diversity in an area can improve plant productivity which may indirectly increase arthropod diversity. Higher plant productivity will increase overall arthropod profusion, and consequently, uncommon species will be able to survive on a more regional scale (Siemann et al. 1998).

Since this study specifically looks at how the manipulation of plant diversity aboveground impacts microarthropod communities belowground, it is important to have an understanding on how manipulations of organisms in one component of an ecosystem affects biodiversity in another. First of all, there are obligate, selective interactions, also called one-to-one linkages. This is when the loss of one species guarantees the loss of the other species.

Secondly, there are asymmetric interactions, also called one-to-many linkages, which mean that the effects of a single species or functional group could influence species richness in the other. For instance, a tree species which provides a habitat for multiple specialists will have implications for all specialists if that host species tree is lost. Lastly, there is casual richness, also called many-to-many linkages. Casual richness means that the diversity in one section of soil causes diversity in the other section of soil (Hooper et al. 2000). For example, an assortment of carbon inputs aboveground will bring about a larger selection of food resources for belowground heterotrophs, consequently sustaining more diverse soil communities by creating greater niche differentiation (Hooper et al. 2000). In part from these interactions, high biodiversity is directly linked with aboveground and belowground sectors. Furthermore, the makeup of what species exist below and above ground is also determined by fluctuations in abiotic conditions, seasonal changes in phenology, annual transformations in climate, decadal controls of progression, and geologic evolutionary associations (Hooper et al. 2000). A seasonal change in phenology refers to the pressure of climate on the return of yearly plant and animal activity, like bird migration and budding. Decadal controls of progression are changes in succession observable every ten years. Succession may be initiated either by the formation of new, unoccupied habitat or by some form of disturbance to an existing community. A geologic evolutionary association encompasses the study of the structural evolutionary changes of the earth between related organisms in a specific area.

Umbrella Arthropod Species Serve as Surrogate Markers of the Health of an Ecosystem

The connection between aboveground and belowground processes is clear when considering the relationship between plants and microarthropods in the soil. During restoration of highly degraded areas, a bottom-up approach must often be taken, restoring a healthy soil system first to then aid native plant growth and healthy root uptake in the soil. Will restoration of plants in an ecosystem result in restoration of other organisms? When it comes to restoring native species diversity to a degraded ecosystem, the dependence on and relationship between arthropod diversity and plant diversity brings a new concept to the forefront: surrogate species. Do specific plant species act as surrogate species to re-establish or maintain arthropod species diversity? Conversely, do specific arthropod species act as surrogate species to re-establish or maintain plant species diversity? The term surrogate species is sometimes interchangeable with the terms umbrella or indicator species (Dalerum et al. 2008). Umbrella species are used to make conservation linked decisions because protecting them indirectly protects many other species that share their habitat (Dalerum et al. 2008). An indicator species is any biological species that classifies a trait or characteristic of the environment (Dalerum et al. 2008). They are used to monitor the health of an ecosystem because they embody any biological species or group of species whose function, population, or standing can be utilized to establish ecosystem integrity (Dalerum et al. 2008). Indicator species can be among the most sensitive species in a region and their depletion from an ecosystem can sometimes operate as an early warning sign to supervising ecologists (Caro and O'Doherty 1999). If one could identify a type of native plant in the Chicago wilderness region that indicated diverse and healthy assemblage of microarthropods, biodiversity conservationist's knowledge of the area would greatly improve.

There have been various studies conducted on the umbrella species concept including how carnivores can act as biodiversity surrogates and how effective surrogate taxa are in designing coral reef reserve systems (Dalerum et al. 2008; Beger et al. 2007). If critical traits of habitats could be used as dependable surrogates of particular target taxa, this would significantly assist suitable preserve selection and maintenance (Dalerum et al. 2008). Furthermore, biodiversity surrogates are essential when comprehensive information on the dispersal of species and populations within an ecosystem is lacking (Hortal et al. 2009). One study examined whether surrogate functioning success could be explicated by taxonomic diversity, nested species distributions, hotspots of biodiversity, species range sizes, or environmental diversity (Lawler and White 2008). Unfortunately, this study found only weak associations between the health of species in an ecosystem and surrogate performance. Due to the enormous number of species and the lack of resources needed to carry out comprehensive studies on invertebrate species it is crucial for surrogate species to be used to represent invertebrate biodiversity in conservation planning and biodiversity assessments (Lovell et al. 2007). To this end, this study sought to determine how well plants act as surrogate species for invertebrates.

The Chicago Context – Background on Chicago Wilderness

This study was conducted within the boundaries of Chicago Wilderness, an area that encompasses 360,000 acres managed by a variety of state and county landowners, from sites found in Lake, DuPage, Cook, and McHenry counties. The Chicago Wilderness Land Management Research Program is working towards an end goal of "100 sites for 100 years." The research mission involves studying 100 plots of land for 100 years in the Chicago Wilderness region, an expanse that reaches from southeast Wisconsin to northeast Illinois and over to northwest Indiana. The 100 sites are comprised of prairie, savanna, and woodland habitats with varying management efforts ranging from highly degraded to pristine environments. These 100 one-hectare research sites will be employed to assess the success of biodiversity management practices in the Chicago Wilderness region, facilitating management practitioners and scientists to confirm, enhance, and discover the most useful restoration practices (Umek and Heneghan 2009). The Chicago Wilderness Land Management Research Program's main goals are to increase regional biodiversity, restore healthy ecosystems, and create models for future restoration using the findings of the long-term observations (Heneghan et al. 2008a). Before significant human settlement, the vegetation of the Chicago Wilderness consisted of prairie, savanna, wooded communities, oak woodland, upland forest, floodplain forest, dune complex, wetlands, swamp, bog, and lakes (Sullivan 2000). Chicago Wilderness is currently composed of three individual physiographic regions that include lake plain, morainal section, and grand prairie. Lake plain refers to a surface of the earth that is comprised of prior lake bottoms formed by the settling of sediments transported into the lake by streams. The physiographic morainal section refers to elevated land with substantial glacial deposits. Grand prairie is a widespread flat-to-gently sloping treeless expanse of land in the temperate locations of central North America, differentiated by deep, rich soil and a cover of coarse grass and herbaceous plants. These three regions vary in their terrain, vegetation, geologic history, soils, and hydrology. Overall, the general restoration goals for the Chicago Wilderness area have always revolved around three standard goals: restore natural processes, restock lost species of plants and animals, and maintain the natural ecosystems in good health (Sullivan 2000). One of the main concerns within the three restoration goals remains loss of space due to anthropogenic effects in addition to invasive species effects, which can continually lead to habitat fragmentation. Organisms require areas large enough to provide sufficient food supplies, denning sites, perches, display areas, and nursery ponds for their continued existence (Greenberg 2002).

One major problematic species within Chicago Wilderness' region is the prevalent invasive species *Rhamnus cathartica (R. cathartica)* also known as common European buckthorn. Both common and glossy buckthorns are tall shrubs or small trees that reach 20-25 feet in height and 10 inches in diameter (Heneghan et al. 2005). Previous research has shown that the removal of *R. cathartica* is a critical first step in the restoration process since *R. cathartica* influences light availability in the forests it invades (Heneghan et al. 2008a). Consequently, the physical removal of this shrub is necessary to re-establish light gradients in the invaded ecosystem. Physical removal must include both mechanical removal of the aboveground section followed by chemical treatment to the shrub's root system. Without removal as well as follow up treatment it is difficult to keep invasive species permanently out of an ecosystem. Thus, monitoring an area that has been restored is imperative to continuing the good health of a restored ecosystem.

The second and more enduring major problem with *R. cathartica* lies in its leaf litter. The leaf litter of the buckthorn shrub has higher nitrogen content than the leaf litter of many native plant species in the region (Heneghan et al. 2008a). Furthermore, *R. cathartica* leaf litter decomposes at a very fast rate in the soil resulting elevated nitrogen and pH levels (Heneghan et al. 2008a). The increased nitrogen levels and rates of decomposition in the soil caused by elevated pH ultimately alter plant productivity (Heneghan et al. 2008a, Greipsson and DiTommaso 2006). In a newly restored ecosystem, positive feedback between plant productivity and soil nitrogen supply is an important factor in soil health and plays a crucial role in improving and sustaining proper nitrogen availability (Baer and Blair 2008). High nitrogen levels present in the soil after restoration make soil more susceptible to reinvasion. With the presence of high levels of nitrogen, resource uptake subsequently decreases while gross resource supply increases, causing the soil to be much easier to invade. Disturbed ecosystems mean more easily invasible habitats; if resource uptake and gross resource supply are more balanced, however, then soil is more resistant to invasion. The relationship between disturbance and resource availability can be further understood by the fluctuating resource hypothesis. The fluctuating resource hypothesis is a theory in which the fluctuation in resource availability is the key factor controlling whether an area is susceptible to invasion. In other words, if there is an increase in the quantity of unused resources, a plant community is more easily invasible (Davis et al. 2000). However, it is important to remember that whether or not a community is invaded by a particular species is complicated and also depends on the characteristics of the invading species and its reproductive demands (Williamson 1999; Lonsdale 1999). Nitrogen deposition from buckthorn shrubs in the Chicago Wilderness has produced lasting effects on soil properties, causing long-term destructive consequences on the development of a healthy ecosystem with native plants and fauna (Heneghan et al. 2006).

This thesis examines how the aboveground manipulations of plant diversity in restoration management practices affect the hyperdiverse assemblage of belowground arthropod communities. The main question is: will a more diverse and healthy native plant community aboveground be positively correlated with an increase in microarthropod diversity belowground? Furthermore, this thesis examines the relationship between soil nutrient content and microarthropod diversity. Will high quality soil nutrient content correlate with high microarthropod diversity belowground?

Microarthropods play a crucial role in the overall health of soil by contributing to healthy nutrient cycling, encouraging microbial development, and enlarging the surface area of organic matter for microbial action. Soil microbes participate in: soil formation, decomposition of organic matter, humus formation, liberation of carbon, nitrogen, sulfur, and phosphorus, the formation of ammonia and nitrates, the fixation of nitrogen, and other important biological interactions like the assimilation of nutrients. The work described in this thesis evaluates the degree to which current restoration practices have resulted in successful maintenance of aboveground diversity and of assemblages of soil organisms, specifically microarthropods. In order to restore both plant and animal communities effectively, a more holistic approach needs to be taken. This research will contribute new tools to the future of restoration management that will result in longer-lasting restorative measures for ecosystems. The ultimate goal is to create restored habitats that can sustain themselves through the application of SEK approaches that will ensure native species survival.

EXPERIMENTAL DESIGN AND METHODOLOGY

Experimental Design

Data were collected from 4 different replicated management treatments along a gradient of management effort in the restoration process. The 4 different levels of management were studied at 11 different sites around Chicago Wilderness; each level was represented with a W0, W1, W2, or W3. W0 represented the most degraded sites that have never been restored or managed and that contain a large number of invasive species. Degraded sites acted as long-term control sites to reveal how degradation progresses since they did not have any management or restoration plans. These control sites allowed this research to show the effects of invasive species on native species survival. Examples of these invasive species in degraded woodlands were buckthorn, honeysuckle, and garlic mustard, while prairie restoration sites and remnant prairies typically contained Eurasian grasses and encroaching shrubs. W1 sites were in the early management stage with between 0-5 years of restoration effort. Restoration effort included removing invasive species, controlled burning, seeding of native plant species, deer control, and uniting area residents to the land as partner stewards. W2 sites were all in the mature management phase with 10 or more years of restoration effort. Lastly, W3 sites were the highest quality sites with no invasive species present.

The goal of this research is to show how heavily degraded sites can be restored to healthier high quality sites. The process of reclassifying a site is controlled by a panel of scientists and environmental management experts. For example, for a site to be reclassified this panel must conduct a thorough analysis of the changes in plant and animal diversity and determine the new quality of the site. To guarantee sustained improvement, Chicago Wilderness has acknowledged a need for a system of indicators of health. These indicators are capable of measuring improvement over time throughout the whole Chicago region along with reporting the actions natural resource managers take in managing certain sites. Detailed site descriptions containing location, vegetation, mean annual precipitation, landform of soil, and other site characteristics have been kept of all of the dissimilarly managed plots and sites, including any management history that existed for the plot (Heneghan et al. 2009).

Plot Description

Chicago Wilderness' goal is to study approximately 27 plots per county. Each plot will be a separately managed unit. Several management units may be grouped in a single reserve. This made certain that each plot stands for a distinct unit for the purposes of statistical analysis. The size of each plot was 1 hectare and had a central marker that was a single GPS point; the plot was circumscribed by a radius stretching roughly 56 meters from this midpoint. While the samplings of organism biodiversity and ecosystem processes within each plot were taken from a single location within the 1 hectare of land, the samplings were representative of the overall hectare.

Study Sites

The sites used in this study include 3 W0 sites, 3 W1 sites, 3 W2 sites, and 2 W3 sites. The 3 W0 sites were Old School, Waterfall Glen South Central, and Ethel's Woods. The 3 W1 sites were Old School, Middlefork Savanna, and Waterfall Glen Cemetery Ridge. The 3 W2 sites were Grassy Lake, MacArthur Woods, and Waterfall Glen Rocky Glen. The 2 W3 sites were Ryerson Woods and Middlefork Savanna.

A separate data table listed in *Appendix A* includes the management stage, location, county, habitat, canopy, undergrowth, herbaceous layer, detritus, soil type, slope, landform soil, 2-D landform position, 3-D landform position, parent material, depth to restrictive feature, drainage class, elevation, frost-free period, mean annual precipitation, and mean annual air temperature for the 11 different studied sites.

Canopy cover was captured using a fish eye lens camera on all 3 plots. Ion resin tools were used at each site in order to record levels of phosphorous (P), total nitrogen (N), nitrate (NO_3N) content, ammonium (NH_4N), calcium (Ca), magnesium (Mg), potassium (K), iron (Fe), manganese (Mn), copper (Cu), zinc (Zn), boron (B), sulfur (S), lead (Pb), and aluminum (Al). All of this information provided a better idea as to the overall quality of the soil.

General Site Descriptions

Old School Forest Preserve is found in central Lake County, Libertyville, Illinois. Old School is located south of Route 176 between St. Mary's Road and Interstate 94. Old School W1 is within 380-acres of woodland ruled by large Oaks along with small prairies containing native prairie plants. This was the first forest preserve in the state of Illinois to join native prairie restoration with recreation facilities. Animals that can be found here include screech owls, bluebirds, and foxes. This type of landscape is similar to what Lake County looked like when it was first settled. Restoring Old School's original prairie and monitoring its wildlife had been a major goal, but the forest preserve needs much more help with the elimination of invasive species and the re-establishment of native species. The two sites studied in this forest preserve were the degraded/unmanaged Old School W0 site, and the early management Old School W1 site.

Waterfall Glen Forest Preserve is located in DuPage County, Lemont, Illinois. Waterfall Glen is located south of I-55 between Cass Avenue and Lemont Road. It is a remarkable plot of open space with glacier-formed ridges, ravines, and potholes. This preserve's largest woodland block is greater than 700 acres. It also includes a dolomite prairie, containing rock close to the surface along with shallow soil. This creates an environment that is home to some plants uncommon to the area. Other habitats that make up Waterfall Glen include prairies, savannas, oak-maple woodlands, and planted pine groves, which are a refuge for a large diversity of plant and animal species. Local ecologists have recorded over 600 native plant species at Waterfall Glen, including 75 percent of all the plants known to grow naturally in DuPage County. Moreover, numerous fish, amphibian, reptilian, mammalian, and greater than 160 avian species can be found on this preserve at some time of the year. The sites studied in this forest preserve are the degraded management WFG South Central W0 site, the early management WFG Cemetery Ridge W1 site, and the mature management WFG Rocky Glen W2 site.

Ethel's Woods Forest Preserve is located in Lake County, Antioch, Illinois. Ethel's Woods is found directly south of Route 173 between US Highway 45 and Crawford Road. The eastern edge of this forest preserve contains 170-acres of 100 year old Bur Oak, White Oak, Shagbark Hickory, and Black Walnut trees. Spread throughout the preserve are small, remote forest ponds that store water in the spring and early fall. These ponds operate in conjunction with wetlands and numerous creeks that run into the preserve's 60-acre Rasmussen Lake, to supply invaluable wildlife habitat and food sources. Rasmussen Lake is located in the southern part of the preserve; it was created in 1957 due to the assembly of a dam across Old Mill Creek.

Downstream of the dam, strong rapids are produced by the outflow of water down the stream corridor. The stream twists and turns through the preserve alongside Box Elder, Cottonwood, Weeping Willow, Green Ash, and other flora. The site studied in this forest preserve is the completely degraded and unmanaged Ethel's Woods W0 site.

Middlefork Savanna Forest Preserve is located in southeast Lake County, Lake Bluff, Illinois. The entrance to Middlefork Savanna is located off of Waukegan Road, north of Route 60 and south of Route 176. Middlefork Savanna is an atypical tallgrass savanna with a mixture of oak savanna and woodlands. It also contains wet and mesic prairies along with sedge meadows and marshes. The preserve sits on 576 acres with over 25 of those acres regarded as the highest quality tallgrass savanna in existence in the United States. Middlefork Savanna is recognized nationwide as an important biological research site. It offers an outdoor classroom for students, researchers, and members of other organizations. The savanna provides important protection for state and federally listed species like the Blanding's turtle. Middlefork Savanna was once part of a large glacial lake that is now an environmentally priceless wetland that runs into the North Branch of the Chicago River. This forest preserve has been acknowledged by Chicago Wilderness as one of the most valuable sites for biodiversity in Northeastern Illinois. Due to Middlefork's large size, it sustains a long list of uncommon birds, butterflies, and additional species that need big open areas to survive. The sites studied in this forest preserve were the early management Middlefork W1 site, and the high quality/pristine condition Middlefork W3 site.

Grassy Lake Forest Preserve is located in southwest Lake County, North Barrington, Illinois. Grassy Lake can be found south of W. Miller Road between N. Old Barrington Road and Route 59. This preserve is characterized by rolling hills, oak woodlands, marshes, and moraines. This forest preserve also contains Wagner Fen and Flint Creek. Wagner Fen is a 100 acre wetland that is home to 8 endangered and threatened species of plants including the bog violet and beaked spike rush. A major project occurred in Wagner Fen years ago to eliminate non-native purple loosestrife from the ecosystem and since then this invasive species has been almost completely eliminated. Flint Creek is one of the healthiest streams in Lake County; it has a quality score of Grade B which is rare for Illinois. The site studied in this forest preserve was the mature management Grassy Lake W2 site.

MacArthur Woods Forest Preserve is found in Lake County, Libertyville, Illinois. The entrance to MacArthur Woods is found north of E. Townline Road between Route 21 and N. St Mary's Road. MacArthur Woods is a 504-acre oak and maple forest that gives refuge to 7 endangered species and more than 40 species of breeding birds. The Illinois Nature Preserve's Commission acknowledges the site as one of Illinois' most important environmental areas and many ecological studies have occurred here. Over 150 acres of this preserve have been purged of invasive woody plants. Continual management of the site is planned for the future, including controlled burns and native plant seeding that will hopefully convert dense shrub thickets to pristine oak forests and flatwoods. In the 70 acres of northern flatwoods, restoration efforts have eradicated 3,000 feet of old drain tiles in order to re-establish natural water levels. The site studied in this forest preserve is the mature management MacArthur Woods W2 site.

Ryerson Woods is found in southeast Lake County, Riverwoods, Illinois. Ryerson Woods is located to the north of Deerfield Road between N. Milwaukee Avenue and Riverwoods Road. Ryerson Woods sits on greater than 500 acres and is a rare northern Illinois landscape because it is a picture-perfect example of a northern flatwoods forest; northeastern Ilinois' last floodplain forest is also found here. This preserve is one of Illinois' most pristine woodlands, providing sanctuary to several threatened and endangered species. These threatened and endangered species include the Veery Thrush, Red-shouldered and Cooper's Hawks, Purple-Fringed Orchids, and Dog Violets. Over 150 bird species and almost 600 flowering plant species have been seen in Ryerson Woods. The species, communities, and natural areas that exist here are so rare that more than half the land is designated as an Illinois Nature Preserve, providing the area with particularly strict rules. The area contains five miles of scenic wooded trails with beautiful wildflowers in the spring and endless colors inside the maple forest come fall. These woodlands ultimately end at the Des Plaines River. The site studied in this forest preserve is the high quality/pristine condition Ryerson Woods W3 site.

Soil Collections

All soil samples were collected during the summer of 2009. Summer is one of the most active times in a microarthropod's life cycle. The soil samples were collected from 4 different replicated management treatments along a gradient of management effort in the restoration process. The assorted management treatment sites were represented with a W0, W1, W2, or W3. Each 1 hectare plot had a center GPS point. Soil cores were taken 10 meters to the north, south, and east of that center GPS point. Each soil core was put on the light extractor separately in their own funnel. The microarthropods were extracted from the soil by taking a soil detritus sample; detritus is non-living particulate organic matter including the bodies or fragments of dead organisms. This soil detritus sample was extracted with a high gradient extractor, a Berlese funnel. There are many different ways to construct Berlese funnels but the basic materials are any type of bucket with a cover, a large funnel that fits down inside, a wire mesh screen, a small cup to hold ethanol, and a light supply. Berlese funnels were used to remove microarthropods from soil and litter samples. These funnels operate under the theory that microarthropods in soil and litter will react negatively to light. A light source placed above the sample will force the microarthropods to move downward, falling into a funnel and subsequently a beaker of ethanol. All samples were left on the light sources for 5 days.

At each plot, the samples were combined into one mass to get a more accurate arthropod diversity measurement. Both arthropods extracted in their adult and juvenile stages were counted. At each stage of the restoration process, soil samples from day 1 through day 5 of the extraction period were sorted for microarthropods using a Nikon SMZ 1500 dissection microscope.

Microarthropod Extraction

The Berlese funnel theory was used to create a modified Tullgren apparatus for the extraction of microarthropods from the soil. When microarthropods were exposed to heat at the soil surface, their natural behavior caused them to migrate downward. The Tullgren apparatus made use of this downward migration behavior. My design was taken from Darin Kopp (2009). When constructing the Tullgren apparatus, ten (114mm) holes were cut into plywood (122 x 61cm) and ten metal funnels (150mm diameter) with Pyrex funnels (145mm diameter) were covered with Aluminum mesh and placed inside. Ten 120V halogen lights with dimmers to control light intensity were secured to an additional piece of plywood and positioned above each funnel. A collection vial partially filled with 70% ethanol was placed under each funnel to catch the microarthropods as they were moving through the soil.

Each sample was placed in the Tullgren apparatus in random order. For 5 days, the samples were gradually heated from the light source to establish a moisture gradient allowing the fauna to migrate out of the sample into the collection vials (Kopp 2009). To avoid overheating the sample and destroying the moisture gradient, the lights were turned off after 5 days (Kopp

2009). The sample numbers with extraction dates corresponding with their respective sites were recorded (see Table 1).

Microarthropod Separation and Evaluation

The contents of each collection vial were transferred to a Petri dish and the microarthropods were separated using a Nikon SMZ 1500 dissection microscope. Due to the fact that the soil samples were suspended above the vials, some debris inevitably collected with the microarthropods. In order to accurately distinguish the microarthropods, a 3 mm grid was developed (Kopp 2009). The Petri dish was placed on top of a transparency with the grid tracing. This prevented eye fatigue and ensured accurate separation. A probe was used to gently move any soil particles away from the microarthropods and each sample was checked twice. The extracted microarthropods were carefully removed using a plastic pipette and sorted into smaller Petri dishes labeled either M (Mite), C (Collembola), or O (Other). Each dish contained 70% Ethanol to preserve the microarthropods. The extracted microarthropods were mounted on slides using mounting media (CMC-10, Masters Company, INC.) and species diversity was assessed (Kopp 2009).

Total abundance and species diversity were assessed under a Nikon E400 compound microscope. With the assistance of Dr. Liam Heneghan mites were identified as the following orders: *Oribatida*, *Prostigmata*, *Astigmata*, and *Mesostigmata* and then when possible further classified into species or otherwise given arbitrary names as identification (Norton 1999). The following mites were identified: *Oribatida*, *Oppiella nova*, *Tectocepheus velatus*, *Liochthonius*, *Microppia Balogh – M. minus*, Species X, *Scheloribates*, *Belba*, *Liacaroid*, *Quadroppia*, *Pergalumna*, *Scutacarus*, *Eulohmannia*, *Eniochthonius*, *Nothrus*, *Hoplophthiracarus*, *Phthiracarus*, *Rhizotricia*, Juvenile 1, Shell, *Liochthonius* Juvenile, *Liacarus*, Tiny-headed

Juvenile, Juvenile w/ Antenna, Tiny-headed Adult, Larger *Scheloribates*, Juvenile Unknown "frog", *Tectocepheus velatus* Juvenile, Large "*Belba*" Turtle Shell w/ antenna, Simple 8-legged Translucent mite, Simple 6-legged Translucent mite with 2 front "arms", *Tydeus*, *Cocceupodes*, *Tarsonemus*, *Tarsonemus* 2, *Prostigmata*, *Thrombid*, Elongated "*Tydeus*", Juvenile Unknown Stick Legs, *Prostigmata* Juvenile, *Astigmata*, *Histiostoma*, *Astigmata* Juvenile, Splayed-legs mite, Large Warted mite, *Mesostigmata*, *Rhodacarus*, *Mesostigmata* 1, *Olodiscus*, *Mesostigmata* 2, *Mesostigmata* 3, *Mesostigmata* 4, *Rhodacarus* Juvenile, *Mesostigmata* "curled", *Mesostigmata* 2 with legs all over, Spider *Mesostigmata*, *Rhodacarus* no back legs, *Mesostigmata* Splayed Legs, Juvenile *Rhodacarus* "curled", and *Mesostigmata* 2 Spiked (Norton 1999).

Microarthropod Photographs

Photographs were taken of all orders and most species of mites using a Nikon DS Camera Control Unit (DS-U2) that connected to the Nikon E400 compound microscope. Photographs were taken on low power to capture the entire mite as well as high power to zoom in on identifying features. A scale was added to each low power photograph to show the relative size of each mite.

Species Diversity Metrics

The microscope and computer were carefully calibrated on low power to depict a red line scaled to 100 micrometers (um) for each microarthropod photo. This gave us an idea of the size of each microarthropod when considering their taxonomic classifications.

Soil Nutrients

Plant root simulator (PRS) probes were used on each of the 11 sites to gather information on the mobility of various nutrients within the soil. The 15 soil nutrients tested for were: nitrogen, nitrate, ammonium, calcium, magnesium, potassium, phosphorous, iron, manganese, copper, zinc, boron, sulfur, lead, and aluminum. A PRS probe is an unconventional soil analysis device that used an ion exchange resin membrane to build an image of dynamic ion flux in the soil and further heterogeneous media (Western Ag Innovations Inc. 2007). With the addition of a chemical, the anion and cation exchange resin membranes displayed exterior traits and nutrient absorption, which strongly resembles a plant root surface. While buried in the soil, PRS probes were able to evaluate nutrient supply rates by constantly soaking up charged ionic species (Western Ag Innovations Inc. 2007).

Soil nutrient values were in ug/10^2 cm/4 weeks. This was a concentration of soil nutrients per area per time. Time was the duration the PRS probes were buried. Soil nutrient values were an average from a pooled sample of 4 cation and 4 anion probes. The results were similar to a 2 replicate pooled soil sample because 2 of each of the probes were placed at 2 locations within 5 meters of the center point of the plot.

Statistical Analysis

An analysis of variance (ANOVA) was performed on the mobility of nutrients (ug/10^2cm/4wks) in the soil to determine if there was a significant difference between management type (W0, W1, W2, W3) and the 15 different soil nutrients included in the test. An ANOVA was also performed on the species abundance, Shannon diversity index, species evenness, and species richness of the Oribatid mites to determine if there was a significant difference between management type and these four biological diversity measures. If the ANOVA was significant, a Tukey test was performed to determine which of the four management treatments (W0, W1, W2, W3) differed from each other in terms of the levels of the 15 nutrients in the soil. Regression analysis was performed to determine how much of each of the 4 biological diversity measures (species abundance, species richness, species evenness, and

Shannon diversity) of microarthropods is relying on the 15 individual soil nutrients. Multiple regression analysis was performed to determine the relationship between species abundance, species richness, species evenness, and Shannon diversity and all the soil nutrient data.

An ANOVA was performed on the level of management and the number of rare species present. The data on the rare species was natural log transformed (ln(x+.5)). Regression analysis was also performed on the level of management and the number of rare species. Linear correlation analysis and factor analysis were performed on natural log transformed abundance values of common mite species to look for species associations and then examine the relationship between these associations, soil characteristics, and management type. Linear correlation analysis was performed on the species abundance values of 12 common mite species to see each of their relationships with individual soil nutrients and management type. Factor analysis reduced the 12 common mite species to a smaller set of 4 assemblages.

RESULTS

Effects of Restoration Treatments on the Diversity and Abundance of Microarthropods

A combined total of 1,529 oribatid mites classified into 64 morphological species were collected from all sampling locations (N=11) (see Table 2). The total number of mite species found in each of the 11 sampling locations was recorded (Table 2). Even as the total species richness found along the management gradient tended to increase, from degraded/unmanaged (W0) to high quality/pristine management (W2), a one-way ANOVA was not significant, meaning there were no significant differences between treatments (see Table 3). There was no significant difference between management type and any dependent variable (Table 3).

Relationship between Restoration Treatments and Soil Nutrient Data

There were no significant effects of management type on soil nutrient availability measured by the PRS probes with the exception of Manganese (see Table 4). The high quality/pristine management (W3) sites differed from the early management (W1) sites in that a higher level of Manganese correlated with high quality/pristine management sites with lower Manganese in the early management sites (Manganese Levels: W3 Average = 655.8 Ug/10 cm^2/4 wks, W1 Average = 594.5 Ug/10 cm^2/4 wks) (Manganese; F=5.68, p=0.0273) (Table 4).

Relationship between Soil Nutrient Data and Oribatid Mite Species Diversity and Abundance

We investigated the relationship between the nutrient status of the soil and the faunal community. Oribatid mite abundance was positively related to the total nitrogen and phosphorus present in the soil (F=6.59, p=0.03, r^2=.41) (see Figure 1a) (F=5.01, p=0.05, r^2=.34) (see Figure 1b). Additionally, the Shannon diversity of oribatid mites was positively related to nitrogen availability in the soil (F=5.2, p=0.05, r^2=.34) (see Figure 2). Total species richness of oribatid mites was also positively related to total nitrogen, phosphorus, and zinc availability in the soil (F=9.19, p=0.01, r^2=.46) (see Figure 3a) (F=6.61, p=0.03, r^2=.41) (see Figure 3b) (F=8.74, p=0.02, r^2=.52) (see Figure 3c).

Relationship between Soil Nutrient Data, the Restoration Treatment of Species Diversity Tests, and Total Mite Abundance (Shannon Diversity, Species Evenness, and Species Richness)

Step-wise multiple regression tests were performed on data from all 11 sites to analyze the relationship between the community traits of total mite abundance, Shannon diversity, species evenness, and species richness, against all 15 soil nutrients tested. Total mite abundance was best explained by soil nitrogen which accounted for 41% of the variation in mite abundance (R^2=0.409, p=0.034) (see Table 5). No additional soil variables significantly contributed to explaining variation in mite abundance. Species richness was explained by zinc in the soil, revealing 52% of the variation in species richness (R^2=0.521, p=0.012) (Table 5). Species richness was better explained by the presence of zinc and lead in the soil, explaining 72% of the variation (R^2=0.722, p=0.006) (Table 5). When the multiple regression was re-run without zinc and lead included, species richness was explained by total nitrogen in the soil which accounted for 47% of the variation in species richness (R^2=0.465, p=0.021) (Table 5). Species richness was better explained by total nitrogen and phosphorus together in the soil, explaining 70% of the variation (R^2=0.703, p=0.008) (Table 5). Without zinc and lead, species richness was even better explained by total nitrogen, phosphorus, and copper in the soil which accounted for 90% of the deviation in species richness (R^2=0.904, p=0.001) (Table 5). Again without zinc and lead, species richness was best predicted by total nitrogen, phosphorus, copper, and magnesium in the soil, explaining 96% of the variation in species richness (R^2=0.957, $p<0.001$) (Table 5). No additional soil variables significantly contributed to explaining variation in species richness. There was no significant relationship found between either species evenness or Shannon diversity and any of the soil nutrients across the restoration treatments.

Microarthropod Facebook

Photographs were taken of all species of oribatid mites located within the study sites. Example photographs of the species found are shown in Appendix B of this thesis. Some of the more common species found amid Chicago Wilderness include: *Oppiella nova, Tectocepheus velatus, Liochthonius species, Scheloribates species, Scutacarus species, Eulohmannia species, Nothrus species, Hoplophthiracarus species, Phthiracarus species, Tydeus species, Cocceupodes species, Astigmata species, Mesostigmata species, and Rhodacarus species*. Several of the rarer species photographed include: *Microppia balogh, Belba species, Liacaroid species, Quadroppia* *species, Pergalumna species, Eniochthonius species, Rhizotricia species, Tarsonemus species, Thrombid species, Histiostoma species, and Olodiscus species.*

Ubiquitous, Common, and Rare Species Found within 11 Management Sites

There were approximately 64 different species found within the 11 Chicago Wilderness sites. Two species, *Astigmata* and *Rhodacarus,* were found at all 11 sites. Twelve species, considered common, were found at more than 70% of the sites. Thirty-two species, considered rare, were found at fewer than 30% of the sites. Of the rare species, 15 were found at only one site. A list of species, their distribution and abundance are provided in *Appendix C*.

The number of rare species able to live on a site would be expected to increase as the amount of beneficial, skilled management increases on the site. However, there was not a significant association between the level of management and the number of rare species but there was a definite trend in the mean ($F = 2.785$, $p = 0.129$, ANOVA; see Figure 4).

The results of the regression analysis showed a significant relationship between the number of rare species and mite species abundance (Number of species=4.8633x-17.676, $r=0.832$, $p<0.001$, $n=11$) (see Figure 5). There was also a significant association between the number of rare species at a site and the level of total nitrogen ($r=0.697$, $p=0.017$, $n=11$) (see Figure 6), phosphorus ($r=0.700$ $p=0.017$, $n=11$) (see Figure 7), and zinc ($r=0.779$, $p=0.005$, $n=11$) (see Figure 8).

Correlations between Common Species Associations and Species Abundance, Soil Characteristics, and Management Type

I used linear correlation analysis and factor analysis on natural log transformed abundance values of the 12 common mite species, excluding juvenile species, to look for species associations and then examine the relationship between these associations, soil characteristics and management type. I used factor analysis to reduce the 12 common mite species to a smaller assemblage of correlated species. The analysis reduced the 12 common mite species to a set of four assemblages with eigenvalues greater than 1 (see Table 6). The assemblages account for, respectively 27.2%, 24.0%, 18.1%, and 15.8%, collectively explaining 85.1% of the total variation in the common mite species (Table 6).

The first common species association was a positive relationship between *Astigmata*, *Cocceupodes*, *Tydeus, and Phthiracarus.* This assemblage had a positive association with total nitrogen in the soil (r = 0.681, n=11, p=0.021) (see Figure 9). Within this set, *Cocceupodes* showed the strongest individual relationship with total nitrogen in the soil (see Figure 10). The second assemblage had a positive association between *Scheloribates sp., Liacaroid,* and *Mesostig sp. 3*. This group had a positive correlation with potassium and phosphorus in the soil (Potassium r= 0.629, n=11, p=0.038) (see Figure 11) (Phosphorus r= 0.636, n=11, p=0.036). The third assemblage included *Histiostoma* and *Rhodacarus*. In this case, the species show a negative relationship with each other. This assemblage is associated with calcium in the soil (r = 0.651, n=11, p=0.030): as calcium increased, *Histiostoma* decreased and *Rhodacarus* increased. The fourth significant association was a positive association between *Eulohmannia and Scutacarus*. This assemblage is associated with aluminum in the soil (r = -0.726, n=11, p=0.011) (see Figure 12): as aluminum increased in the soil, *Eulohmannia and Scutacarus* mite abundance decreased.

There was no significant association between any of these 4 species assemblages and management type (Species Association 1: F = 2.511, Sig. = 0.142; Species Association 2: F = 0.582, Sig. = 0.645; Species Association 3: F = 0.148, Sig. = 0.928; Species Association 4: F = 2.927, Sig. = 0.109) although Species Association 1 did show some possible association (see Figure 13). The species represented in the first association, *Astigmata* and *Tydeus* are graphed against management level (see Figures 14, 15). As the management level increased, the number of individuals of *Astigmata* and Tydeus both increased in the soil (Figures 14, 15).

DISCUSSION

The goal of my research was to study how the aboveground manipulation of plant diversity in restoration management practices affected the hyperdiverse assemblage of belowground arthropod communities. Additionally, I studied the relationship between soil nutrient content and belowground microarthropod diversity. My results showed no significant restoration treatment effects. That is, the field management aimed at vegetation recovery had few effects on the microarthropods. While there were few effects seen, there were some trends seen between individual species and management level. There was significant explanatory value to the nutrient data. My work could potentially allow for a simple test to evaluate the relationship between the soil quality of a specific site and belowground diversity.

Overall, my research showed that there was no relationship between aboveground restoration management and belowground diversity of microarthropods. As the level of restoration management increased, microarthropod diversity did not increase. In contrast to my work, a related study done on seminatural grasslands of Northern Europe did find that restoration practices have been successful in regards to restoring ant species richness (Dahms et al. 2010). Ants were chosen in that study because they are biological indicators, a species used to help monitor the health of an entire ecosystem (Dahms et al. 2010). While ants are indicators of changes in aboveground processes, my study points out how microarthropod diversity can also function as indicators of the healthiness of the belowground food web.

This discussion will consider the relationship between restoration management and biodiversity both above and belowground. It will also describe what encompasses a healthy soil system and how this system relates back to belowground diversity.

Oribatid Mite Background

Oribatid mites live in soil and degraded leaves called litter. They are the most diverse and often the most abundant of the microarthropods. Oribatid mite's main source of sustenance is microflora and decaying plant material (Whitford et al. 1989). It is important to understand how microarthropods and soil reciprocally influence each other since restoration success depends on understanding how to manage this intricate and extremely key connection. Decomposition and mineralization are essential processes in an ecosystem's nutrient cycling. The rates of these processes are regulated by the activity of soil animals that feed on the soil microflora (Whitford et al. 1989). When considering the diversity of these microarthropods in the soil, some basic questions spring to mind. Do more complex habitats house more diverse mite faunas than simple habitats? Is there a characteristic assemblage of oribatid species active in a particular litter-type? In order to begin to answer these questions we must examine the influence of litter composition on the oribatid mite diversity inhabiting it.

The question that often surrounds oribatid mites is: how does a single habitat sustain high diversity despite competing species having apparently identical feeding behaviors? Why doesn't competition between oribatid mite species lead to the extinction of one species over another? The answer is that their habitats and feeding behaviors are not as similar as they may seem to the naked eye. With 4 horizons, O, A, B, and C, the soil allows for a specific species of oribatid mite to primarily exist in its own horizon (Hansen and Coleman 1997). When comparing litter types at all individual depths, the mixed litters hold a considerably larger assortment of microhabitats and contain more species than the simple litters (Hansen and Coleman 1997). This reveals that microhabitat variation occurs to a greater degree in deeper layers of the soil where the mixed litter complexity is highest (Hansen and Coleman 1997). Another relationship is a higher abundance and diversity of mites in litters with increased decomposition rates (Hansen and Coleman 1997). The greatest density of microarthropods is normally surrounding plant roots in the mycorrhizal section of the soil (Hansen and Coleman 1997).

There are many mite communities where the structure tends to show an association between soil type and disturbance. Soil acidity, humidity, forest type, competition, predator-prey interactions, and abiotic or biotic disturbances are major drivers in determining the structure of oribatid mite communities (Maraun and Scheu 2000). Oribatid mites utilize a variety of resources which can be diminished by disturbances. These disturbances act as the decisive factor of community structure (Maraun and Scheu 2000). There are common opportunistic species that are able to survive in heavily disturbed areas better than the rare, sensitive species.

Correlation between Plant Diversity and Microarthropod Diversity

While my study did not see a trend of increased aboveground restoration management leading to increased microarthropod diversity in the soil, there are studies that have shown this relationship. A previous study done on the relationship between plant diversity and arthropod diversity found that increasing the number of plant species and functional groups also increased arthropod species richness, but not abundance (Siemann et al. 1998). Interestingly, supplementing more plant functional groups could possibly be as successful in increasing arthropod diversity as adding more plant species (Siemann et al. 1998). Since increasing plant diversity can also directly increase plant productivity, adding plant diversity to an area may increase arthropod diversity (Siemann et al. 1998). Increasing arthropod diversity may allow rare species to return to the area (Siemann et al. 1998). When predicting arthropod diversity, this particular study discovered that plant taxonomic diversity was a better forecaster than plant functional diversity (Siemann et al. 1998).

Aboveground and Belowground Interactions

Does the relationship between above and belowground processes give us a clue as to why we found no significant relationships between the amount of restoration management and the amount of microarthropod diversity? In order to stabilize and maintain ecosystem processes and keep keystone species thriving, healthy connections between above and belowground biodiversity are essential. When assessing how to conserve biodiversity belowground, a species level assessment will not give you an adequate representation of how higher taxonomic levels are affected (Hooper et al. 2000). As a group, organisms at these higher taxonomic levels drive larger ecosystem processes (Hooper et al. 2000). A previous study showed that disturbances caused a decrease in plant diversity that led to diminished species richness and abundance in termites and nematode populations (Hooper et al. 2000). Similarly, the general trend of the species diversity data from my study showed an upward progression from degraded/unmanaged sites (W0), containing the lowest average species diversity, to mature management sites (W2), containing the highest average species diversity (Averages W0=27.33, W1=38.67, W2=49.33). However, the average of the high quality/pristine management sites (W3) was less than the average of the mature management sites (W2) (Average W3=42.5). The high quality/pristine management sites (W3) may have had a lower average due to the fact that there were only two sites sampled instead of three. Another possible explanation is that the average species diversity of the Middlefork high quality/pristine management site (W3) was affected by the site's long history of aggressive restoration.

Manganese

There was a significantly higher level of manganese discovered in the high quality/pristine sites (W3) (Ryerson and Middlefork) in comparison to the early management sites (W1) (Middlefork, Waterfall Glen Cemetery Ridge, and Old School). When Middlefork was removed from the data set and the ANOVA was rerun, there was no longer a significant difference in manganese levels between the remaining 10 sites. Middlefork is an outlier in the data. There have been several studies done on how nutrient availability in the soil effects soil biota and plant growth. One study in particular came to the conclusion that high nutrient availability effects competition between species of successional plants (Deyn et al. 2004). This competition is not just decided by nutrient acquisition and growth rates but also by the amount of interaction with existing soil biota (Deyn et al. 2004).

A study was done on the restoration of biological soil crusts (BSCs) in arid regions of the world to determine if lower soil fertility hinders re-colonization (Bowker et al. 2005). It was discovered that the dispersal of BSC organisms is mostly influenced by soil fertility (Bowker et al. 2005). In the past, micronutrients had not been seen as essential to restoration success. The focus had always been on the more obvious macronutrients like nitrogen and phosphorus (Bowker et al. 2005). In this particular analysis, however, the micronutrients manganese (Mn) and zinc (Zn) were repeatedly significant factors (Bowker et al. 2005). When Mn ($\geq$8.0 ppm) and Zn ($\geq$ 0.4 ppm) were present at higher levels in the soil, there was a positive correlation with the amounts of lichens and moss (Bowker et al. 2005). This is why mineral nutrients have been described as "the fundamental currency of vegetation processes at scales from the individual to ecosystems and landscapes" (Grime et al. 1997).

Striking Relationship between Soil Nutrient Data and Microarthropod Community

While there were no effects of management on microarthropod diversity, the presence of certain nutrients in the soil was a strong predictor of microarthropod diversity. For all 11 sites, there was a positive correlation between: total nitrogen, phosphorus, and oribatid mite abundance; total nitrogen and the Shannon diversity index of oribatid mites; total nitrogen, phosphorus, zinc, and species richness of oribatid mites. Nitrogen and phosphorus are important predictors of the diversity of microarthropods; they drive microhabitat processes which in turn can stimulate microhabitat structure.

The carbon and nitrogen cycle is largely tied to the microarthropod community through its effect on all pools and fluxes of nutrients (Osler and Sommerkorn 2007). There are two ways in which soil fauna play a part in the nitrogen cycle. First, they directly contribute mineral nitrogen to the soil increasing net nitrogen mineralization and second, microarthropods produce dissolved organic matter (DOM) that gets released into the soil (Osler and Sommerkorn 2007). Nitrogen is mineralized when carbon and nitrogen ratios of microbial food sources are beneath a threshold (Osler and Sommerkorn 2007). This then causes there to be surplus nitrogen for the accessible carbon (Osler and Sommerkorn 2007). When this nitrogen is expelled as ammonium the nitrogen is mineralized (Osler and Sommerkorn 2007). When the substrate level surpasses the threshold, the microbes turn out to be progressively more nitrogen limited. The microbial biomass holds the nitrogen, removing it from the inorganic pool and initiating nitrogen immobilization (Osler and Sommerkorn 2007). With regards to DOM, litter bag research shows that the existence of microarthropods on organic matter substrates like particulate organic matter increases mass loss by an average of 23%; this increase is mainly because of carbon loss. Not many studies have found that soil fauna affects nitrogen loss from organic matter (Osler and

Sommerkorn 2007). Soil fauna affect all of the pools within the soil nitrogen cycle through their effects on microbial biomass, inorganic nitrogen pools, supply of DOM, and mass loss of organic matter (Osler and Sommerkorn 2007). My data found that there is a strong relationship between the amount of soil nutrients present and the amount of microarthropod diversity in the soil.

Along with the importance of the integration of individual nutrients into the carbon and nitrogen cycle, the effects of other organisms' actions can have major impacts on the abundance and diversity of microarthropods in the soil. A previous study found that the density of microarthropods in the soil was thirty to forty times higher in ant nest soils than in the control soils (Wagner et al. 1997). As a result of these high densities of microarthropods and protozoa, this study showed that there is greater resource availability in soils containing ant nests because ant nests bring spatial heterogeneity to the soil (Wagner et al.1997). This heterogeneity promotes healthy soil biota and chemistry. Furthermore, soils with ant nests all contained higher concentrations of nitrate, ammonium, phosphorus, and potassium, reinforcing the importance of nitrogen and phosphorus shown in my study. Once these ant colonies die, the nutrient-laden ant nest areas can be occupied by plant species in need of more fertile soil (Wagner et al. 1997). This relationship increases both heterogeneity in microarthropods and plant species diversity (Wagner et al. 1997). Overall, the results of this study propose that ant nests offer an added supply of spatial heterogeneity that is equally important to both community structure and the chemistry of soils (Wagner et al. 1997). However, because of the results obtained in my study, it is important to begin to consider looking at above and belowground processes separately. This is due to the lack of relationship between the amount of restoration management aboveground and the diversity of microarthropods belowground.

Decoupling Aboveground from Belowground Processes

My results showed no relationship between management treatment and microarthropod diversity. Since above and belowground processes may not be as related as originally thought, it is necessary to come up with a new set of tools that look at each process separately. SEK is still needed to restore degraded ecosystems. SEK can be used to direct restoration practice to include soils as part of the ecosystem. Separate from aboveground goals, the results suggest that soil nutrients can serve as a strong predictor of belowground diversity and could be used as a management or monitoring tool to reach restoration goals.

The success of SEK relies upon the extent to which the restoration goal strives to attain attributes of a particular reference state (Heneghan et al. 2008b). If a plot of land is considerably degraded, the practitioner needs to consider the health of the soil (Heneghan et al. 2008b). If an ecosystem has been extremely degraded to the point where native plants are unable to grow, the project may be forced to focus first on the health of the soil to regain essential processes that would allow re-vegetation (Heneghan et al. 2008b). For example, this could be accomplished by plowing or reshaping compressed substrates to better ventilate, permeate, and aid root growth (Heneghan et al. 2008b). This could also be achieved by eliminating harmful chemicals or changing the pH level of the soil (Heneghan et al. 2008b). Sometimes, this simply means "pausing" for the existing microbe communities to operate on the harmful toxins (Heneghan et al. 2008b). The most degraded ecosystems need to have their physical template fixed before species restoration can be achieved (Heneghan et al. 2008b). Often by altering one factor that is negatively affecting the health of the soil, a chain reaction positively alters other aspects in the soil (Heneghan et al. 2008b).

Chemical manipulation of the soil uses chemicals or fertilizers as a tool to reach restoration goals. For example, a nitrogen or phosphorus fertilizer, the nutrients my research found most important, can be used to restore soil health in grazing land (Heneghan et al. 2008b). Previous studies have supported the finding that proper levels of nitrogen and phosphorus produce ideal soil conditions (Heneghan et al. 2008b). Due to many years of fertilization, land that has previously been utilized for agriculture may contain top soil extremely high in inorganic nitrogen (Heneghan et al. 2008b). This soil may need alterations in order to support native vegetation that is acclimatized to soil with limited nitrogen availability (Heneghan et al. 2008b). However, with alterations to soil chemistry and nutrition, it is very important to have a good understanding of the secondary mechanisms that also affect plant and soil health (Heneghan et al. 2008b). Some of these secondary mechanisms include mycorrhizal symbiotes, microbes living in the soil, and soil texture, depth, density, and porosity (Heneghan et al. 2008b). In order to ensure restoration achievement, it is important to always keep in mind the complete soil system and the many relationships it has with all the ecosystem's components.

The organisms that live in the soil can greatly influence the health of the soil. While in this study the connection between plants and microarthropods was not significant, the connection between microarthropods and existing soil nutrients was exceptionally strong. Organisms living within the soil affect the fluctuation of soil nutrients and plant population diversity and growth. Soil biota is comprised of macroinvertebrates, microarthropods, nematodes, bacteria, and fungi (Heneghan et al. 2008b). Many studies in the past have looked at how heavily degraded ecosystems influence soil biota. The common consensus is that a healthy soil biota community is a sign that restoration has been successful (Heneghan et al. 2008b).

Healthy mycorrhizae spores and soil inoculates have frequently been shown to improve soil fertility (Heneghan et al. 2008b). Before application of mycorrhizal fungi or any other particular restoration practice, it is essential to attain knowledge of soil, vegetation, and other related characteristics of the site locations (Heneghan et al. 2008b). Some growth conditions unfavorable to mycorrhizal fungi are the presence of heavy metals or extremely low or high levels of nutrients in the soil. This is especially true when excess nitrogen from fertilizer application is present (Heneghan et al. 2008b). Furthermore, it is important to know that plants tend to show less dependence on mycorrhizae with increasing phosphorus availability in the soil (Heneghan et al. 2008b). This supports my finding that phosphorus is important for optimal soil health. When attempting to restore a plant community to its pristine condition, a well-rounded SEK model is essential to successfully integrate mycorrhizal into the soil. Soil nutrient balance is essential. It is time to look at above and belowground processes individually and to focus on the health of the soil.

Soil Ecological Knowledge

One of the most essential uses of SEK is to fight against invasive species. An ecosystem is much more vulnerable to invasive species when the system is disturbed or has higher than normal resource availability (Heneghan et al. 2008b). A classic example of excess resource availability is agricultural land that has been fertilized for years (Heneghan et al. 2008b). This creates a soil environment that is better suited for invasive species growth than native plant growth. In order to fix this soil environment, defertilization is often used. Defertilization of this land involves the introduction of more carbon into the soil, allowing microbes to better use the present nitrogen (Heneghan et al. 2008b). In prairie restorations, this decreases the success of invasive species (Heneghan et al. 2008b).

It is vital to have an understanding of soil quality because invasive species tend to drastically alter it. Soil quality is measured by its ability to efficiently uphold animal and plant life, preserve or improve water and air properties, and sustain human habitat (Heneghan et al. 2008b). To run a study on the quality of soil in an area, some evaluation tools include: a visual soil appraisal process, soil quality information sheets, soil physical condition scorecards, and commercially obtainable soil quality experiment equipment (Heneghan et al. 2008b). The evaluation of soil quality is useful for determining the resistance of soil to degradation and the resilience of soil to rebound after degradation has occurred (Heneghan et al. 2008b). The ability of SEK to successfully heal a degraded ecosystem chiefly depends on properly evaluating the quality of the soil.

Umbrella Species

By focusing conservation efforts on umbrella species, also known as surrogate or indicator species, many other species are indirectly protected (Baldi 2003). In this study, it is important to consider the possibility that the protection of a single plant or microarthropod species could indirectly protect many other valuable species. A previous study questioned whether or not higher taxa are good surrogates of species richness in three groups of arthropods: Coleoptera, Diptera, and Acari (Baldi 2003). It was found that both genus and family levels could provide good surrogates for species diversity. A limitation to this finding is that the diversity of one taxon can influence the diversity of another only at the species level (Baldi 2003). A similar study in the tropics looked at using higher-taxon richness as a surrogate for species richness. Separate from differences in the size of the site, it was discovered that the family taxon level and general richness of sites were closely connected with their species richness (Balmford et al. 1996). Efficient application of the higher-taxon tactic is a beneficial method for enhancing the cost efficiency of local field conservation development assessments in the tropics (Balmford et al. 1996).

Lawler and White (2008) tested if surrogate performance could be explained by taxonomic diversity, nested species distributions, “hotspots” of biodiversity, species range sizes, or environmental diversity. These researchers discovered that good surrogates are usually geographically rare, taxonomically diverse, exhibit relatively unnested distributions, and occupy diversity “hotspots” (Lawler and White 2008). Surrogate performance was not explained by environmental diversity because spatial scales masked finer level ecological relationships and species diversity was not closely linked to environmental diversity (Lawler and White 2008). The distribution data on biodiversity surrogates can be used to estimate distribution data for lesser understood species (Hortal et al. 2009). In my study, microarthropod diversity can be seen as a surrogate, revealing the overall healthiness of the soil and its other existing biota.

Another study looked at the application of species assemblage patterns and species density to identify commonly-categorized surrogates at a local scale (Lovell et al. 2007). This surrogate categorization was utilized to evaluate cross-taxon association versus merely taxonomic positions using nine invertebrate taxa (Lovell et al. 2007). While the research did uncover some cross-taxon associations, the links were insubstantial and as a result, surrogates could not be identified (Lovell et al. 2007). It was found that this method would only be practical in species-poor genera or families and only in areas where the biological diversity was completely known. From the previous study, higher taxa shows promise as a surrogate for lower taxa (Lovell et al. 2007). Since there were no close associations found amongst invertebrate taxa, the employment of a multi-taxa tactic for the integration of invertebrates into conservation management is needed (Lovell et al. 2007). If this invertebrate taxa association proves true, my study would require the employment of this multi-taxa tactic.

Invasive Species

Urban landscapes, like Chicago Wilderness, that have had anthropogenic disturbances are confronted with an array of problems including hydrological changes, habitat fragmentation, invasive species, nutrient loading, loss of structural diversity, altered fire regimes, and erosion (Heneghan et al. 2008a). With all of the threats to biodiversity that are inherently present with human occupation, a balance must be created between the environment's biophysical needs and human's social needs (Heneghan et al. 2008a). By working towards this balance humans will develop a healthier, mutually beneficial relationship with their natural environment (Heneghan et al. 2008a). The only way this balance can be fully achieved is through cooperation between researchers and practitioners in developing and implementing efficient restoration goals (Heneghan et al. 2008a).

Because successful invaders often lack significant competition from native species, the spread and permanent removal of invasive species is one of the most serious reoccurring problems faced by restorationists (Heneghan et al. 2008a). One of the main difficulties with invasive species is that they inflict changes to ecosystem processes that remain even following their physical elimination (Heneghan et al. 2008a). In my study, *R cathartica* was a likely cause of such ecosystem changes. There is little doubt that this invasive species was a contributing factor to the degraded/unmanaged sites' (W0) poor soil quality. A major issue is that *R. cathartica* has higher nitrogen levels in its leaf litter compared to native litters (Heneghan et al. 2008a). While higher nitrogen levels were found to promote an increase in microarthropod diversity, if a certain threshold of nitrogen is surpassed excess nitrogen can have a negative effect on soil quality (Heneghan et al. 2008a). Even if only one invasive species is present, belowground processes can be negatively affected.

Common and Rare Species Diversity Numbers

Twelve common species were present at over 70% of the sites in this study. Thirty-two species were present at less than 30% of the sites and fifteen of these species were unique to one site. While the rare species data allows us to examine ecologically important rare microarthropods, studying common species allows us to examine overall species associations and the relationships between management and mite abundance.

Rare Species Diversity

While there was not a significant association between the level of management and the number of rare species, there was a definite trend seen in the mean. As management level increased, the total number of rare species also increased. In other words, these results reveal a tentative relationship between increasing management on a site and increasing rare species diversity of mites on that same site. There was a significant association found between the number of rare species present and total mite abundance. As mite abundance increased, the total number of rare species found also increased. This demonstrates that when the number of mites an area can sustain increases species diversity will increase as well.

The Relationship between Rare Species and Nutrients in the Soil

The soil nutrients that were determined to be associated with rare species diversity were nitrogen, phosphorus, and zinc. Total nitrogen present in the soil was very important for enhancing mite species diversity; as nitrogen levels increased, rare mite species also increased. Along that same line, phosphorus was significant; as phosphorus levels increased, rare mite species increased. Notably, the micronutrient zinc revealed that it is an important factor driving the diversity of mites; as zinc levels increased, numbers of rare mite species increased. The application of these three significant nutrients to the soil could potentially help increase the numbers of rare mite species on a site and in turn increase the general diversity of mites in an entire area.

Specific Common Mite Species Associations and their Relationships with Soil Nutrients

There were four interesting associations found amongst the twelve common mite species. As expected, there was no significant relationship found between any of these four associations and management type. The first association was between *Astigmata*, *Cocceupodes*, *Tydeus*, *and Phthiracarus* mite species. *Cocceupodes* and *Tydeus* are in the suborder *Prostigmata* while *Phthiracarus* is in the suborder *Oribatida*. This group survived best with adequate nitrogen in the soil. There was an indication that sites with no restoration work had lower levels of this assemblage. *Astigmata*, *Cocceupodes,* and *Tydeus* may be associated together in the soil because they share a similar feeding type; they all feed on fungal hyphae, making them all mycophages, primarily eating living members of the fungi kingdom. *Phthiracarus* feeds on decaying wood in the soil and may simply be associated with *Astigmata*, *Cocceupodes,* and *Tydeus* because these mite species live and eat in rich resource spots where *Phthiracarus* also enjoys feeding. *Astigmata's* main food source is dead plant material and microflora (Petersen et al. 1982). *Cocceupodes* and *Tydeus'* main food source is micro- and mesofauna, detritus, microflora, and plant roots (Petersen et al. 1982). *Phthiracarus'* main food source is plant litter (macrophytophages), mixed dead organic material and microflora (panphytophages), and microflora (microphytophages) (Petersen et al. 1982).

The second association was between *Scheloribates sp.*, *Liacaroid,* and *Mesostig sp. 3*. *Scheloribates sp.* and *Liacaroid* are in the suborder *Oribatida* while *Mesostig sp. 3* is in the suborder *Mesostigmata* (Petersen et al. 1982). As with general mite diversity, this group showed a positive correlation with phosphorus but also showed a positive association with potassium. As potassium levels increased, this group and level of management also showed a general increase. *Scheloribates sp.* and *Liacaroid* may be associated together in the soil because they also share a similar feeding type; they get nourishment from fungal hyphae and are therefore both mycophages. *Mesostig sp. 3* is a predator, feeding on other mite species, and may be associated with *Scheloribates sp.* and *Liacaroid* because they may be its prey. *Mesostigmata's* main food sources are dead plant material and microflora (*Uropodina*) and micro- and mesofauna (*Gamasina*) (Petersen et al. 1982).

The third association was negative between the species *Histiostoma* and *Rhodacarus*. *Histiostoma* is in the suborder *Astigmata* while *Rhodacarus* is in the suborder *Mesostigmata* (Petersen et al. 1982). The soil nutrient calcium showed a significant association with this mite assemblage; calcium had a negative effect on *Histiostoma* species population but an increasing, beneficial effect on *Rhodacarus* survival. *Histiostoma* and *Rhodacarus* may be negatively associated in the soil simply because *Rhodacarus* is a predator, feeding on other mite species, and *Histiostoma* is potential prey for *Rhodacarus*. It is not clear how calcium affects this species assemblage.

The fourth association was between *Eulohmannia and Scutacarus*. *Eulohmannia* is part of the Suborder *Oribatida* while *Scutacarus* is part of the Suborder *Prostigmata* (Petersen et al. 1982). This assemblage had an interesting relationship with aluminum in the soil: as aluminum and management level increased, the number of *Eulohmannia and Scutacarus* in the soil decreased. The reason behind the relationship between *Eulohmannia and Scutacarus* is unclear, but they may be associated because they both feed on microflora (Petersen et al. 1982).

Individual Species Relationships with Management Level

There was a trend seen between *Astigmata* species and management level: as management level increased, the mean density of *Astigmata* also increased. Could *Astigmata* possibly be a potential biological indicator species for restoration management? In other words, could the presence of a high or low mean density of *Astigmata* in the soil represent a trait or characteristic of the environment to help restorationists regulate individual sites? Since *Astigmata's* main food source is dead plant material and microflora, perhaps adequate amounts of those two components in the soil signify the start of a healthy soil system, promoting diversity of organisms in other areas. While *Astigmata* showed the most remarkable trend, *Tydeus* species also showed this same notable trend to a slightly lesser degree, indicating that it too could one day act as an indicator species for an ecosystem. *Tydeus'* (*Prostigmata*'s) main food source is micro- and mesofauna, detritus, microflora, and plant roots. Perhaps the presence of a healthy root system in the soil signifies the development of a healthy belowground food web. A healthy food web would initiate diversity in other areas of the ecosystem.

Restoration Management Implications

As my results show, the presence of certain nutrients in the soil can have a large impact on microarthropod diversity. In general, higher microarthropod diversity results in a more healthy soil system that promotes a healthier ecosystem. When attempting to restore a soil system, the restored ecosystem should contain the assemblage of species present in the reference ecosystem (Carey 2006). The restored ecosystem should also have all functional groups necessary to sustain itself through natural colonization and be able to sustain its reproducing populations (Carey 2006). The restored environment should be able to integrate itself into the larger ecosystem, including its interactions with both abiotic and biotic drifts and connections (Carey 2006).

Unfortunately, restoring ecosystems can be a difficult process. This is especially true for urban environments where invasion has occurred, there is incomplete knowledge of species and processes, inadequate follow-up after restoration efforts have occurred, or a lack of public knowledge on the aims of urban restoration (Heneghan et al. 2008). To achieve long-term restoration goals, soil nutrients must be optimum for native plants to thrive.

A system tends to be easily invasible when the gross resource supply surpasses the amount of resource uptake in the plant population (Heneghan et al. 2008). Many restoration theories call for the modification of soil properties prior to the reseeding of native plant species (Heneghan et al. 2008). The results of my study support a restoration theory that emphasizes balanced macro and micro nutrient levels to promote belowground and potentially aboveground diversity. To combat encroaching invasive species, prior alteration of soil processes by restorationists is necessary before the successful reintroduction of native plant species is possible (Heneghan et al. 2008).

CONCLUSION

There is no significant relationship between the aboveground level of plant restoration management and the belowground diversity of microarthropods. This study has shown that management levels are not driving microarthropod diversity. Therefore, researchers need to evaluate above and belowground processes separately before initiating individual restoration projects. However, there was significant explanatory value to the nutrient data. For all eleven sites, total nitrogen and phosphorus levels had a positive correlation with Oribatid mite abundance. There was a correlation between total nitrogen in the soil and the Shannon diversity index. Total nitrogen, phosphorus, and zinc also showed a correlation with Oribatid mite species richness. This demonstrates that nitrogen and phosphorus levels are important predictors of microarthropod diversity. These two nutrients drive microhabitat processes, stimulating microhabitat structure. Managing nutrient levels in the soil is an important aspect to achieving successful long-term restoration. The rare species data provides insight into the specific impact of management on rare species diversity and the common species data allows us to examine species associations and the relationship between management and mite abundance. It is important to incorporate Soil Ecological Knowledge into future restoration plans. Soil Ecological Knowledge uses a soil first approach dependent on properly evaluating the quality of the soil in order to successfully heal a degraded ecosystem. Furthermore, Soil Ecological Knowledge is an important tool in the fight against invasive species presence and persistence. Overall, this study offers a valuable test to evaluate the relationship between the soil quality of a site and belowground microarthropod diversity. This research supports the need for a balance between macro and micro nutrient levels in the soil. A balanced soil structure promotes healthy belowground biodiversity that is essential for a healthy ecosystem. A complete understanding of how this belowground biodiversity connects with the soil system is vital to achieve restoration goals.

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Table 1: Sample Extraction Dates and Locations

Site	Management Stage	Sample Number	Extraction Dates
Old School	W0	10A	6/26/09-7/1/09
		14A	6/26/09-7/1/09
		20A	6/26/09-7/1/09
Waterfall Glen South Central	W0	28B	7/2/09-7/6/09
		29B	7/2/09-7/6/09
		30B	7/2/09-7/6/09
Ethel's Woods	W0	37A	7/17/09-7/21/09
		38A	7/17/09-7/21/09
		39A	7/17/09-7/21/09
Old School	W1	12A	6/26/09-7/1/09
		17A	6/26/09-7/1/09
		18A	6/26/09-7/1/09
Middlefork Savanna	W1	11A	6/26/09-7/1/09
		16A	6/26/09-7/1/09
		19A	6/26/09-7/1/09
Waterfall Glen Cemetery Ridge	W1	40A	7/21/09-7/25/09
		41A	7/21/09-7/25/09
		42A	7/21/09-7/25/09
Grassy Lake	W2	22B	7/1/09-7/5/09
		24B	7/1/09-7/5/09
		27B	7/1/09-7/5/09
MacArthur Woods	W2	23B	7/1/09-7/5/09
		25B	7/1/09-7/5/09
		26B	7/1/09-7/5/09
Waterfall Glen Rocky Glen	W2	43B	7/28/09-8/1/09
		44B	7/28/09-8/1/09
		45B	7/28/09-8/1/09
Ryerson Woods	W3	31A	7/8/09-7/12/09
		33A	7/8/09-7/12/09
		35A	7/8/09-7/12/09
Middlefork Savanna	W3	32A	7/8/09-7/12/09
		34A	7/8/09-7/12/09
		36A	7/8/09-7/12/09

Table 2: Average Number of Oribatid Mite Species Found in 11 Sampling Locations

Sampling Location	Restoration Level	Total Number of Mite Species Found	Average
Old School	W0	22	
Ethel's Woods	W0	25	
Waterfall Glen South Central	W0	35	
			27.33
Old School	W1	14	
Middle Fork	W1	46	
Waterfall Glen Cemetery Ridge	W1	56	
			38.67
Grassy Lake	W2	57	
MacArthur Woods	W2	26	
Waterfall Glen Rocky Glen	W2	65	
			49.33
Middle Fork	W3	47	
Ryerson	W3	38	
			42.5

Table 3: Effects of Management Type on the Four Biological Diversity Measures (Species Abundance, Shannon Diversity Index, Species Evenness, and Species Richness)

ANOVA Test-Dependent Variable	F-Value	P-Value
All 11 Sites		
Abundance	1.09	0.41
Shannon Diversity	0.62	0.62
Evenness	1.22	0.37
Richness	0.7	0.58

Table 4: Effects of Management Type on Soil Nutrient Availability

ANOVA Test-Dependent Variable – All 11 Sites	F-Value	P-Value
Nitrogen	0.82	0.524
NO3	0.29	0.833
NH4	1.98	0.205
Ca	1.81	0.233
Mg	0.71	0.575
K	0.41	0.749
P	0.98	0.456
Fe	1.37	0.330
Mn	**5.68**	**0.027**
Cu	0.62	0.622
Zn	1.4	0.321
B	0.1	0.955
S	2.38	0.155
Pb	0.08	0.968
Al	0.82	0.521

Table 5: Effects of Soil Nutrients on Total Mite Abundance, Shannon Diversity, Species Evenness, and Species Richness

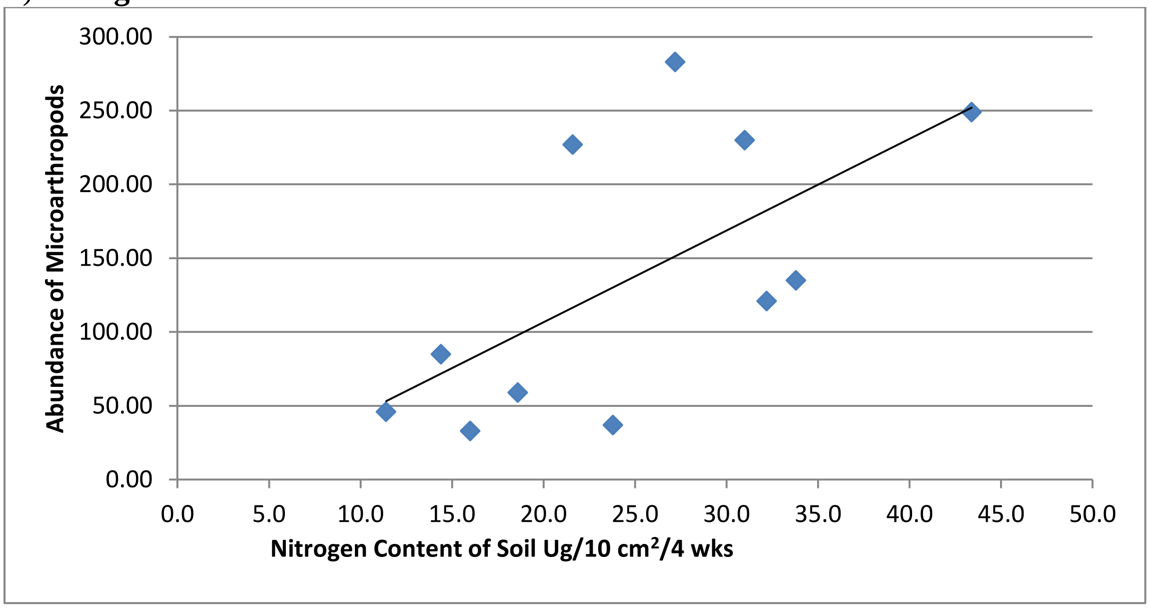
Diversity Measure	Variable	R^2 Value	P Value
Total Mite Abundance	Total Nitrogen	0.409	0.034
Shannon Diversity Index	not significant	-	-
Species Evenness	not significant	-	-
Species Richness	Zinc	0.521	0.012
	Zinc, Lead	0.722	0.006
Species Richness (w/o Zinc, Lead)	Total Nitrogen	0.465	0.021
	Total Nitrogen, Phosphorus	0.703	0.008
	Total Nitrogen, Phosphorus, Copper	0.904	0.001
	Total Nitrogen, Phosphorus, Copper, Magnesium	0.957	<0.001

Table 6: Four Significant Common Species Associations

Species Name	Factors			
	1	2	3	4
Oppiella nova	.548	-.398	-.111	.362
Scheloribates sp.	.236	.654	.332	.413
Liacaroid	.127	.873	.133	.052
Scutacarus	.277	.437	-.402	.682
Eulohmannia	-.145	.097	.131	.930
Phthiracarus	.829	.169	.426	.164
Tydeus	.678	.527	-.376	.052
Cocceupodes	.838	.389	-.166	-.143
Astigmata	.897	.260	.279	-.077
Histiostoma	.050	-.284	-.853	.338
Rhodacarus	.186	-.024	.838	.277
Mesostig sp. 3	.327	.851	-.011	.109

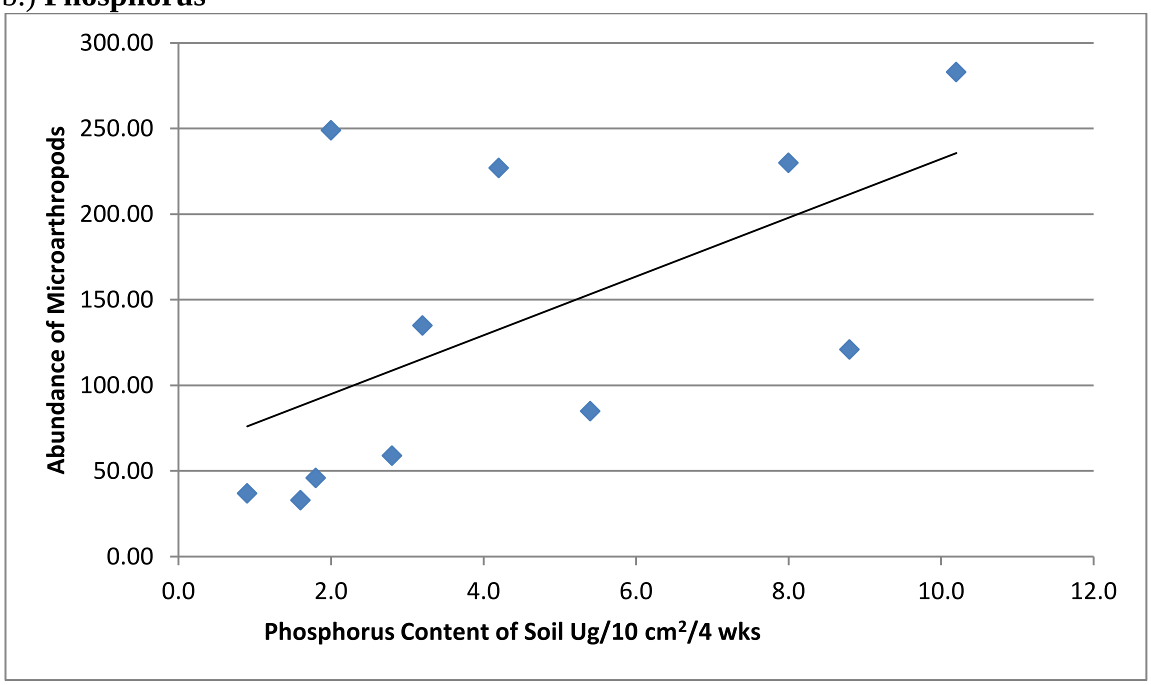
Figure 1 – Species Abundance of Microarthropods Across Restoration Gradient vs. Significant Nutrients Found in the Soil (All 11 Sites)

a.) **Nitrogen**



$y = 6.2132x - 17.608; r^2 = 0.4092$

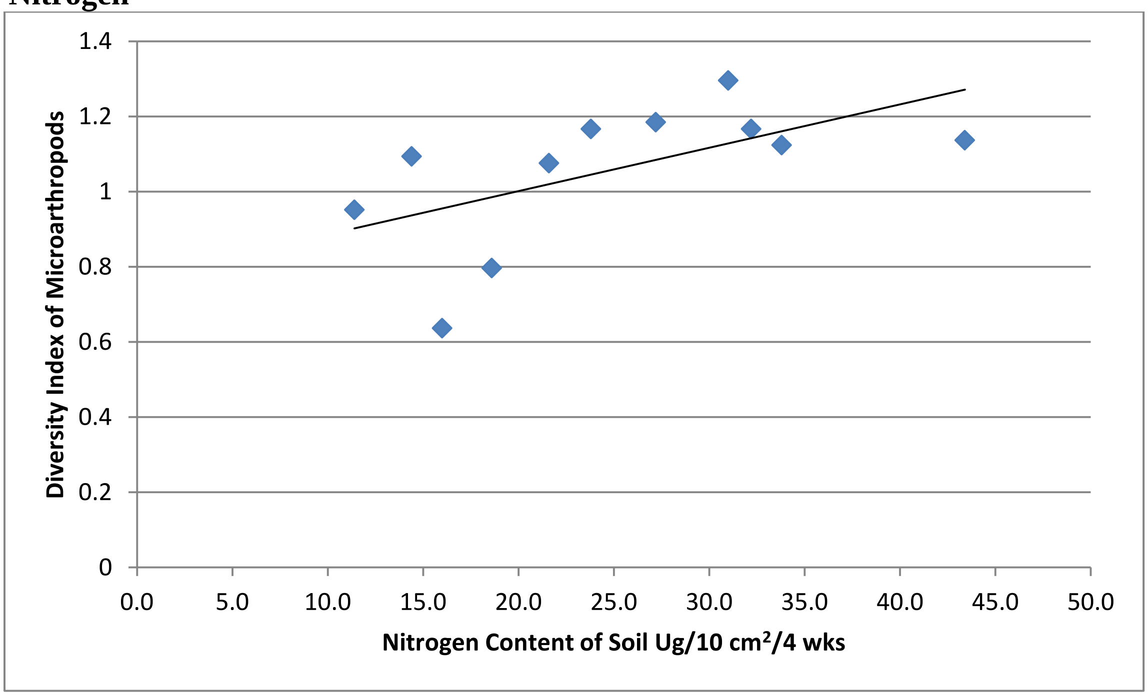
b.) **Phosphorus**



$y = 17.159x + 60.537; r^2 = 0.3437$

Figure 2 – Shannon Diversity of Microarthropods Across Restoration Gradient vs. Significant Nutrients Found in the Soil (All 11 Sites)

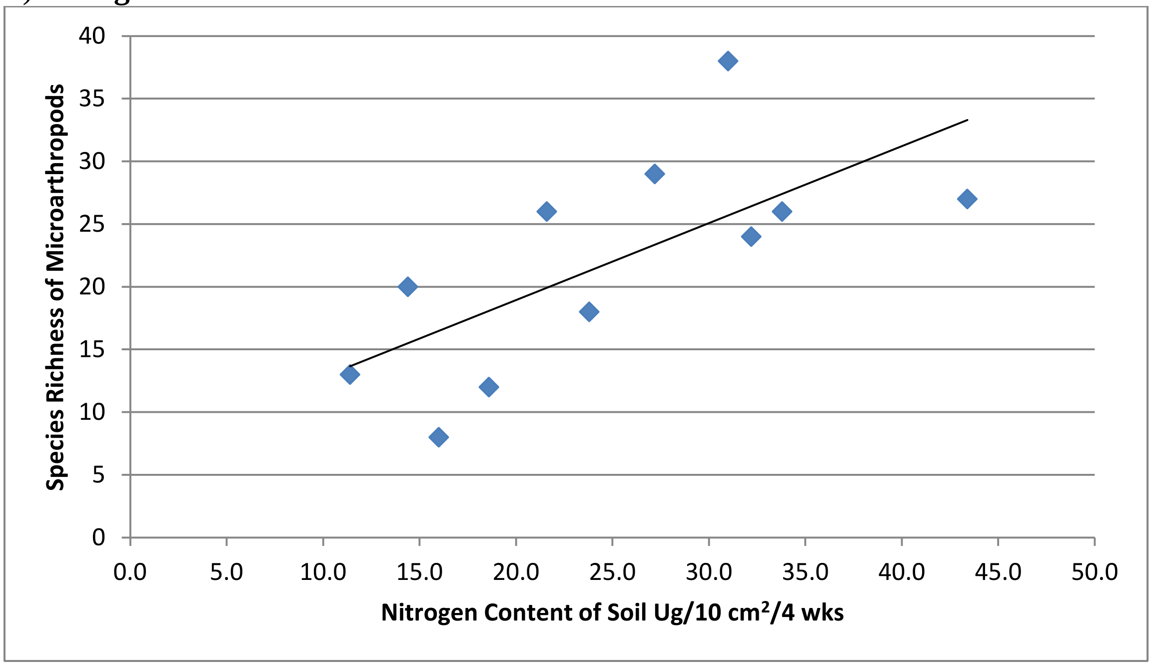
Nitrogen



$y = 0.0115x + 0.7707$; $r^2 = 0.3427$

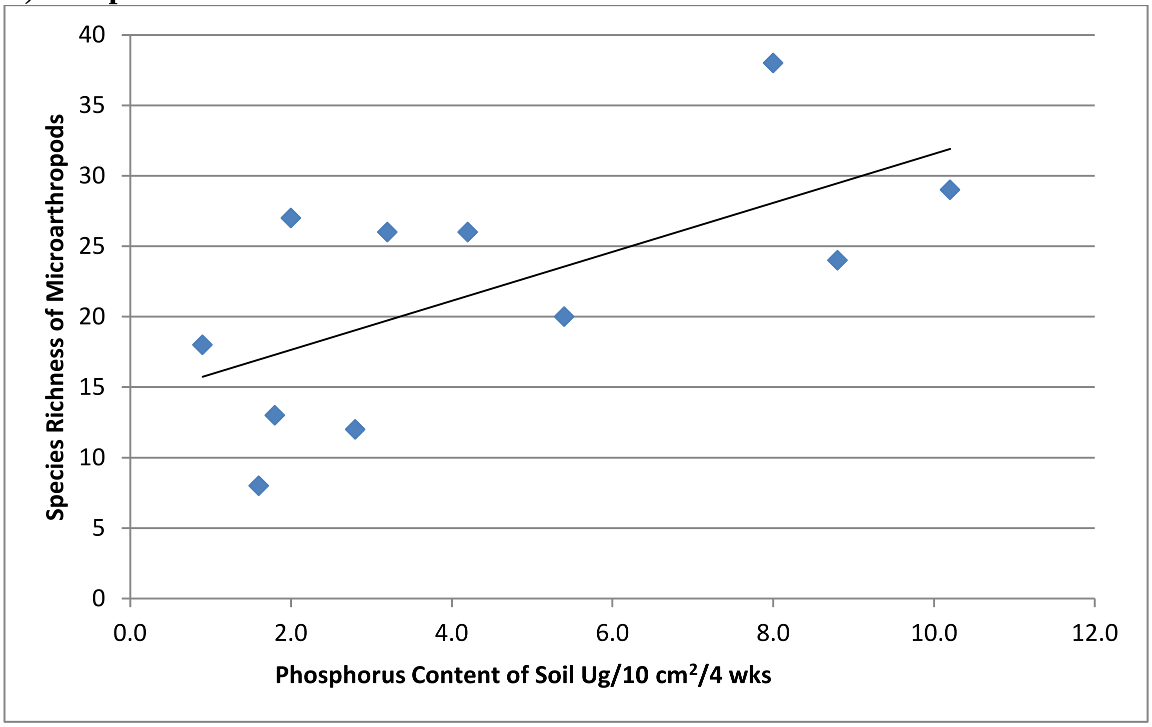
Figure 3 – Species Richness of Microarthropods Across Restoration Gradient vs. Significant Nutrients Found in the Soil (All 11 Sites)

a.) **Nitrogen**:



$y = 0.6141x + 6.6471$; $r^2 = 0.4649$

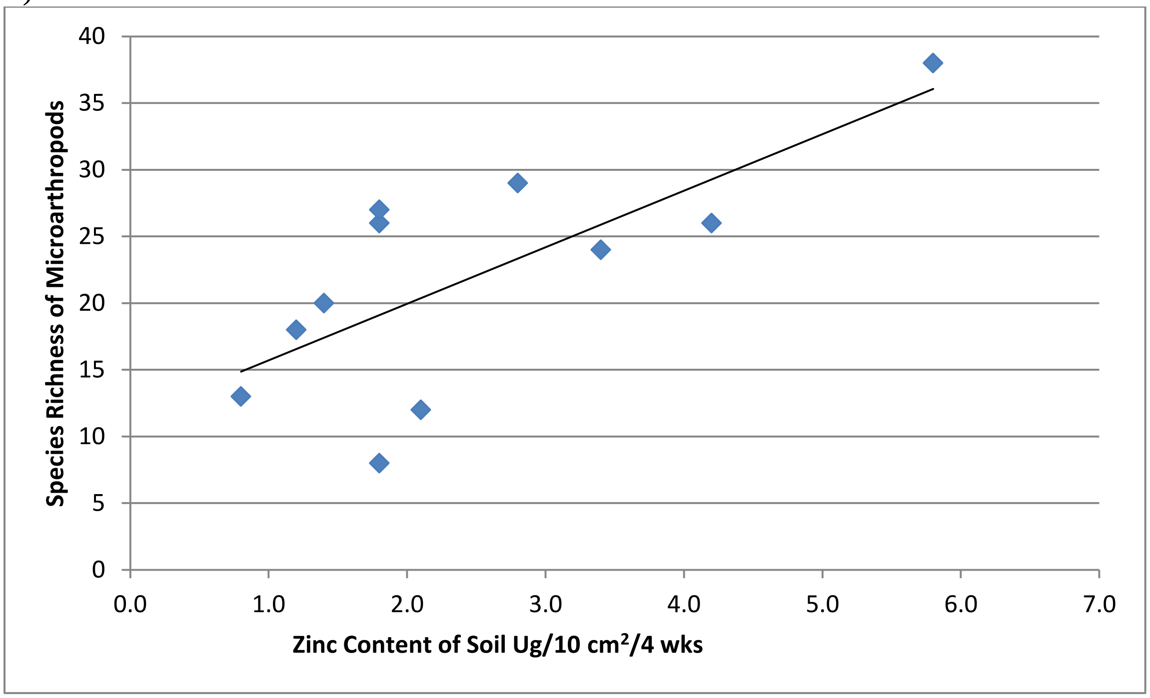
b.) **Phosphorus**



$y = 1.7381x + 14.182$; $r^2 = 0.4102$

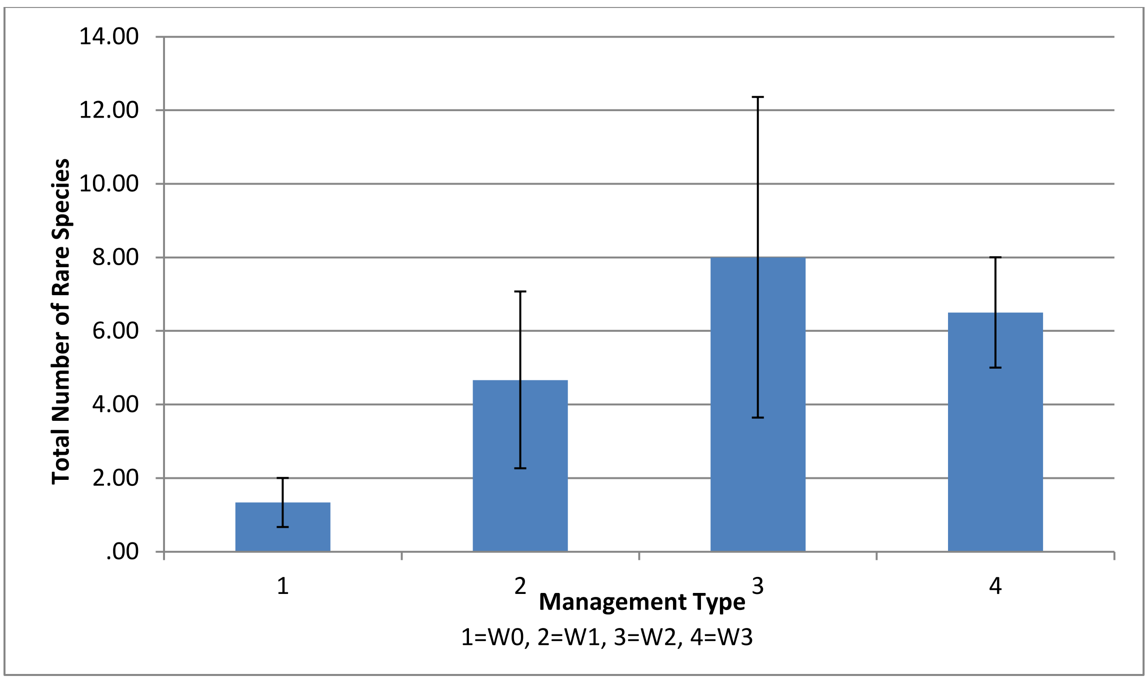
Figure 3 – Species Richness of Microarthropods Across Restoration Gradient vs. Significant Nutrients Found in the Soil (All 11 Sites)

c.) **Zinc**



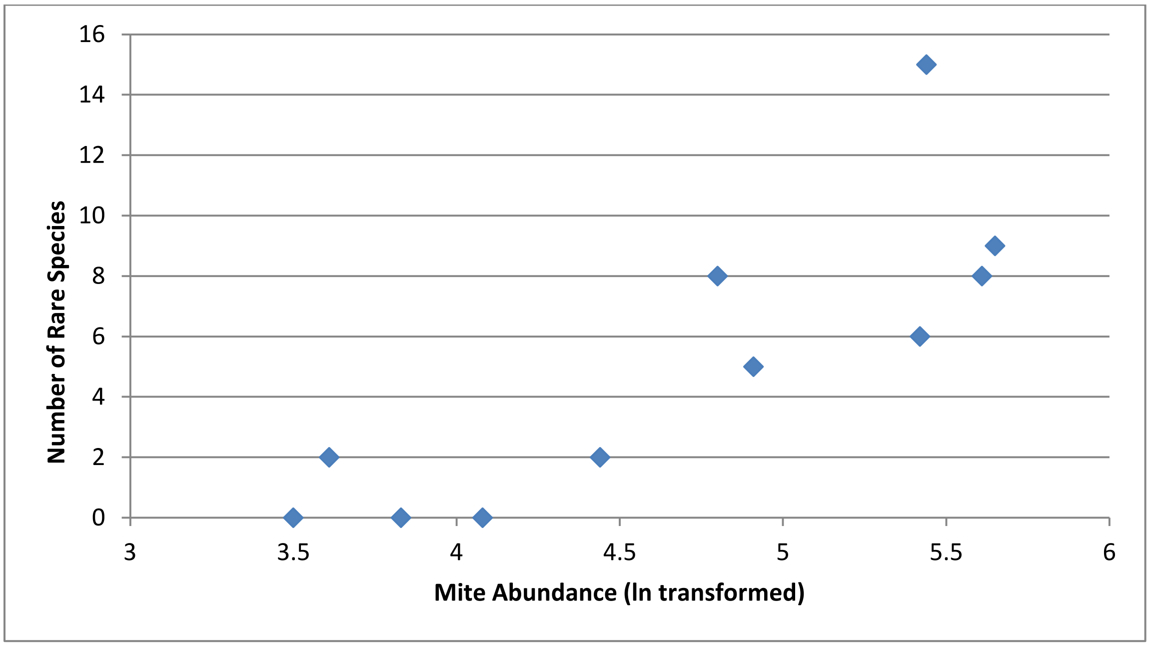
$y = 4.241x + 11.461$; $r^2 = 0.5207$

Figure 4 – Total Number of Rare Species vs. Management Type



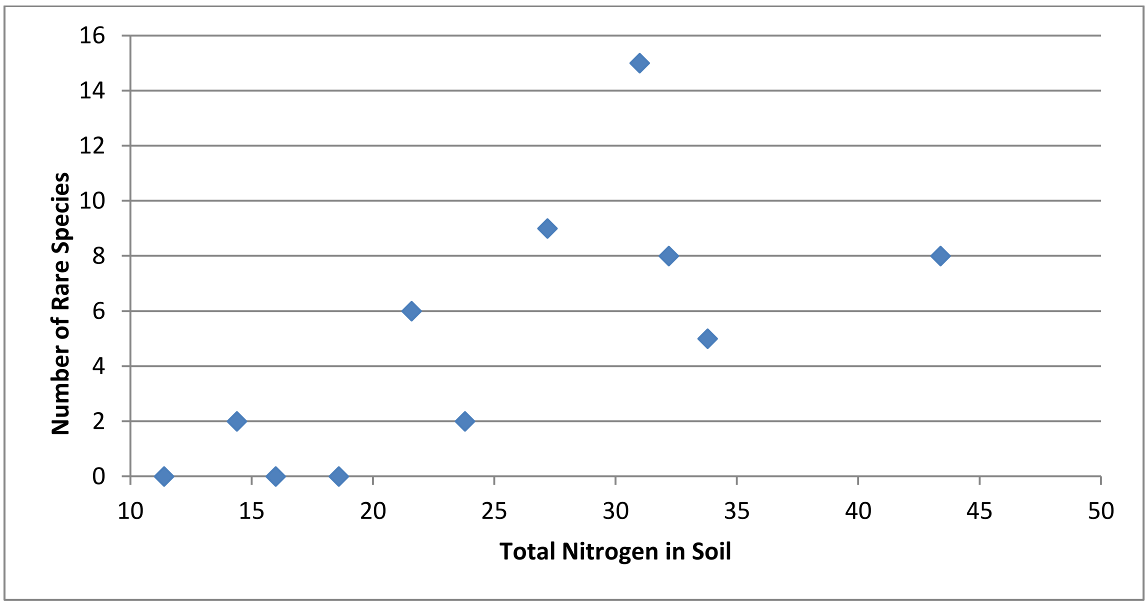
When considering the 15 rarest species, this bar graph shows a general increase in the total number of rare species present as management type increases with standard error bars included.

Figure 5- Relationship between Number of Rare Species and Abundance of Mites



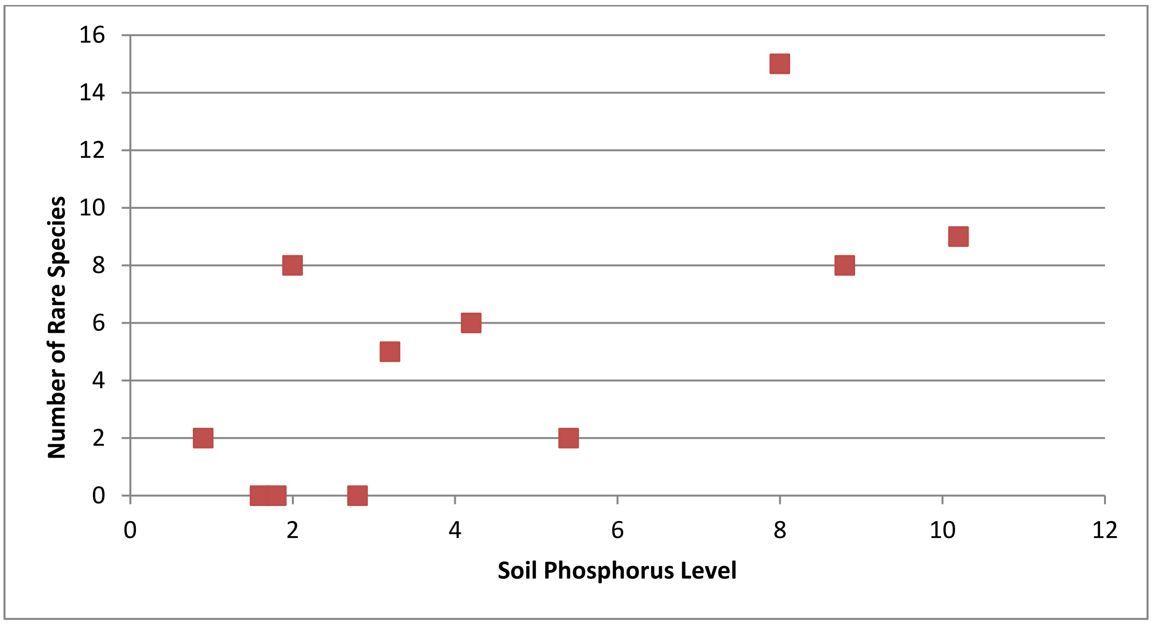
This scatter-plot graph shows an increase in the number of rare species of mites present as mite abundance increases.

Figure 6- Relationship between Number of Rare Species and Total Nitrogen in the Soil



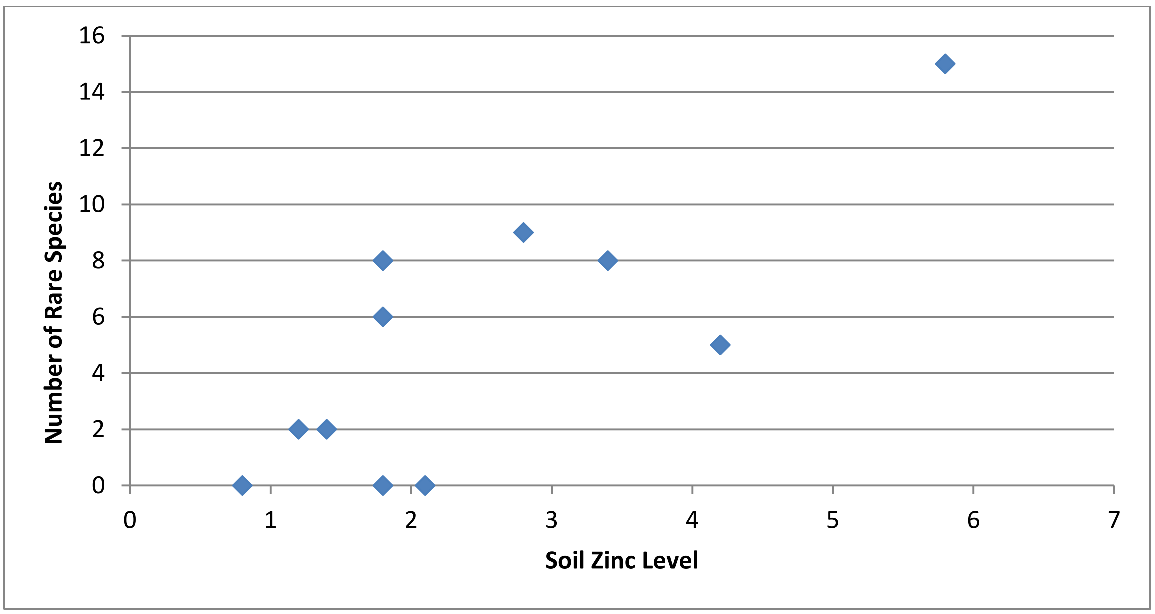
This scatter-plot graph shows an increase in the number of rare species of mites as the total nitrogen level in the soil increases.

Figure 7- Relationship between Number of Rare Species and Soil Phosphorus Level



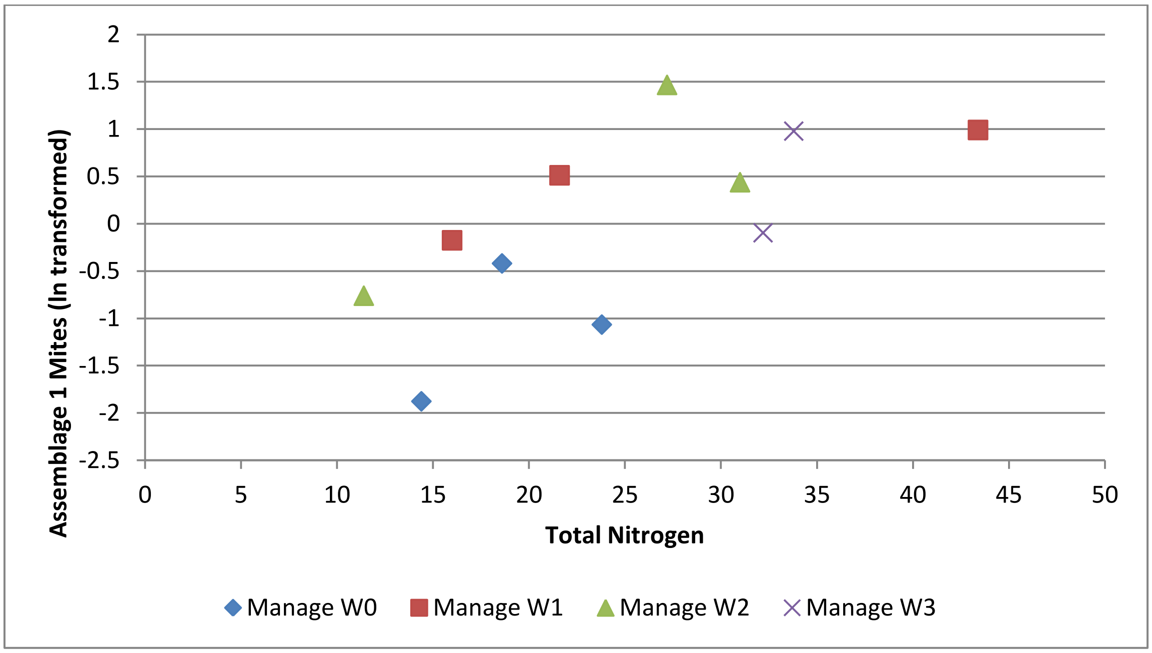
This scatter-plot graph shows a general increase in the number of rare species present as phosphorus levels in the soil increase.

Figure 8- Relationship between Number of Rare Species and Soil Zinc Level



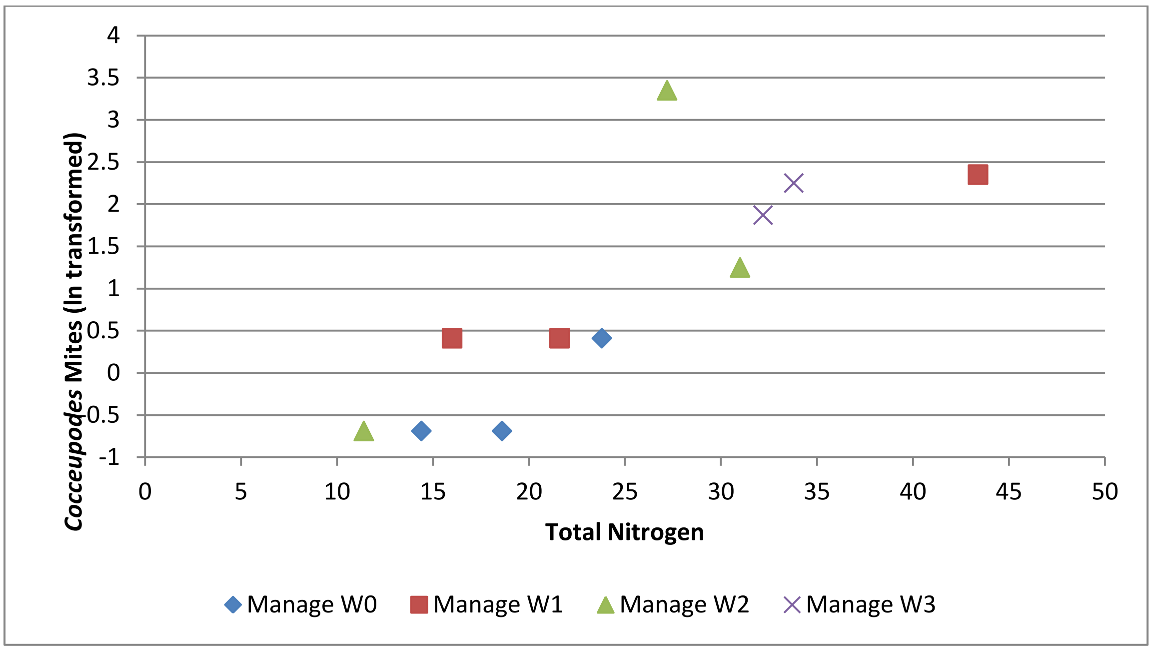
This scatter-plot graph shows an increase in the number of rare species of mites as levels of zinc in the soil increase.

Figure 9- Relationship between Management Type, Assemblage 1, and Total Nitrogen in the Soil



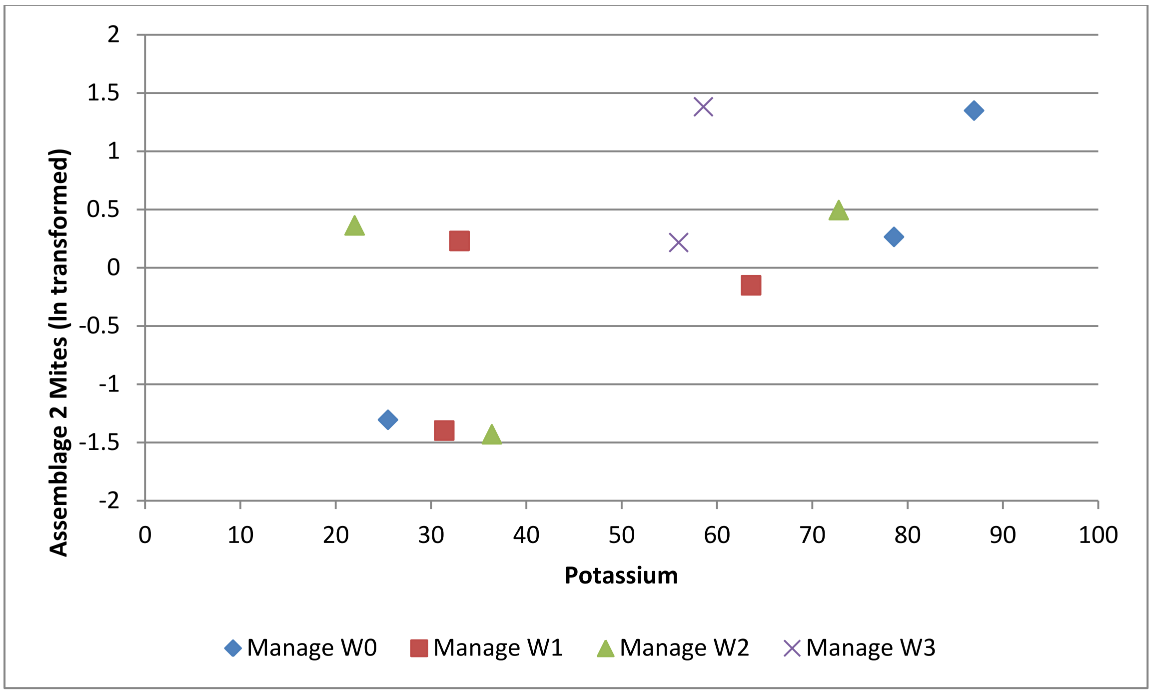
This scatter-plot graph shows a general increase in Assemblage 1 mites (*Astigmata*, *Cocceupodes*, *Tydeus, and Phthiracarus*) with management type as total Nitrogen increases in the soil.

Figure 10- Relationship between Management Type, Cocceupodes (Assemblage 1), and Total Nitrogen in the Soil



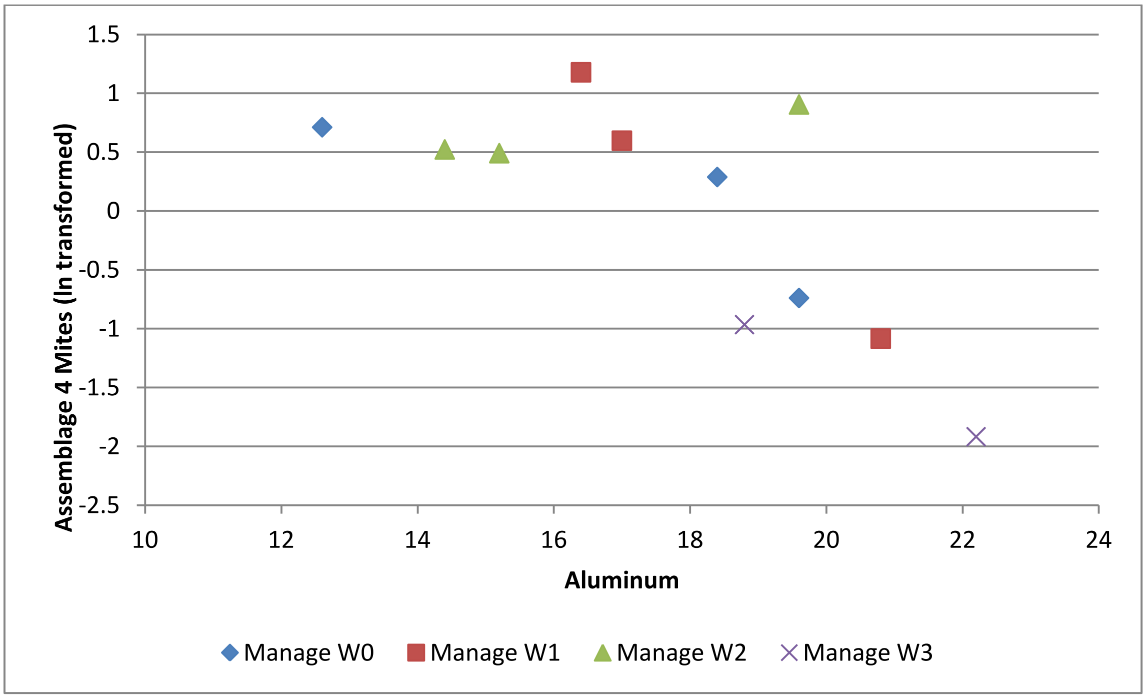
This scatter-plot graph shows a general increase in *Cocceupodes* species mites with management type as total Nitrogen increases in the soil.

Figure 11- Relationship between Management Type, Assemblage 2, and Potassium in the Soil



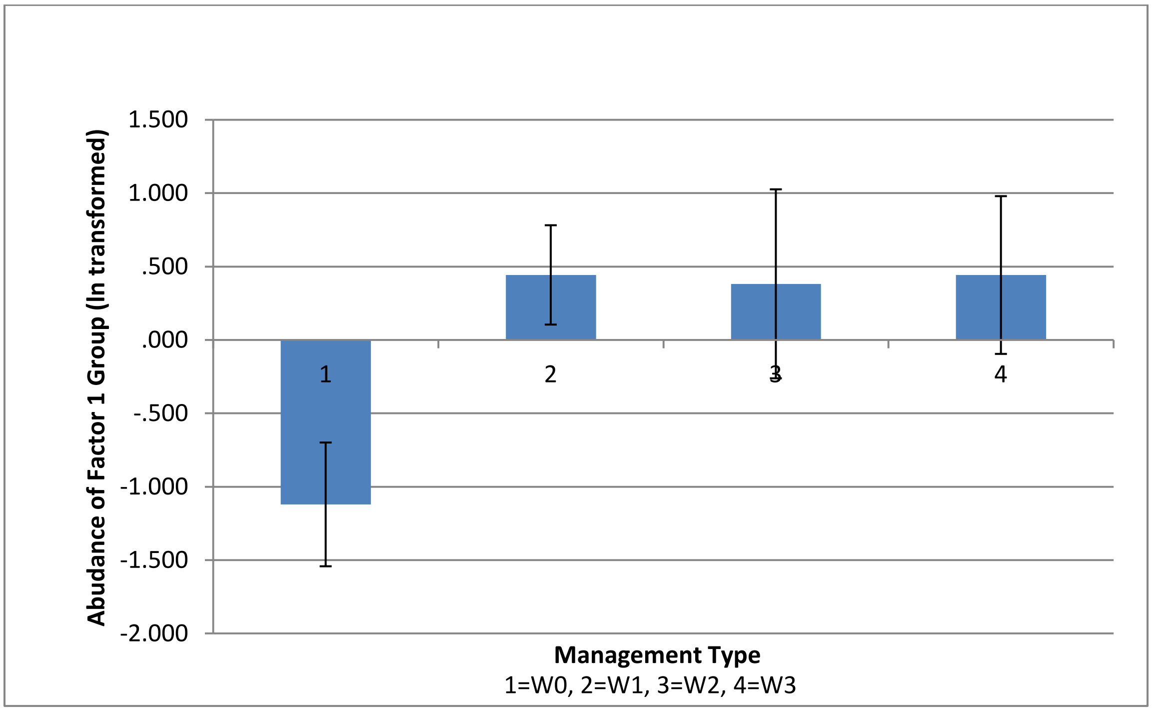
This scatter-plot graph shows a general increase in Assemblage 2 mites (*Scheloribates sp.*, *Liacaroid*, and *Mesostig sp. 3*) with management type as Potassium increases in the soil.

Figure 12- Relationship between Management Type, Assemblage 4, and Aluminum in the Soil



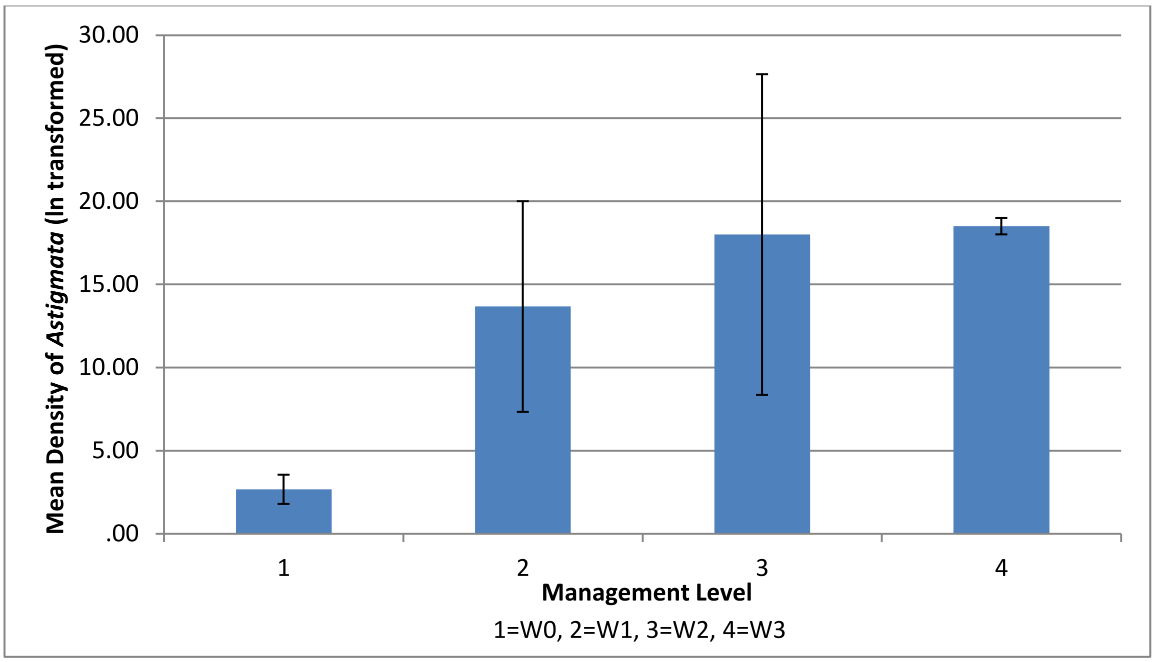
This scatter-plot graph shows a general decrease in Assemblage 4 mites (*Scutacarus* and *Eulohmannia*) with management type as Aluminum increases in the soil.

Figure 13- Relationship between Management Type and Abundance of Factor 1 Group



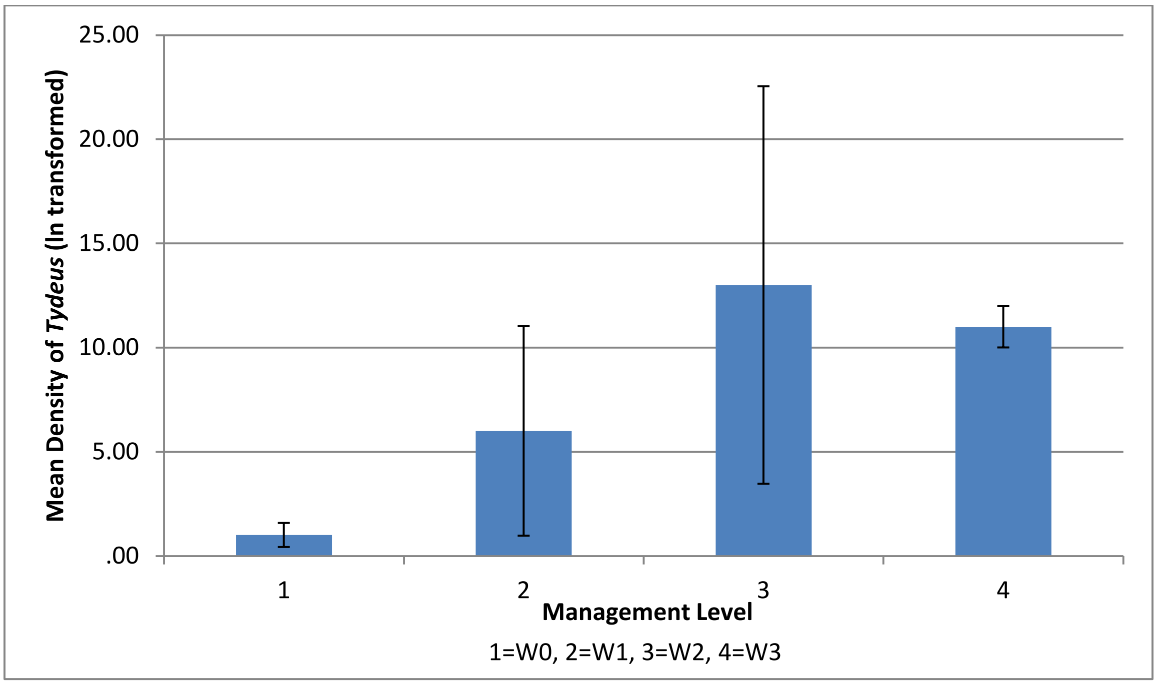
This bar graph shows a slight trend that as the abundance of the factor 1 group increases, the management type also increases.

Figure 14- Relationship between Mean Density of Astigmata and Management Level



This bar graph shows that as the mean density of the *Astigmata* species increases, the level of management also increases.

Figure 15- Relationship between Mean Density of Tydeus and Management Level



This bar graph shows a general trend that as the mean density of *Tydeus* species increases, the level of management increases.

Appendix A - Physical Site Descriptions

Site	Management Stage	Location	County	Habitat	Canopy
Old School (W0)	Degraded / Unmanaged	Libertyville	Lake	Woodland	Mature Red and White Oak (Buckthorn present but not overtaking)
Waterfall Glen South Central (W0)	Degraded / Unmanaged	Lemont	DuPage	Woodland	Dominated by Red Oak with some Buckthorn and Elm
Ethel's Woods (W0)	Degraded / Unmanaged	Antioch	Lake	Woodland	Shagbark Hickory, Red Oak, Swamp White Oak
Old School (W1)	Early Management	Libertyville	Lake	Woodland	Mature Red and White Oak, Buckthorn present
Middlefork Savanna (W1)	Early Management	Lake Bluff	Lake	Woodland	Mostly White Oaks, Some Red Oaks
Waterfall Glen Cemetery Ridge (W1)	Early Management	Lemont	DuPage	Woodland	Burr Oak, younger Red and White Oak, Ash
Grassy Lake (W2)	Mature Management	North Barrington	Lake	Woodland	Burr Oak, Hickory, Elm
MacArthur Woods (W2)	Mature Management	Libertyville	Lake	Woodland	White Oak
Waterfall Glen Rocky Glen (W2)	Mature Management	Lemont	DuPage	Woodland	Hickory, Maple, Elm
Ryerson Woods (W3)	High Quality / Pristine Management	Riverwoods	Lake	Woodland	Mostly Maple with some Slippery Elm and Hickory
Middlefork Savanna (W3)	High Quality / Pristine Management	Lake Bluff	Lake	Woodland	Mature Oaks

Appendix A - Physical Site Descriptions

Site	Undergrowth	Herbaceous Layer	Detritus
Old School (W0)	Hawthorn, Hickory, Elm shrubs	Buckthorn seedlings, Honeysuckle, Hickory	Great deal of detritus
Waterfall Glen South Central (W0)	-	Ash seedlings, Buckthorn seedlings, Polygonum, weeds	Adequate amount of detritus, abundance of fallen Oak branches
Ethel's Woods (W0)	Buckthorn, Hawthorn	Wild geranium	-
Old School (W1)	Hawthorn, Hickory, Elm shrubs	Buckthorn seedlings, Honeysuckle, Hickory	Not a great deal of detritus
Middlefork Savanna (W1)	Fair amount of shrubs	Raspberry bushes	Mulch on ground
Waterfall Glen Cemetery Ridge (W1)	-	Carex, Aster,Golden Rod	-
Grassy Lake (W2)	Minimum shrub layer	Solidago, minimal Buckthorn seedlings	-
MacArthur Woods (W2)	Tilia, Iron Wood, Maple shrub layer	Young Polyonum	Minimum detritus with some dead buckthorn stems
Waterfall Glen Rocky Glen (W2)	Thick shrubby layer of Honeysuckle, some buckthorn	Hardly any layer present	-
Ryerson Woods (W3)	Quite a lot of litter	Minimal layer present	-
Middlefork Savanna (W3)	-	Lots of understory - Vetch or Fabaceae invasion	-

Appendix A - Physical Site Descriptions

Site	Soil Type	Slope	Landform Soil	2-D Landform Position	3-D Landform Position
Old School (W0)	Montgomery silty clay loam	0-2%	Lake Plains	Toeslope	N/A
Waterfall Glen South Central (W0)	Ozaukee silt loam	20-30%	End Moraines, Ground Moraines	Backslope	Side slope
Ethel's Woods (W0)	Ozaukee silt loam	2-4%	End Moraines, Ground Moraines	Backslope, summit	Interfluve
Old School (W1)	Nappanee silt loam	2-4%	Ground Moraines, End Moraines, Lake Plains	Footslope, backslope	Interfluve
Middlefork Savanna (W1)	Montgomery silty clay loam	0-2%	Lake Plains	Toeslope	N/A
Waterfall Glen Cemetery Ridge (W1)	Ozaukee silt loam	4-6%	Ground Moraines, End Moraines	Backslope, shoulder	Interfluve
Grassy Lake (W2)	Zurich silt loam	4-6%	Outwash Plains, Stream Terraces	Shoulder, backslope	N/A
MacArthur Woods (W2)	Montgomery silty clay loam	0-2%	Lake Plains	Toeslope	-
Waterfall Glen Rocky Glen (W2)	Faxon silty clay loam	0-2%	Flood Plains	N/A	N/A
Ryerson Woods (W3)	Zurich and Nappanee silt loams	0-2%	Outwash Plains, Lake Plains	Footslope, backslope	N/A
Middlefork Savanna (W3)	Nappanee silt loam	2-4%	Ground Moraines, End Moraines	Backslope, footslope	Interfluve

Appendix A - Physical Site Descriptions

Site	Parent Material	Depth to Restrictive Feature (inches)	Drainage Class	Elevation (feet)
Old School (W0)	Lacustrine deposits	>80	Poorly drained	540-1,020
Waterfall Glen South Central (W0)	Thin mantle of loess	20-45	Moderately well drained	540-930
Ethel's Woods (W0)	Thin mantle of loess	20-45	Moderately well drained	540-930
Old School (W1)	Thin mantle of loess	30-60	Somewhat poorly drained	540-930
Middlefork Savanna (W1)	Lacustrine deposits	>80	Poorly drained	540-1,020
Waterfall Glen Cemetery Ridge (W1)	Thin mantle of loess	20-45	Moderately well drained	540-930
Grassy Lake (W2)	Loess	>80	Moderately well drained	510-970
MacArthur Woods (W2)	Lacustrine deposits	>80	Poorly drained	540-1,020
Waterfall Glen Rocky Glen (W2)	Drift over bedrock	20-40	Poorly drained	680-1,020
Ryerson Woods (W3)	Thin mantle of loess	24-60	Somewhat poorly drained	540-970
Middlefork Savanna (W3)	Thin mantle of loess	30-60	Somewhat poorly drained	540-930

Appendix A - Physical Site Descriptions

Site	Frost-free Period (days)	Mean Annual Precipitation (inches)	Mean Annual Air
Old School (W0)	140-180	28-40	45-52
Waterfall Glen South Central (W0)	140-180	28-40	45-52
Ethel's Woods (W0)	140-180	28-40	45-52
Old School (W1)	140-180	28-40	45-52
Middlefork Savanna (W1)	140-180	28-40	45-52
Waterfall Glen Cemetery Ridge (W1)	140-180	28-40	45-52
Grassy Lake (W2)	140-180	28-40	45-52
MacArthur Woods (W2)	140-180	28-40	45-52
Waterfall Glen Rocky Glen (W2)	140-180	28-40	45-52
Ryerson Woods (W3)	140-180	28-40	45-52
Middlefork Savanna (W3)	140-180	28-40	45-54

Appendix B

Microarthropod Facebook

Heneghan Lab

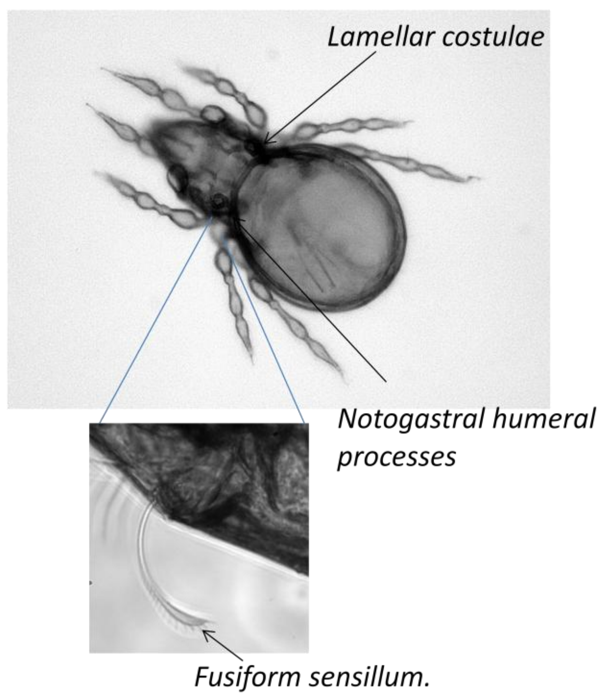
Photographs and text by Claire Gilmore and Liam Heneghan

Appendix B

Class Arachnida; Subclass Acari, Order Oribatida (also Cryptostigmata used):

Oppiella nova (Oudemans, 1902)

- Family Oppidae, *Grandjean 1951*; subfamily Oppiellinae *Seniczak, 1975,* genus *Oppiella*, *Jacot, 1937*
- Subfamily recognized by the presence of lamellar costulae *;* genus recognized by the presence of notogastral humeral processes. *O. nova* can be distinguished in most samples by the fusiform/ curviform sensillum.
- Present in most sample from 100 sites, possibly the commonest arthropod in samples in the Chicago region (this is a cosmopolitan species).



Appendix B

Tectocepheus velatus (Michael, 1880)

- Family: Tectocepheidae Grandjean, 1954; genus Tectocepheus
- Fairly distinctive
- Need better photos of both underside and back.
- Need detail on sensillus
- Color: yellowish brown to dark-brown
- Measurements: Body length 352-376 micrometers, width 198-218 micrometers
- Prodorsum:
  - Rostrum smoothly rounded
  - Rostral and lamellar setae unilaterally barbed
  - Lamellae broad, lamellar cusps nearly as broad as the width of lamellae
  - Swollen portion of sensillus nearly equal or longer than its stalk
- Notogaster:
  - Shape is nearly oval, being a little narrower posteriorly than anteriorly
- Epimeral region:
  - Surface almost smooth
  - Epimeral setae short, thin
- Ano-genital region:
  - Genital aperture with 5 rounded, blunt corners
  - Anal aperture nearly triangular and pear-shaped
  - 6 pairs of genital setae short and thin
- Legs:
  - Monodactylous, dorsal surface of each claw with a few and fine serration
  - Surface of leg segments granulated

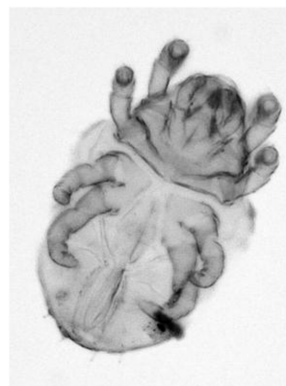
http://sciencelinks.jp/j-east/article/199914/000019991499A0456745.php

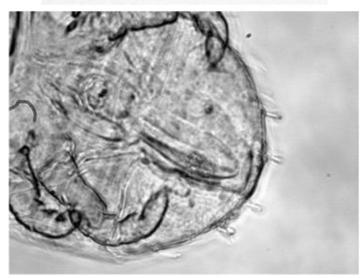
http://zipcodezoo.com/Animals/T/Tectocepheus_velatus_sarekensis/#SimilarSpecies

Appendix B

Liochthonius sp.

- Family Brachychthoniidae Thor, 1934
- Need a picture of dorsal region of this animal
- Among the smallest mites of Oribatida; length 160-223 um
- Unlike many soil microarthropods, can tolerate the disturbance of cropping, maintaining high diversity and abundance
- Prodorsal and notogastral setae ciliated
- Na with a pair of eye-like spots
- Sensillus strongly clavate and with two rows of cilia
- Smooth setae on the pygidial shield



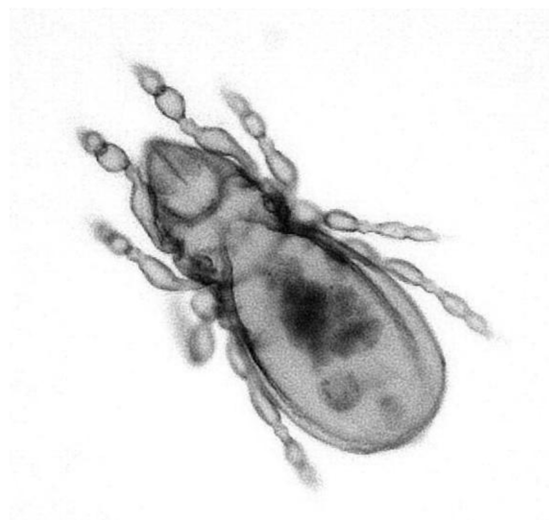


http://www.royalalbertamuseum.ca/natural/insects/research/_pubs/Almanac_AB_Oribatida_20091209_part2.pdf

Appendix B

Microppia Balogh*, 1983* possibly M. *minus*

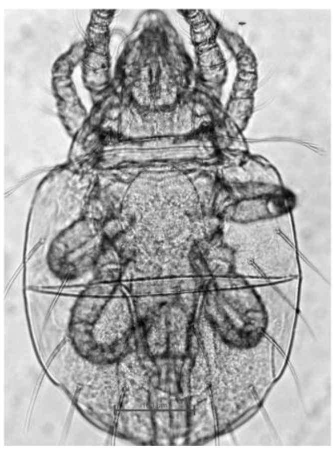
- Anterior (uppermost part) of notogaster (the shield covering back and side aspects of the abdomen) has small tubercles (protuberances).
- Need picture of sensillus (which should be lanceolate).
- Need scale
- Right-skewed phenology

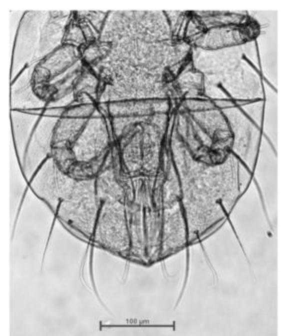


http://ezproxy.jmls.edu:2093/stable/pdfplus/3545191.pdf

Appendix B

Species X





Appendix B

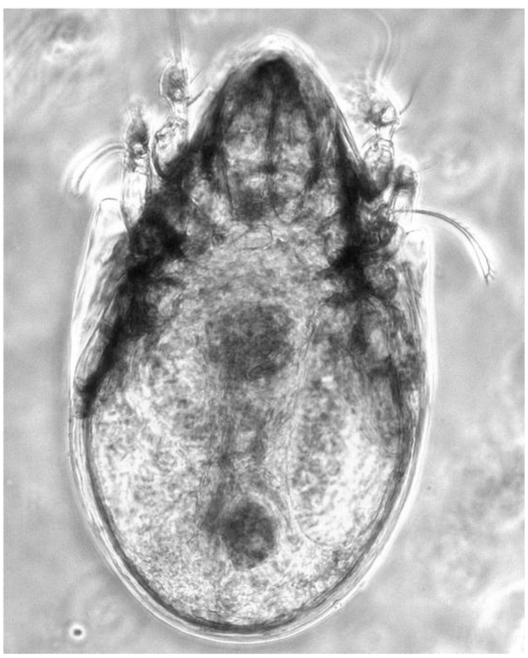
Scheloribates sp.

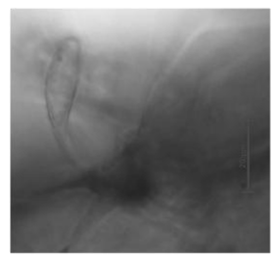
- Cohort Brachypylina
- Body length about 424 um and 288 um in width
- Dark reddish brown in color
- Needs to be confirmed with better photographs..
- The pteromorphs (“wings” at side of notogaster) curl around body so hard to see. Get a better dorsal shot and a ventral one.
- Can feed on both fresh and decomposing vegetal parts, fungi, algae, and other materials
- The stage of chemical decay of food is very important to oribatid mites food choice

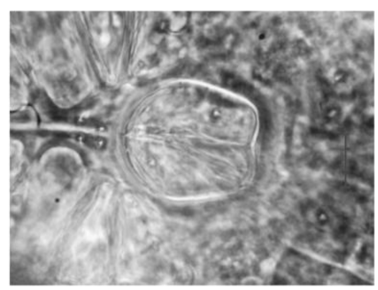
http://www.springerlink.com/content/u83651mj0440w266/
http://www.springerlink.com/content/qn1445523hh4w6j3/fulltext.pdf

Appendix B

Scheloribates sp. cont.







Appendix B

Belba sp.

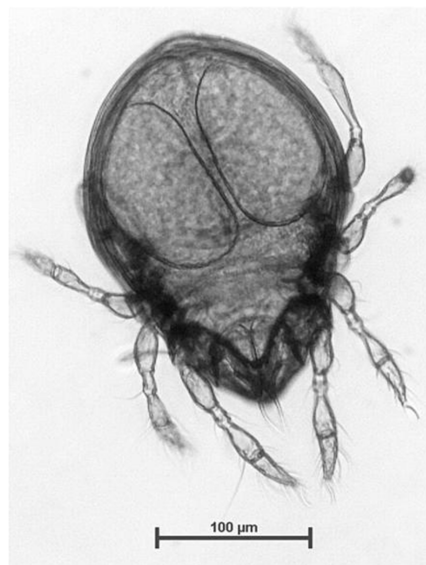
- Needs more work… distinctive mite, so should be re-identified easily
- Family Belbidae
- Prefers a semi-humid environment
- Brown in color
- Only a few hairs on the abdomen and legs
- No tectal plate, no wings to abdomen, tarsi with but one claw, no wing-like expansions to cephalothorax, legs long and slender, the hind pair as long as body, the joints nodulate and with simple hairs, the ventral apertures in the typical forms are widely separated
- Length 450-600 um
- Mainly in decaying animal substances but frequently found in moss, under bark, and on the ground

http://ezproxy.jmls.edu:2093/stable/pdfplus/25076633.pdf

Appendix B

Liacaroid

- Family Liacaridae
- Elongated oval mites with a glabrous or sculptured integument, contiguous or convergent lamellae, 2 pairs of humeral bristles, 5 or 6 pairs of genital setae, a genital opening smaller than and widely separated from the larger anal opening, and legs III and IV inserted somewhat medially and remote from the lateral margins and hysterosoma

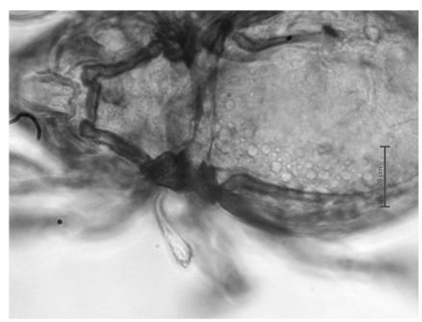


http://ezproxy.jmls.edu:2093/stable/pdfplus/25083634.pdf?acceptTC=true

Appendix B

Quadroppia

- Family Quadroppiidae Balogh, 1983
- Costulae trapeziform, sensillus capitate with short stalk, rostrum broad and not incised, crista strongly developed, extending posteriorly at least to 1/3 to 2/3 of notogastral length
- Nine pairs of notogastral setae present, 5 pairs of genital setae present
- Prodorsum: Rostrum wide, rounded, rostral setae smooth and pointed at the tip
- Notogaster: Notogastral cristae square
- Length 200-230 um, width 110-133 um

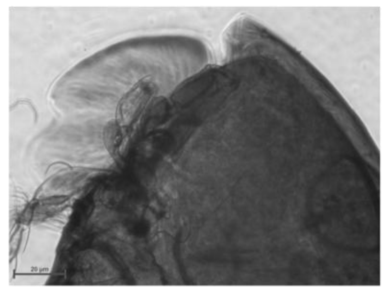


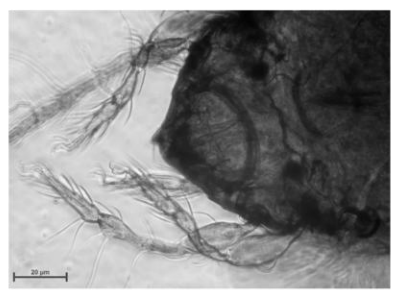
http://journals.tubitak.gov.tr/zoology/issues/zoo-08-32-2/zoo-32-2-5-0607-11.pdf

Appendix B

Pergalumna sp.

- See “wings” (pteromorphs) to the side with notch
- If one big shield = Galumna
- Microbi-detritivores, medium size
- Oribatids in genera considered to be omnivorous, feeding on plant and fungal matter, carrion, and opportunistically on nematodes
- Body dark brown to yellowish-brown
- Body length 676 um; width of notogaster 502 um; length of notogaster 578 um
- Lamellar lines present, sublamellar lines absent; interlamellar setae relatively short, smooth; prodorsal setae medium-long, setiform, smooth or finely barbed; sensillus moderately long

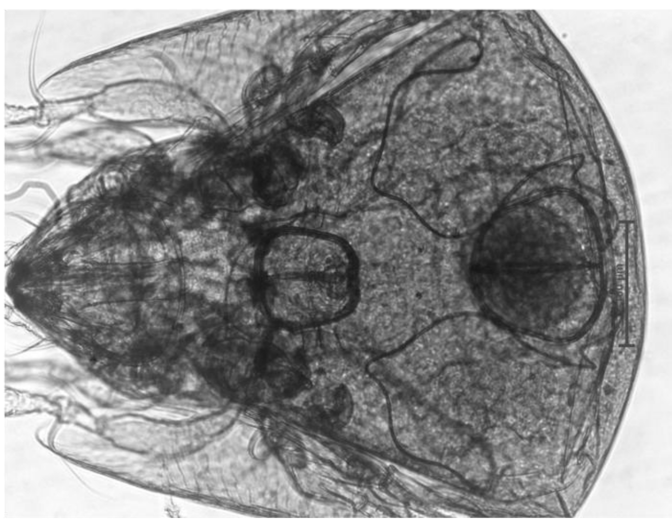




http://zoolstud.sinica.edu.tw/2010%20OnlineFirst/990513.pdf

Appendix B

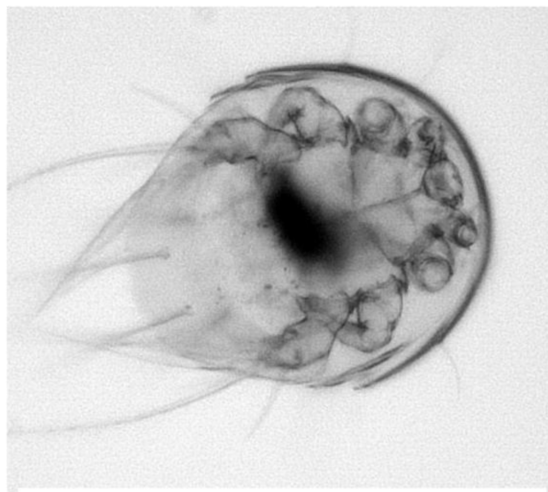
Pergalumna cont.



Appendix B

Scutacarus sp.

- Family Scutacaridae Gros (has a claw on tibiotarsus I)
- Distinctive shield-like shape.
- 4-segmented leg IV, usually with short tibiotarsus bearing 7 setae (rarely 6) and without pretarsus, claws and empodium; leg I is also 4-segmented, and may or may not have claws; there are always 4 solenidia of varying forms on tibiotarsus I
- Genus worldwide in distribution; 8 species have previously been known from North America



NEW YORK ENTOMOLOGICAL SOCIETY
LXXXVI(2), 1978, pp. 87–101

TERRESTRIAL MITES OF NEW YORK—VII. KEY TO THE SPECIES OF SCUTACARIDAE AND DESCRIPTIONS OF NEW SPECIES[1]

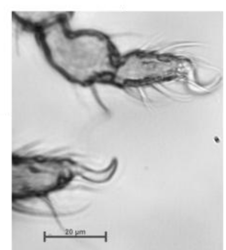
M. D. Delfinado and E. W. Baker

http://ezproxy.jmls.edu:2093/stable/pdfplus/25008996.pdf?acceptTC=true

Appendix B

Eulohmannia sp. Berlese 1910

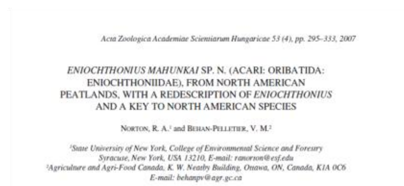
- Family Eulohmanniidae
- Member of the "Lower" Oribatid mites
- Only one genus in the family
- Detailed photographs should reveal distinctive constricting at base of proterosoma (upper part of body)



Appendix B

Eniochthonius sp.

- Family Eniochthoniidae
- Need picture – we may not have this.
- Feed on fungal hyphae and spores
- Length 309-343 um
- Smooth, shiny, pale brownish-yellow
- Notogaster moderately arched laterally and obovate dorsally with relatively long setae; bothridial seta slightly broadened and flattened distally, with 2-4 long tines and sparse small barbs; aggenital region with 3 separate plates

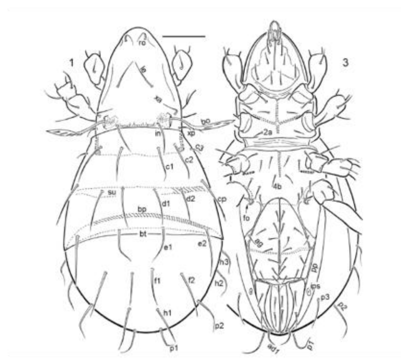


Acta Zoologica Academiae Scientiarum Hungaricae 53 (4), pp. 295–333, 2007

ENIOCHTHONIUS MAHUNKAI SP. N. (ACARI: ORIBATIDA: ENIOCHTHONIIDAE), FROM NORTH AMERICAN PEATLANDS, WITH A REDESCRIPTION OF *ENIOCHTHONIUS* AND A KEY TO NORTH AMERICAN SPECIES

NORTON, R. A.[1] and BEHAN-PELLETIER, V. M.[2]

[1]*State University of New York, College of Environmental Science and Forestry Syracuse, New York, USA 13210, E-mail: ranorton@esf.edu*
[2]*Agriculture and Agri-Food Canada, K. W. Neatby Building, Ottawa, ON, Canada, K1A 0C6 E-mail: behanpv@agr.gc.ca*



http://actazool.nhmus.hu/53/4/azh53_4_norton.pdf

Appendix B

Nothrus sp.

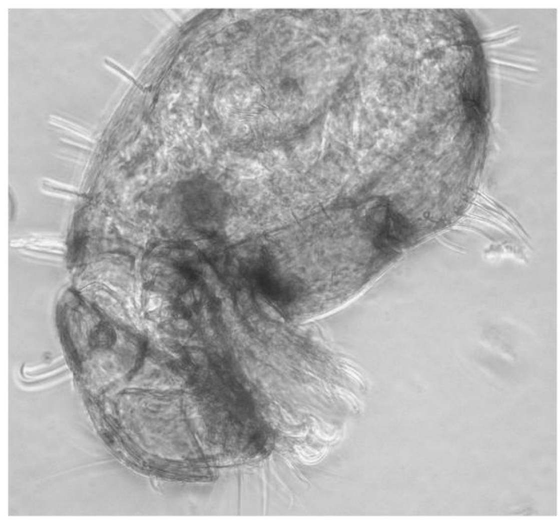
- Family Nothridae
- Brownish in color
- Pseudostigmatic organs burred; interlamellar and notogastral bristles short, the latter overreaching barely half the interspaces, clavate, the posterior bristles nodose, strongly clavate; bristles reaching posterolateral corners of abdomen; bristles el porrect, with broad nodose head
- Abdomen more sharply rounded behind; rostral bristles short, pointed; lamellar bristles much larger, clavate; abdomen with deep, narrow, dorsal groove distant from edge about twice its width, 4 bristles along lateral edge

http://ezproxy.jmls.edu:2093/stable/pdfplus/25004711.pdf
http://www.biol.uni.wroc.pl/cassidae/Nothroid%20mites.pdf
http://ezproxy.jmls.edu:2093/stable/pdfplus/2420500.pdf

Appendix B

Hoplophthiracarus sp.

- Family Phthiracaridae
- Need better picture of notogaster
- Notice genital and anal plates like "French Windows"
- Golf ball like surface ("pits")
- Aspis smoothly rounded in both lateral and dorsal aspects; rostrum in lateral aspect, with rounded blunt end and slender rim; rostral bristles short and straight; lateral bristles absent; vertex bristles quite long; pseudostigmata with well-developed rim; notogaster low, posterior end flattish; collar narrow, lapet poorly developed



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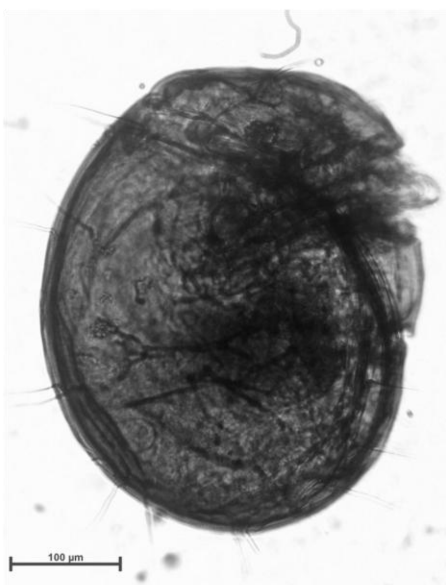
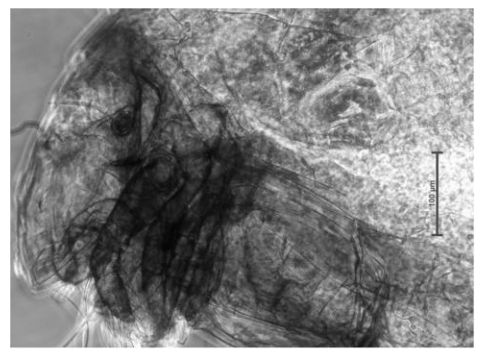
Appendix B

Phthiracarus sp. (perhaps 2 species - one smaller)

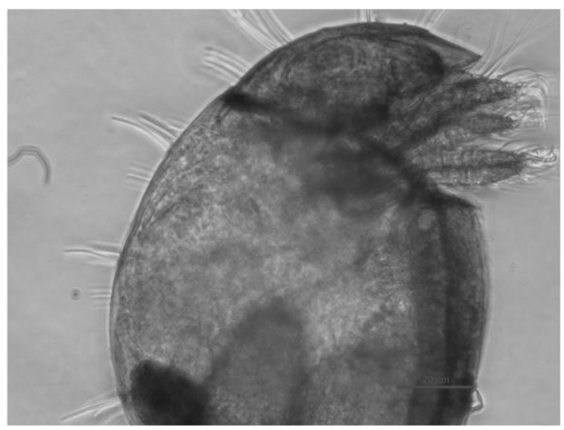




Appendix B

Phthiracarus sp. cont.

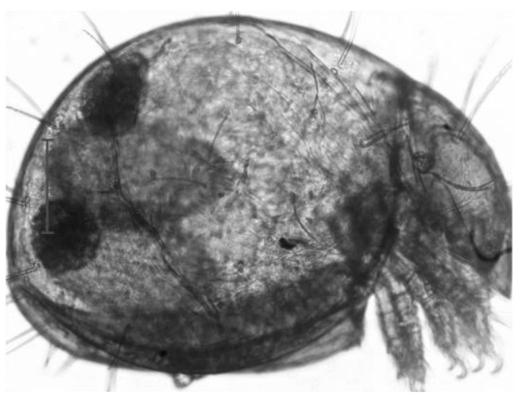
- Like Hoplophtiracarus but no “pits” on the surface.
- Box mite
- Length 428-485 um
- Rostrum with slight, but distinct projecting rim; aspis broadly curved; length of pseudostigmatic organ as long as distance from dorsal edge of collar to ventral edge of notch
- Surface of aspis finely vermiculate; rostral bristles inseted nearly twice their lengths from anterior edge of rostrum; surface of notogaster finely vermiculate, profile broadly oval as viewed from side, antero-dorsal margin decurved less abruptly than posterior margin



http://ezproxy.jmls.edu:2093/stable/pdfplus/2422056.pdf

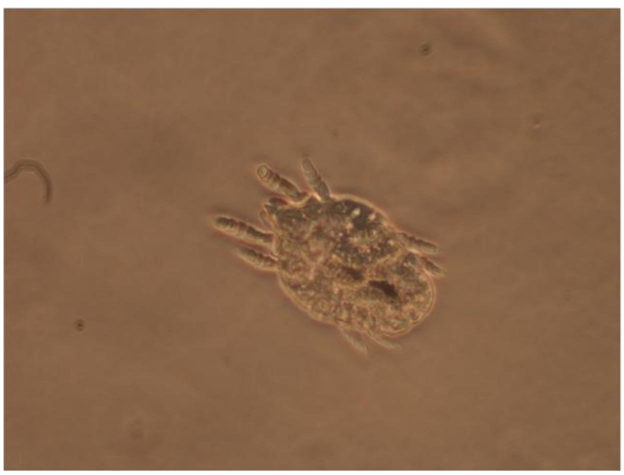
Appendix B

Rhizotricia



Appendix B

Prostigmata

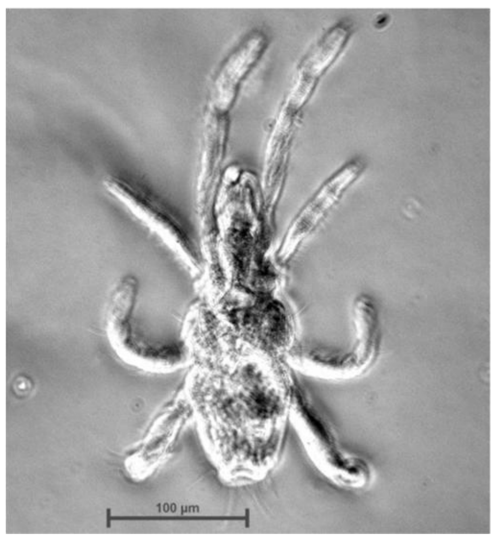


- Family Teneriffiidae
- Body elongated, with running legs
- Front prolonged anteriorly, with 3 specific pairs of setae
- 2 widely separately, paired eyes
- “Anus” is terminal and visible from above and below
- Elongated genital pore covered by 2 sickle-shaped flaps with a few setae
- Legs simple with many setae
- Rostrum short and broad; 4 small, blunt papillae and 2 pairs of hairs on distal end of labium
- Chelicerae 2 segmented, claw-like, with 2 small hairs on the dorsal side
- 5 thick, powerfully bent, segmented palps

http://ezproxy.jmls.edu:2093/stable/pdfplus/3669424.pdf

Appendix B

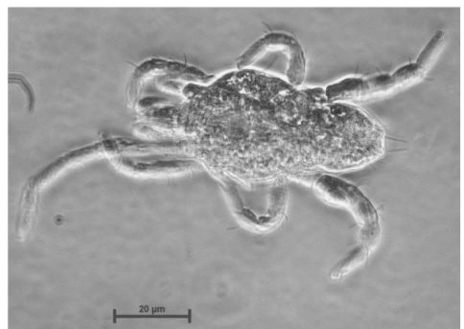
Prostig sp.

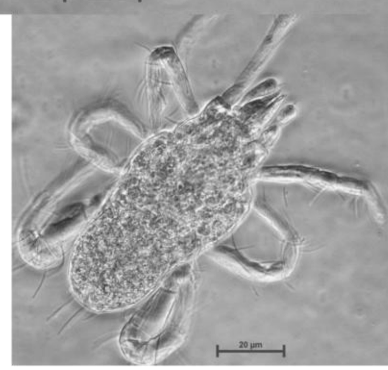


Appendix B

Tydeus sp.

- Prostigmata
- Photos of top of Notogaster (shield of abdomen surface)… if it has a little “wart” it is *Eupodes sp*. If there is a thumbprint quality to the surface – *Tydeus*
- Length 200-300 um
- Normally predaceous on small insects and other mites
- Yellow, pink, or red coating (integument)
  - Integument shows an endocuticle, exocuticle, and epicuticle
- Cuticle usually 2-4 microns thick
- Regular series of bumps and depressions on dorsum surface of mite
  - 1 of these bumps is a “campaniform sensillus”, a sensory receptor, that is believed to respond to air pressure or vibrations



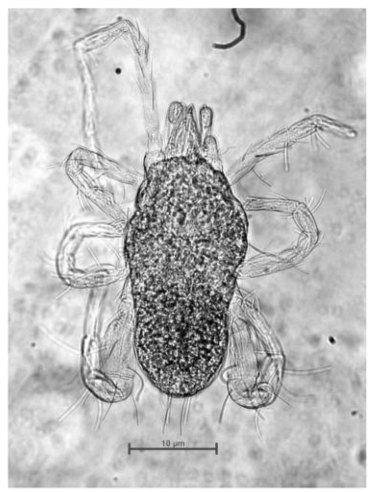


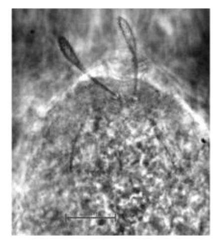
http://ezproxy.jmls.edu:2093/stable/pdfplus/25006160.pdf?acceptTC=true

Appendix B

Cocceupodes

- Prostigmata; Family Eupodidae
- Body Length 200-425 um long; small-very small mite, soft-bodies mites
- Transverse suture on podosoma normally absent
- Body setae of varying length except usually shorter than in *Eupodes*
- Setae clavate or threadlike, inseted on dorsum just posterior to the epivertex
- 2 pairs of anal setae
- Cheliceral seta is ciliated



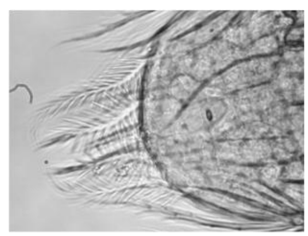


http://hbs.bishopmuseum.org/pi/pdf/13%281%29-75.pdf

Appendix B

Tarsonemus sp.

- Prostigmata; Family Tarsonemidae
- Length idiosoma 255 um; width 166 um
- Body oval, widest at about first hysterosomal seta (broadest at posterior of metapodosoma)
- Shiny, light brown in color
- Dorsal propodosomal setae with third pair longest, second shortest, fourth longer than first
- Gnathosoma about as wide as long; dorsal and ventral setae similar in length and size; external setae lacking; palpal external setae minute; pharynx slender, tubular and not enlarged
- Dorsal plates of idiosoma minutely punctate; pseudostigmatis organs capitate; vertical setae slender and smooth



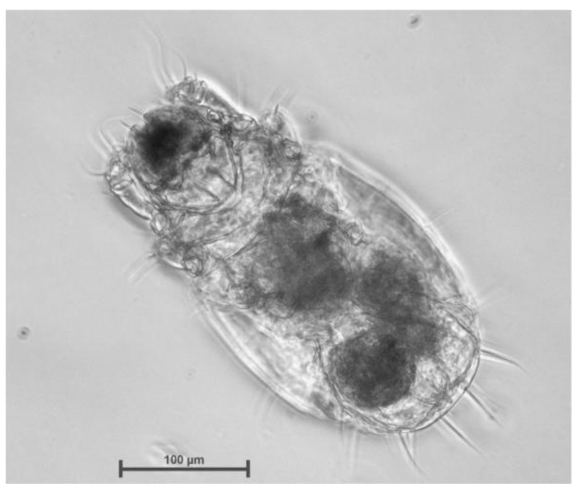
http://ezproxy.jmls.edu:2093/stable/pdfplus/3493188.pdf?acceptTC=true

http://ezproxy.jmls.edu:2093/stable/pdfplus/25009100.pdf

http://ezproxy.jmls.edu:2093/stable/pdfplus/3492593.pdf

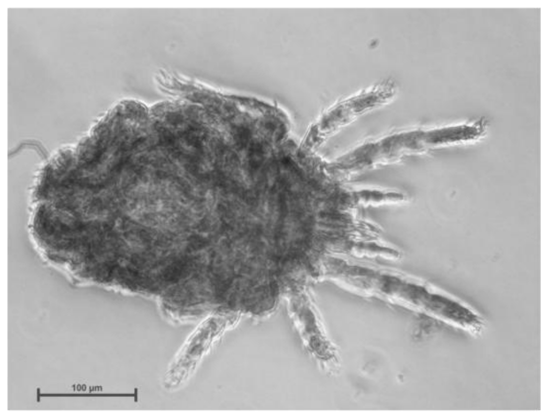
Appendix B

Tarsonemus sp. 2



Thrombid sp.

- Prostigmatid mite
- The velvet mites – family Thrombiidae
- This should be red under the microscope
- Very large – bright, red, puffy, and velvety
- The larvae are external parasites of insects
- This mite is predatory on insect eggs, larvae, pupae, and other small arthropods

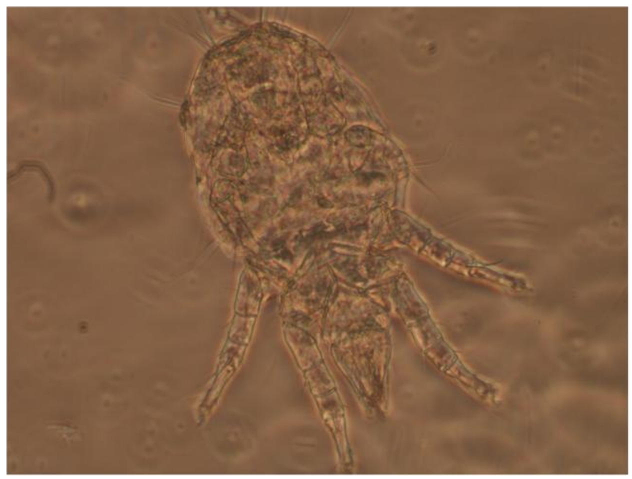


http://soilbugs.massey.ac.nz/acari.php

Appendix B

Astigmata

- Mainly weakly armored mites
- Vary in size from about 200 um – 1200 um
- Chelicerae are mostly chelate
- Body is usually divided into an anterior and posterior part and may sometimes have shields
- Genital orifice is generally a longitudinal slit, positioned in the intercoxal region
- Tibial solenidion is normally long and whiplike
- Tracheal openings are never present
- Algivorous, fungivorous, detritus feeders, suspension feeders, and the order includes a large number of parasites for vertebrates

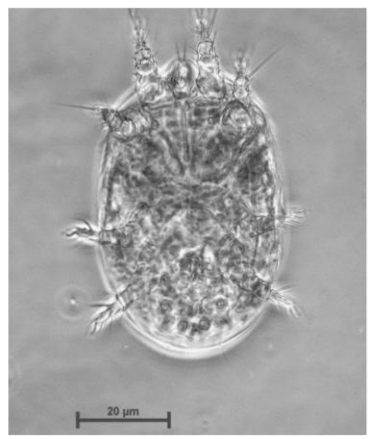


http://hbs.bishopmuseum.org/pim/pdf/pim25-174.pdf

Appendix B

Histiostoma

- Length about 267-347 um
- Hysterosoma barrel-shaped, blunt at posterior margin; whitish, opaque
- Hypopus with suctorial plate with more than 3 pairs of discs or suckers, no spoon-shaped terminal tarsal seta on leg IV, claw undivided on legs I-III
- Reduced pedipalpi with fleshy, movable terminal segment that projects laterally and bears 2 flagellum-like setae; laterally directed pair of setae on ventral aspect of gnathosoma; chelicerae having a dentate fixed digit but no observable movable digit
- 9 teeth with first long, slender, projecting anteriorly, second long, thicker than first, projecting laterally, next 7 short, thick, and of uniform size
- Dorsal sulcus separating propodosoma and metapodosoma distinct; single falcate claw terminating each leg; dorsal setae with curled ends



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Appendix B

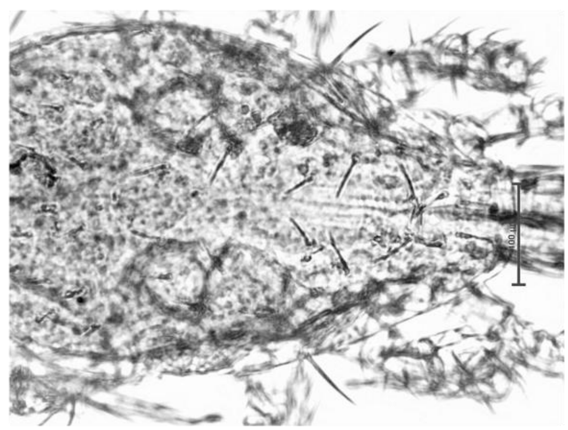
Mesostigmata

- Anatomy: has chelicera, palp, tectum, legs I-IV, opisthonotal shield, horn, podonotal shield, subcapitulum, sternal, genital, ventri-, and anal section
- Setiform hypostomal setae 1 is a plesiomorphic character shared by most groups of Mesostigmata
- The shape of the anterior edge of the gnathotectum varies between families of Mesostigmata: it can be curved, triangular, or blunt
- Horn-shaped corniculi are typical of Mesostigmata
- The dorsum of Mesostigmata is covered with a number of small glands

http://www.biosci.ohio-state.edu/~acarolog/pdf/Lekveishvili%20JNatHist2006%20Sejid.pdf

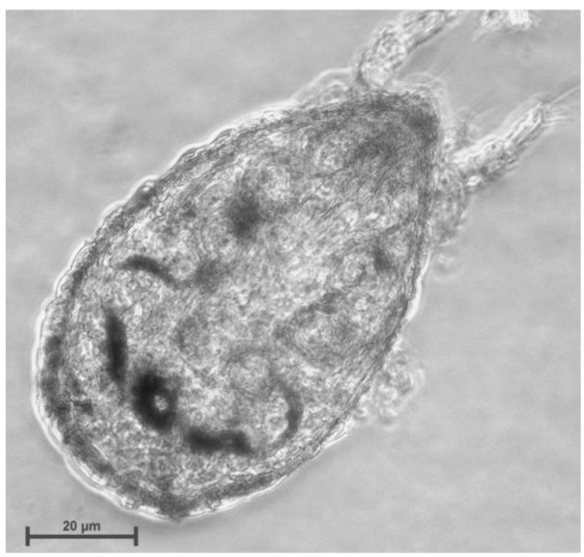
Appendix B

Mesostigmata sp. 1



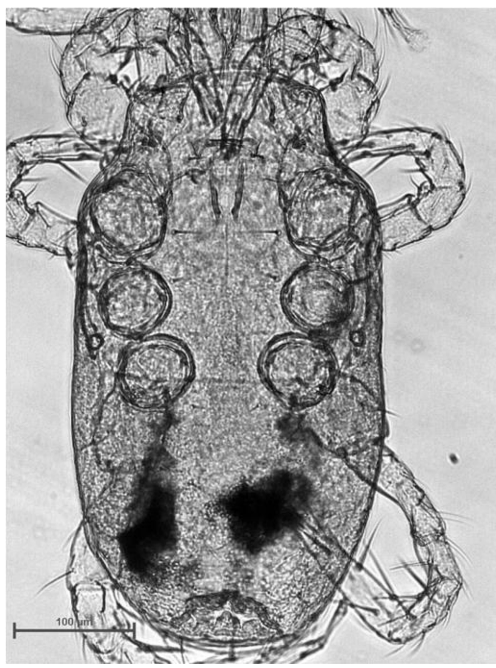
Appendix B

Mesostigmata sp. 2



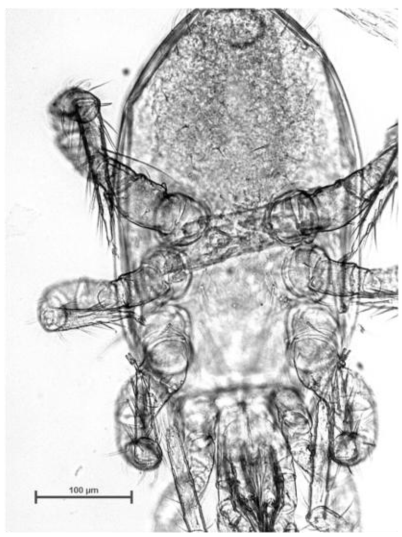
Appendix B

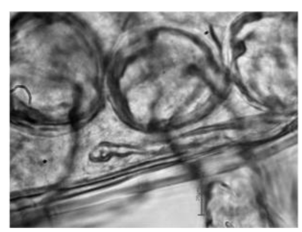
Mesostigmata sp. 3



Appendix B

Mesostigmata sp. 4

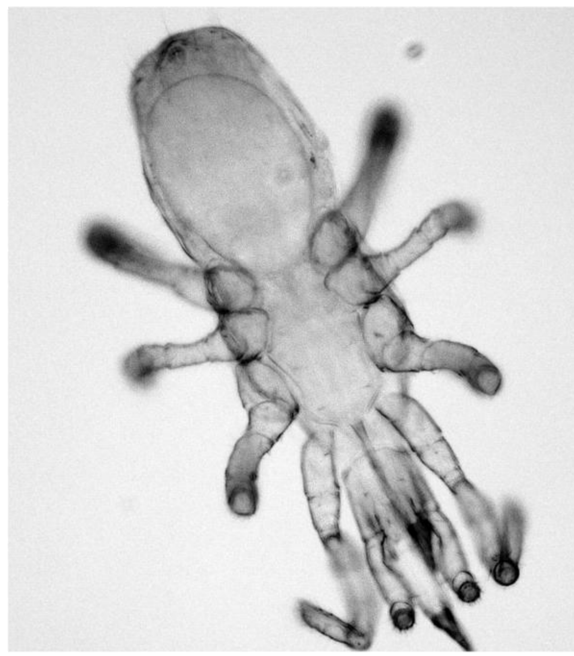




Appendix B

Rhodacarus sp.

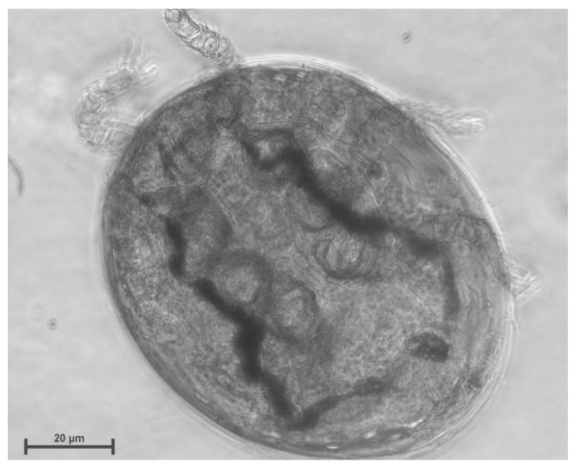
- Mesostigmatid mite
- There should be other Mesostigs…. Let's find more.
- Superfamily Rhodacaroidea
- Small-bodied and predatory that feeds almost solely on nematodes
- 4 pairs of setae on sternal shield
- Dorsal shield divided, 4 scleronoduli on pododnotal shield
- Chelicerae usually with arthrodial brush



http://keys.lucidcentral.org/keys/v3/mites/Invasive_Mite_Identification/key/Mesostigmata/Media/Html/Rhodacaridae.htm

Olodiscus sp.

- Very distinctive Mesostigmatid mite



Appendix C: Breakdown of Number of Species Found in Individual Sites and Samples

Species Name	**Number of Sites That Contained the Species (11 Total Sites)**	**Number of Samples That Contained the Species (33 Total Samples)**	**Number of Individuals Collected (1,529 Total Individuals)**
Ubiquitous/Common Species:			
Oppiella nova	10 (91%)	27 (82%)	212 (13.9%)
Order: Astigmata	11 (100%)	20 (61%)	140 (9.2%)
Rhodacarus sp.	11 (100%)	26 (79%)	105 (6.9%)
Scheloribates sp.	10 (91%)	23 (70%)	100 (6.5%)
Tydeus sp.	9 (82%)	20 (61%)	82 (5.4%)
Mesostig sp. 3	8 (73%)	16 (49%)	66 (4.3%)
Scutarus sp.	10 (91%)	16 (49%)	59 (3.9%)
Cocceupodes	8 (73%)	12 (36%)	59 (3.9%)
Eulohmannia sp.	10 (91%)	20 (61%)	46 (3.0%)
Liacaroid	8 (73%)	10 (30%)	27 (1.8%)
Histiostoma	8 (73%)	11 (33%)	20 (1.3%)
Phthiracarus sp.	8 (73%)	10 (30%)	16 (1.0%)

Appendix C: Breakdown of Number of Species Found in Individual Sites and Samples

Species Name	**Number of Sites That Contained the Species (11 Total Sites)**	**Number of Samples That Contained the Species (33 Total Samples)**	**Number of Individuals Collected (1,529 Total Individuals)**
Moderately Common Species:			
Nothrus sp.	4 (36%)	7 (21%)	85 (5.6%)
Belba sp.	6 (55%)	8 (24%)	39 (2.6%)
Juvenile w/ Antenna	7 (64%)	12 (36%)	38 (2.5%)
Liochthonius Juvenile	7 (64%)	9 (27%)	36 (2.4%)
Astigmata Juvenile	6 (55%)	8 (24%)	37 (2.4%)
Liochthonius sp.	6 (55%)	7 (21%)	36 (2.4%)
Rhodacarus Juvenile	6 (55%)	8 (24%)	31 (2.0%)
Mesostig sp. 4	6 (55%)	9 (27%)	19 (1.2%)
Elongated "Tydeus sp."	6 (55%)	8 (24%)	17 (1.1%)
Hoplophthiracarus sp.	7 (64%)	10 (30%)	16 (1.0%)
Microppia Balogh - M. minus	6 (55%)	7 (21%)	15 (1.0%)
Mesostig "curled"	6 (55%)	7 (21%)	15 (1.0%)
Tectocepheus velatus	7 (64%)	8 (24%)	14 (<1%)
Tiny-headed Juvenile	7 (64%)	8 (24%)	13 (<1%)
Juvenile 1	7 (64%)	9 (27%)	13 (<1%)
Mesostig Splayed Legs	6 (55%)	9 (27%)	14 (<1%)
Quadroppia	5 (46%)	5 (15%)	14 (<1%)
Mesostig sp. 1	5 (46%)	6 (18%)	9 (<1%)
Tarsonemus sp.	5 (46%)	6 (18%)	7 (<1%)
Order: Prostigmata	5 (46%)	5 (15%)	9 (<1%)
Species X	4 (36%)	5 (15%)	9 (<1%)

Appendix C: Breakdown of Number of Species Found in Individual Sites and Samples

Species Name	**Number of Sites That Contained the Species (11 Total Sites)**	**Number of Samples That Contained the Species (33 Total Samples)**	**Number of Individuals Collected (1,529 Total Individuals)**
Rare Species:			
Tarsonemus sp. 2	3 (27%)	4 (12%)	7 (<1%)
Pergalumna sp.	3 (27%)	3 (9%)	6 (<1%)
Shell	3 (27%)	4 (12%)	4 (<1%)
Olodiscus sp.	3 (27%)	3 (9%)	4 (<1%)
Rhizotricia	3 (27%)	3 (9%)	3 (<1%)
Extremely long-legged mite	3 (27%)	3 (9%)	3 (<1%)
Tiny-headed Adult	2 (18%)	2 (6%)	16 (1.0%)
Mesostig Round w/ Hair	2 (18%)	2 (6%)	9 (<1%)
Simple 6-legged Translucent mite w/ 2 front "arms"	2 (18%)	3 (9%)	8 (<1%)
Prostig Juvenile	2 (18%)	2 (6%)	6 (<1%)
Juvenile Rhodacarus "curled"	2 (18%)	2 (6%)	6 (<1%)
Splayed-legs Mite	2 (18%)	3 (9%)	4 (<1%)
Mesostig sp. 2	2 (18%)	2 (6%)	4 (<1%)
Prostig	2 (18%)	2 (6%)	3 (<1%)
Very Long Antennas Mite	2 (18%)	2 (6%)	3 (<1%)
Mesostig sp. 2 w/ legs all over	2 (18%)	2 (6%)	2 (<1%)
Spider Mesostig	2 (18%)	2 (6%)	2 (<1%)
Large "Belba" Turtle Shell w/ antenna	1 (9%)	1 (3%)	4 (<1%)
Larger Scheloribates	1 (9%)	1 (3%)	2 (<1%)
Simple 8-legged Translucent mite	1 (9%)	1 (3%)	2 (<1%)
Large Warted Mite	1 (9%)	1 (3%)	2 (<1%)
Liacarus sp.	1 (9%)	1 (3%)	1 (<1%)
Juvenile Unknown "frog"	1 (9%)	1 (3%)	1 (<1%)
Tectocepheus velatus Juvenile	1 (9%)	1 (3%)	1 (<1%)
Large hairy "turtle shelled" mite	1 (9%)	1 (3%)	1 (<1%)
Thrombid sp.	1 (9%)	1 (3%)	1 (<1%)
Juvenile Unknown Stick Legs	1 (9%)	1 (3%)	1 (<1%)
Large mite with 2 large "eyes"	1 (9%)	1 (3%)	1 (<1%)
Rhodacarus sp. no back legs	1 (9%)	1 (3%)	1 (<1%)
Mesostig sp. 2 Spiked	1 (9%)	1 (3%)	1 (<1%)
Pincher Mite	1 (9%)	1 (3%)	1 (<1%)
Curled Antenna Mite	1 (9%)	1 (3%)	1 (<1%)