INFLUENCES OF VEGETATION MANAGEMENT STRATEGIES ON POLLINATOR ASSEMBLAGES ON POWERLINE RIGHTS-OF-WAY

by

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Abstract

E.S. McPhail. Influences of Vegetation Management Strategies on Pollinator Assemblages on Powerline Rights-of-way, 106 pages, 20 tables, 30 figures, 2 appendices, May 2018.

Pollination carried out by insects is an essential ecosystem function required by 87% of angiosperms and contributing an estimated annual $170 billion in services worldwide. Unfortunately, pollinator populations are declining due to a variety of factors, including introduced pathogens/parasites, pesticide use, and habitat loss/degradation, all of which are caused or facilitated by humans. Powerline rights-of-way (ROWs) have been proposed as conservation/restoration areas as these habitats are able to provide nesting substrates and foraging resources. Field plots were located along powerline ROWs in central New York and in Ohio with explicit goals being to: 1) compare operational vegetation management (IVM) and experimental vegetation management techniques, 2) compare experimental techniques to one another, and 3) compare invasive-exotic plant removal on powerline ROWs by quantifying pollinator parameters (abundance, family richness, diversity, evenness), and describing assemblages to elucidate relationships between pollinators and IE plant prevalence. In New York field plots, management techniques included: tree removal using mechanical means followed by application of herbicide to cut stumps, foliar herbicide application, and brush hog mowing. In Ohio, three management outcomes and their effects on pollinators were evaluated, including tree removal, tree and woody invasive removal, and removal of all woody plants. Throughout the growing season, pollinators were collected with pan traps and sweep netting. Community measures were compared between operational and experimental treatments using paired t-tests and among treatment groups, while relationships among assemblages, treatments, months, and vegetation information were explored using multi-variate analyses. Few treatment effects were observed within community measures, however there were demonstrated differences between pollinator assemblages in operational IVM areas and brush hog mowing areas. Presence of showy honeysuckle, *Lonicera bella*, and glossy buckthorn, *Frangula alnus*, was associated with a change in pollinator assemblages and decreased pollinator abundance, richness, and diversity. Curculionidae, Vespidae, Colletidae, and Crabronidae were indicator families in plots where IE species had been removed. Additionally, Halictidae and Hesperidae were associated with disturbance levels associated with treatment methods. In order to further investigate treatment effects, researchers must follow managed areas throughout one full treatment cycle – this would allow determination of treatment half-life and variation in effects throughout the cycle.

KEY WORDS: Powerline rights-of-way, Hymenoptera, Diptera, Lepidoptera, Coleoptera, invasive-exotic, vegetation management, IVM, invasive management, IPM, herbicide

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Chapter 1

Literature Review and Project Summary

Importance of Pollinators

Pollination is an essential ecosystem function. Over 87% of the world's angiosperms are pollinated by animals, with insects being a majority of these pollinators (Kluser and Peduzzi 2007). Many important agricultural crops rely on insect pollination (Watanabe 1994) and so pollinators have a direct impact on human diets, aiding in reproduction of common food crops (e.g., potatoes, citrus fruits, squashes). Pollinators also indirectly impact human diets as they contribute to pollination of alfalfa, an extremely important food source for cattle, which provide both dairy products and meat for human diets (Wojcik 2017). In addition to their important contributions to food availability, pollinators play an extremely important role economically with insects annually contributing an estimated $15 billion in services for crop production, which includes an estimated $11.7 billion attributable to honey bees alone (Watanabe 1994; Calderone 2012). Beyond the scope of impacts on the human population, insect pollinators are vital within the global environment as they contribute to the success of flowering plants which are essential to primary energy production, provide habitat to a variety of life forms, feed consumers, and add to environmental diversity.

Pollinators in Decline

Unfortunately, pollinating insect populations are declining (Pollinator Health Task Force 2015a). In the last 140 years alone, there have been significant declines in overall bee species richness and particularly in abundance of three species (*Bombus affinis* Cresson, *Bombus pensylvanicus* (DeGeer), and *Bombus ashtoni* (Cresson), all of which are experiencing recent and rapid population collapses (Bartomeus et al. 2013). Many factors are contributing to pollinator declines including climate change (Hickling et al. 2006; Williams et al. 2007), introduction of alien species (including pests (Stout and Morales 2009), pathogens (Eyer et al. 2009), and plants

(Morandin and Kremen 2013)), pesticides (Cresswell 2011; Gill et al. 2012; Henry et al. 2012; Palmer et al. 2013), and land use changes (Ricketts et al. 2008; Winfree et al. 2009). Every year, urbanization increases to meet the growing needs of the increasing human population. This results in habitat loss, which has been a long-term contributor to bee population declines (Goulson et al. 2008; Potts et al. 2010; Goulson et al. 2015). Land use changes can also lead to local and/or regional extirpation of pollinator species, which can result in altered plant-pollinator assemblages (Burkle et al. 2013).

As urbanization and agriculture increase, pollinator foraging and nesting habitat is destroyed and fragmented (Kleijn and Raemakers 2008; Garibaldi et al. 2011); for example, the UK and Netherlands experienced a 70% drop in abundance of wildflowers between the 1980's and early 2000's (Kluser and Peduzzi 2007). Urbanization and agricultural intensity also bring about an increase in pesticide use, which negatively impacts pollinators. Brittain et al. (2010) documented lowered species richness of wild bee and butterfly populations in areas with high pesticide loads. Neonicotinoids, common systemic insecticides, have a variety of adverse effects on pollinators including death (Cresswell 2011), impaired brain function (Palmer et al. 2013), disruption of navigational abilities (Henry et al. 2012), reduced foraging performance (Gill et al. 2012), and reduced growth rates (Whitehorn et al. 2012).

All of the above discussed issues causing declines are exacerbated by climate change (Goulson et al. 2015). Climate change is predicted to cause range shifts both in plants and pollinators –resulting in pollinator declines on climatic range edges (Williams and Osborne 2009, Forister et al. 2010). This issue is further compounded by inhibition of compensatory species migration due to habitat loss and fragmentation (Williams and Osborne 2009). Specialists are especially vulnerable to habitat changes (Biesmeijer et al. 2006; Williams and

Osborne 2009) and along with the phenological asynchronies climate change creates among plants and their pollinators, overall pollinator habitat is more at risk of being dominated by introduced exotic habitat generalists (Warren et al. 2001; Memmott et al. 2007).

Public concern has risen in response to a highly visible decline in iconic pollinators, e.g., honey bees, bumble bees, and monarch butterflies (Pollinator Health Task Force 2015b; Nowak and Fierke 2016). To slow down, and hopefully, stop these declines, it is necessary to limit factors causing pollinator declines. Through the Presidential Memorandum, "Creating a Federal Strategy to Promote the Health of Honey Bees and Other Pollinators", and the Pollinator Research Action Plan, President Barak Obama created a framework to reduce honey bee loss, increase Eastern monarch butterfly populations, and restore over 2.8 million hectares of land for pollinator habitat in the United States (Pollinator Health Task Force 2015a) This memorandum provides a foundation to tackle the issue of habitat loss and fragmentation with an overall goal to find/restore large contiguous areas where pollinator populations can successfully forage, nest, and reproduce.

Powerline Rights-of-Way and Pollinators

Over 3.2 million ha of powerlines run throughout the United States (Johnson et al. 1979). Areas beneath these powerlines, known as rights-of-way (ROWs), are left relatively free of disturbance, with the exception of vegetation management. Results of this management are corridors held in early succession and dominated by herbaceous plants and small shrubs, rather than large woody plants, which can interfere with electircal transmissions. This makes powerline ROWs an excellent option to manage for pollinator habitat as it provides both foraging opportunities and nesting sites, such as bare areas for ground nesting Hymenoptera (Kevan 2001; Wojcik and Buchmann 2012).

For many butterflies, these areas provide all habitat requirements: warm, open areas, escape/protective cover, bare ground, nectar sources, and diverse herbaceous plants for oviposition (Lanham et al. 2002). ROWs have a greater abundance, richness, and diversity of butterflies than clear-cut areas, nearby forests, forest roads, or pasture lands (Berg et al. 2011; 2016). Operationally managed ROWs have a high abundance of parasitic and cavity nesting bees (Russell et al. 2005), spatially and numerically rare species (Russell et al. 2005; David L Wagner et al. 2014), and even species previously believed to be regionally extinct (Wagner and Ascher 2008). Powerline ROWs have also been shown to be important areas for dispersal and source habitat within a varied landscape.

Vegetation Management on Powerline Rights-of-Way

Vegetation of powerline ROWs is managed to prevent interference with delivery of electricity from one hub to the next, with the overarching goal being to eradicate tall-growing trees species (Whittier 2003) and encourage growth of low-growing species of grasses, forbs, and shrubs (Nowak and Ballard 2005). Nowak et al. (2014) provides an overview of the history of vegetation management on powerline ROWs, which has been executed in increasingly complex ways. In the earliest days of electric transmission (1890s through 1950s), ROWs were maintained by mechanical hand cutting and removal of "pest" species, primarily tall-growing trees. In the 1940s, herbicides were first created and synthesized on a large scale, which were incorporated as chemical vegetation controls. By the 1960s, broad-scale application of herbicides, often from helicopters, along the entirety of powerline ROWs, became standard practice due to the cost-efficiency of applying herbicides in this way – even today, chemical methods are less costly and more effective in the long run (Nowak and Van Splinter 2017). However, broad-scale herbicide application was soon documented as inadequate in preventing power outages and interruptions, raising concerns over this management technique; additionally, the public became concerned over such a high volume of herbicides (e.g., broad-spectrum herbicides like glyphosate and selective herbicides like triclopyr, 2,4-D, and picloram) being released into the environment – especially considering broad herbicide application from helicopters isn't always precise.

These societal concerns came to a head and as a result, regulations were developed for ROW vegetation management. In order to accommodate these regulations, while still maintaining the goal of limiting tall-tree growth, a new style of management, known as Integrative Vegetation Management (IVM), was conceived in the 1980s and 90s. IVM incorporates and adapts integrated pest management (IPM) core principals to the complexity of ROW vegetation. In both management techniques, pest species are identified with the goal being to reduce population levels in the way(s) that make the most economic and ecological sense. IVM defines "pest" as plants that grow to interfere with electrical lines (Nowak et al 2014). These plants are then removed selectively and judiciously throughout the ROW.

Six cross-linked component steps comprise IVM practices: 1) understanding pest and ecosystem dynamics, 2) setting management objectives and tolerance levels, 3) compiling treatment options, 4) accounting for economic and ecological effects of treatments, 5) site-specific implementation of treatments, and 6) adaptive management and monitoring (Nowak and Ballard 2005). In order to eliminate pest species, managers utilize both mechanical methods (e.g., hand cutting, brush hog mowing, etc.) and chemical methods (e.g., foliar herbicide application, cut-stump herbicide application, etc.). By eliminating tall-growing trees, managers foster areas dominated by forbs, shrubs, and grasses, all of which are low-growing. As these desirable species come to dominate the ROW, they suppress growth of undesirable tall-growing trees and encourage development of areas dominated by shrubs, herbs, and forbs. Over time, the ROW will require less input of chemical and mechanical management due to autoregulation of vegetation.

Since the new millennium, IVM has grown to include sustainability considerations in order to keep up with socioeconomic mores. Additionally, new professional management standards have been put in place by the North American Electric Reliability Council in the wake of the largest blackout in U.S. history which was caused by ROW mismanagement which left 8 dead, and cost more than $6 billion in lost economic activity (Cieslewicz et al. 2005) . IVM is central to the new management standards, known collectively as ANSI A300, which set out criteria for vegetation height and include hefty fines for transmission lines deviating from guidelines. While the resulting vegetation structure is strictly dictated by standards and legislation, the specific prescription of management for each ROW is left to the discretion of each company, which results in individualized regimes of herbicides and mechanical methods with which to manage their ROWs.

Impacts of Management on Pollinators

It is expected that there are significant interactions among management techniques, the vegetation community, and pollinator assemblages on powerline ROWs, as vegetation management both indirectly and directly impacts pollinators (Fig. 1.1). IVM practices dictate what vegetation grows along a ROW, indirectly impacting pollinator assemblages (Hopwood et al. 2010). This is due to indirect relationships between floral assemblage/diversity and pollinator assemblage/diversity (Potts et al. 2003). As trees are cut and removed from ROW by vegetation management, tree cover is decreased and desirable species (e.g., forbs, shrubs, other flowering plants) providing resources to pollinators increase (Sydenham et al. 2016).

While a high percentage of tree cover and tall vegetation often have negative impacts on pollinator assemblages (Bramble et al. 1999; Lensu et al. 2011; Berg et al. 2013), the desirable low-growing species are extremely important to those same assemblages along ROWs. Shrubs, forbs, and other small plants provide floral resources that foster pollinator assemblages. As floral resource density and diversity on ROWs increase, bumblebee and butterfly richness/abundance also increase (Berg et al. 2013; Hill and Bartomeus 2016; Leston and Koper 2017). Areas created by vegetation management can even closely mimic natural areas – in fact, pollinators have been shown to thrive on ROWs that functionally replicate natural areas (Forup and Memmott 2005; Hopwood et al. 2010). Interestingly, properly managed ROWs can even provide better habitats than those naturally available, providing enhanced foraging and nesting to a wider variety of bees, including those that are rare or otherwise locally extinct (Smallidge et al. 1996; Russell et al. 2005; Wagner and Ascher 2008; Berg et al. 2011; David L Wagner et al. 2014).

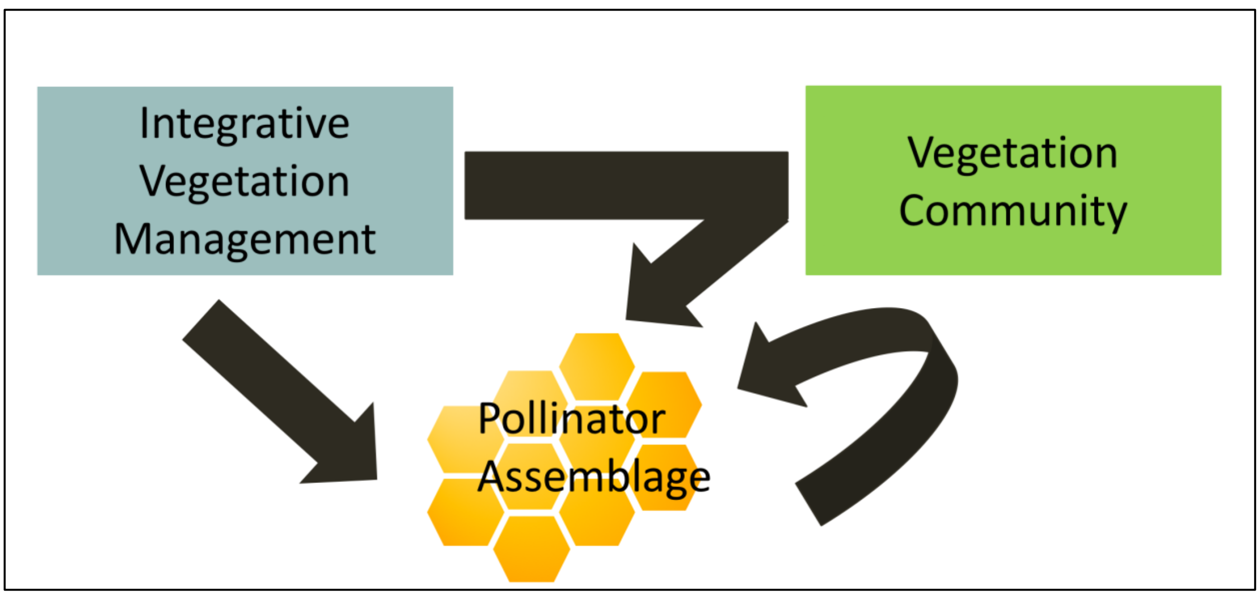

Figure 1.1. Conceptual framework of the pollinator/ROW system.

Treatments applied to ROWs can also directly impact pollinators via two main pathways: 1) being directly sprayed or 2) ingesting herbicide that has mixed with pollen and/or nectar. While effects of herbicide in the context of powerline ROWs remains under studied, bees exposed to chronic sub-lethal doses of herbicides in other systems, e.g., agricultural areas, exhibit physiological and behavioral changes (reduced learning performance (Herbert et al. 2014), impaired navigation (Balbuena et al. 2015), decreased nerve and muscle function (Boiley et al 2013; Zhu et al 2017), increased degradation of proteins (Hedri Helmer et al. 2014), and increased lipid peroxidation (Junmarie et al. 2017)). These impacts are associated with the larger and/or more frequent application rates found in agricultural systems, whereas powerline ROWs are generally treated only once every four or more years. Studies have shown that in the context of glyphosate used in operational areas (like powerline ROWs), there is a low risk of acute toxicity to bees (Thompson et al. 2014; Zhu et al. 2015).

Invasive Plants, Pollinators, and Powerline Rights-of-Way

Invasive exotic (IE) species pose one of the greatest threats to biodiversity in an ecosystem (Fritts and Rodda 1998; Wilcove et al. 1998), often outcompeting native plants for space and resources (Crawley 1987). IE plants tend to be “super generalists” when it comes to pollinators (Bartomeus et al. 2008) while native plants often rely on more specialized relationships with pollinators (Stouffer et al. 2014). Similar terms describe pollinator relationships with the flowers they pollinate, i.e. either they are generalists pollinating a variety of plants or specialists serving one particular or a few closely related species. Generalist pollinators, especially those belonging to orders Hymenoptera or Hemiptera, are more likely to visit invasives, while specialists tend to only interact with exotics when they are also semi-social or when the IE is closely related to their native mutualist (Lopezaraiza-Mikel et al. 2007; Stouffer et al. 2014). The question remains, however, as to whether introduction of IE species (e.g., dandelions, buckthorn, multiflora rose) negatively or positively impact plant-pollinator networks.

In short, effects IE plants have on native plant species depends on the extent of the invasion, density of invasives, how attractive the IE flowers are, how nutritious their nectar is, whether or not they are closely related to any existing native species, and the particular species of invader (Aizen et al. 2008; Bartomeus et al. 2008; Morales and Traveset 2009). In cases where there is a single invading IE species, it may integrate into the plant-pollinator network without obvious evidence of disturbing native species (Vilà et al. 2009). In these particular cases, the IE species may even facilitate native plant-pollinator interactions (Lopezaraiza-Mikel et al. 2007), increase pollinator species richness (Stouffer et al. 2014), and increase overall pollinator abundance by attracting pollinators not otherwise sustained by a particular area (Bartomeus et al. 2008). In the majority of cases, however, IEs do not positively impact plant-pollinator networks, rather they reduce pollinator visitation to native plants (Brown et al. 2002) and lower native plant fitness by lowering seed set due to lost pollination service (Muñoz and Cavieres 2008).

Effects IEs have on pollinators are also influenced by environmental context. For example, in mature hedgerow sites, wild bees are more abundant, rich, and diverse on native plants, but in restored areas bee richness and diversity were the same for both native and invasive plant hosts (Morandin and Kremen 2013). Powerline ROWs have been documented to be an area where IE plants occur and expand quickly (Zink et al. 1995; Cameron et al. 1997; Merriam 2003; Dubé et al. 2011). This is due to increased light availability (Bramble and Byrnes 1983; Luken et al. 1992; Rubino et al. 2002), disturbances to upper layers of soil (Hobbs and Atkins 1988; Johnston and Johnston 2004; Jodoin et al. 2008), reduction of native competitors (Parendes and Jones 2000), and decrease of wind barriers to IE pollen and seed dispersal (Hill et al. 1995;

Parendes and Jones 2000). Powerline ROWs have a higher occurrence of IE species than surrounding areas (Wagner et al. 2014). Within the specific context of powerline ROWs, the exact effects of IE's on pollinators are unknown.

Insect Pollinator Function and Diversity

Pollinators are animals that aid in angiosperm sexual reproduction by facilitating transfer of pollen grains from the androecium to the gynoecium where sperm will meet with the female gametophyte to form a zygote. Pollinators enhance outcrossing as they transfer pollen among flowers as they forage. Of all animals, insects are the most numerous pollinators, with the most important being various Hymenoptera, Diptera, Lepidoptera, and Coleoptera species (Gilgert and Vaughan 2011).

Hymenoptera

The insect order Hymenoptera is comprised of bees, wasps, ants, and sawflies – and these animals are responsible for a majority of pollination globally (Kevan and Baker 1983). Within the Hymenoptera, bees' contribution to pollination is unparalleled. In the United States, there are >4,000 native bee species (Moisset and Buchmann 2011) and worldwide, bees alone pollinate over two thirds of the world's agricultural crops (Hatfield et al. 2012). Their pollination success is due to the nature of their relationship with the flowers they visit. While adult bees drink flower nectar, as is common for many pollinators, they also purposefully collect pollen to feed to their young. Pollen clings to the hairs on their bodies and can be packed into corbicula, specialized pollen carrying structures located on the tibia of many bee species. As pollen is gathered, it is also transferred from flower to flower, enabling cross-pollination. Most bees are oligolectic, specializing on one or a few closely related plant species, while others are either polylectic, collecting pollen from various species of flowers, or cleptoparasitic, stealing pollen and other food sources from other bees.

Compared to bees, other hymenopterans (e.g., wasps, ants) have a minimal role in pollination. Although a few wasp species can carry similar amounts of pollen to what bees can carry (Pérez-Balam et al. 2012), the vast majority do not carry a significant amount of pollen due to a lack of pollen-carrying structures. Wasps and bees can also have similar flower visitation rates, however wasps typically have significantly lower pollination performance in comparison to bees due to their lower abundance (Pérez-Balam et al. 2012). Exclusive pollination by ants is extremely rare with only a dozen known ant pollination systems in nature (Kincaid 1963; Hickman 1974; Wyatt 1981; Beattie 1982; Beattie et al. 1984). Sawflies are phytophagous and have an extremely limited role in pollination and are mentioned in less than a handful of pollination studies (e.g., Armstrong 1979; Brantjes 1981).

Diptera

Fossils indicate early angiosperm pollination was carried out by flies (Order Diptera) (Thien 1980), and they are still important pollinators, second only to bees in overall pollination performance (Forup and Memmott 2005). Pollinating flies are generally categorized into two main groups: hoverflies (Family Syrphidae) and all other flies. Hoverflies are the largest fly contributors to pollination (Holloway 1976; Gilbert 1981; Kevan and Baker 1983), however, there is a large variety of pollinating Dipterans, e.g., fungus knats (Family Mycetophilidae), male mosquitos (Family Culicidae). Flies visit flowers for a variety of reasons ranging from phytophagy to predation and/or parasitism upon other flower-visiting and flower-dwelling arthropods. Many flies are covered in hairs, to which pollen will stick and then be transferred to other flowers, making them effective pollinators – with some being even more efficient than some bees (Pérez-Balam et al. 2012).

Coleoptera

Though beetles (Order Coleoptera) are also one of the earliest insect lineages associated with pollination (Baker and Hurd 1968; Proctor and Yeo 1973; Faegri and van der Pijl 1978), they are only responsible for approximately the same amount of pollination as lepidopterans (Orford et al. 2015). Beetles tend to be associated with pollinating basal angiosperm lineages while bees pollinate more derived lineages (Gottsberger 1974; Leppik 1977). Beetles are some of the only pollinators, other than a few Diptera, which have no interest in floral nectar – as they are primarily herbivores, eating their way through flowers, consuming petals and other parts of the flowers to get to pollen, their ultimate reward. During this feeding process, pollen adheres to the outside of the beetle and is transferred to other flowers the beetle visits. Beetles vary in their form, from extremely hairy to lacking hairs altogether, with the hairier forms transferring more pollen.

Lepidoptera

Butterflies and moths (Order Lepidoptera) are some of the most recognized pollinators by the general public as they have colorful wing patterns. Lepidopterans visit flowers in order to drink nectar, and while perched on the flower, pollen will stick to the hairs on their legs and bodies and then be transferred to the next flower the insect visits. Unlike bees, butterflies do not have specific morphological structures designed to hold pollen and so are significantly less effective in pollen transfer (Kevan and Baker 1983; Fishbein and Venable 1996); however, butterflies do play an important role in the environment – serving as indicator species, i.e. as a “barometer” of health and diversity within a system due to their being sensitive to environmental disruption

(Bramble et al. 1997).

Pollinator Sampling Methods

While insects are sampled with a variety of techniques, pan traps and sweep netting are the most commonly used for pollinators as they are considered effective for measuring both pollinator abundance and richness (Roulston et al. 2007; Westphal et al. 2008; Wilson et al. 2008; Nielsen et al. 2011). By far, pan trapping is the most commonly used method to sample bees and other pollinators (Leong and Thorp 1999; Campbell and Hanula 2007; Gollan et al. 2011). This is perhaps because pan traps have no collector/observer bias (Leong and Thorp 1999). Unfortunately, there is no standard method of trap color or placement among pollinator biologists as some recommend blue pan traps (Campbell and Hanula 2007) others recommend yellow (Namaghi and Husseini 2009) and the relative effectiveness of pan trap color can vary by habitat (Saunders and Luck 2013). Different colors attract different assemblages of pollinators, so it is generally recommended that two or more distinct colors be used, e.g., blue and yellow (Cane et al. 2000; Vrdoljak and Samways 2012). As for trap placement, some studies recommend pans be elevated to vegetation height (Tuell and Isaacs 2009) while others advocate for ground-level traps (Abrahamczyk et al. 2010).

Sweep netting is used less as a pollinator sampling method due to collector bias as well as being more labor-intensive and even dangerous, i.e. handling stinging insects comes with costs. There are many different styles of sweep netting, however, belt-transects are documented as the best ways to sample bees, as opposed to timed observations or vegetation sweeping (Benedek 1970; Banaszak 1980). One solution to collector bias is to have sweepers sample intensely along pre-determined transects (Jazen 1973; Roulston et al. 2007) without consideration for targeting particular vegetation or pollinators.

Pan traps and sweep netting are not equivalent sampling methods when considering common variables of interest, e.g., abundance, richness, composition (Cane et al. 2000; Souza-Silva et al. 2001; Roulston et al. 2007; Popic et al. 2013). While effectiveness of each sampling method depends on the vegetation community, resource availability, and pollinator assemblage composition (Cane et al. 2000; Baum and Wallen 2011; Gollan et al. 2011), sweep netting has been documented as the better of the two methods in a vast majority of cases (Cane et al. 2000; Roulston et al. 2007). It is important to capture functionally important flower-visiting insects in order to understand pollinator networks and since pan trap samples are not tied to floral resource availability (Popic et al. 2013) they don't necessarily sample functionally important pollinators (Bascompte and Jordano 2007; Kaiser-Bunbury et al. 2010). Pollinators collected by pan traps are also not a true representation of the absolute pollinator assemblage either; instead, they are representative of a subset of the population which are attracted to traps under a certain set of conditions (Southwood and Henderson 2000). Sweep net catches, on the other hand, are related to floral resource availability and so they do sample functionally important pollinators (Bascompte and Jordano 2007; Kaiser-Bunbury et al. 2010; Popic et al. 2013). One limitation of sweep netting is that this method functions best at times of increased floral resource availability and if sampling cannot be accomplished during that time, then pan traps may be more suitable in situations where there will be lower or varying levels of resource availability (Popic et al. 2013)

Research Objectives

Without intervention, pollinator populations across the globe will continue to decline, which will negatively impact human food resources. In order to address habitat needs, powerline ROWs are being studied as areas where pollinators are known to live and forage. What is unknown is how ROW management can directly and indirectly impact pollinator assemblages. In order to understand this and evaluate which techniques create habitats that foster pollinators, pollinator sampling and vegetation inventories are necessary for several different management techniques.

Several vegetation management techniques, including herbicide application, mechanical removal, and invasive-exotic plant removal were investigated during this research and will be discussed in detail in the following chapters. Specific objectives included:

1. Compare impacts of common mechanical and chemical vegetation management practices on pollinator parameters and assemblages
   A. Document and describe pollinator assemblages along ROWs
   B. Quantify overall pollinator abundance, richness, diversity, and evenness
   C. Compare pollinator abundance, richness, diversity, and evenness between mechanical and chemical management
2. Describe effects of vegetation management on pollinator parameters and assemblages
   A. Document pollinator assemblages over the 2016 and 2017 growing seasons
   B. Compare measurements of late season pollinator assemblages (August 2016) to measurements of pollinator assemblages in the immediate aftermath of vegetation management techniques (August 2017)
3. Analyze the influence IE plant species have on pollinator assemblages
   A. Compare IE species prevalence to pollinator assemblage
   B. Determine relationship between IE prevalence and pollinator abundance, family richness, diversity, and evenness

Chapter 2

Vegetation Management Effects on Pollinator Assemblages Along Powerline Rights-of-way in Central New York

Abstract

Insects are the most numerous and diverse angiosperm pollinators, responsible for contributing $15 billion annually in service to crop pollination. Unfortunately, pollinator populations are declining due to a variety of factors, including habitat loss and degradation caused by anthropomorphic sources. Powerline rights-of-way (ROWs) have been shown to be effective conservation/restoration areas for pollinators as they are large connected expanses of land managed in a way that could promote pollinator habitat. The goals of this study were to compare operational vegetation management techniques to experimental vegetation management techniques and to compare experimental techniques to one another on powerline ROWs by quantifying pollinator abundance, family richness, diversity, and evenness, and assemblage composition to elucidate relationships between assemblage and treatment and month. Management techniques evaluated included operational integrative vegetation management (OP), experimental IVM using only cut stump herbicide application (CS), experimental IVM using only foliar herbicide application (FH), and mechanical brush hog mowing (BH). Pollinator assemblages were sampled in June, July, and August in 2016 and 2017 with pan traps and sweep nets. Brush hog mowing resulted in significantly lower pollinator abundance, family richness, and diversity in comparison to paired operational management plots, as well as resulting in significantly different pollinator assemblages. Comparisons of experimental management techniques did not yield any treatment-level effects, possibly due to treatments being applied seven years prior to this study. In order to investigate this possibility, researchers would need to follow pollinator assemblages throughout the entirety of a vegetation treatment cycle.

Keywords: Powerline right-of-way, pollinator, Hymenoptera, Diptera, Lepidoptera, Coleoptera, vegetation management

Introduction

In the United States powerline rights-of-way (ROWs) cover more than 3.2 million ha (Johnson et al. 1979) and are relatively free of development (e.g., agriculture and buildings). Vegetation is managed to remove tall-growing trees resulting in linear corridors held in early succession dominated by herbaceous plants and small shrubs. This results in powerline ROWs being an excellent option to manage for pollinator habitat (Wojcik and Buchmann 2012), as it provides both foraging and nesting habitat, such as bare areas for ground nesting Hymenoptera (Kevan 2001). The potential for pollinator conservation is huge – with such a large area managed by strict regimens, ROW's have characteristics favorable to preserve and restore pollinators (Russell et al. 2005).

Powerline ROWs are managed to prevent interference with delivery of electricity from one hub to the next, with the most important aspect being eradication of tall-growing tree species, thereby encouraging low-growing grasses, forbs, and shrubs (Whittier 2003; Nowak and Ballard 2005**.** Nowak et al. (2014) provides an overview of the history of vegetation management on powerline ROWs, which has been executed in increasingly complex ways. In the earliest days of electric transmission (1890s through 1950s), ROWs were maintained by mechanical hand cutting and removal of "pest" species, primarily tall-growing trees. In the 1940s, herbicides were first created and synthesized on a large scale, which were incorporated as chemical vegetation controls. By the 1960s, broad-scale application of herbicides, often from helicopters, along the entirety of powerline ROWs, became standard practice due to the cost-efficiency of applying herbicides in this way – even today, chemical methods are less costly and more effective in the long run (Nowak and Van Splinter 2017). However, broad-scale herbicide application was soon documented as inadequate in preventing power outages and interruptions, raising concerns over this management technique; additionally, the public became concerned over such a high volume of herbicides (e.g., broad-spectrum herbicides like glyphosate and selective herbicides like triclopyr, 2,4-D, and picloram) being released into the environment – especially considering broad herbicide application from helicopters isn't always precise.

These societal concerns came to a head and as a result, regulations were developed for ROW vegetation management. In order to accommodate these regulations, while still maintaining the goal of limiting tall-tree growth, a new style of management, known as Integrative Vegetation Management (IVM), was conceived in the 1980s and 90s. IVM incorporates and adapts integrated pest management (IPM) core principals to the complexity of ROW vegetation. In both management techniques, pest species are identified with the goal being to reduce population levels in the way(s) that make the most economic and ecological sense. IVM defines "pest" as plants that grow to interfere with electrical lines (Nowak et al 2014). These plants are then removed selectively and judiciously throughout the ROW.

Six cross-linked component steps comprise IVM practices: 1) understanding pest and ecosystem dynamics, 2) setting management objectives and tolerance levels, 3) compiling treatment options, 4) accounting for economic and ecological effects of treatments, 5) site-specific implementation of treatments, and 6) adaptive management and monitoring (Nowak and Ballard 2005). In order to eliminate pest species, managers utilize both mechanical methods (e.g., hand cutting, brush hog mowing, etc.) and chemical methods (e.g., foliar herbicide application, cut-stump herbicide application, etc.). By eliminating tall-growing trees, managers foster areas dominated by forbs, shrubs, and grasses, all of which are low-growing. As these desirable species come to dominate the ROW, they suppress growth of undesirable tall-growing trees and encourage development of areas dominated by shrubs, herbs, and forbs. Over time, the

ROW will require less input of chemical and mechanical management due to autoregulation of vegetation.

Since the new millennium, IVM has grown to include sustainability considerations in order to keep up with socioeconomic expectations. Additionally, new professional management standards have been enacted by the North American Electric Reliability Council in the wake of the largest blackout in U.S. history caused by ROW mismanagement, which left 8 dead, and cost more than $6 billion in lost economic activity (Cieslewicz et al. 2005) . IVM is central to these standards, known collectively as ANSI A300, which set out criteria for vegetation height and include hefty fines for lines deviating from these guidelines. While the vegetation structure is strictly dictated by standards and legislation, specific prescriptions of management for each ROW is left to the discretion of individual companies, which creates variable regimens of herbicides and mechanical methods being implemented along ROWs.

There are significant interactions among management techniques, the vegetation assemblage, and the pollinator assemblage of powerline ROWs. As IVM practices dictate what vegetation can grow along a ROW this indirectly impacts pollinator assemblages associated with that tract of land (Hopwood et al. 2010). This is due to direct relationships between floral assemblage/diversity and pollinator assemblage/diversity (Potts et al. 2003). As trees are cut and removed from ROWs, tree cover is decreased and desirable species (e.g., forbs, shrubs, other flowering plants) that provide resources to pollinators increase (Nowak et al. 2014; Sydenham et al. 2016). While a high percentage of tree cover and tall vegetation often have negative impacts on pollinator assemblages (Bramble et al. 1999; Lensu et al. 2011; Berg et al. 2013), the desirable low-growing species generated by ROW management are extremely important to those same assemblages.

Shrubs, forbs, and other low-growing plants provide a plethora of floral resources that help maintain pollinator assemblages. As floral resource density and diversity on ROWs increase, bumblebee and butterfly richness/abundance also increase (Berg et al. 2013; Hill and Bartomeus 2016; Leston and Koper 2017). Areas created by vegetation management can even closely mimic natural areas – in fact, pollinators have been shown to thrive on roadside and powerline ROWs that replicate natural areas (Forup and Memmott 2005; Hopwood et al. 2010). Interestingly, research has documented that properly managed ROWs can even provide habitats better than those naturally available, providing foraging and nesting area to a wider variety of bees, including species that are rare or otherwise locally extirpated (Smallidge et al. 1996; Russell et al. 2005; Wagner and Ascher 2008; Berg et al. 2011; Wagner et al. 2014).

Treatments applied to ROWs can also directly impact pollinators via two main pathways: 1) being directly sprayed or 2) ingesting herbicide that has mixed with pollen and/or nectar. While effects of herbicide in the context of powerline ROWs remains under studied, bees exposed to chronic sub-lethal doses of herbicides in other systems, e.g., agricultural areas, exhibit physiological and behavioral changes, e.g., reduced learning performance (Herbert et al. 2014), impaired navigation (Balbuena et al. 2015), decreased nerve and muscle function (Boiley et al 2013; Zhu et al 2017), increased protein degradation (Helmer et al. 2014), and increased lipid peroxidation (Junmarie et al. 2017). This research is associated with the larger and/or more frequent application rates found in agricultural systems, whereas powerline ROWs are generally treated only once every four or more years. Studies have shown that in the context of glyphosate used in operational areas (like powerline ROWs), there is a low risk of acute toxicity to bees (Thompson et al. 2014; Zhu et al. 2015).

The overall goal of this research was to compare effects of vegetation management techniques on pollinators in the context of powerline ROWs. Specific objectives were to compare abundance, richness, diversity, evenness, and assemblage of pollinators among vegetation management treatment groups. Findings will inform utility managers decisions to better serve pollinator assemblages on powerline ROWs.

Materials and Methods

Study Sites

This research was conducted along two powerline ROWs running directly beside and parallel to one another along a 24 km stretch near Rome, NY (Fig. 2.1). The Volney-Marcy (VM) electric transmission line runs from Volney to Marcy, NY with vegetation maintained by the New York Power Authority (NYPA). The Fitzpatrick-Edic (FE) electric transmission line runs from the Tug Hill Plateau to the Mohawk Valley with vegetation maintained by National Grid (Whittier 2003).

We used 18 previously established paired control and experimental plots (Table 2.1) associated with a study on effects of herbicide treatment schemes on plant assemblage composition (Whittier 2003). Nine operational IVM plots were along the FE ROW, which carries out removal of "pest" tree species. The remaining nine plots were along the VM ROW, where three experimental vegetation management techniques were applied to remove "pest" trees via 1) mechanical cutting followed by applying herbicide to the cut stump (CS), 2) application of foliar herbicide (FH), and 3) brush hog mowing (BH). Plots were last treated in 2010 and all plots were 0.081 ha, extending 14.2 m on each side of the center transmission line. Distances between treatment plots ranged from being back to back to nearly 2 km. Areas between experimental plots on the VM ROW were maintained by operational IVM techniques.

Our study was conducted six years post-treatment on the FE ROW in summer 2016 and six and seven years post-treatment on the VM ROW in both 2016 and 2017.

Figure 2.1. Study plots (colored boxes) were located along a 22 km stretch of powerline ROWs near Rome, NY in Oneida County. Plots along the Fitzpatrick-Edic are grey = operational IVM . Plots along the Volney-Marcy are yellow = cut stump, blue = foliar, and red = brush hog.

Table 2.1. Location and description of 19 pollinator ROW study sites used in Central New York. Treatments were cut stump herbicide (CS), foliar herbicide (FH), brush hog mowing (BH), and operational IVM (OP).

Line	Plot	Treatment	Plot Coordinates	Notes
Volney-Marcy	126-2B	CS	43.35908, -75.54178	Inadvertently treated in late July 2017
	126-3	FH	43.35890, -75.54100	Inadvertently treated in late July 2017
	128-1	CS	43.35792, -75.53675	
	8-134-4	BH	43.35395, -75.52215	Inadvertently treated in late July 2017
	134-1B	FH	43.35320, -75.51940	
	8-135-1A	BH	43.35295, -75.51855	Inadvertently treated in late July 2017
	193-1	FH	43.30140, -75.34065	Only used in 2017, sampling disrupted in 2017, no operational IVM pair
	193-2	CS	43.30025, -75.33985	Used only in 2016
	195-2	CS	43.29900, -75.33720	Landowner issues – sampling disrupted in 2017
	8-199-3	BH	43.28290, -75.31511	
Fitzpatrick-Edic	126-2B	OP	43.35862, -75.54189	
	126-3	OP	43.35845, -75.54117	
	128-1	OP	43.35745, -75.53695	
	8-134-4	OP	43.35352, -75.52239	
	134-1B	OP	43.35273, -75.51962	Edge of plot mowed just prior to Aug 2016 sampling
	8-135-1A	OP	43.35249, -75.51876	
	193-2	OP	43.30118, -75.34127	
	195-2	OP	43.29858, -75.33766	
	8-199-3	OP	43.28253, -75.31544	

Field Sampling Methods

Overall sampling methods were modeled after previous pollinator research along ROWs (Hopwood 2008; Wagner et al. 2014). Plots were sampled once per month in June, July, and August 2016 and 2017 on favorable weather days. In 2016 and 2017, we used pan traps (blue and yellow plastic party bowls) secured to shelving brackets and supported by fiberglass rods. Rods were placed securely in the ground 10 m apart (Fig. 2.2) and trap colors alternated. Bowls were filled 1/3 full with soapy water and collected 24–26 hr after deployment (Wagner et al. 2014). Samples from pan traps were combined to the plot level, regardless of color.

Pan trap sampling was supplemented with a 20 min sweep netting effort (usually carried out by two people sweeping for 10 min), at peak daily activity times (as documented by Bramble et al. 1997) following methods modified from Wagner et al. (2014), as described below. In 2016, sweep netting consisted of sweeping continuously throughout the entire plot using a grid pattern (Fig. 2.2) for 20 effort minutes during the morning between 900–1100 hr and 20 additional effort minutes in the afternoon between 1200–1500 hrs. Due to concern about trampling vegetation and interfering with concurrent vegetation studies, sweep netting methodology was altered for 2017 sampling. In 2017, sweep netting consisted of sweeping back and forth along four 10 m linear transects for 20 effort minutes (Fig. 2.3). Differences in abundance of pollinators caught between years was dramatically different even when corrected for sampling effort differences. For this reason, sweep net catches were not compared between years – only within years – when evaluating treatment effects.

Captured specimens were considered pollinators if previous literature documented that species ability to transfer pollen. Each specimen was identified to the lowest taxonomic level possible, with most identified to species-level using Discover Life (http://www.discoverlife.org), as well as Bees of the Eastern United States I (Mitchell 1960) and Bees of the Eastern United States II (Mitchell 1962), Beetles of Eastern North America (Evans 2014), Insects and their Natural History and Diversity (Marshall 2006), The Butterflies of North America: A Natural History and Field Guide (Scott 1986), and Field Guide to Northeastern Longhorned Beetles (Yanega 1996). To verify identifications, representative specimens were compared to expertly identified material at Cornell University. Voucher specimens were deposited in the State University of New York College of Environmental Science and Forestry insect museum in Syracuse, New York.

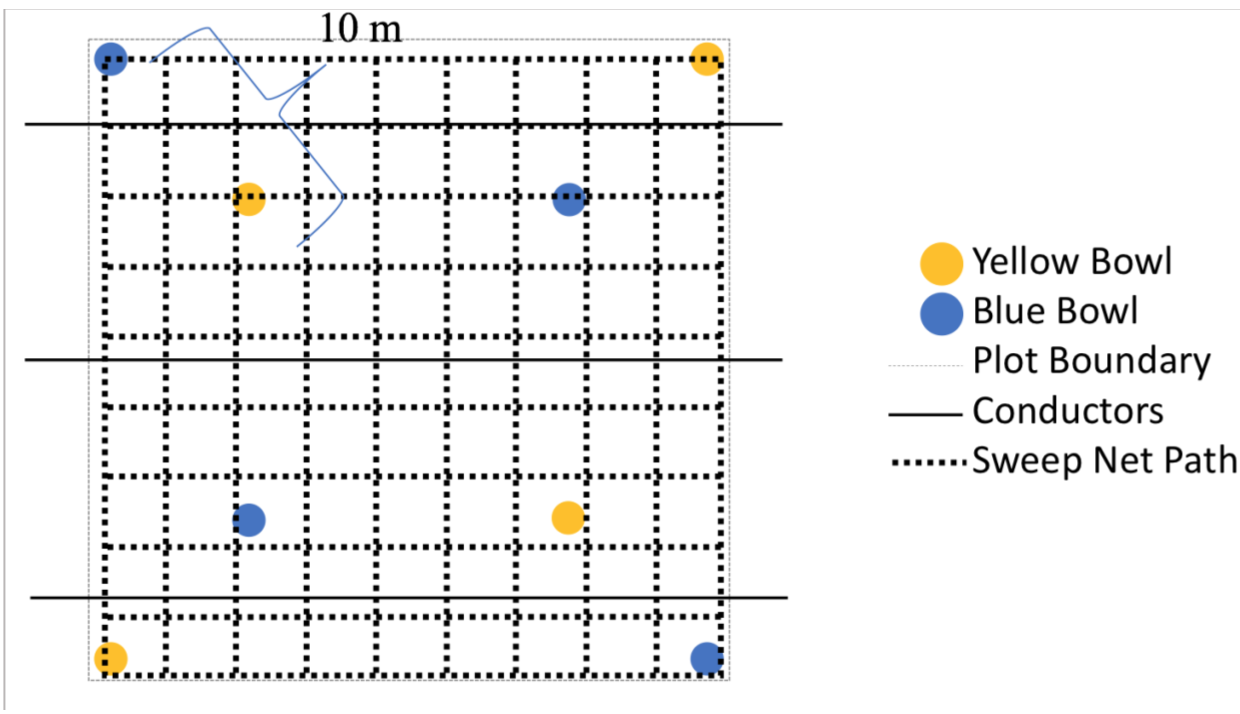

Figure 2.2. Sweep netting grid pattern used in 2016 in ROWs sampled for pollinators near Rome, NY.

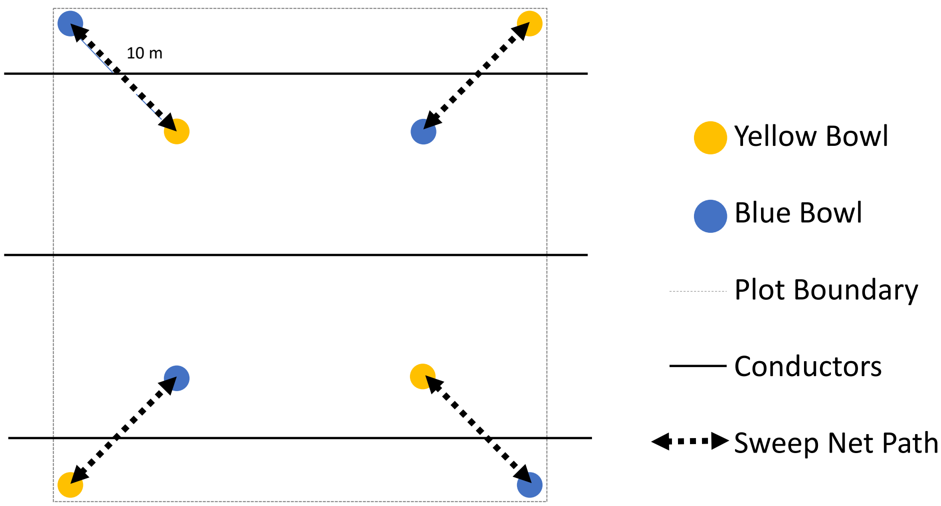

Figure 2.3. Sweep netting transect pattern used in 2017 in ROWs sampled for pollinators near Rome, NY.

Data Analysis

Pollinator data were analyzed at the family level due to some specimens being difficult to identify (e.g., Lasioglossum spp, and for some this was due to a cold storage malfunction in 2016). Pollinator abundance was standardized to a per plot basis (mean individuals/plot) to account for bowls lost during the 24 hr sampling period (generally due to curious wildlife). Pollinator abundance for pan traps was standardized to a per plot basis (mean individuals/plot) to account for bowls lost during the 24 hrs sampling period (generally due to curious wildlife) using the following equation (where n equals the number of bowls undisturbed):

$$Bowl\ Abundance = Raw\ Abundance \times \frac{8}{n}$$

An alpha level of 0.10 was used throughout to test for significance.

Paired t-tests were used to test for differences in pollinator abundance, family richness, diversity, and evenness between operational IVM plots (control) and BH, CS, and FH treatment groups (test groups). Analysis of variance (ANOVA) with Type III sums of squares was used to test for differences in pollinator abundance, family richness, diversity, and evenness among treatments and sampling months in 2017 using the *car* package in the R statistical programming environment (Fox et al. 2016). Shannon-Weiner diversity was calculated using function *diversity* in the *vegan* package (Oksanen et al. 2013). Evenness was calculated using function *Evar* in the *fundiv* program (Bartomeus 2013). This measure was used to demonstrate the distribution of abundance among pollinator families; it was chosen because it is independent of the number of families present and has been shown to have no severe problems as a measure of evenness, unlike other common measures (Smith and Wilson 1996). Tukey's HSD test was used to determine significant differences among groupings if ANOVA tests were significant.

Multivariate analyses were conducted using the *vegan* package in R to investigate assemblage differences among treatment and temporal groups and incorporate vegetation conditions (Oksanen et al. 2013). Permutational ANOVA (PERMANOVA) was used to test for differences in pollinator assemblages among treatment and months. Function *mrpp* was used to test separation of groupings. In order to run this analysis, a dummy species with an abundance of one for each replicate was added to community matrices, because there were some replicates with zero counts; mrpp analyses require all replicates to have a count above zero (Clarke et al. 2006). This method, known as zero-adjusted Bray-Curtis analysis (Clarke et al. 2006), is a way to restructure data so it can be analyzed with mrpp analyses (Correia et al. 2012; Gasca et al. 2012; Schmidt et al. 2012; Félix et al. 2013).

A matrix consisting of sampling site by date sampled (11 sites sampled on 3 sample dates and 8 sites with 6 sample dates, n = 81) and occasions by pollinator families (n = 37) was evaluated with nonmetric multidimensional scaling (NMS) to elucidate relationships between pollinator assemblages and treatment using *metaMDS*; this was then overlain with significant grouping variables, and vectors indicating correlations of matrix data and individual pollinator families with axes of the community ordination. Length and direction of vectors representing pollinator families indicated relative significance of the relationships to each axis. Function *envfit* tested environmental and treatment variables to determine if any of these were associated with pollinator assemblages. To compare NMDS ordinations, procrustes analyses were conducted using function *procrustes* (Jackson 1995).

Four plots (listed in Table 2.1) were sprayed with herbicides two weeks before August sampling in 2017. Though unfortunate, this incident allowed the opportunity to study immediate effects of herbicide on pollinator assemblages. To analyze impacts of herbicide treatments on this subset of plots, a paired t-test was used to compare measured pollinator assemblage variables of interest on those plots between August 2016 and August 2017. These plots were not removed from August 2017 analyses comparing experimental management techniques to one another, as they were not significantly different, and removing them decreased treatment replicates to the point where statistical analyses were not possible (n = 2 or n = 1 for treatment groups).

Results

Across both years, in all plots, using both pan traps and sweep netting, we collected 3,088 pollinators representing 5 orders and 37 families (Table 2.2). Hymenoptera and Diptera accounted for > 80% of pollinators caught compared to other orders. Apidae, Tabanidae, and Halictidae accounted for 50% of individuals caught (Table 2.3). The most abundant pollinators caught were *Chrysops spp.*, a common deer fly (Family Tabanidae), with 18 caught in pan traps and 399 in sweep netting. *Apis mellifera*, the European honeybee was also abundant with 23 caught in pan traps and 287 in sweep netting, as were *Lassioglossum spp*., with 89 caught in pan traps and 182 in sweep netting. All were caught in similar numbers across treatments. Asymmetry in rank-abundance order of pollinator families recovered from 120 matched samples for the two sampling methods, sweep netting and pan traps, demonstrated differences in pollinator assemblage and abundance recovered by each method (Figure 2.4). Three of the top most abundant taxa caught by sweep netting (Cantheridae, Tephritidae, Colletidae) had extremely low abundances in pan traps. Sweep netting caught 11 unique families not seen in pan traps, while pan traps caught 5 unique families not seen in sweep nets. There were also some pollinator families unique to vegetation management strategies: 3 families were unique to brush hog mowing plots, 3 families were unique to foliar herbicide plots, and 4 families were unique to operational IVM plots.

Table 2.2. Pollinator diversity in vegetation management plots along a powerline ROW in Oneida County, New York.

Order	**No. individuals**	**(% of total)**	**No. families**
Hymenoptera	1310	42.4	7
Diptera	1217	39.4	13
Coleoptera	490	15.9	10
Lepidoptera	47	1.5	10
Hemiptera	24	0.8	1
	3,088		40

Table 2.3 The ten most commonly sampled pollinator families (listed in decreasing total abundance) captured in pan traps and sweep nets along a powerline in Oneida County, NY (combining all plots and dates).

Family	**Order**	**No. caught in pan traps**	**No. caught with nets**	**Total**	**Cumulative %**
Apidae	Hymenoptera	87	497	584	18.9
Tabanidae	Diptera	40	456	496	35.0
Halictidae	Hymenoptera	136	320	456	49.77
Cantharidae	Coleoptera	4	382	386	62.27
Syrphidae	Diptera	66	248	314	72.44
Tephritidae	Diptera	3	273	276	81.38
Colletidae	Hymenoptera	5	126	131	85.62
Muscidae	Diptera	28	34	62	87.62
Curculionidae	Coleoptera	7	36	43	89.01
Crabronidae	Hymenoptera	2	38	40	90.31

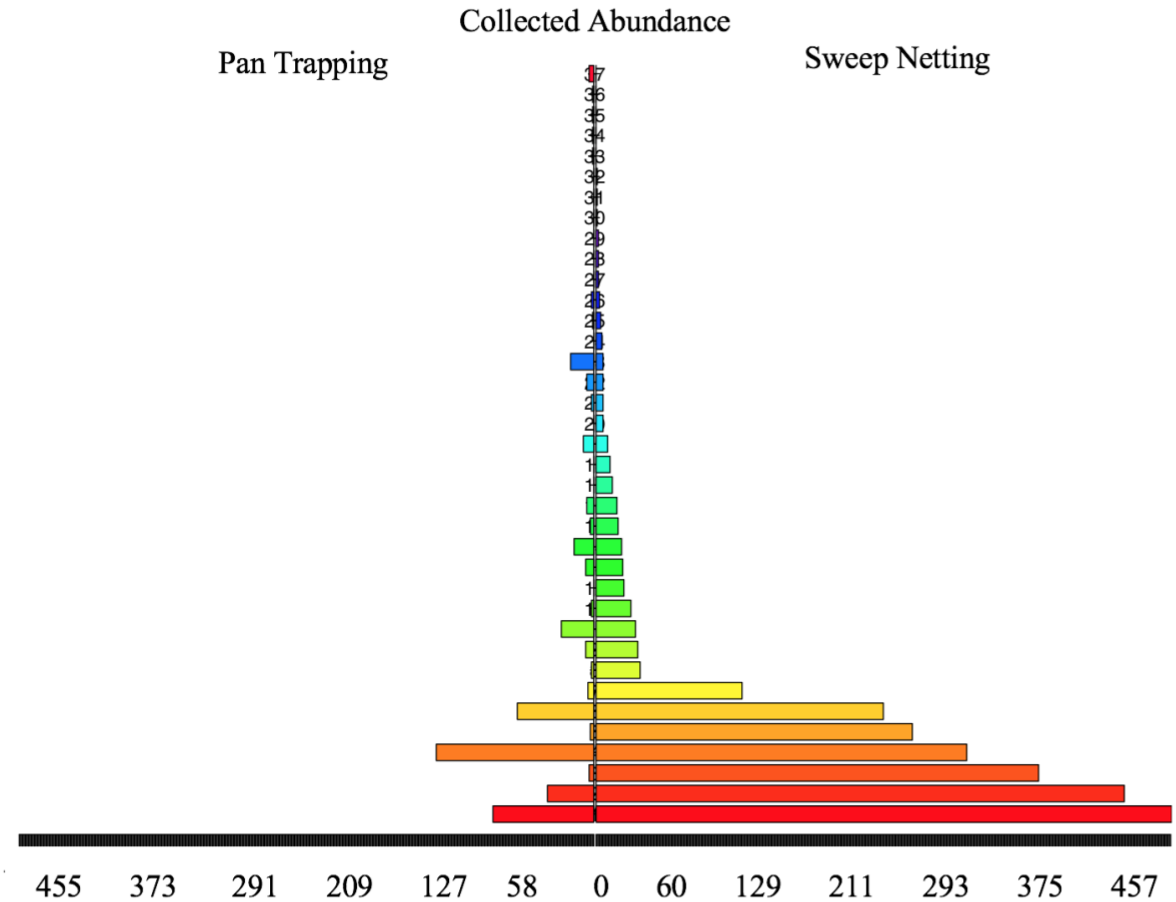

Figure 2.4. Complementarity plot for 120 matched sweep netting and pan trapping samples from 20 vegetation management plots along a powerline ROW in Oneida County, NY. Lines to right represent families ranked in the order of their summed abundance (all plots and dates) from sweep netting samples; lines to left correspond to same families (summed) abundance from pan trapping samples. Please see Table 2.3 to know families as these are given here based on abundance in sweep net samples (e.g., Apidae is represented by the bottom bar followed by Tabanidae, Cantharidae, and Halictidae).

Experimental Treatments vs Operational IVM

Community Measures

Pollinator assemblage parameters in 2016 varied among plots treated with operational IVM (control) and experimental plots (Table 2.4). Data analyses indicated pollinator parameters on Brush Hog plots varied most from control plots (Table 2.5) with abundance of pollinators caught in sweep nets in Brush Hog plots being significantly lower than paired control plots (Fig. 2.5).

Abundance of pollinators caught by pan traps in Foliar Herbicide plots was significantly higher than paired control plots (Fig. 2.6). In both sweep nets and pan traps, pollinators assemblages in Brush Hog plots had significantly lower richness and diversity than paired control plots (Fig 2.7; Fig 2.8).

Table 2.4. Mean (±SE) of various parameters of pollinator assemblages collected on experimental ROW vegetation management plots and operational (control) ROW management plots near Rome, New York in 2016 (n = 18). Treatments: OP = operational integrated vegetation management, CS = cut stump herbicide, FH = foliar herbicide, BH = brush hog.

	Sweep Nets			
	Abundance	**Richness**	**Diversity**	**Evenness**
CS	31.08 (7.58)	5.42 (1.24)	1.17 (0.23)	0.70 (0.06)
OP	40.50 (17.22)	6.42 (1.65)	1.14 (0.28)	0.71 (0.08)
FH	61.56 (18.10)	8.33 (1.50)	1.38 (0.20)	0.54 (0.08)
OP	57.11 (13.09)	7.44 (1.66)	1.23 (0.26)	0.55 (0.09)
BH	19.22 (8.86)	3.67 (1.62)	0.69 (0.29)	0.79 (0.08)
OP	36.33 (12.37)	6.33 (2.23)	1.08 (0.35)	0.71 (0.10)
	Pan Traps			
CS	4.08 (1.62)	1.67 (0.51)	0.47 (0.17)	0.92 (0.04)
OP	3.83 (1.30)	2.08 (0.66)	0.63 (0.19)	0.92 (0.03)
FH	8.78 (2.67)	3.67 (0.96)	1.00 (0.25)	0.86 (0.05)
OP	3.33 (1.13)	2.22 (0.78)	0.64 (0.23)	0.94 (0.03)
BH	2.33 (1.34)	1.33 (0.75)	0.36 (0.21)	0.83 (0.11)
OP	5.67 (2.39)	2.89 (0.77)	0.88 (0.23)	0.91 (0.05)

Table. 2.5. Paired t-test results for 2016 pollinator collection in paired ROW vegetation management plots near Rome, NY.

		Sweep Net			Pan Trap		
		df	**t**	**p-value**	**df**	**t**	**p-value**
Abundance	**OP-CS**	11	-0.59	0.57	11	0.13	0.90
	OP-FH	8	0.21	0.84	**8**	**2.35**	**0.05****
	OP-BH	**8**	**-2.52**	**0.04****	8	-1.35	0.21
Richness	**OP-CS**	11	-0.78	0.45	11	-0.63	0.54
	OP-FH	8	0.62	0.55	8	1.53	0.16
	OP-BH	**8**	**-2.70**	**0.03****	**8**	**-2.48**	**0.04****
Diversity	**OP-CS**	11	0.11	0.92	11	-0.75	0.47
	OP-FH	8	0.82	0.44	8	1.28	0.24
	OP-BH	**8**	**-2.13**	**0.06***	**8**	**-2.71**	**0.03****
Evenness	**OP-CS**	11	-0.18	0.92	11	-0.08	0.94
	OP-FH	8	-0.04	0.97	8	-1.76	0.12
	OP-BH	8	1.22	0.26	8	-0.72	0.49

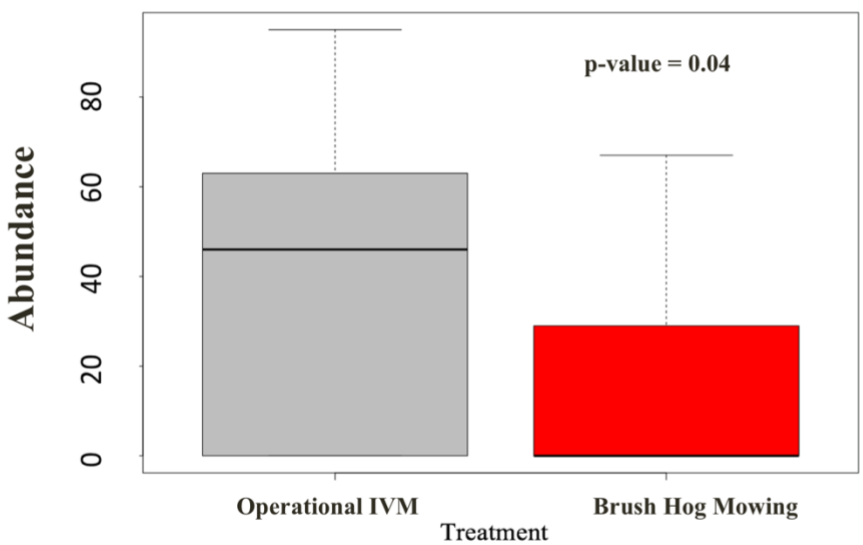

Figure 2.5. Abundance of pollinators in 2016 sweep nets on ROW operational management and Brush Hog vegetation management plots near Rome, NY.

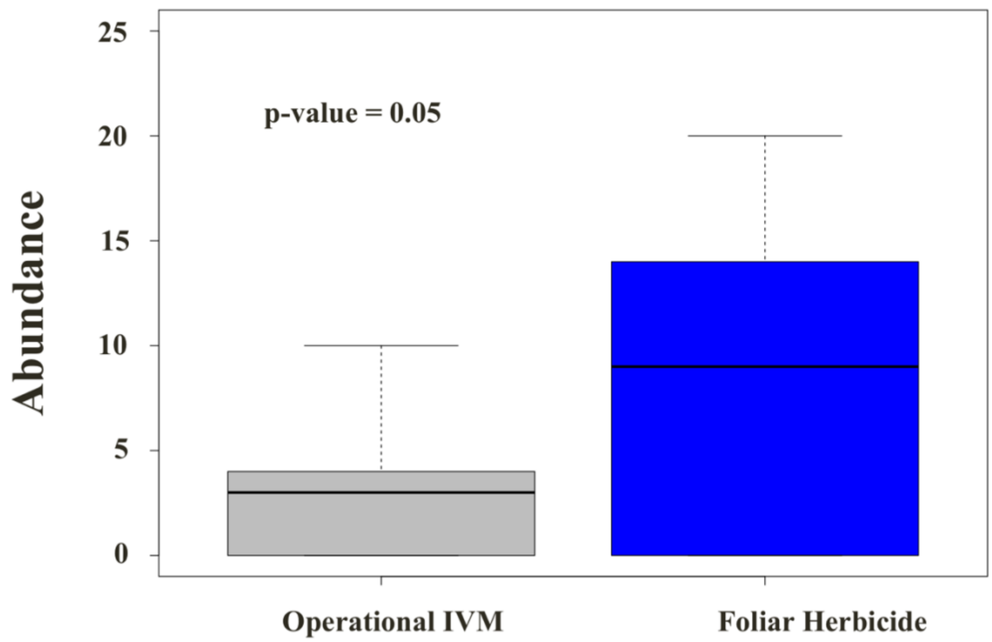

Figure 2.6. Abundance of pollinators in 2016 pan traps on ROW operational management and Foliar Herbicide vegetation management plots near Rome, NY.

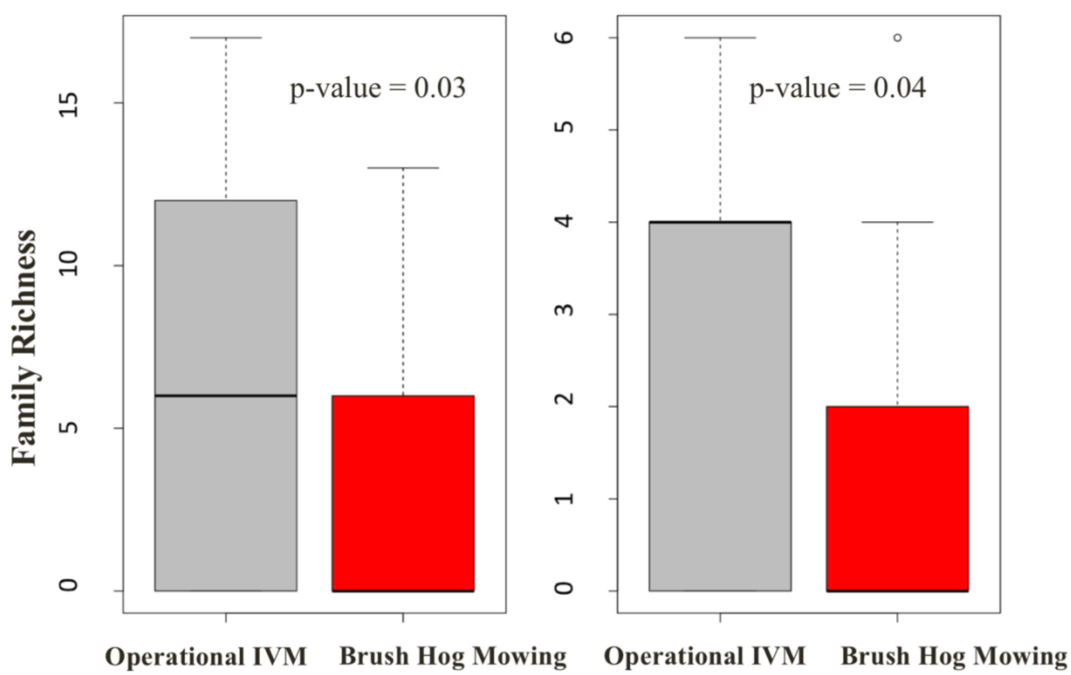

Figure 2.7. Family richness of pollinators in 2016 sweep nets (left) and pan traps (right) on ROW operational management and Brush Hog vegetation management plots near Rome, NY.

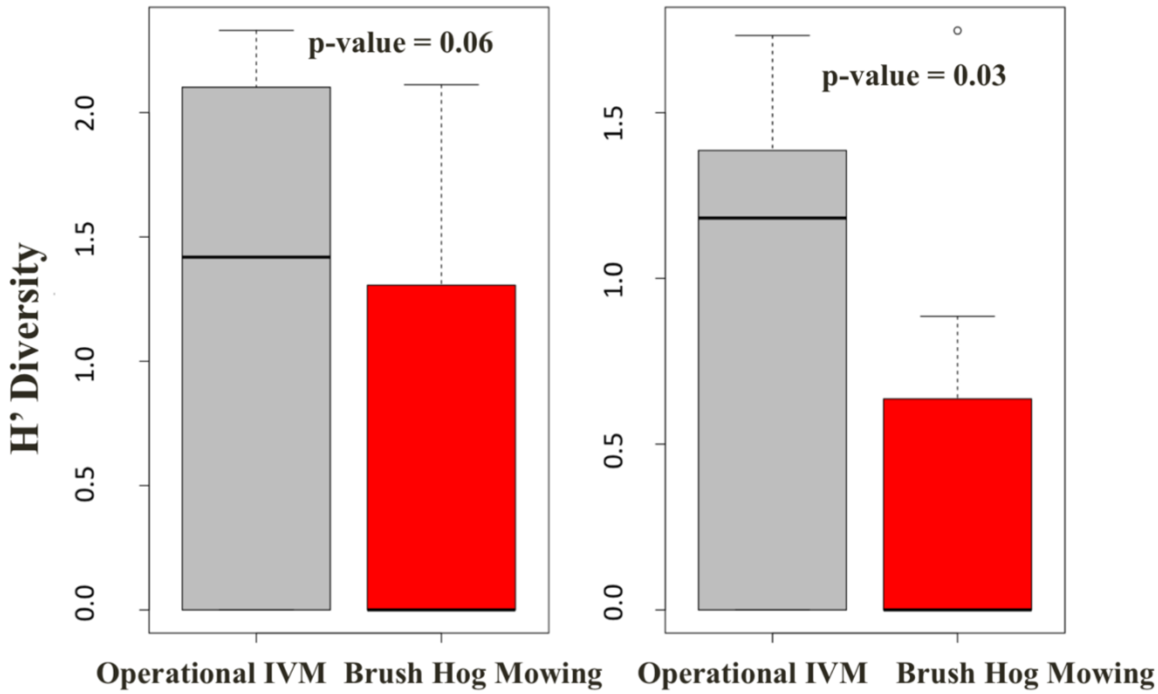

Figure 2.8. Diversity of pollinators in 2016 sweep nets (left) and pan traps (right) on ROW operational management and Brush Hog vegetation management plots near Rome, NY.

Assemblage Comparisons

Procrustes analyses demonstrated associations between experimental vegetation treatment plots and control plots (Table 2.6). Cut Stump Herbicide and Foliar Herbicide plot assemblages were not significantly different than associated control plots. Brush Hog plot assemblages, however, were significantly different than associated control plots.

Table 2.6. Procrustes analyses comparing experimental vegetation treatment plots to operational control plots on a ROW near Rome, NY.

Experimental Treatment	m^2	p-value
CS	0.79	0.18
FH	0.91	0.59
BH	**0.61**	**0.07 ***

Comparison Among Treatments

Community Measures

Pollinator assemblage parameters varied by sampling method, treatment, and month sampled in 2017 (Table 2.7). Data analyses indicated pollinator parameters varied significantly more by month sampled than by treatment (Table 2.8). In sweep netting, pollinator abundance did not vary with month, however foliar herbicide plots had significantly more pollinators than cut stump herbicide plots. Family richness (Fig 2.9b) and diversity (Fig. 2.9c) were highest in June and August, lowering significantly in July, while these measures did not vary by treatment. Pollinator family evenness in sweep nets in Cut Stump Herbicide plots was significantly higher than family evenness in Foliar Herbicide plots and did not vary by treatment (Fig. 2.9d). Pollinator parameters in pan traps did not vary by treatment. Pollinator abundance (Fig.2.10a), family richness (Fig. 2.10b), and diversity (Fig. 2.10c) in pan traps were highest in June and decreased throughout the season. Pollinator family evenness in pan traps was lowest in June and increased throughout the season (Fig. 2.10d).

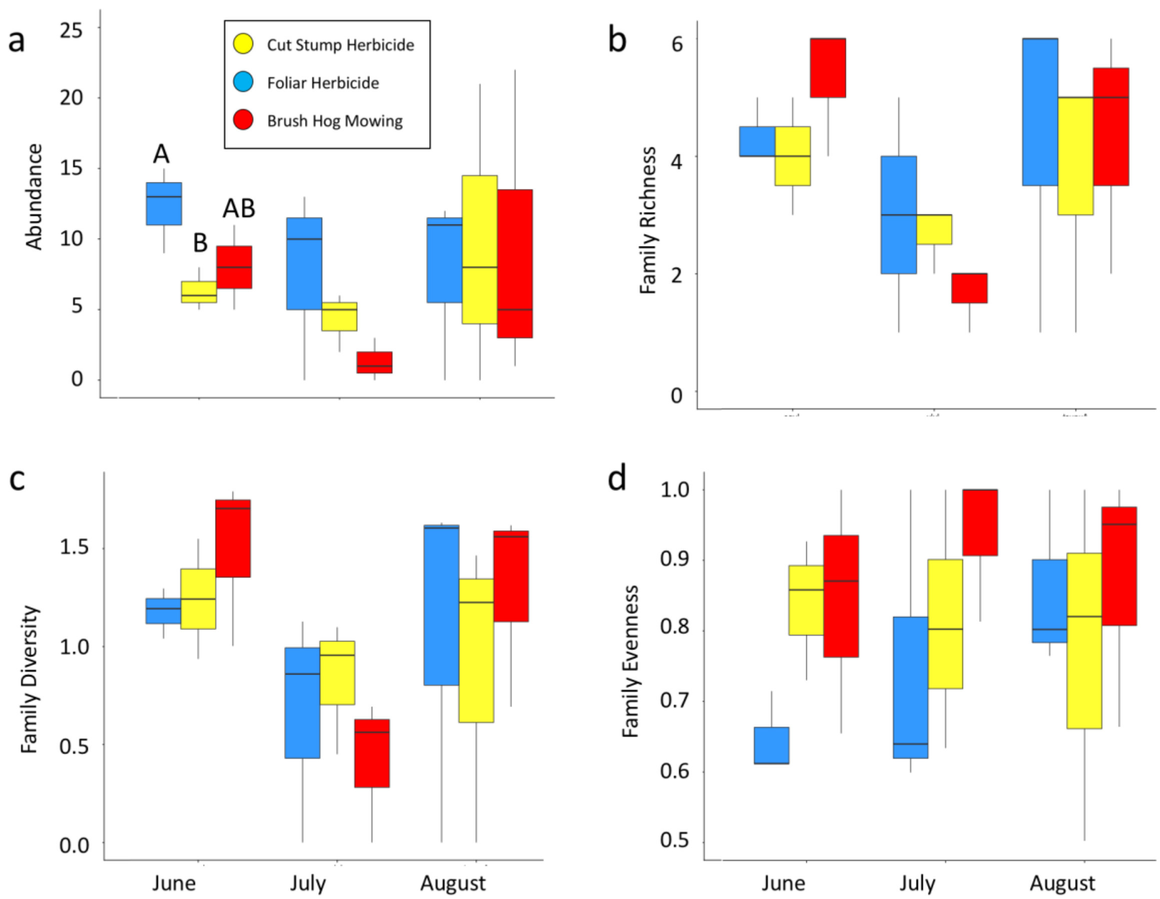

Figure 2.9. Pollinator parameters at the family level from sweep net samples in June, July, and August 2017 on ROW vegetation management plots near Rome, NY.

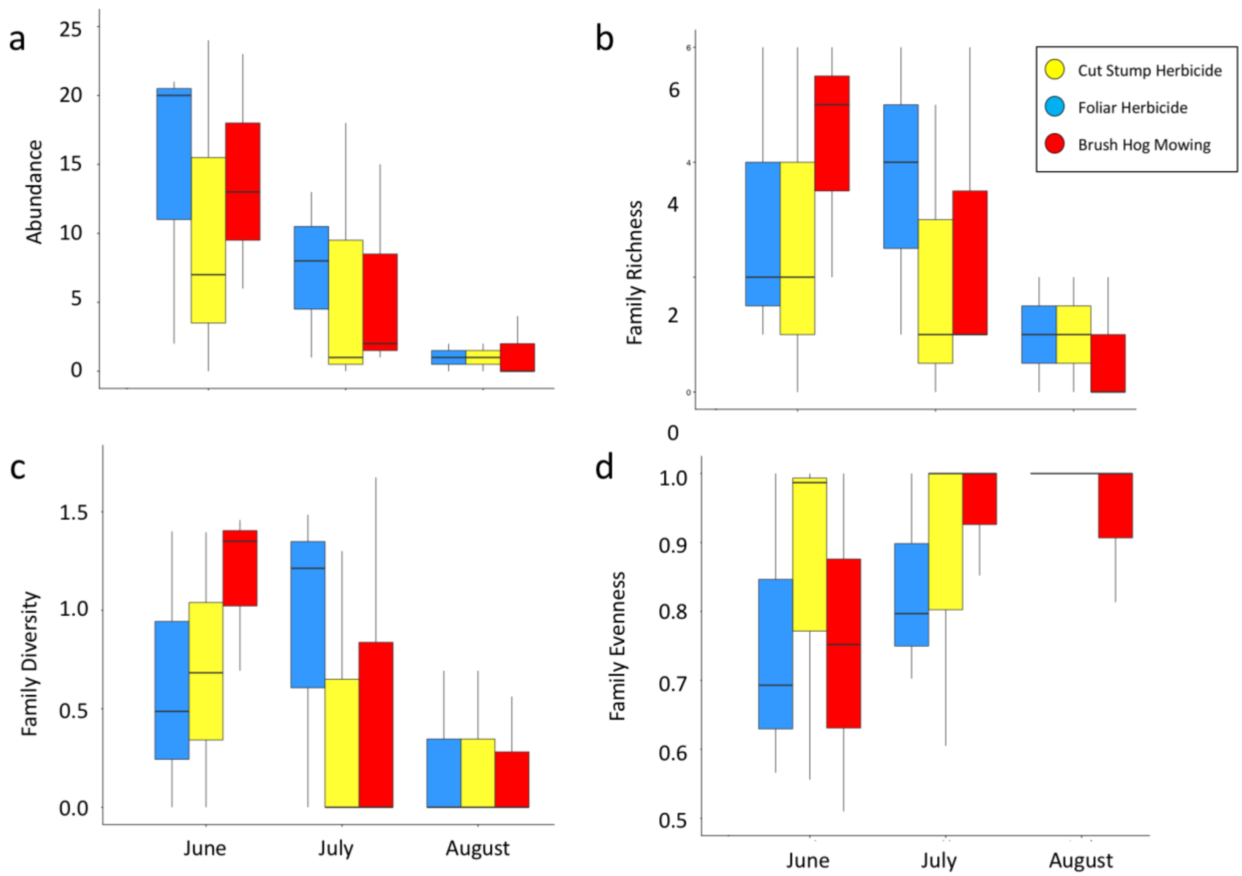

Figure 2.10 Pollinator parameters at the family level from pan trap samples in June, July, and August 2017 on ROW vegetation management plots near Rome, NY.

Table 2.7. Means (±SE) of various parameters of pollinator assemblages collected by sweep netting on ROWs in New York in summer 2017.

		Abundance (insects/sample)			Family Richness		
	Treatment	**June**	**July**	**August**	**June**	**July**	**August**
Sweep Netting	**BH**	8.0 (1.7)	1.3 (0.88)	9.3 (6.4)	4.3 (0.67)	0.67 (0.33)	3.7 (1.5)
	CS	4.8 (1.7)	3.3 (1.4)	7.3 (5.0)	2.3 (0.85)	1.3 (0.48)	2.0 (1.2)
	FH	12.3 (1.8)	7.7 (3.9)	7.7 (3.8)	3.3 (0.33)	2.0 (1.2)	3.3 (1.7)
Pan Traps	**BH**	14.0 (4.93)	6.0 (4.51)	1.3 (1.33)	4.3 (1.20)	2.7 (1.67)	0.67 (0.67)
	CS	7.8 (5.66)	4.8 (4.42)	0.75 (0.48)	2.0 (1.41)	1.5 (1.19)	0.75 (0.48)
	FH	14.3 (6.17)	7.3 (3.48)	1.0 (0.58)	3.0 (1.53)	3.7 (1.45)	1.0 (0.58)
		H' Diversity			**E_{var} Evenness**		
		June	**July**	**August**	**June**	**July**	**August**
Sweep Netting	**BH**	1.30 (0.28)	--	0.98 (0.50)	0.83 (0.12)	--	0.87 (0.10)
	CS	0.74 (0.28)	0.33 (0.19)	0.59 (0.34)	0.93 (0.04)	0.98 (0.02)	0.84 (0.11)
	FH	0.98 (0.07)	0.52 (0.27)	0.97 (0.49)	0.69 (0.04)	0.82 (0.13)	0.86 (0.07)
Pan Traps	**BH**	1.2 (0.24)	0.56 (0.56)	0.19 (0.19)	0.75 (0.14)	0.95 (0.05)	0.94 (0.06)
	CS	0.52 (0.33)	0.33 (0.33)	0.17 (0.17)	0.89 (0.11)	0.90 (0.10)	1.00 (0.00)
	FH	0.63 (0.41)	0.90 (0.46)	0.23 (0.23)	0.75 (0.13)	0.83 (0.09)	1.00 (0.00)

Table 2.8. ANOVA and PERMANOVA results for pollinator sampling in 2017 in ROW vegetation management plots near Rome, NY.

		Sweep Netting			Pan Traps		
		df	**F-value**	**p-value**	**df**	**F-value**	**p-value**
Abundance	Block	1	6.48	0.02	1	0.95	0.34
	Treatment	2	0.08	0.92	2	0.00	1.00
	Month	2	1.33	0.29	2	2.02	0.16
	Treatment:Month	4	0.48	0.75	4	0.08	0.99
	Residuals	18			18		
Richness	Block	1	1.84	0.19	1	1.20	0.20
	Treatment	2	0.27	0.77	2	0.02	0.98
	Month	2	**3.95**	**0.04****	2	2.01	0.16
	Treatment:Month	4	0.53	0.72	4	0.32	0.86
	Residuals	18			18		
Diversity	Block	1	1.86	0.19	1	2.02	0.17
	Treatment	2	0.14	0.87	2	0.00	1.00
	Month	2	**4.87**	**0.02****	**2**	**1.88**	**0.10 ***
	Treatment:Month	4	0.63	0.65	4	0.45	0.77
	Residuals	18			18		
Evenness	Block	1	0.09	0.77	1	0.73	0.41
	Treatment	2	0.28	0.76	2	0.13	0.88
	Month	2	0.94	0.41	2	1.20	0.32
	Treatment:Month	4	0.79	0.55	4	0.32	0.86
	Residuals	18			18		
Assemblage	Block	1	1.14	0.31	1	0.06	0.17
	Treatment	2	0.84	0.57	2	0.45	0.93
	Month	2	**1.82**	**0.07 ***	2	**3.10**	**0.01 ***
	Treament:Month	4	0.71	0.80	4	0.26	1.00
	Residuals	18			18		

Assemblage Associations

NMDS ordination of pollinator family assemblages in both sweep nets and pan traps were not significantly associated with treatment (Fig 2.11). Family assemblage was, however, significantly associated with sampling month for both sampling methods (Fig. 2.12). A family joint plot overlay revealed five families were negatively associated with pollinator assemblages in sweep nets and seven families highly associated with pollinator assemblages in pan traps ($p < 0.05$; Fig. 2.13).

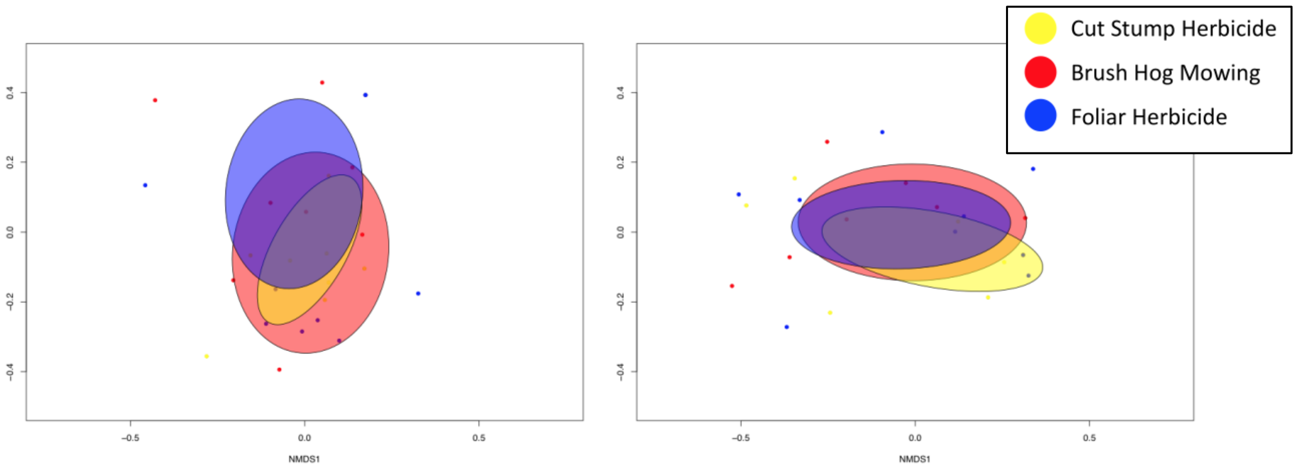

Figure 2.11. NMDS ordination of 2017 sweep net (left) and pan trap (right) assemblages in ROW vegetation management plots near Rome, NY. Dots indicate sites, ellipses indicate treatment. Sampling month is loaded onto x-axis with time increasing from left to right.

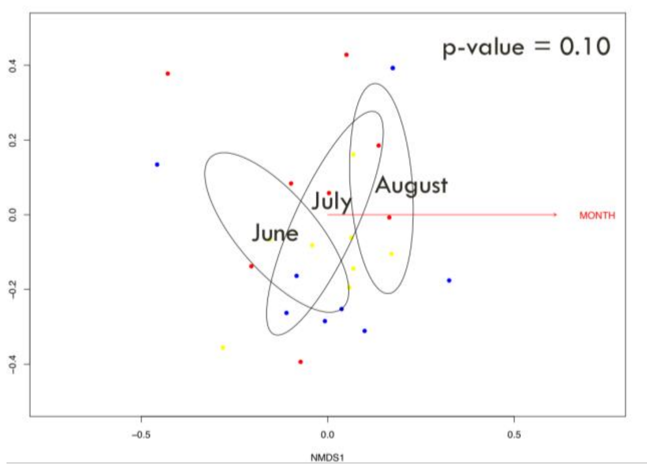

Figure 2.12. NMDS ordination of 2017 sweep net (left) and pan trap (right) assemblages in ROW vegetation management plots near Rome, NY. Dots indicate sites, ellipses indicate sampling month. Sampling month is loaded onto x-axis with time increasing from left to right, as indicated by “MONTH” vector.

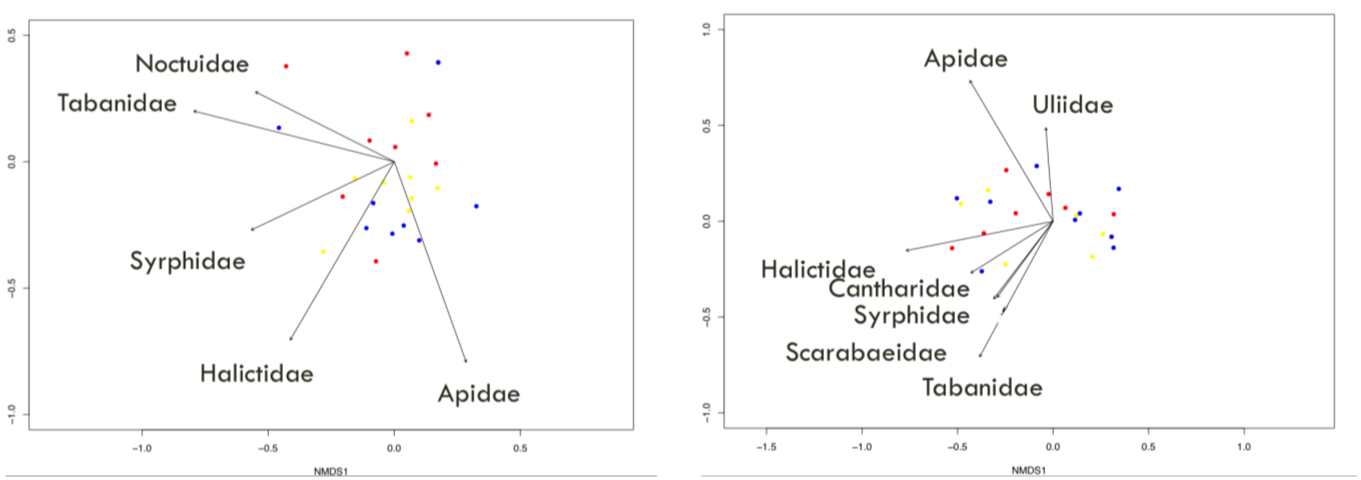

Figure 2.13. NMDS ordination of 2017 sweep net (left) and pan trap (right) assemblages in ROW vegetation management plots near Rome, NY. Dots indicate sites. Lines indicate pollinator families associated ($p < 0.05$) with x and y-axes. Sampling month is loaded onto x-axis with time increasing from left to right.

Immediate impact of vegetation treatment

There were no differences in measured pollinator parameters from pan trap captures between plots sprayed with herbicide in August of 2016 when compared to August 2017. Two of the plots (8-134-4-VM and 8-135-1A-VM) did not have any pollinators present in August of either year. Plot 126-2B-VM increased in abundance, richness, and diversity in 2017, while plot 126-3-VM decreased in pollinator abundance, richness, and diversity (Table 2.9).

Table 2.9. Differences among pollinator parameters for pan trap captures in August 2016 and immediately after treatment in August 2017 for four plots accidentally treated with herbicides. "Treatment" here refers to the original treatment group to which each site belonged. All areas were treated in the same manner with the same herbicide in July 2017.

		Abundance		**Richness**		**Diversity**		**Evenness**	
	Treatment	**2016**	**2017**	**2016**	**2017**	**2016**	**2017**	**2016**	**2017**
126-2B-VM	CS	0	2	--	2	--	0.69	--	1.00
126-3-VM	F	5	1	5	1	1.61	--	1.00	--
8-134-4-VM	BH	0	0	--	--	--	--	--	--
8-135-1A-VM	BH	0	0	--	--	--	--	--	--

Discussion

Comparison to similar studies

To our knowledge, there is no other published research documenting pollinators from multiple orders on powerline ROWs as previous studies focused mainly on bees (Apoidea). The number of apoid pollinators we captured (1225 in 19 plots) is less than what has been caught by previous studies relative to the number of plots used and overall sampling effort (2924 in 16 plots by Russell et al. 2005; 1274 in 14 sites by Hopwood 2008; and 3899 in 19 plots by Wagner et al. 2014). The most common bee families in our study (Apidae and Halictidae) were also most abundant on powerline ROWs in Connecticut (Wagner et al. 2014); however, two of the more abundant families found in that study, Andrenidae and Megachilidae, were not as common in this study (30 and 24, respectively). However, the relative number of European honeybees, *Apis mellifera*, was much higher in our study (25%) than in similar studies (0.7% for Russell et al. 2005; 3.4% for Wagner et al. 2014). This study also recovered four bee species that are uncommon/declining in New York state – *Andrena crategi* (declining in the Northeast), *Bombus auricomus* (declining), *Bombus ternarius* (declining), and *Osmia collinsiae* (uncommon). Similar studies have noted finding similar numbers of new/noteworthy species (Wagner et al. 2014).

Temporal patterns of a decline in pollinator abundance and richness from early to late season in pan trap assemblages observed in this study have also been seen in previous ROW studies in Maryland (Russell et al. 2005). In contrast, Hopwood (2008) reported bee abundance and richness peaked mid-season in Kansas. This is perhaps because in this study sweep net and pan trap assemblages were analyzed separately, while Hopwood (2008) combined all sampling efforts for analyses. Pan traps and sweep nets are known to catch different pollinator assemblages (Cane et al. 2000, Roulston et al. 2007). When combined, the assemblages caught by the two methods could perhaps follow different temporal patterns than the assemblages would when analyzed separately.

Experimental vegetation management vs. control plots

Foliar Herbicide and Cut Stump Herbicide plot assemblages were not significantly different than associated control plots in almost any way, while Brush Hog plot assemblages were significantly different than associated control plots in nearly every analysis. This is likely due to similarities and differences among these treatment types. Operational IVM treatments utilize a variety of techniques to manage vegetation, including foliar and cut stump herbicide applications. These three methods strategically remove only “pest” species and leave many of the same types of favorable plants, while Brush Hog treatments uniformly cut down all plants, regardless of their compatibility with ROW management standards.

Our findings inform the question of which management practices are/are not suited to foster pollinators. It is clear from this study that the Brush Hog treatment was not as beneficial to pollinator assemblages as treatments using more selective management, which underlies IVM practices. To further explore possible similarities and differences between Operational IVM, Cut Stump Herbicide, and Brush Hog Herbicide treatments, it is important to analyze pollinator resource availability, including floral resources, bare ground/ground nesting area, and nesting substrates. These factors could further elucidate which vegetation management treatments create environmental conditions best suited to pollinators. Additionally, it would be useful to elucidate slight differences in assemblage composition and determine the relative importance of these particular pollinators within the ROW system.

Temporal effects on community measures and sampling methods

Sweep net parameters were highest in June and August, while pan trap values generally demonstrated a gradient of high-to-low throughout the season (Table 2.7). This is likely due to the different assemblages caught by each sampling method. It is well-documented that pan traps and sweep nets collect a different assemblage of pollinators with pan traps often missing species caught by sweep nets (Cane et al. 2000; Roulston et al. 2007). This was true in our study, most notably with the 11 families unique to sweep netting (Lygaeidae, Cerambycidae, Mordellidae, Chrysomelidae, Elateridae, Lycaenidae, Meloidae, Sphingidae, Noctuidae, Pyrochroidae, and Stratiomyidae) and with Cantharidae (4 in pan traps to 382 in sweep nets), Tephritidae (3 in pan traps to 273 in sweep nets), and Colletidae (5 in pan traps to 126 in sweep nets). Reasons for this may include pollinator body size (ability to escape pan traps) and certain families not being attracted to pan traps.

Limited treatment effects

We detected very few treatment-level effects of IVM ROW management treatments on pollinator abundance, richness, diversity, evenness, or assemblage. If treatment effects on these measures exist, there are two possibilities as to why we did not detect any. First, this study took place six and seven years after the last treatment in 2010 (Nowak and Fierke 2016). It is possible that treatment effects on community measures could be significant in the year(s) directly following vegetation management; however, half-life effects could last less than six years, making them undetectable by our study. Secondly, there were no pre-treatment measurements to which we could compare our samples. This makes it impossible to know if there were any plot-level impacts on pollinator measures or assemblages.

Sweep net methodology changes

Sweep netting methodology changed drastically from 2016 to 2017. This was due to concern about interfering with vegetation studies occurring on the same plots. Sweep net surveys from 2016 were conducted throughout the entirety of the plots and in both the morning and afternoon and caught a total of 2427 pollinators. In 2017, this was pared down to sampling four quadrats in the afternoon and numbers were appreciably lower at 200 pollinators. The differences in abundance of pollinators caught between the years was dramatically different, even when data were corrected for the amount of sampling effort (40 min/plot in 2016 vs 20 min/plot in 2017). It is clear that samples along transects where collectors doubled back and resampled the same area for the length of time needed for effort-based measurements were not as effective as the grid-style sweeping conducted in 2016.

Immediate Impact of Vegetation Treatment

Four of our plots were treated in late July 2017, but we did not detect any immediate post-treatment effects when comparing pan trap results in those plots between August 2016 and 2017. However, our sample size was extremely small (n = 4), and abundance of pollinators caught in pan traps in August was limited (mean raw abundance in 2016 was < 2 pollinators per plot, while June averaged nearly eight and July averaged slightly over six). This low abundance could be due to a seasonal low in floral resource availability that have been observed in late summer (Tepedino and Stanton 1980). To better study these impacts, it would be necessary to sample plot immediately before and after herbicide treatment at a point in the season where pollinator activity is heightened (perhaps in July).

This study is the first to explore impacts of vegetation management on pollinators within the context of powerline ROWs. Management on powerline ROWs is currently solely focused on removal of "pest" species (i.e. tall trees) that can interfere with powerlines. This does not take pollinators into consideration. We found that overall, full-plot brush hog mowing has a negative impact on pollinator assemblages compared to IVM practices. While IVM practices are common in the northeast, there are still places where brush hogging is the only method of vegetation management that is used. IVM offers ROW managers a variety of tools with which to control vegetation height that can not only help pollinators, but it can also save utility companies and land managers significant amounts of money and man-hours in the long run.

Chapter 3

Invasive-exotic Plant Species Influence Pollinator Assemblages on Powerline Rights-of-ways in Northeastern Ohio

Abstract

Invasive exotic (IE) plant species pose one of the greatest threats to biodiversity as they compete with native species for space and resources, as well as pollination services. Impacts IE plants have on pollinators is understudied and within our system of interest, powerline rights-of-way (ROWs), impacts are virtually unknown. ROWs, as linear corridors managed in a way that likely promotes pollinator foraging, have only recently been studied as potential conservation/ restoration areas for pollinators. The goal of this study was to examine effects of integrated vegetation management (IVM), including removal of IEs on pollinator assemblage composition, abundance, richness, diversity, and evenness. Management techniques included: 1) removal of all woody plants, 2) removal of only undesirable tall-growing plants, and 3) removal of tall-growing trees and woody IE species. Pollinator assemblages were sampled in July and August 2016 and again in May, July, and September 2017 with pan traps and sweep nets, three years post-treatment. There were significant differences in measured pollinator parameters among treatments and seasonally. Ordination and species indicator analyses indicated presence of two IE species, showy fly honeysuckle (*Lonicera bella*), and glossy buckthorn (*Frangula alnus*), were associated with changes in pollinator assemblages. We did note IE plants were again present in our IE removal plots when pollinator sampling was conducted three years post-treatment, indicating management was not sustained in the vegetation community and so would need retreatment on a regular basis to remain IE-free.

Keywords: Pollinators, rights-of-way, powerlines, vegetation management, invasive-exotic plants, *showy fly honeysuckle*, *Frangula alnus*, *Rubus*

Introduction

Pollination is an essential ecosystem function. Over 87% of the world's angiosperms are pollinated by animals, with insects being a majority of these pollinators (Kluser and Peduzzi 2007). Many important agricultural crops rely on insect pollination (Watanabe 1994) and so pollinators have a direct impact on human diets, aiding in reproduction of common food crops (e.g., potatoes, citrus fruits, squashes). Pollinators also indirectly impact human diets as they contribute to pollination of alfalfa (Olmstead and Wooten 1987), an important food source for cattle, which provide both dairy products and meat for human diets. In addition to their important contributions to food availability, pollinators play an important role economically with insects annually contributing an estimated $15 billion in services for crop production, which includes an estimated $11.7 billion attributable to honey bees alone (Watanabe 1994; Calderone 2012). Beyond impacts on human populations, insect pollinators are vital within the global environment, aiding in the success of flowering plants that contribute to primary energy production, provide habitat to a variety of life forms, feed consumers, and add to environmental diversity.

Unfortunately, pollinating insect populations are declining (Pollinator Health Task Force 2015a). In the last 140 years alone, there have been significant declines in overall bee species richness and abundance of three species, *Bombus affinis* Cresson, *Bombus pensylvanicus* (DeGeer), and *Bombus ashtoni* (Cresson), all of which are experiencing recent and rapid population collapses (Bartomeus et al. 2013). Many factors are contributing to pollinator declines including climate change (Hickling et al. 2006; Williams et al. 2007), land use change (Ricketts et al. 2008; Winfree et al. 2009), pesticides (Cresswell 2011; Gill et al. 2012; Henry et al. 2012; Palmer et al. 2013), and introduction of alien species, including pests (Stout and Morales 2009), pathogens (Eyer et al. 2009), and plants.

Invasive exotic (IE) plant species pose one of the greatest threats to biodiversity in an ecosystem (Fritts and Rodda 1998; Wilcove et al. 1998), often outcompeting native plants for space and resources (Crawley 1987). Not only do these IE plants negatively impact native plants, but they also can impact native pollinators. IE plants also tend to be “super generalists” when it comes to pollinators (Bartomeus et al. 2008), while native plants rely on more specialized relationships with pollinators (Stouffer et al. 2014). Similar terms describe pollinator relationships with the flowers they pollinate, i.e. either they are generalists pollinating a variety of plants, or they are specialists serving one particular, or a few closely related, species. Generalist pollinators, especially those belonging to orders Hymenoptera or Hemiptera, are more likely to visit invasives, while specialists tend to only interact with exotics when they are also semi-social or when the IE is closely related to their native mutualist (Lopezaraiza-Mikel et al. 2007; Stouffer et al. 2014). The question remains, however, as to whether introduction of IE species, e.g., honeysuckle (*Lonicera* spp.), buckthorn (*Frangula* spp.), multiflora rose (*Rosa multiflora* Thunb.), negatively or positively impact plant-pollinator networks.

Effects IE plants have on native plant species likely depend on the extent of invasion, density of invasives, how attractive the IE flowers are, how nutritious their nectar is, whether or not they are closely related to any existing native species, and the particular species of invader (Aizen et al. 2008; Bartomeus et al. 2008; Morales and Traveset 2009). In cases where there is a single invading IE species, it may integrate into the plant-pollinator network without disturbing native species (Vilà et al. 2009). In these particular cases, the IE species may facilitate native plant-pollinator interactions (Lopezaraiza-Mikel et al. 2007), increase pollinator species richness (Stouffer et al. 2014), and increase overall pollinator abundance by attracting pollinators not otherwise sustained by a particular area (Bartomeus et al. 2008). In the majority of cases, however, IEs do not positively impact plant-pollinator networks, rather they reduce pollinator visitation to native plants (Brown et al. 2002) and lower native plant fitness by lowering seed set due to lost pollination services (Muñoz and Cavieres 2008). Effects IEs have on pollinators are also influenced by environmental context. For example, in mature hedgerow sites, wild bees were more abundant, rich, and diverse on native plants, but in restored areas bee richness and diversity were the same on both native and invasive plant hosts (Morandin and Kremen 2013).

Powerline rights-of-way (ROWs) are large spans of linear corridors held in early succession and dominated by herbaceous plants and small shrubs, rather than large woody plants, making them an excellent option to manage for pollinator habitat (Wojcik and Buchmann 2012). These areas provide both foraging and nesting habitat, such as bare areas for ground-nesting Hymenoptera (Kevan 2001). The potential for ROWs is huge – with such a large area managed by strict regimens, they have characteristics favorable to preserve and restore pollinators.

Invasive-exotic plants expand quickly in long, connected spans of land (Benninger-Truax et al. 1992; Jodoin et al. 2008; Kalwij et al. 2008). This has been well-documented specifically on powerline ROWs (Zink et al. 1995; Cameron et al. 1997; Merriam 2003; Dubé et al. 2011). This is due to increased light availability (Bramble and Byrnes; Luken et al 1992; Rubino et al 2002; Wagner et al 2014b), disturbances to upper layers of soil (Hobbs 1988; Johnston 2004; Jodoin 2008), reduction of native competitors (Parendes 2000), and decrease of wind barriers to IE pollen and seed dispersal (Hill 1995; Parendes 2000). Powerline ROWs have a higher occurrence of IE species than surrounding areas (Wagner et al 2014b). Within the specific context of powerline ROWs, the exact effects of IE's on pollinators are unknown. The overall goal of this research is to examine the effects of IEs on pollinators on powerline ROWs. Specific objectives are to compare abundance, richness, diversity, evenness, and assemblage of pollinators with IE presence and abundance.

Materials and Methods

Study Sites

The Juniper-Harding electric transmission line and its associated ROW run through northeastern Ohio in the greater Cleveland area. Vegetation is maintained by FirstEnergy on a four-year cycle using integrative vegetation management (IVM) practices to remove undesirable tall-growing plants that could interfere with powerline transmission. These ROWs run through Cuyahoga Valley National Park and the Cleveland Metro Parks, both of which are heavily used by the public in a variety of ways and run through multiple wildlife management areas.

Treatments

This research used five blocks of three experimental plots (Fig. 3.1, Table 3.1). Plots were originally established in 2013 for a FirstEnergy and Electrical Power Research Institute (EPRI) study on associations between presence and movement of IE plants and IVM (Nowak and Ballard 2016). One plot of each treatment type of increasing disturbance (Table 3.2) per block was established (Figs 3.2 and 3.4). Treatments included: 1) remove all woody plants (denoted in the color “blue” throughout this paper), 2) remove only undesirable tall-growing trees (denoted as “yellow”), and 3) remove undesirable tall-growing trees and woody IE species (denoted as “grey”). All vegetation was managed by foliar herbicide application using IVM principals. Plot sizes ranged from 0.04–0.08 ha. This observational study on pollinators was conducted three years post-IVM treatment.

Table 3.1. Location and description of integrated vegetation management study sites used to assess pollinators in northeastern Ohio.

Block	Year Treated	Dates Surveyed	Treatments	Plot Coordinates	Overall Block Comments
Hub Park East	2013	Late July and August 2016	Remove tall-growing trees Remove all woody plants Remove tall-growing trees and IEs	41.365524, -81.589757 41.365548, -81.590196 41.365569, -81.590625	• Close to industrial park • South slopes uphill • Steep drop-off on east • Thick woods to north • Plots surrounded by active ATV trails • Deer and other wildlife present
Hub Park West	2013	Late July and August 2016	Remove tall-growing trees Remove all woody plants Remove tall-growing trees and IEs	41.365439, -81.594445 41.365401, -81.594842 41.365434, -81.596670	• Elevation decreases in west • Thick woods to north • River to west • Yellow plot dominated by tall-growing vegetation • Deer and other wildlife present • Access adjacent to south side of plots
Substation East	2014	May, early July, and September 2017	Remove tall-growing trees Remove all woody plants Remove tall-growing trees and IEs	41.353613, -81.837749 41.353814, -81.835944 41.353600, -81.836897	• Blue plot extremely muddy and wet during May and July • Quadrat areas heavily wooded, deer paths throughout • Deer and other wildlife present • Mowed corridors for plot access
Substation West	2014	May, early July, and September 2017	Remove tall-growing trees Remove all woody plants Remove tall-growing trees and IEs	41.353312, -81.841135 41.353325, -81.841669 41.353312, -81.842035	• Area surrounding block flooded in May and July • Mowed corridors for plot access • Grass in mowed corridors nearly 2 m tall in September • Deer and other wildlife present
Mills Run	2014	May, early July, and September 2017	Remove tall-growing trees Remove all woody plants Remove tall-growing trees and IEs	41.353438, -81.850047 41.353476, -81.850448 41.353501, -81.850933	• Walking path to east • Small wood line to north and south • Deer and other wildlife present

Figure 3.1 Study blocks were along a 16 km stretch of powerline ROWs in Cuyahoga County, Ohio. HPE and HPW were in Cuyahoga Valley National Park (right); MR, SW, and SE were in the Cleveland Metro Parks (left).

Table 3.2. Vegetation treatment groups used on ROWs in Cuyahoga County, Ohio categorized by level of vegetation disturbance. Disturbance value indicates relative amount of disturbance caused by each treatment type.

Treatment	Level of disturbance	Disturbance Value
Remove tall-growing trees	Least	1
Remove tall-growing trees and woody IEs	↓	2
Remove all woody plants	Most	3

Field Sampling Methods

Overall sampling methods were modeled after previous pollinator research along ROWs (Hopwood 2008; Wagner et al. 2014). In 2016, the six plots treated in 2013 (Table 3.1) which were located in the Hub Park East and Hub Park West blocks (Fig 3.2) were sampled once per month in late July (7/12–7/14/16) and August (8/2–8/4/16) and in 2017 the nine plots treated in 2014 and located in the Substation East, Substation West, and Mills Run blocks (Fig 3.4) were sampled in May (5/16/17), July (7/3/17), and September (9/4/17). Sampling was carried out on favorable weather days using pan traps (blue and yellow plastic party bowls) secured to shelving brackets and supported by fiberglass rods. Rods were placed securely in the ground 10 m apart (Fig. 3.3; Fig. 3.5) and trap colors alternated. Bowls were filled 1/3 full with soapy water and collected 24–26 hr after deployment (Wagner et al. 2014). Samples from pan traps were combined to the plot level, regardless of color.

Pan trap sampling was supplemented with a 20 min sweep netting effort, in general carried out by two people sweeping for 10 min, at times documented to be peak daily activity times (Bramble et al. 1997) following methods modified from Wagner et al. (2014). In 2016, sweep netting consisted of sweeping continuously throughout the entire plot using a grid pattern (Fig. 3.3) twice daily for 20 effort minutes during the morning between 900–1100 hrs and 20 effort minutes in the afternoon between 1200–1500 hrs. In 2017, sweep netting consisted of sweeping back and forth along two 20 m linear transects for 20 effort minutes (Fig. 3.5). This modification was instituted due to concerns with vegetation trampling and because of these sampling differences, sweep net catches were not comparable, or combinable, between years.

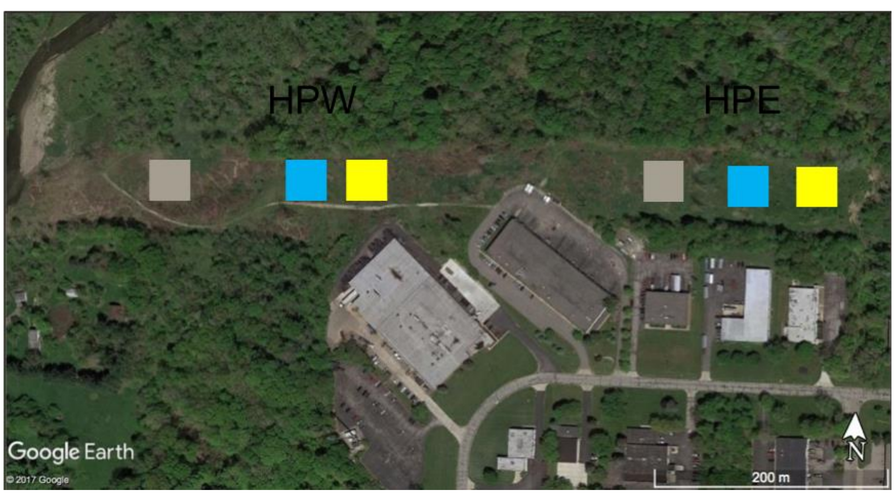

Figure 3.2. Layout of integrated vegetation management plots in the Hub Park East and Hub Park West blocks (blue = remove all woody plants, yellow = remove only undesirable, tall-growing trees, grey = remove tall- growing trees and woody invasive exotic species).

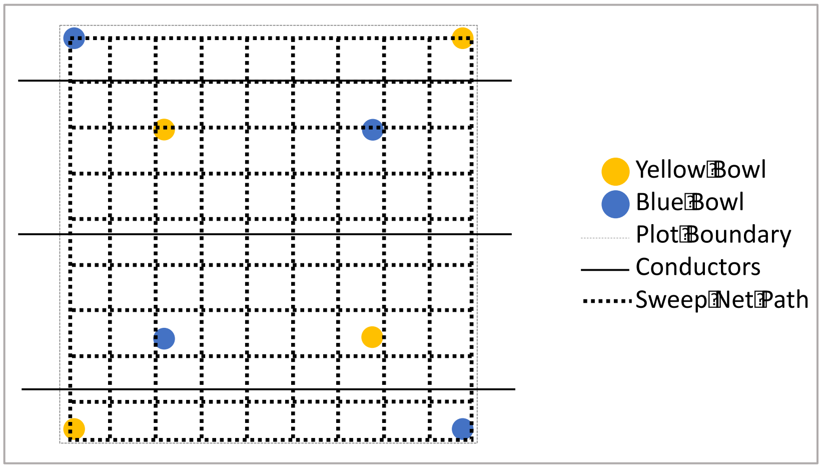

Figure 3.3. Plots in HPE and HPW blocks were square – pan traps were placed 10 m apart on the corners of concentric squares and left for 24 hr, while sweep netting was carried out twice for 20 effort minutes in a grid-pattern in the morning and afternoon.

Figure 3.4 Layout of integrated vegetation management plots in the Substation East, Substation West, and Mills Run blocks (blue = remove all woody plants, yellow = remove only tall-growing trees, grey = remove tall-growing trees and woody invasive exotic species).

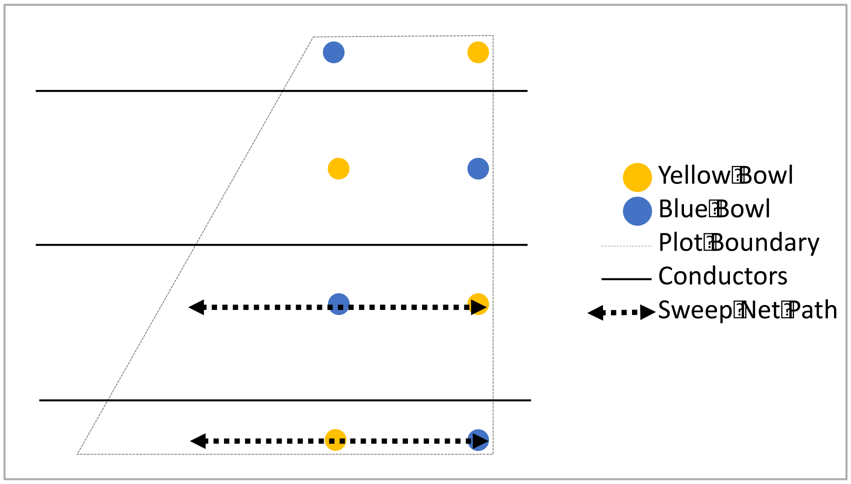

Figure 3.5. Integrated vegetation management plots in the SE, SW, and MR blocks were irregularly shaped. Pan traps were placed 10 m apart in two parallel lines that were also 10 m apart, alternating colors. Sweep netting was carried out for 20 effort minutes along two 20 m transects.

Captured specimens were considered pollinators if previous literature documented that species ability to transfer pollen. Every effort was made to identify each pollinator to the lowest taxonomic level possible, with most identified to species-level using Discover Life (http://www.discoverlife.org), as well as Bees of the Eastern United States I (Mitchell 1960) and Bees of the Eastern United States II (Mitchell 1962), Beetles of Eastern North America (Evans 2014), Insects and their Natural History and Diversity (Marshall 2006), The Butterflies of North America: A Natural History and Field Guide (Scott 1986), and Field Guide to Northeastern Longhorned Beetles (Yanega 1996). To verify identifications, representative specimens were compared to expertly identified material provided by Cornell University. Voucher specimens were deposited in the State University of New York College of Environmental Science and Forestry insect museum in Syracuse, NY.

Data Analyses

Pollinator data were analyzed at the family level due to some specimens being difficult to identify (e.g., *Lasioglossum*, and for others this was due to a cold storage malfunction in 2016). A large outlier collection of *Olibrus spp.* beetles (>1500 individuals collected) was omitted from analyses as it was much more abundant than any other group and due to this beetle's size and morphology, it is likely not a critical pollinator. Pollinator abundance for pan traps was standardized to a per plot basis (mean individuals/plot) to account for bowls lost during the 24 hr sampling period (generally due to curious wildlife) using the following equation (where n equals the number of bowls undisturbed):

$$Bowl\ Abundance = Raw\ Abundance\ \times \frac{8}{n}$$

To isolate comparison of treatments to one another, pan trap data from July 2016 and 2017 for each block were combined into one data set to reflect 5 replicates of each treatment. This was the most robust data available from a similar time frame since treatments were applied (in 2013 and 2014, see Table 3.1). To further elucidate possible treatment-effects, the reduced data set from 2017 (n = 3 replicates of each treatment) for both pan trap and sweep net collections were analyzed. Abundance was calculated by adding standardized pan trap abundances to unaltered sweep net catches. An alpha level of 0.10 was used throughout to test for significance.

Analysis of variance (ANOVA) with Type III sums of squares was used to test for differences in pollinator abundance, family richness, diversity, and evenness among treatments using the *car* package in the R statistical programming environment (Fox et al. 2016). Shannon diversity was calculated using the function *diversity* in the *vegan* package (Oksanen et al. 2013). Evenness was calculated using *Evar* in the *fundiv* program (Bartomeus 2013). This measure was used to demonstrate the distribution of abundance among pollinator families; it was chosen because it is independent of the number of families present and has been shown to have no severe problems as a measure of evenness, unlike many other common measures (Smith and Wilson 1996). *Post- hoc* multiple comparisons were conducted using Tukey's HSD. Multivariate analyses were conducted using the *vegan* package to investigate assemblage differences among treatment and temporal groups and incorporate vegetation conditions (Oksanen et al. 2013).

Permutational ANOVA (PERMANOVA) was used to test for differences in pollinator assemblages among treatment and months. Function *mrpp* was used to test separation of groupings. In order to run this analysis, a dummy species with an abundance of one for each replicate was added to community matrices, because there were some replicates with zero counts; mrpp analyses require all replicates to have a count above zero (Clarke et al. 2006). This method, known as zero-adjusted Bray-Curtis analysis (Clarke et al. 2006), is a way to restructure data so it can be analyzed with mrpp analyses.

A matrix consisting of sampling site by date sampled (6 sites sampled on 2 sample dates in 2016 and 9 sites with 3 sample dates in 2017, n = 39) by pollinator families (n =35) was evaluated with nonmetric multidimensional scaling (NMS) to elucidate relationships between pollinator assemblages and measured vegetation variables using *metaMDS*. NMS plots were rotated to load sampling month onto Axis 1. This was then overlain with significant grouping variables, vectors indicate correlations of matrix data and individual pollinator families with ordination axes. Length and direction of vectors representing pollinator families indicate relative significance of variables with each axis. Function *envfit* tested environmental and treatment variables to determine if any of these were associated with pollinator assemblages.

Results

Across both years, in all plots, using both pan traps and sweep netting, we collected 2,340 pollinators representing 4 orders and 33 families (Table 3.3). Hymenoptera and Diptera accounted for >80% of pollinators caught compared to other orders, and Apidae, Halictidae, and Syrphidae accounted for >65% of individuals caught (Table 3.4). The most abundant pollinator caught was *Toxomerus marginatus*, a common hover fly (Family Syrphidae), with 163 caught in pan traps and 217 in sweep netting. *Apis mellifera*, the European honeybee, was also abundant with 14 caught in pan traps and 207 in sweep netting, as were *Lassioglossum spp*., with 103 caught in pan traps and 195 in sweep netting. All were caught in similar numbers across treatments. Asymmetry in rank-abundance order of pollinator families recovered from 39 matched samples from two sampling methods, sweep netting and pan traps, demonstrates differences in pollinator assemblage and abundance recovered by each method (Fig. 3.6). Sweep netting caught 6 unique families not seen in pan traps, while pan traps caught 4 unique families not seen in sweep nets. There were also some pollinator families unique to vegetation management strategies: 1 family was unique to plots where tall-growing trees were removed, 6 families were unique to plots where tall-growing trees and woody invasive exotic species were removed, and 3 were unique to plots where all woody plants were removed.

Table 3.3. Pollinator diversity in integrated vegetation management treatment plots along a powerline ROW in Cuyahoga County, Ohio.

Order	Abundance	(% of total)	No. Families
Hymenoptera	1345	57.5	8
Diptera	633	27.1	11
Coleoptera	289	12.4	6
Lepidoptera	82	< 0.1	8

Table 3.4. The five most commonly sampled pollinator families (listed in decreasing total abundance) captured in pan traps and sweeping along a powerline ROW in Cuyahoga County, OH (combining all plots and dates).

Family	Order	No. Traps	No. Sweeps	Total	Cumulative %
Apidae	Hymenoptera	86	489	578	24.7
Halictidae	Hymenoptera	148	420	571	49.1
Syrphidae	Diptera	176	242	418	67.0
Cantharidae	Coleoptera	47	97	145	73.2
Tabanidae	Diptera	61	71	132	78.8

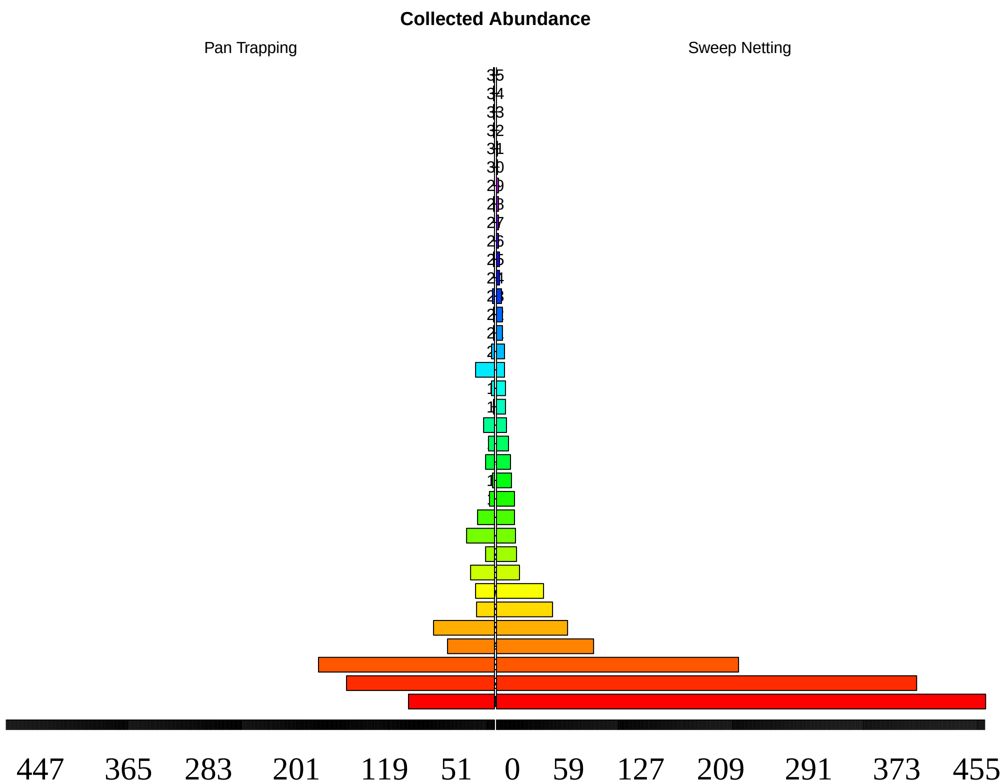

Figure 3.6. Complementarity plot for 39 matched sweep netting and pan trapping samples from 15 integrated vegetation management plots along a powerline ROW in Ohio. Lines to right represent families ranked in the order of their summed abundance (all plots and dates) from sweep netting samples; lines to left correspond to the same families (summed) abundance from pan trapping samples. Please see Table 3.4 to know most abundant families as these are given here based on abundance in sweep net samples (e.g., Apidae is represented by the bottom bar followed by Halictidae).

Comparison of Vegetation Management Techniques

Community Measures

Analysis of pan trap data from all five blocks (n = 15 plots) in July 2016 and July 2017, three years post-treatment, indicated pollinator assemblage parameters varied by treatment (Table 3.5). Abundance ranged from 7.8–15.6. Richness ranged from 3.8–6.2. Diversity ranged from 1.1–1.4. Evenness ranged from 0.7–0.9.

Table 3.5. Means (±SE) of various parameters of pollinator assemblages captured in pan traps deployed in July 2016 and 2017 in 15 experimental integrated vegetation management treatment plots on a powerline ROW in Cuyahoga County, OH.

Treatment	Abundance (insects/plot)	Family Richness	H' Diversity	E_{var} Evenness
Remove all woody plants	13.8 (1.8)	4.6 (0.9)	1.2 (0.2)	0.7 (0.1)
Remove tall-growing trees and woody IE species	15.6 (4.8)	6.2 (1.4)	1.4 (0.2)	0.8 (0.1)
Remove undesirable, tall-growing trees	7.8 (1.4)	3.8 (0.8)	1.1 (0.2)	0.9 (0.03)

Analyses indicated pollinator parameters varied with both block and treatment (Table 3.6). Family richness in plots where tall-growing trees and woody IE species were removed was significantly higher than plots where only tall-growing trees were removed (Fig. 3.7).

Table 3.6. ANOVA and PERMANOVA results for analyses of pollinators captured in pan traps deployed in July 2016 and 2017 in five experimental ROW integrated vegetation management blocks (n = 15 plots) along a powerline ROW in Cuyahoga County, OH.

		df	F value	p-value
Abundance	Block	4	1.37	0.33
	Treatment	2	1.97	0.20
	Residual	8		
Richness	**Block**	**4**	**12.14**	**0.002****
	Treatment	**2**	**6.14**	**0.02**
	Residual	8		
Diversity	**Block**	**4**	**5.05**	**0.03****
	Treatment	2	0.76	0.50
	Residual	8		
Evenness	Block	4	0.51	0.73
	Treatment	2	1.10	0.38
	Residual	8		
Assemblage	**Block**	**4**	**1.86**	**0.007****
	Treatment	2	0.82	0.67
	Residual	14		

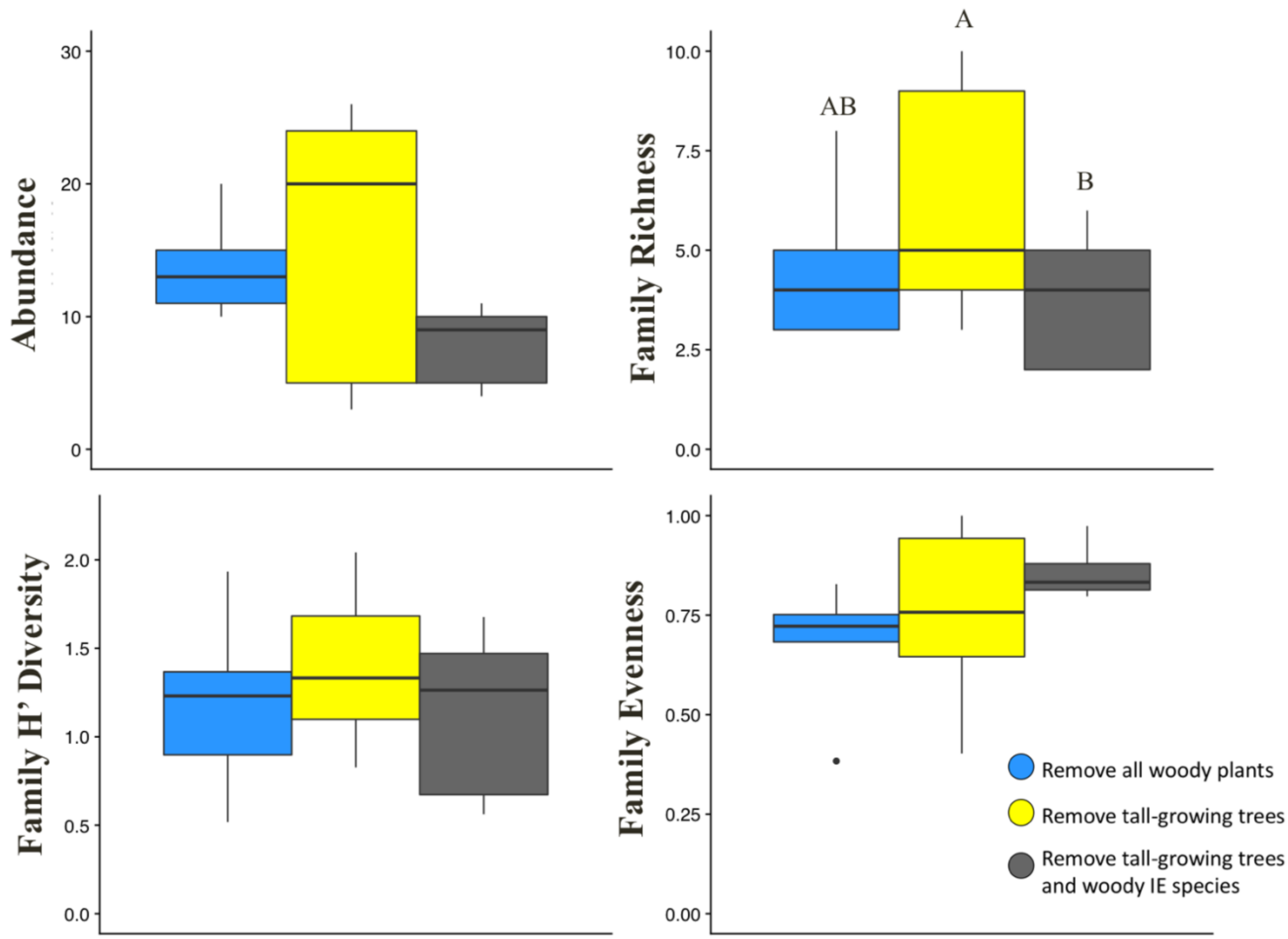

Figure 3.7. Mean (±SE) of community measures for pollinators captured in July 2016 and July 2017 in pan traps deployed in 15 experimental integrated vegetation management plots along a powerline ROW in Ohio. Letters indicate significant differences among treatments using Tukey's HSD at $\alpha = 0.10$.

Assemblage Associations

Pollinator family assemblages caught in pan traps were not significantly associated with treatment; NMDS ordination followed by overlaying a family joint plot revealed seven families highly associated with overall assemblages ($p < 0.05$; Fig. 3.8). Additionally, two families, Crabronidae and Calliphoridae, were positively correlated with level of disturbance caused by vegetation management.

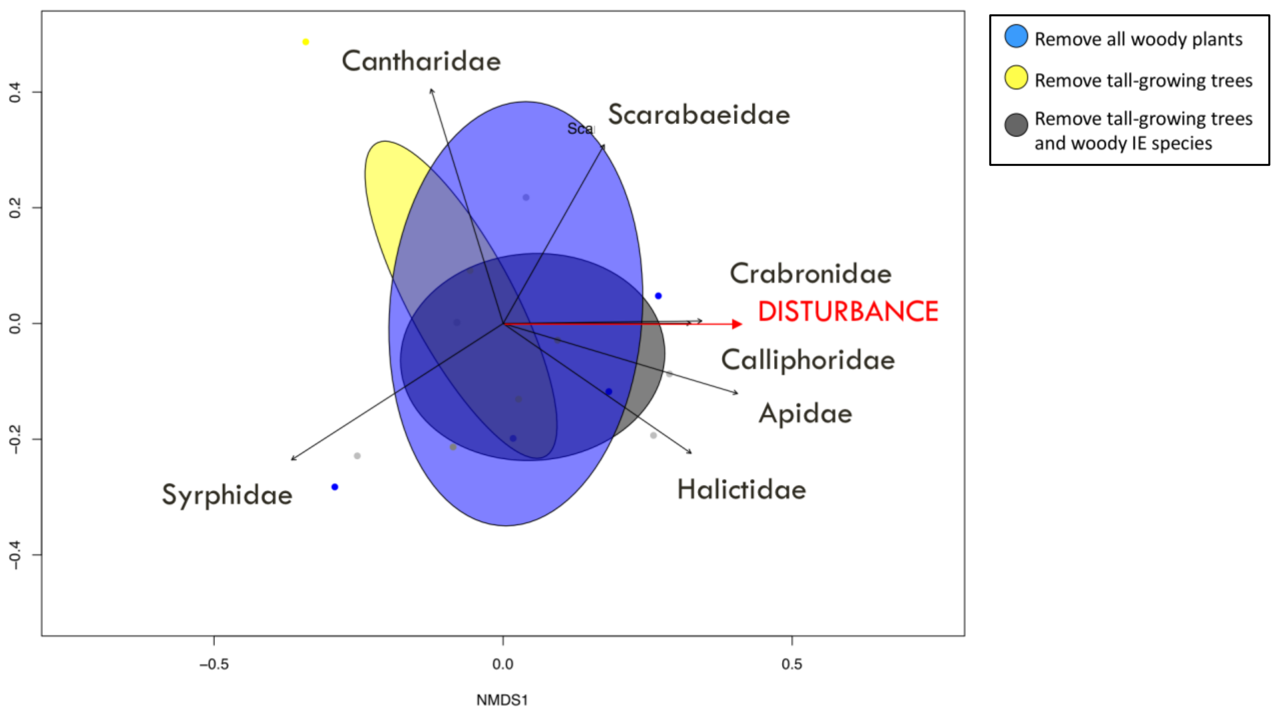

Figure 3.8. NMDS ordination of mid-season pan trap assemblages from 2016 and 2017 in 15 experimental ROW integrated vegetation management plots in Cuyahoga County, Ohio. Dots indicate sites and ellipses indicate treatments. Disturbance level of treatment has been loaded onto the x-axis. Vectors indicate pollinator families associated ($p < 0.05$) with x and y-axes.

Comparison of treatments throughout flowering season

Community Measures

Combined pan trap and sweep data from three blocks (n = 9 plots) in May, July, and August of 2017, three years post-treatment of integrated vegetation management, suggest variability in pollinator assemblage parameters by sampling method, treatment, and month sampled (Table 3.7). Data analyses indicated month was the most important factor in differences in pollinator parameters for both sweep nets and pan traps (Table 3.8). For pan traps, all parameters varied by month, however, for sweep netting the largest month effects were on richness, diversity, and overall assemblage.

Table 3.7. Means (±SE) of various parameters of pollinator assemblages captured in integrated vegetation management plots in 2017 on a powerline ROW in Cuyahoga County, Ohio.

	Treatment	**Month**	**Abundance (insects/sample)**	**Family Richness**	**H' Diversity**	**E_{var} Evenness**
Sweep Nets	Remove all woody plants	May	33.7 (16.2)	5.7 (1.8)	1.1 (0.14)	0.50 (0.10)
		July	41.3 (13.9)	9.3 (0.88)	1.8 (0.16)	0.54 (0.13)
		September	33.3 (13.2)	3.3 (0.67)	0.79 (0.32)	0.37 (0.20)
	Remove tall-growing trees and woody IE species	May	17.7 (8.4)	5.00 (2.0)	1.0 (0.52)	0.74 (0.13)
		July	44.0 (19.8)	5.3 (0.67)	1.2 (0.11)	0.47 (0.08)
		September	36.7 (11.8)	3.7 (0.33)	0.89 (0.19)	0.46 (0.11)
	Remove undesirable, tall-growing trees	May	19.3 (7.7)	3.7 (0.88)	0.96 (0.15)	0.66 (0.16)
		July	53.7 (24.6)	7.0 (1.5)	1.5 (0.15)	0.54 (0.17)
		September	38.7 (9.4)	3.7 (0.67)	0.76 (0.10)	0.45 (0.01)
Pan Traps	Remove all woody plants	May	71.0 (26.4)	7.0 (1.3)	1.4 (0.14)	0.37 (0.05)
		July	14.3 (3.0)	3.3 (0.33)	0.88 (0.21)	0.61 (0.11)
		September	2.3 (1.9)	1.3 (0.88)	0.34 (0.34)	0.96 (0.04)
	Remove tall-growing trees and woody IE species	May	29.3 (9.5)	7.7 (1.9)	1.6 (0.20)	0.60 (0.07)
		July	11.3 (7.4)	4.0 (0.58)	1.1 (0.15)	0.78 (0.19)
		September	6.0 (1.0)	2.7 (0.88)	0.74 (0.38)	0.89 (0.06)
	Remove undesirable, tall-growing trees	May	22.3 (4.8)	6.7 (1.2)	1.5 (0.10)	0.58 (0.04)
		July	6.7 (2.2)	2.7 (0.67)	0.83 (0.22)	0.86 (0.06)
		September	2.3 (0.88)	1.7 (0.33)	0.42 (0.21)	0.94 (0.06)

Table. 3.8. ANOVA and PERMANOVA results for pollinator sampling in 2017 in ROW integrative vegetation management plots in Cuyahoga County, OH.

		Sweep Nets			Pan Traps		
		df	**F value**	**p-value**	**df**	**F value**	**p-value**
Abundance	Block	2	2.38	0.12	2	2.38	0.12
	Treatment	2	0.07	0.93	**2**	**3.33**	**0.06**
	Month	2	1.67	0.22	**2**	**13.85**	**< 0.001**
	Treatment:Month	4	0.24	0.91	**4**	**2.08**	**0.08****
	Residuals	16			16		
Richness	**Block**	2	0.68	0.52	**2**	**3.15**	**0.07****
	Treatment	2	1.35	0.29	2	1.32	0.30
	Month	**2**	**7.29**	**0.006****	**2**	**27.72**	**< 0.001*****
	Treatment:Month	4	1.11	0.39	4	0.09	0.98
	Residuals	16			16		
Diversity	**Block**	**2**	**3.70**	**0.05****	2	1.13	0.35
	Treatment	2	0.61	0.56	2	1.34	0.29
	Month	**2**	**8.63**	**0.003****	**2**	**13.46**	**< 0.001*****
	Treatment:Month	4	0.73	0.58	4	0.08	0.99
	Residuals	16			16		
Evenness	Block	2	0.09	0.91	2	0.39	0.68
	Treatment	2	0.14	0.87	2	2.12	0.15
	Month	2	1.25	0.31	**2**	**15.38**	**< 0.001*****
	Treatment:Month	4	0.39	0.82	4	0.98	0.45
	Residuals	16			16		
Assemblage	Block	2	1.22	0.27	2	1.30	0.21
	Treatment	2	0.54	0.89	2	1.21	0.27
	Month	**2**	**4.72**	**0.001*****	**2**	**4.70**	**0.001*****
	Treatment:Month	4	0.58	0.93	4	1.01	0.48
	Residuals	16			16		

Abundance of pollinators in sweep nets did not vary with month or treatment (Table 3.8, Fig. 3.9a). Pollinator family richness in sweep nets in July was significantly higher ($p = 0.006$; Table 3.9b) than in May and September. Diversity in sweep nets in July was significantly higher ($p = 0.003$) than in May and September; however, diversity did not vary with treatment (Fig. 3.9c). Evenness did not vary by treatment or month (Fig. 3.9d).

To further investigate pollinator assemblage patterns throughout the flowering season, collections from each month were analyzed separately. In May and September, there were no treatment-level effects; however, in July, pollinator family richness in plots where all woody plants were removed was significantly higher than pollinator family richness in plots where only tall-growing trees were removed ($F_{2,2}$ = 6.81, p = 0.05; Fig. 3.9b).

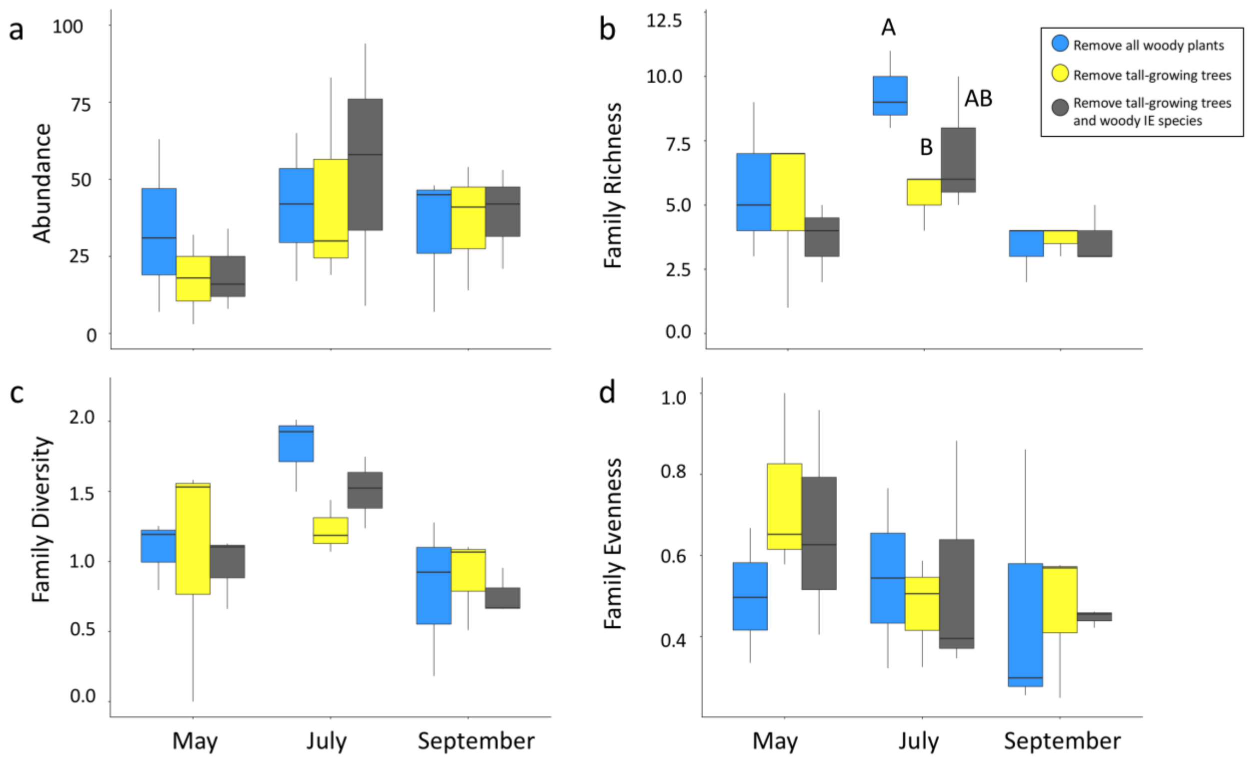

Figure 3.9. Mean (±SE) of community measures for pollinators captured in sweep nets in 2017 along a powerline ROW in Cuyahoga County, Ohio. Letters indicate significant differences among months using Tukey's HSD at α = 0.10.

Abundance of pollinators captured in pan traps varied by month (Table 3.8) with abundance in May significantly higher than in July (p = 0.006) and September (p = 0.001; Fig. 3.10a). Pollinator family richness in pan traps in May was significantly higher than in July (p < 0.01 and September (p = 0.001; Fig. 3.10b). Diversity in pan traps in May was significantly higher than in July (p = 0.03) and September (p < 0.01), and diversity in July was significantly higher than in September (p=0.09), but diversity did not vary with treatment (Fig. 3.10c). Evenness in pan traps in May was significantly lower than in July (p = 0.02) and September (p = 0.008), and evenness in July was significantly lower than in September (p = 0.07; Fig. 3.10d).

To further investigate pollinator assemblage patterns throughout the flowering season, collections from each month were analyzed separately. In September, there were no treatment-level effects. In July pollinator family richness in plots where tall-growing trees were removed was significantly higher than pollinator family richness in plots where tall-growing trees and woody IE species were removed ($F_{2,2} = 8.00$, $p = 0.05$; Fig. 3.10b). In May, pollinator family evenness was lowest in plots where all woody plants were removed ($F_{2,2} = 12.24$, $p = 0.03$; Fig. 3.10d).

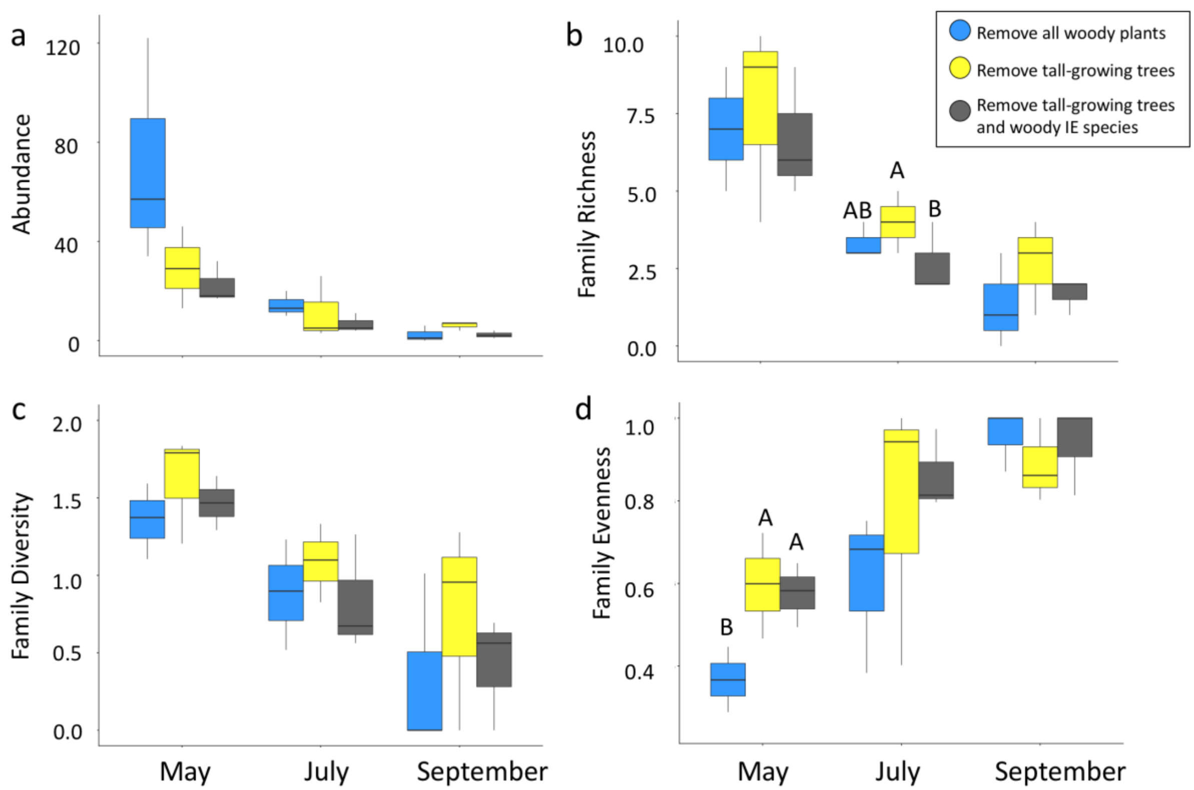

Figure 3.10. Mean (±SE) of community measures for pollinators captured in pan traps in 2017 along a powerline ROW in Cuyahoga County, Ohio. Letters indicate significant differences among months using Tukey's HSD at α = 0.10.

Assemblage Associations

Pollinator family assemblages in neither pan traps nor sweep nets were associated with treatment (Fig. 3.11), however assemblages from both sampling methods were associated with sampling month (p = 0.001; Table 3.8; Fig. 3.12). Family joint plot overlays revealed five families highly correlated with sweep net assemblages and five families highly correlated with pan trap assemblages (Fig. 3.13). Sampling month was loaded onto the x-axis. In sweep nets, weevils (Family Curculionidae) were most negatively associated with sampling month. In pan traps, no family was significantly associated with sampling month. A vector representing treatment disturbance levels was overlain. In sweep nets, the families Hesperiidae and Halictidae were most negatively associated with disturbance levels. In pan traps, no families appeared to be negatively associated with disturbance levels and the families Tabanidae and Halictidae were positively associated

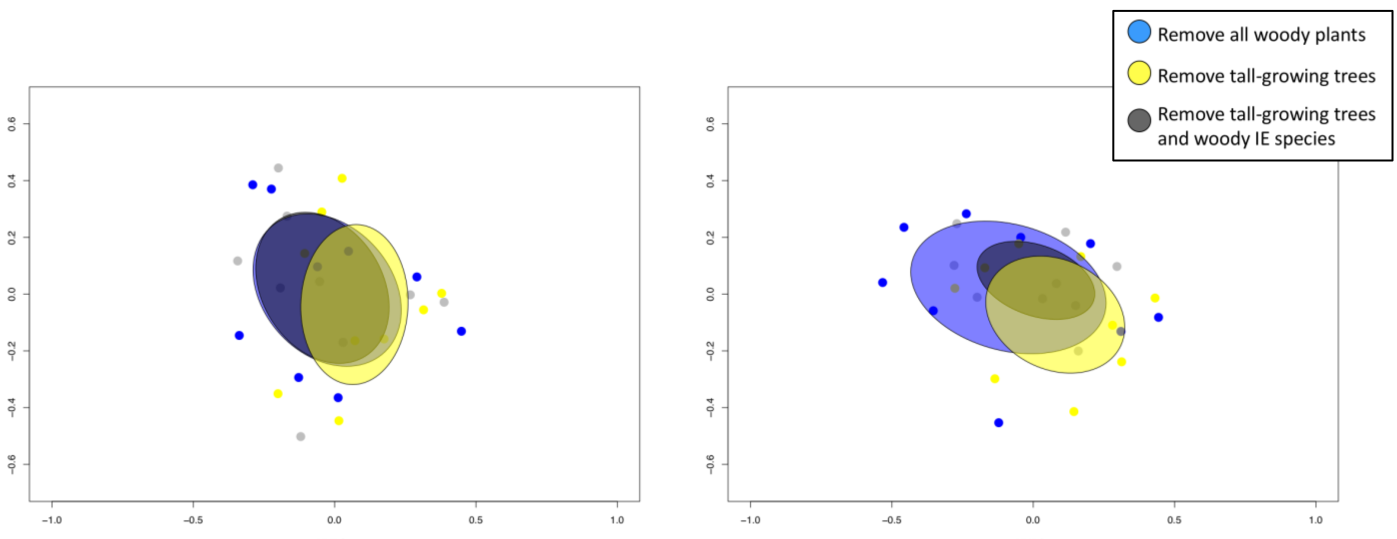

Figure 3.11. NMDS ordination of 2017 sweep net (left) and pan trap (right) assemblages captured in integrated vegetation management treatment plots in a powerline ROW in Ohio. Dots indicate sites and ellipses indicate treatments. Treatment vector indicates level of disturbance associated with treatment.

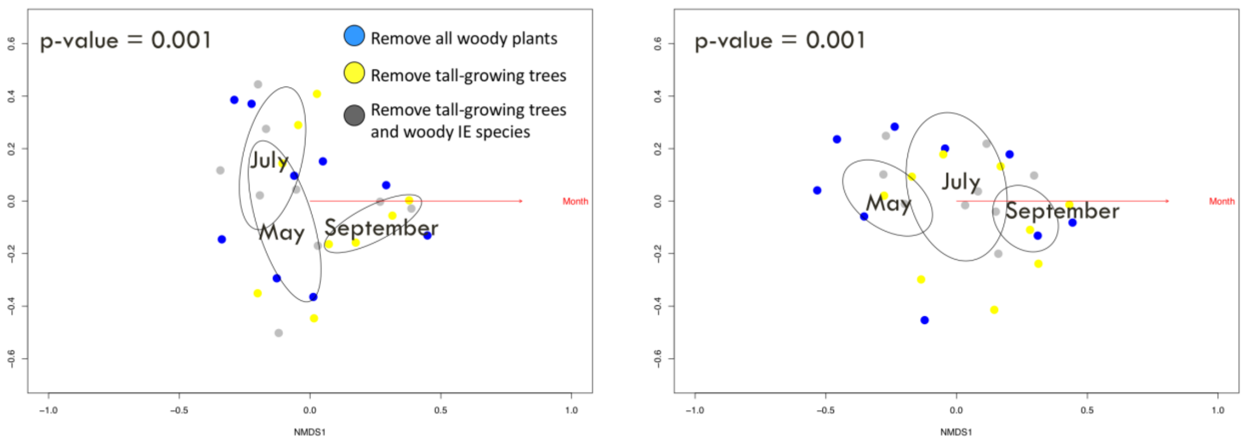

Figure 3.12. NMDS ordination of 2017 sweep net (left) and pan trap (right) assemblages captured in integrated vegetation management treatment plots in a powerline ROW in Ohio. Dots indicate sites and ellipses indicate month. Sampling month was loaded onto the x-axis.

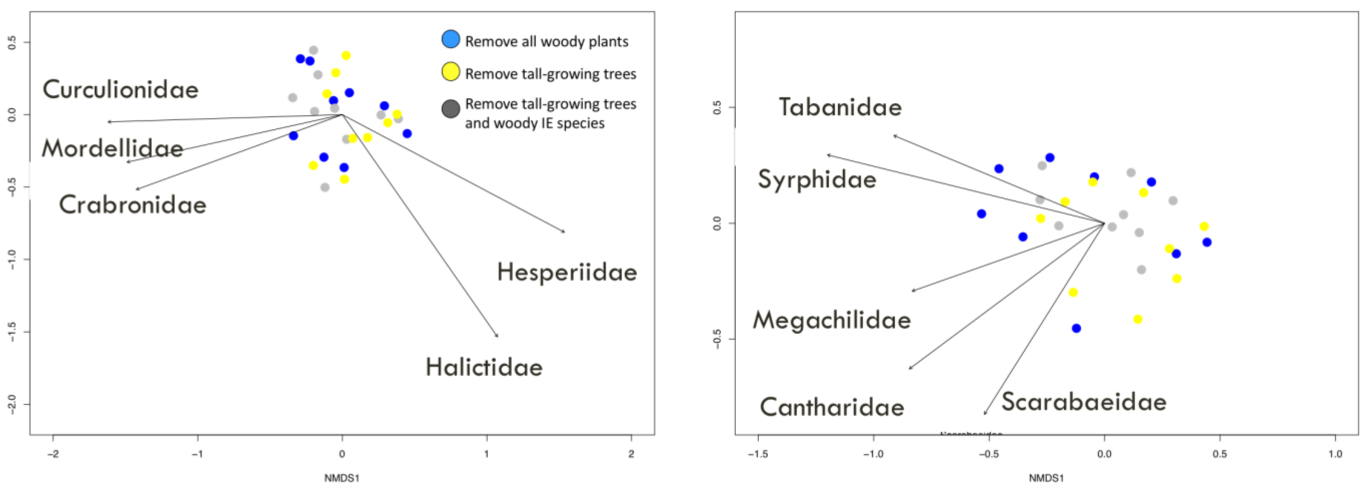

Figure 3.13. NMDS ordination of 2017 sweep net (left) and pan trap (right) assemblages captured in integrated vegetation management treatment plots in a powerline ROW in Ohio. Dots indicate sites. Vectors indicate pollinator families associated ($p < 0.05$) with x and y-axes.

Pollinator assemblage and IE species

While sweep net assemblages were not significantly associated with any IE species, pan trap assemblages were significantly associated with showy fly honeysuckle, *Lonicera bella*, under 2 m in height and glossy buckthorn, *Frangula alnus*, under 2 m in height (Table 3.9), and these plants were negatively associated with each other (Fig. 3.13). Families Tachinidae, Chrysomelidae, and Vespidae were most positively associated with showy fly honeysuckle prevalence, while Lygaeidae and Uliididae were positively associated with glossy buckthorn.

Table 3.9. Invasive-exotic species impacting pollinator assemblages in pan traps on integrated vegetation treatment plots along a powerline ROW in 2017 in Ohio.

	Pan Trap Assemblage		**Sweep Net Assemblage**	
	R^2	**Pr (>r)**	**R^2**	**Pr (>r)**
Glossy Buckthorn (*Frangula alnus*)	0.26	0.027**	-	-
Showy Fly Honeysuckle (*Lonicera bella*)	0.27	0.033**	-	-

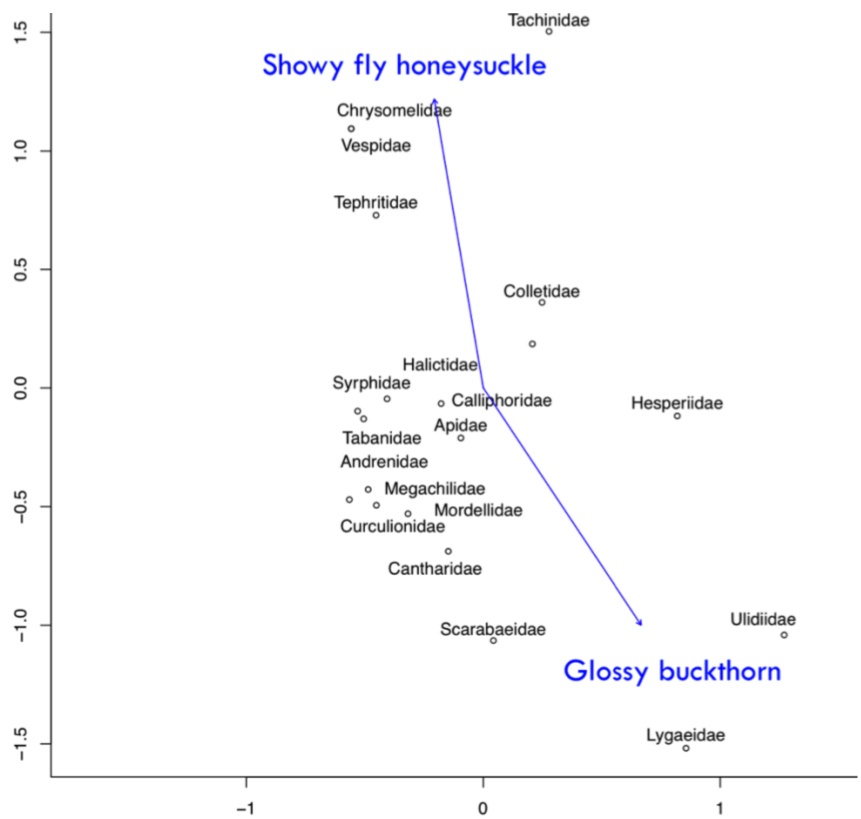

Figure 3.13 Relationship between showy fly honeysuckle and glossy buckthorn ground cover and pan trap pollinator assemblage captured in integrated vegetation management treatment plots along a powerline ROW in Ohio.

Discussion

Comparison to Previous Studies

To our knowledge, no other research efforts have set out to study multiple orders of pollinators on ROWs, especially experimentally in association with vegetation management treatments. The few previous studies undertaken on powerline ROWs have focused mainly on bees (Apoidea). The number of apoid pollinators we captured (1267) is similar to previous studies relative to the sampling effort (2924 in 16 plots by Russell et al. 2005; 1274 in 14 sites by Hopwood 2008; and 3899 in 19 plots by Wagner et al. 2014; 1225 in 18 sites in our NY study (Ch. 2)). The most common bee families from our study (Apidae and Halictidae) have also been documented as the most abundant bee families in another recent powerline ROW study (Wagner et al. 2014); however, two of the more abundant families found in that study, Andrenidae and Megachilidae, were not as common in this study (27 and 23, respectively). These relative abundances, however, were comparable to our study in New York state. However, relative number of European honeybees, *Apis mellifera*, was much higher in our study (17%) than in similar studies (0.7% for Russell et al. 2005; 3.4% for Wagner et al. 2014).

Measured pollinator parameters varied by sampling month. The differences in temporal patterns between collection methods are likely due to different pollinators coinciding with different flowering times (Petanidou and Vokou 1993; Olesen et al. 2008). Declines in the temporal patterns of community measures from early to late season in pan trap assemblages in this study have also been seen in previous ROW studies (Russell et al. 2005). Hopwood (2008) reported bee abundance and richness peaking in mid-season in sweep nets – and our results reflect this pattern as well. Different pollinator assemblages were found in sweep netting and pan traps in both 2016 and 2017, which is consistent with previous literature showing pan traps often miss insects that are abundant in sweep net samples (Cane et al. 2000; Roulston et al. 2007; Wagner et al. 2014).

Richness differences at treatment level

When comparing data measurements from July in each plot, we found that family richness was higher in plots where tall-growing trees and woody IE species were removed than in plots where only tall-growing trees were removed. This pattern was seen in all five sampling blocks (Table 3.10). The largest relative differences (50%) were seen in HPE and MR blocks. These blocks were both characterized by evidence of a high deer numbers and other wildlife, close proximity to developed areas, and wood lines to the north of the block. In this context, it seems that the slight differences among these plots three years post-management had a measurable impact on pollinator richness.

Table 3.10. Comparison of family richness of pollinators caught in pan traps on integrated vegetation treatment plots along a powerline ROW in 2017 in Ohio in plots where tall-growing trees and woody IE species were removed and plots where only tall-growing trees were removed by block.

	HPE	HPW	MR	SE	SW
Remove tall-growing trees and woody IE species	10	9	4	5	3
Remove undesirable, tall-growing trees	5	6	2	4	2

Lack of treatment effects

We observed very few treatment-level effects of IE plant management on pollinator abundance, richness, diversity, evenness, or assemblage. It may that there simply are no treatment effects; however, more likely initial limitations impacted our results, including:

1. sampling occurred in two different years, with yearly variation being likely
2. distance between treatment plots were not sufficient, i.e. beyond the flight range of many pollinators

3. lack of pre-treatment measurements, and
4. presence of IEs in plots 3 years post treatment indicates vegetation management objectives were not sustained

Each block was studied three years post-vegetation management; however, because treatments occurred over two years (in 2013 and 2014), i.e. not every block was initially treated in the same year, yearly variability may have overridden any treatment differences. Studies have documented that pollinator assemblages vary in composition and abundance by year (Williams et al. 2001); therefore, it is not possible to know whether or not there would have been treatment-level differences if all blocks had been on the same treatment and sampling schedule.

Within each block, plots were quite close to one another, often sharing a border. This is much less than the documented foraging distance for a majority of bee pollinators (Zurbuchen et al. 2010). It is likely, therefore, that pollinators readily moved between and even among our plots, transcending possible differences among treatments. In order to avoid pollinator cross over of this type, it is essential to not only treat large spans of ROW, but to also put a considerable distance (e.g., > 200 m) between treatment plots to minimize overlap with foraging distance of a majority of pollinators.

There were no pre-treatment measurements to which we could compare our samples. It is likely that not all plots contained identical pollinator assemblages prior to experimental vegetation management efforts. This makes it impossible to know if there were any plot-level changes to pollinator measures or assemblage.

Finally, vegetation management efforts did not sustain desired vegetation conditions (Nowak et al. 2016) three years post-treatment, when pollinator sampling was conducted. It is possible, however, that treatment effects on pollinators would exist closer to the time of vegetation management as one-year post-treatment assessment indicated vegetation conditions were still significantly associated with applied vegetation management techniques, i.e., plots treated with removal of undesirable, tall-growing plant species were devoid of trees with remaining plants intact; plots treated with removal of all woody plants were shifting toward a grass-dominated community; plots treated with removal of undesirable, tall- growing species and woody invasive-exotic species were both devoid of all trees and were shifting toward a slightly grass-dominated community (Nowak et al. 2016). Implications of short-lived treatment effects on vegetation is that these effects on pollinators may also be shorter-lived than three years.

NMDS ordinations indicate presence of two IE plants impacted pollinator assemblages on our study plots. Going forward, it is important to determine if there are any treatment effects on pollinators closer to treatment initiation, i.e. if there is a treatment effect early on, and then document what the half-life of these effects are. If effects had shorter half-lives, it could call for the need to manage IE plants more often to improve conditions for pollinator assemblages.

Levels of Disturbance and Associated Pollinators

Two families were associated with treatment disturbance levels. Skippers (Family Hesperidae) are one of the few butterfly families captured in this study. Butterflies in general are sensitive to environmental disturbance (Bramble et al. 1997) and Hesperidae's negative association as determined by NMDS analyses with disturbance level reflects this. Halictid bees were positively associated with disturbance levels. Previous research documented this family can flourish in areas of disturbance, e.g., recently harvested forests (Lee et al. 2001) and areas disrupted by agriculture (Klein et al. 2002).

Invasive-exotic plant species and pollinator community

Showy fly honeysuckle prevalence impacted pan trap pollinator assemblages. Many honeysuckle species are invasive bushes, including the closely related amur honeysuckle (*Lonicera maackii*).

Though no research could be found on the impact of showy fly honeysuckle on pollinators, a number of papers discuss amur honeysuckle's habit and impact on pollinators. Amur honeysuckle is an effective invasive due to its extended leaf display (Hutchinson and Vankat 1997), which shades areas below it (McKinney and Goodell 2010). This has both direct and indirect negative impacts on pollinators. Increased shade directly negatively impacts pollinators in a variety of ways. With a lower availability of light, ambient temperature is lower than it is in sun patches, and pollinators are less abundant (Herrera 1995). This is because pollinators are ectotherms, and their body temperature is determined by air temperature and direct sunlight (Bishop and Armbruster 1999). Light availability also indirectly impacts pollinator behavior; lower light availability prevents plants from growing to full potential and producing large floral displays, both of which are important factors to facilitating pollination (Conner and Rush 1996; Grindeland et al. 2005; Kilkenny and Galloway 2008). Additionally, increased shade is known to decrease plant species richness and abundance in the immediate area (Collier et al. 2002), reducing plant resources available to pollinators. For what plant species remain after an amur honeysuckle invasion, pollinator visitation rates are decreased simply due to the competitive presence of the invasive plant (McKinney and Goodell 2010).

Glossy buckthorn prevalence also impacted pan trap pollinator assemblages. Abundance of this woody shrub/small tree is increased in logged areas (Burnham and Lee 2010), which are similar in many aspects to powerline ROWs as canopy trees are removed. Once released after tree removal, this species can be extremely successful due to its suppression of succession (Fagan and Peart 2004). Invasion of glossy buckthorn, like honeysuckle, is characterized by lowered light availability in the surrounding area (Fiedler and Landis 2012). Glossy buckthorn abundance is negatively associated with seedling density, herb cover, and species richness

(Frappier et al. 2003), and associated with shifts in plant communities toward an increase in shade-tolerant species (Fiedler and Landis 2012). With such impacts on the plant community, pollinator assemblages are also negatively impacted. With regards to pollinators, recent research indicates glossy buckthorn is associated with a lower abundance and diversity of super family Anthophila (Fiedler et al. 2012).

Tachinidae, Chrysomelidae, and Vespidae were positively associated with showy fly honeysuckle prevalence. This supports another study indicating Tachinid flies are associated with honeysuckle on powerline ROWs (Inclan and Stireman 2011). Chrysomelid beetles are herbivores on honeysuckle species (Waipara et al. 2007), which could explain why this family was associated with honeysuckle in our plots. Vespid wasps have previously been observed in abundance in areas with honeysuckle (Dvorak 2007), visiting flowers (Larson et al. 2002), and collecting pollen (Guitian et al. 1993). This relationship can be explained by the morphology of honeysuckle flowers, which fit the needs of Vespid wasps (Robertson 1917).

This study is the first to explore impacts of vegetation management to control IE plant species on pollinators within the context of powerline ROWs. Management on powerline ROWs is currently focused on removal of "pest" species (i.e. tall trees) that can interfere with powerlines. This doesn't get rid of invasive plants – as many are considered "compatible" with industry height standards. Unfortunately, invasive plants can have negative impacts on pollinators. We found that making the specific effort to remove IE species was associated with increased in pollinator richness in comparison to areas where IE species had not been managed. This information helps inform land and ROW managers who aim to improve conditions for pollinators and with slight changes to management protocols, pollinator assemblages may receive large benefits.

Chapter 4

Evaluation of Research and Opportunities for Future Research on Pollinators of ROWs

Evaluation of Research Objectives

As outlined in Chapter 1, my research objectives were:

1. **Compare impacts of mechanical and chemical vegetation management practices on pollinator assemblages**

Because pollinators are essential to many aspects of life for humans and plants, it is extremely important to develop solutions to their decline. Powerline rights-of-way (ROWs) are proposed as extensive areas that could be managed for pollinator conservation. To further improve these areas as pollinator habitat, it is vital to understand how ROW vegetation management practices impact vegetation community measures and pollinator assemblages. This study represents the first time impacts of experimental ROW vegetation management techniques on pollinator assemblages were formally investigated.

Results of research from summer 2016 demonstrated treatment-level effects on pollinator community measures (abundance, family richness, diversity, and evenness) when comparing experimental management strategies to operational IVM (control) plots. Foliar Herbicide and Cut Stump Herbicide plot assemblages were not significantly different than associated control plots in almost any way, while Brush Hog plot assemblages were significantly different than associated control plots in nearly every analysis. We also found different pollinator families were associated with some treatments and not others. We did not, however, detect any treatment-level differences in measured pollinator parameters when comparing experimental management strategies to one another in summer 2017, though it is possible that treatment effects on community measures could exist at some point earlier in the timeline after treatment. A considerable amount of time had passed since initial treatment, 7 years as of 2017. Additionally, we do not have pre-treatment measurements, so it is possible that different vegetation management techniques impacted measured pollinator parameters relative to their previous conditions. A suggestion is to use this study as a pre-treatment measurement of pollinators for another study going forward.

2. Describe effects of vegetation management on pollinator assemblages

In addition to comparing different management techniques, we were presented with the opportunity to study the immediate and direct impacts of vegetation treatment when four plots were treated with herbicide two weeks before sampling in August 2017 (Fig. 4.1). Nearly all vegetation on these plots was dead and dried during sampling (Fig. 4.2). We only found a total of three pollinators in all of these plots post-treatment. Unfortunately, we did not detect a statistically significant impact on pollinator assemblages or community measures. This was likely due to small sample size (n = 4), close proximity of plots to untreated areas, and pre-existing low pollinator abundances in those plots during that sampling time in the previous year, and overall low abundance in all plots in 2017 (Table 4.1). For studies aiming to document direct impacts of vegetation management on pollinator assemblages, it would be useful to study plots treated earlier in the season when pollinator abundance is higher.

Table 4.1. Differences in pollinator abundance captured in pan traps in August 2016 and August 2017. Blue highlights indicate plots accidentally treated with herbicides in late July 2017.

	2016	2017
8-134-4-VM	0	3
8-135-1A-VM	0	1
8-199-3-VM	14	3
126-2B-VM	2	2
128-1-VM	15	3
126-3-VM	5	1
134-1B-VM	2	2
193-1-VM	0	0

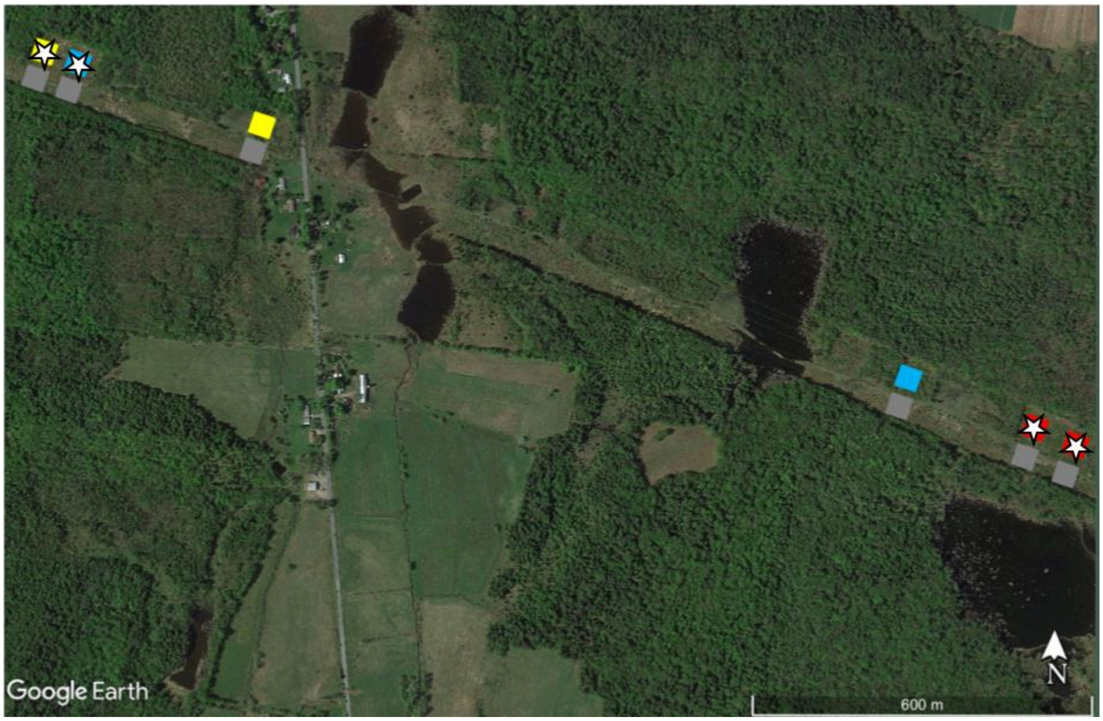

Figure 4.1. Map of western sampling sites. Plots treated with herbicides prior to August 2017 sampling marked with white stars.

Figure 4.2. Photograph of 8-134-4-VM site during August 2017 sampling demonstrating destruction in the immediate aftermath of ROW herbicide application.

3. Analyze influences of IE species on pollinator assemblages

Powerline ROWs are known areas where IE plant species occur and spread rapidly. IE plant species can disrupt native plant-pollinator networks through excluding native plants and competing for resources. Understanding how IE plants impact pollinator assemblages in the context of powerline ROWs is important when considering vegetation management techniques to improve conditions in these areas to benefit pollinators.

When comparing data measurements from July in each plot, we found that family richness was higher in plots where tall-growing trees and woody IE species were removed than in plots where only tall-growing trees were removed. This pattern was seen in all sampling blocks (Table 3.10). The largest relative differences (50%) were seen in HPE and MR blocks. These blocks were both characterized by a higher presence of deer and other wildlife, close proximity to developed areas, and wood lines to the north of the block. In this context, it seems that the slight differences between these plots three years post-management had a large impact on pollinator richness. More treatment-level effects may have existed at one point; however, we did not detect them. This is likely because IE removal was not maintained after initial treatment three years prior to pollinator studies. Our results also indicated prevalence of showy-fly honeysuckle and common buckthorn impacted pollinator assemblages.

Suggestions for Future Research

To fully document impacts of vegetation management techniques on pollinator assemblages, it is essential to study pollinators pre-treatment as well as post-treatment. Additionally, it is necessary to maintain certain aspects of management as needed (e.g., invasive plant removal). This would allow researchers to determine if impacts on pollinator assemblages exist and how they do or do not change over time. Results of this nature could help to inform land managers looking to develop protocols incorporating treatments that improve ROW conditions for pollinators.

It is important to have good working relationships with both utility companies and private landowners in order to study systems like powerline ROWs. Throughout the course of this study, our team worked closely with utility companies, like NYPA, and utility governing bodies, like EPRI. With a close relationship, we were able to secure study sites and receive permission for sampling throughout two field seasons. Unfortunately, relationships with private landowners can be more challenging. For all studies occurring on private land, it is best to develop and maintain a transparent relationship with landowners in order to control site conditions and retain access. While utility companies do possess a legal right-of-way to perform maintenance on powerline equipment and vegetation, landowners aren't always happy about what they see as encroachment on their land rights, and so it is also crucial they are kept informed of study objectives and timing. As an example, two study plots for this research were on a parcel of privately owned land, the owner of which was unhappy with something being done on his land that he didn't know about (research) and he felt the research efforts impeded his use of the property. In the future, it is recommended that research teams reach out to land owners early to let them know about upcoming field seasons and what is going on with the research. An increase in communication could avoid conflict between landowners and researchers.

In closing, it is essential we find solutions to the decline of pollinators. A part of this is creating habitat to replace what has been lost due to anthropomorphic forces. ROWs are large areas that already exist – the simplest solution is to work with land managers to adjust management protocols to improve conditions for pollinators, though it is understood there may be tradeoffs with time and costs associated with additional management and these must be balanced. Through cooperation among pollination biologists, utility companies, and land owners, addition and expansion of areas of higher quality pollinator habitat is possible.

Appendices

Appendix 1. Pollinator species collected by all sampling methods from all sampling occasions in ROW vegetation management plots near Rome, New York.

			Treatments			
Pollinator Species	**Order**	**Treatments**	**Brush Hog**	**Cut Stump Herbicide**	**Foliar Herbicide**	**Operational IVM***
Ancistronycha abdominalis	Coleoptera	1	1	0	0	0
Atalantycha spp.	Coleoptera	4	1	6	4	12
Chauliognathus pensylvanicus	Coleoptera	1	0	1	0	0
Dendroides canadensis	Coleoptera	1	0	0	1	0
Diabrotica undecimpunctata	Coleoptera	2	0	0	4	2
Hemicrepidius memnonius	Coleoptera	1	1	0	0	0
Limonius quercinus	Coleoptera	1	3	0	0	0
Limonius sp.	Coleoptera	1	1	0	0	0
Lytta sayi	Coleoptera	1	0	0	2	0
Metacmaeops vittata	Coleoptera	1	0	0	0	1
Mordelestina sp.	Coleoptera	1	0	0	0	1
Mordella spp.	Coleoptera	4	2	1	2	1
Mordellistena spp.	Coleoptera	3	0	1	1	1
Odontocorynus umbellae	Coleoptera	4	3	2	5	3
Orthophagus hecate	Coleoptera	2	1	0	1	0
Podabrus rugosulus	Coleoptera	2	2	1	0	0
Podabrus spp.	Coleoptera	3	0	27	6	2
Popillia japonica	Coleoptera	4	2	2	2	14
Rhagonycha atra	Coleoptera	1	1	0	0	0
Rhagonycha elongata	Coleoptera	1	1	0	0	0
Rhagonycha imbecillis	Coleoptera	3	0	13	15	21
Rhagonycha mollis	Coleoptera	4	13	27	180	39
Rhagonycha spp.	Coleoptera	2	0	6	0	1

Rhinocyllus conicus	Coleoptera	2	0	0	2	11
Rhinocyllus spp.	Coleoptera	3	0	2	2	13
Tolidopalpus spp.	Coleoptera	1	0	2	0	0
Typocerus confluens	Coleoptera	1	0	0	2	0
Typocerus relutions	Coleoptera	1	3	0	0	0
Typocerus velutinus	Coleoptera	4	5	1	1	1
Archytas spp.	Diptera	3	2	0	1	1
Blera sp.	Diptera	1	0	0	1	0
Calliphora spp.	Diptera	4	1	1	2	7
Campiglossa albiceps	Diptera	3	4	2	0	8
Campiglossa spp.	Diptera	1	0	0	0	8
Chaetopsis fulvifrons	Diptera	3	4	4	11	0
Chrysops ater	Diptera	1	0	0	1	0
Chrysops carbonarius	Diptera	2	5	0	2	0
Chrysops cincticornis	Diptera	2	6	4	0	0
Chrysops excitans	Diptera	1	0	0	3	0
Chrysops indus	Diptera	3	4	1	1	0
Chrysops niger	Diptera	1	1	0	0	0
Chrysops spp.	Diptera	4	39	95	94	189
Chrysops vittatus	Diptera	1	0	0	3	0
Chrysotoxum pubescens	Diptera	1	0	0	0	1
Chrysotoxum spp.	Diptera	2	2	1	0	0
Drosophila sp.	Diptera	1	0	0	0	1
Eristalis interrupta	Diptera	1	0	0	0	1
Euaresta bella	Diptera	4	1	4	1	6
Euaresta festiva	Diptera	1	1	0	0	0
Euaresta sp.	Diptera	1	0	0	1	0
Eutreta noveboracensis	Diptera	4	2	20	6	36
Graphomya spp.	Diptera	1	0	0	0	2
Hemyda sp.	Diptera	1	0	0	0	1
Hermetia sp.	Diptera	1	0	0	1	0
Hiatomyia sp.	Diptera	1	1	0	0	0

Huebneria sp.	Diptera	1	0	0	1	0
Hybomitra bechumani	Diptera	1	0	0	2	0
Hybomitra bimaculata	Diptera	2	1	0	0	1
Hybomitra lasiophthalma	Diptera	1	2	0	0	0
Hybomitra spp.	Diptera	4	3	6	10	13
Icterica sp.	Diptera	1	0	0	0	1
Lejops bilinearis	Diptera	1	0	0	0	1
Lestica confluenta	Diptera	2	1	0	0	2
Lestica spp.	Diptera	4	1	2	1	2
Linnaemya sp.	Diptera	1	0	0	1	0
Lucilia caesar	Diptera	1	0	1	0	0
Lucilia silvarum	Diptera	1	0	0	1	0
Lucilia spp.	Diptera	4	6	6	2	11
Melangyna spp.	Diptera	2	0	1	0	1
Melanostoma spp.	Diptera	3	2	1	0	1
Musca autumnalis	Diptera	4	9	3	12	17
Musca spp.	Diptera	2	4	0	0	2
Muscina spp.	Diptera	2	0	1	0	9
Oestrophasia sp.	Diptera	1	0	0	0	1
Parachytas decisus	Diptera	1	0	0	0	1
Parachytas sp.	Diptera	1	0	0	0	1
Peleteria spp.	Diptera	2	1	0	1	0
Physocephala spp.	Diptera	2	0	0	1	3
Platycheirus spp.	Diptera	4	2	1	1	5
Pollenia sp.	Diptera	1	0	0	0	1
Psilotta sp.	Diptera	1	0	1	0	0
Sarcophaga spp.	Diptera	1	0	3	0	0
Sphaerophoria spp.	Diptera	4	3	1	1	1
Stonemyia spp.	Diptera	2	0	0	1	2
Stylogaster neglecta	Diptera	1	1	0	0	0
Syritta flaviventris	Diptera	1	0	0	0	1
Syritta spp.	Diptera	1	0	0	0	2

Tabanus bromius	Diptera	1	1	0	0	0
Tabanus spp.	Diptera	3	2	0	1	3
Temnostoma sp.	Diptera	1	0	1	0	0
Teuchocnmeis spp.	Diptera	1	0	2	0	0
Toxomerus geminatus	Diptera	4	15	23	25	105
Toxomerus marginatus	Diptera	4	4	11	15	69
Urophora cardui	Diptera	2	0	1	0	57
Urophora quadrifaciatus	Diptera	3	0	4	1	107
Xanthomyia sp.	Diptera	1	0	0	0	1
Agapostemon sp.	Hymenoptera	1	0	0	0	1
Agapostemon splendins	Hymenoptera	1	1	0	0	0
Agapostemon texanis	Hymenoptera	2	1	0	0	1
Agapostemon virescens	Hymenoptera	1	0	2	0	0
Ancistrocerus antilope	Hymenoptera	1	0	0	0	2
Ancistrocerus spp.	Hymenoptera	3	0	4	6	7
Andrena alleghaniensis	Hymenoptera	2	0	2	1	0
Andrena ardineri	Hymenoptera	**1**	**1**	**0**	**0**	**0**
Andrena crataegi	Hymenoptera	**1**	**2**	**0**	**0**	**0**
Andrena spp.	Hymenoptera	3	0	1	6	17
Anthidium oblongatum	Hymenoptera	1	0	0	0	1
Anthidium sp.	Hymenoptera	1	0	1	0	0
Anthophora sp.	Hymenoptera	1	0	0	1	0
Anthophora terminalis	Hymenoptera	1	0	0	0	1
Apis mellifera	Hymenoptera	4	26	31	67	186
Augochlora pura	Hymenoptera	4	24	7	12	28
Augochlorella aurata	Hymenoptera	4	2	14	13	24
Augochlorella persimilis	Hymenoptera	3	4	4	7	0
Augochloropsis metallica	Hymenoptera	1	0	1	0	0
Bicyrtes sp.	Hymenoptera	1	0	0	1	0
Bombus auricomus	Hymenoptera	1	0	0	0	2
Bombus impatiens	Hymenoptera	3	0	4	3	11
Bombus spp.	Hymenoptera	3	1	0	1	6

Bombus ternarius	Hymenoptera	1	0	0	0	2
Ceratina aurata	Hymenoptera	1	0	0	0	3
Ceratina calcarata	Hymenoptera	4	7	5	6	12
Ceratina dupla	Hymenoptera	4	18	37	49	46
Ceratina spp.	Hymenoptera	2	0	2	2	0
Ceratina strenua	Hymenoptera	4	2	17	19	1
Cercercis spp.	Hymenoptera	3	0	1	2	1
Chelostoma philidelphis	Hymenoptera	1	0	0	1	0
Chelostoma rapunculi	Hymenoptera	2	2	0	0	1
Chelostoma spp.	Hymenoptera	1	0	0	0	4
Colletes sp.	Hymenoptera	1	0	0	1	0
Crabro spp.	Hymenoptera	3	0	1	2	1
Diodontus sp.	Hymenoptera	1	1	0	0	0
Ectemnius continuus	Hymenoptera	1	0	0	0	1
Ectemnius spp.	Hymenoptera	4	1	1	15	1
Eumenes fraternus	Hymenoptera	1	0	1	0	0
Eumenes sp.	Hymenoptera	1	0	0	0	1
Halictus ligatus	Hymenoptera	3	0	1	2	14
Halictus spp.	Hymenoptera	3	0	1	3	6
Hoplitis producta	Hymenoptera	1	0	0	0	2
Hylaeus affinis	Hymenoptera	2	0	0	3	6
Hylaeus annulatus	Hymenoptera	2	0	0	2	10
Hylaeus communis	Hymenoptera	3	0	6	1	20
Hylaeus leptocephalus	Hymenoptera	2	0	2	0	2
Hylaeus mesillae	Hymenoptera	4	1	6	2	16
Hylaeus modestus	Hymenoptera	4	1	2	2	3
Hylaeus spp.	Hymenoptera	4	2	12	16	15
Lasioglossum spp.	Hymenoptera	4	30	48	76	117
Megachile spp.	Hymenoptera	2	0	0	1	7
Nomada cressonii	Hymenoptera	1	0	1	0	0
Nomada gracilis	Hymenoptera	2	1	0	3	0
Nomada luteoloides	Hymenoptera	2	1	2	0	0

Nomada maculata	Hymenoptera	1	0	0	1	0
Nomada spp.	Hymenoptera	1	0	0	0	2
Odynerus sp.	Hymenoptera	1	0	1	0	0
Osmia collinsine	Hymenoptera	1	1	0	0	0
Osmia proxima	Hymenoptera	1	2	0	0	0
Parancistrocerus sp.	Hymenoptera	1	0	0	0	1
Polistes dominula	Hymenoptera	1	0	0	0	1
Polistes fuscatus	Hymenoptera	3	0	1	1	1
Polites peckius	Hymenoptera	1	0	0	0	2
Sphecodes autumnalis	Hymenoptera	1	0	1	0	0
Sphecodes hylinatus	Hymenoptera	1	0	0	1	0
Sphecodes sp.	Hymenoptera	1	0	0	0	1
Symmorphus spp.	Hymenoptera	1	0	0	0	2
Vespula maculifrons	Hymenoptera	2	1	1	0	0
Vespula squamosa	Hymenoptera	1	0	0	0	1
Xylocopa spp.	Hymenoptera	1	0	3	0	0
Xylota spp.	Hymenoptera	2	2	0	0	4
Anania funebris	Lepidoptera	1	0	0	0	1
Anatrytone logan	Lepidoptera	2	0	3	1	0
Celastrina neglecta	Lepidoptera	1	0	0	0	1
Colias eurytheme	Lepidoptera	1	1	0	0	0
Ctenucha virginica	Lepidoptera	2	0	0	2	1
Everes comyntas	Lepidoptera	1	0	0	0	1
Haploa confusa	Lepidoptera	1	0	0	0	2
Hemaris diffins	Lepidoptera	1	0	0	1	0
Hemaris thysbe	Lepidoptera	1	0	0	0	1
Megisto cymela	Lepidoptera	1	0	0	0	1
Olethreutes bipartitana	Lepidoptera	1	0	0	0	1
Phyciodes cocyta	Lepidoptera	1	0	0	0	1
Phyciodes spp.	Lepidoptera	2	1	0	1	0
Phyciodes tharos	Lepidoptera	1	0	0	1	0
Poanes hobomok	Lepidoptera	4	5	1	7	5

Poanes sp.	Lepidoptera	1	0	0	0	1
Polemius spp.	Lepidoptera	2	0	3	0	1
Polygonia interrogationis	Lepidoptera	1	0	0	0	1
Pompeius verna	Lepidoptera	1	0	0	1	0
Satyrodes eurydice	Lepidoptera	1	0	0	1	0
Speyeria cybele	Lepidoptera	1	0	0	0	1
		Totals:	**313**	**524**	**779**	**1418***

*Note: these are from 9 plots and other treatments are from 3 plots each.

Appendix 2. Pollinator species collected by all sampling methods from all sampling occasions in ROW vegetation management plots in Cuyahoga County, Ohio.

			Treatments		
Species	Family	Treatments	Remove all woody plants	Remove tall-growing trees	Remove tall-growing trees and woody IEs
Atalantycha neglecta	Coleoptera	3	85	18	30
Atalantycha spp.	Coleoptera	3	2	1	4
Chauliognathus marginatus	Coleoptera	1	0	1	0
Chauliognathus pensylvaticus	Coleoptera	1	2	0	0
Chrysochus auratus	Coleoptera	1	0	3	0
Diabrotica undecimpunctata	Coleoptera	2	1	0	1
Lema spp.	Coleoptera	1	0	1	0
Mordella atrata	Coleoptera	3	2	2	2
Mordella spp.	Coleoptera	3	9	6	8
Mordellistena spp.	Coleoptera	3	1	2	3
Odontocorynus umbellae	Coleoptera	3	16	8	4
Oulema spp.	Coleoptera	1	0	5	0
Podabrus rugosulus	Coleoptera	1	0	0	1
Popillia japonica	Coleoptera	3	22	27	18
Rhagonycha sp.	Coleoptera	1	0	1	0
Rhinocyllus umbellae	Coleoptera	1	1	0	0
Typocerus velutinus	Coleoptera	1	2	0	0
Archytas spp.	Diptera	2	1	0	1
Calliphora spp.	Diptera	2	3	0	1
Campiglossa spp.	Diptera	1	1	0	0
Chaetopsis fulvifrons	Diptera	3	2	7	2
Chaetopsis spp.	Diptera	1	0	0	1
Chrysops spp.	Diptera	3	59	45	12
Cupido comyntas	Diptera	1	0	1	0
Dioxyna picciola	Diptera	1	2	0	0

Dioxyna spp.	Diptera	1	1	0	0
Drosophila spp.	Diptera	1	0	0	1
Eristalis transerva	Diptera	1	0	1	0
Euaresta bella	Diptera	1	0	0	1
Euaresta spp.	Diptera	2	1	1	0
Eupeodes americanus	Diptera	1	0	1	0
Eutreta noveboracensis	Diptera	2	2	13	0
Hybomitra ciureai	Diptera	1	0	0	1
Hybomitra spp.	Diptera	3	3	3	5
Hylaeus mesillae	Diptera	3	10	2	3
Icterica spp.	Diptera	1	0	0	2
Lucilia sericata	Diptera	2	3	0	1
Lucilia silvarum	Diptera	2	3	2	0
Lucilia spp.	Diptera	3	9	5	20
Musca autumnalis	Diptera	1	0	0	3
Musca sp.	Diptera	1	0	0	1
Muscina spp.	Diptera	2	0	1	2
Nomada affabilis	Diptera	1	0	1	0
Physocephala spp.	Diptera	2	4	0	8
Rivellia spp.	Diptera	2	0	1	2
Sarcophaga spp.	Diptera	1	0	0	1
Sphaerophoria contigua	Diptera	1	1	0	0
Sphaerophoria spp.	Diptera	3	1	3	2
Stauzia sp.	Diptera	1	0	0	1
Syritta pipiens	Diptera	1	0	1	0
Syritta sp.	Diptera	1	0	0	1
Syrphus spp.	Diptera	3	2	1	1
Tabanus spp.	Diptera	2	1	1	0
Toxomerus geminatus	Diptera	3	4	6	12
Toxomerus marginatus	Diptera	3	176	83	121
Trichopoda pennipes	Diptera	1	1	0	0
Trichopoda spp.	Diptera	2	2	0	2

Lygaeus kalmii	Hemiptera	2	1	0	1
Oncopeltus fasciatus	Hemiptera	2	1	0	1
Agapostemon spp.	Hymenoptera	1	0	1	0
Agapostemon virescens	Hymenoptera	1	1	0	0
Ancistrocerus campestris	Hymenoptera	1	0	0	2
Ancistrocerus spp.	Hymenoptera	2	3	1	0
Andrena canadensis	Hymenoptera	1	0	2	0
Andrena femingeri	Hymenoptera	1	0	1	0
Andrena gardineri	Hymenoptera	1	0	0	1
Andrena integra	Hymenoptera	2	0	1	2
Andrena spp.	Hymenoptera	3	5	5	7
Andrena wilkella	Hymenoptera	1	1	0	0
Anthidium manicatum	Hymenoptera	1	1	0	0
Anthidium oblongatum	Hymenoptera	1	0	0	2
Apis mellifera	Hymenoptera	3	64	77	80
Arge spp.	Hymenoptera	1	0	0	1
Astata spp.	Hymenoptera	1	0	0	1
Augochlora pura	Hymenoptera	3	66	23	34
Augochlorella aurata	Hymenoptera	3	26	18	18
Augochlorella persimilis	Hymenoptera	3	3	4	2
Augochorella aurata	Hymenoptera	1	0	0	1
Auplopus spp.	Hymenoptera	1	1	0	0
Bicyrtes quadrifaciatus	Hymenoptera	1	2	0	0
Bicyrtes spp.	Hymenoptera	1	1	0	0
Bombus impatiens	Hymenoptera	3	29	10	20
Ceratina aurata	Hymenoptera	1	0	4	0
Ceratina calcarata	Hymenoptera	3	32	10	15
Ceratina dupla	Hymenoptera	3	72	45	43
Ceratina spp.	Hymenoptera	2	0	3	13
Ceratina strenua	Hymenoptera	3	22	13	10
Chelostoma campanularum	Hymenoptera	1	1	0	0
Chelostoma campnularum	Hymenoptera	1	0	0	1

Colletes nudus	Hymenoptera	1	0	1	0
Crabro spp.	Hymenoptera	3	2	1	1
Diodontus spp.	Hymenoptera	1	1	0	0
Dolichovespula maculata	Hymenoptera	1	0	1	0
Ectemnius continuus	Hymenoptera	1	0	0	1
Ectemnius spp.	Hymenoptera	2	2	0	3
Eumenes fraternus	Hymenoptera	1	0	0	1
Halictus confusus	Hymenoptera	2	5	0	4
Halictus ligatus	Hymenoptera	3	10	2	25
Halictus rubicundus	Hymenoptera	1	2	0	0
Halictus spp.	Hymenoptera	3	6	2	1
Heriades leavitti	Hymenoptera	3	1	1	2
Heriades rapunculi	Hymenoptera	1	1	0	0
Hoplitis producta	Hymenoptera	2	1	0	1
Hylaeus affinis	Hymenoptera	3	2	2	5
Hylaeus annulatus	Hymenoptera	2	1	0	3
Hylaeus communis	Hymenoptera	3	2	1	2
Hylaeus floridanus	Hymenoptera	3	1	3	3
Hylaeus modestus	Hymenoptera	2	7	4	0
Hylaeus nelumbonis	Hymenoptera	1	2	0	0
Hylaeus rubicundus	Hymenoptera	1	1	0	0
Hylaeus spp.	Hymenoptera	3	7	8	16
Lasioglossum spp.	Hymenoptera	3	118	65	118
Megachile addenda	Hymenoptera	1	0	0	1
Megachile brevis	Hymenoptera	1	0	0	2
Megachile frigida	Hymenoptera	1	1	0	0
Megachile rugifrons	Hymenoptera	1	2	0	0
Megachile spp.	Hymenoptera	2	2	0	1
Melisodes compoides	Hymenoptera	1	2	0	0
Melissodes bimaculata	Hymenoptera	1	0	1	0
Melissodes boltoniae	Hymenoptera	1	1	0	0
Melissodes compoides	Hymenoptera	1	2	0	0

Milesia virginiensis	Hymenoptera	1	1	0	0
Nomada gracilis	Hymenoptera	1	0	1	0
Nomada pygmaea	Hymenoptera	1	0	0	1
Osmia cornifrons	Hymenoptera	1	2	0	0
Parancistrocerus pensylvanicus	Hymenoptera	1	1	0	0
Polistes dominula	Hymenoptera	2	2	0	1
Polistes metricus	Hymenoptera	1	1	0	0
Polistes spp.	Hymenoptera	2	1	0	1
Protoandrena abdominalis	Hymenoptera	1	1	0	0
Pseudopanurgus labrosus	Hymenoptera	1	1	0	0
Solierella spp.	Hymenoptera	3	2	1	3
Sphecodes sp.	Hymenoptera	1	0	0	1
Symmorphus sp.	Hymenoptera	1	0	0	1
Vespula alascensis	Hymenoptera	1	2	0	0
Xylocopa sp.	Hymenoptera	1	0	0	1
Xylocopa virginica	Hymenoptera	3	2	2	2
Cercyones pegala	Lepidoptera	1	0	1	0
Cercyonis pegala	Lepidoptera	1	0	1	0
Colias philodice	Lepidoptera	1	0	1	0
Epargyreus clarus	Lepidoptera	1	0	1	0
Erynnis baptisiae	Lepidoptera	2	2	7	0
Erynnis spp.	Lepidoptera	1	0	1	0
Everes comyntas	Lepidoptera	1	0	1	0
Haploa clymene	Lepidoptera	1	0	0	2
Limenitis archippus	Lepidoptera	1	0	0	1
Papilio glaucus	Lepidoptera	1	1	0	0
Phyciodes morpheus	Lepidoptera	1	0	1	0
Phyciodes tharos	Lepidoptera	2	0	2	2
Pieris rapae	Lepidoptera	3	8	2	6
Poanes hobomok	Lepidoptera	3	2	4	4
Poanes spp.	Lepidoptera	1	0	0	6
Poanes zabulon	Lepidoptera	2	3	3	0

Polites peckius	Lepidoptera	2	7	2	0
Polites spp.	Lepidoptera	3	2	1	1
Thorybes spp.	Lepidoptera	1	0	0	1
Hemaris diffinis		1	0	0	2
		Totals:	990	596	760

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Curriculum Vitae

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Education

State University of New York, College of Environmental Science and Forestry
Syracuse, New York
Master of Science – Entomology
Thesis "Influences of Chemical, Mechanical, and Integrative Vegetation Management Strategies on Pollinator Assemblage on Powerline Rights-of-way in New York and Ohio"
Thesis advisor: Melissa Fierke

Hartwick College
Oneonta, New York
Bachelor of Arts – Biology
Bachelor of Arts – French

Research Interests and Experience

Pollinators (Hymenoptera, Diptera, Coleoptera, etc.) **2016 – Current**
Comprehensive Inventory, Study for Powerline Right-of-Way Management
Funded by the Electric Powerline Research Institute (EPRI)
Identified pollinator samples (including Hymenopteran, Dipteran, Lepidopteran, and Coleopteran)
Explored relationships between pollinator assemblages and ROW vegetation management strategies

Dragonflies and Damselflies (Odonata) **2015 – 2016**
Comprehensive Inventory, Study for Bioindication
Worked in partnership with the New York State Office of Parks, Recreation and Historic Preservation and the New York Natural Heritage Program
Expanded existing species inventory
Developed field skills – collection, handling of specimens, insect identification, etc.

Grants and Fellowships

2016 Henriette and John Simeone Fellowship in Forest Entomology, SUNY ESF. $5,000.00
Moneys given to successful student
2015 Environmental Science and Policy Grant, Hartwick College. $3,670.24
Completed a comprehensive Inventory of Odonates at Robert V. Riddell State Park

Publications

Nowak, C., M. Fierke, and E. McPhail. 2016. Pollinator diversity on power corridors in New York and Ohio: Study initiation. Electric Power Research Institute Technical Update 3002008535, Palo Alto, CA.

Presentations and Public Outreach

New York State Association of Foresters Conference **January 2018**
Syracuse, New York
Influences of Invasive Plant Management on Pollinator

Assemblages on Powerline Rights-of-Way in Ohio

New York State Association of Foresters Conference **January 2018**
Syracuse, New York
Invasive Exotic Plant Management and Pollinator Assemblages
on Powerline Rights-of-Way in Northeastern Ohio

Entomological Society of America Annual Meeting **November 2017**
Denver, Colorado
Influences of chemical and mechanical vegetation management
on pollinator assemblages on powerline rights-of-way in New York

Bees, butterflies and other pollinators will benefit from **May 2017**
First Energy's habitat improvements at transmission corridors
Middleburg Heights, Ohio
Newspaper Interview with James McCarty for Cleveland Metro News

New York State Association of Foresters Conference **January 2017**
Syracuse, New York
Elucidating Pollinator Assemblages Along
Powerline Rights-of-Way in Ohio and New York

Pollinator Protection Symposium **November 2016**
Syracuse, New York
Presentation – *Powerline Rights-of-Way (ROWs) as Pollinating Insect Habitat*

Collecting Pollinators in Power Line Right of Ways **August 2016**
Syracuse, New York
Video Interview with Terry Ettinger for "Going Green" News Segment

Supplemental Pollinator Identification Education

New York Power Authority Pollinator Workshop **August 2017**
Marcy, New York

NY DEC Bee Identification Workshop **May 2017**
Huyck Preserve – Rensselearville, New York

Alabama Bee Workshop **December 2016**
Auburn University – Auburn, Alabama

Teaching Assistance and Experience

Graduate Teaching Assistant – Biology 101 **Fall 2016**
EFB Department, SUNY ESF
Lead workshops to compliment lecture material
Reviewed and graded student assignments and exams
Held office hours to assist students on a one-on-one basis

Teaching Assistant – French 102 **Spring 2016**
Department of Modern Languages, Hartwick College
Taught sections on vocabulary and grammar
Planned lessons and assignments, lead discussions