

ABSTRACT

MARSHALL, WILLIAM SAMUEL. The Effects of Lawn Plant Diversity on Arthropod Diversity. (Under the direction of Dr. David Orr).

There are currently 40 million acres of lawn throughout the United States, and are normally under chemical-intensive pesticide and fertilizer programs. Small but growing number of institutions are implementing organic management programs. Local government municipalities throughout the United States and Canada have adopted pesticide bans or alternative strategies, including organic management. Although perceived to be environmentally friendly, the effects of organic practices on arthropod biodiversity and the implications they may have for pest management are not understood. This paper reviews the relevant literature to organic management systems, focusing on potential impacts to arthropod biodiversity and pest management. Although interest is growing, there are no clear definitions or guidelines that address organic management as it relates to turf, illustrating that properly defined regulations or policies could be useful for its implementation. Definitions, background, and implementation of organic lawn management are discussed. In agroecosystems and urban systems alike, increasing the diversity of vegetation has shown to enhance ecological services provided by insects, including increase in rates of parasitism and predation. The effects of vegetative diversity on lawn pest management are less clear. Abundance of predatory taxa of insects vary in different turfgrass varieties. Under conventional, IPM, consumer-managed, or organic, it has been demonstrated that ground beetles are not affected by herbicide management program. However, small but significant decreases in seed-feeding taxa of ground beetles are indirectly impacted by a reduction in weed density resultant from herbicide treatments. Previous studies have focused on

predaceous and herbivorous insects, but have not assessed how parasitic insects are impacted, which can be important for pest management. Also neglected is the value that nonpest insect herbivores have on other wildlife species, including songbirds. Future studies should assess how lawn plant diversity resultant from organic management practices might impact insect species biodiversity, and in turn, pest and wildlife management. The impact of lawn plant diversity was assessed in 40 residential lawns in Raleigh, NC. This experiment used a factorial design to examine the effects of lawn diversity and surrounding vegetative diversity in four treatments: low lawn plant diversity and low surrounding vegetative diversity (homogeneous-simple); homogeneous-complex; diverse-simple; and diverse-complex. Ground-dwelling and foliar arthropods were sampled using pitfall trap and vacuum sampling methods, identified to the family level, and categorized into one of three functional groups: beneficial, pest, or nonpest herbivore. Abundance of selected families was also analyzed. Diverse-complex treatments hosted more diverse communities of foliar beneficial insects as well as the highest diversity and abundance of pest and nonpest insect species. Abundance of beneficial ichneumonid, mymarid, and scelionid parasitoid wasps was higher in diverse-complex treatments and pest abundance of membracid and phytophagous mirids was higher in diverse-complex treatments. Abundance of ground-dwelling granivorous beetles, spiders, and spider egg parasitoids was not influenced by lawn plant diversity or surrounding vegetative complexity. However, cricket abundance was higher in diverse-complex treatments. Findings of this study provide evidence that surrounding vegetative complexity had more of an influence on insect species diversity than vegetative diversity of all three functional groups of foliar arthropods. Specifically, pest species populations that can be economically damaging to plants of aesthetic value are enhanced by an increase in vegetative

complexity and an increase in natural enemy diversity does not always effectively suppress pest populations. Diversity of nonpests was positively influenced by increasingly diverse yards, which have also been shown to positively influence urban wildlife abundance.

Findings of this study imply that a reduction of plant species diversity in a lawn does not have an influence on arthropod diversity, which has implications for pest management.

Future studies should evaluate the mechanisms behind vegetative complexity and increased insect species diversity and evaluate its influence on efficacy of natural enemy to control pest species in urban areas.

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The Effects of Lawn Plant Diversity on Arthropod Diversity

by
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DEDICATION

This thesis is dedicated to all of my science teachers throughout high school and college who supported and believed in me and helped foster my passion for science.

BIOGRAPHY

Sam Marshall grew up in the foothills of North Carolina, where the majority of his youth was spent fishing, canoeing, and camping. Sam graduated from Appalachian State University in 2008, with a degree in Environmental Biology/Ecology and a minor in sustainable development. Upon completion of his degree, he spent a month travelling the Western United States. In May of 2009, he moved to Jarbidge, Nevada where he worked as a range technician for the USDA Forest Service. During this time, he had the opportunity to travel some more, exploring much of the Sawtooth Wilderness in Idaho and the Redwood Forests of Northern California. When he isn't studying insects, Sam enjoys travelling, reading, mountain biking, playing handball, and homebrewing.

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A REVIEW OF ORGANIC LAWN CARE PRACTICES AND POLICIES IN NORTH AMERICA AND THE IMPLICATIONS ON LAWN PLANT DIVERSITY AND INSECT PEST MANAGEMENT

Abstract

There are approximately 40 million acres throughout the United States, most of which are managed under chemical-intensive pest and fertilizer programs. “Organic lawn care” is being adopted more widely; however unlike the formally defined policies and regulations that govern organic agriculture; the label organic lawn management has not been formally defined and is used to describe a variety of practices. Neighborhoods, cities, states, and provinces across North America are adopting policies regulating the use of pesticides and fertilizers in the landscape. In addition a small but growing number of public institutions and individual consumers are successfully adopting alternative lawn care methods, including organic lawn care. Although perceived as environmentally friendly, the effects of organic management on insect diversity and pest management remain understudied. Organic lawn management leads to increased plant diversity, which in agroecosystems has enhanced ecological services provided by beneficial insect species. Effects of vegetative diversity on lawn pest management are less clear. Vegetative complexity in urban landscapes may enhance insect predator efficacy. Abundance of predatory taxa of insects varies between turfgrass varieties in response to prey populations. Mortality of insectivorous and granivorous ground beetles while not directly impacted by pest management programs in turfgrass may be indirectly impacted by a reduction in the prevalence of plant species that provide alternative food resources. Previous studies have focused on predaceous and herbaceous insects and have not included parasitic insects, which can be important in pest management. Future studies should assess how lawn plant diversity resulting from organic management practices might impact insect communities.

Introduction

As a result of the economic boom in the mid-twentieth century, the middle-class changed its way of life, increasing urban sprawl due to movement away from city centers (Robbins and Sharp 2003a). From the mid-1950s to 1986, almost 69 million acres of natural habitat was converted to urban or suburban areas (Grey and Deneke 1986) and from 2000 to 2010, urban growth in the U.S. increased by 12% each year (U.S. Census Bureau 2012). In 2012, over 80% of the U.S. population lived in urban areas (U.S.

Census Bureau 2012). Construction of homes and buildings often leads to a loss of natural vegetation (Blubaugh, Caceres, Kaplan, Larson, Sadof, and Richmond 2011), which is often replaced with turfgrass systems (Tallamy 2007). Public policies and housing regulations impose guidelines to maintain aesthetic property values, which often influence homeowners' needs to maintain lawns (Jenkins 1994). However, arguably the most influential is the social pressure from neighbors who often enforce lawn regulations, to which homeowners often conform (Byrne 2005).

There are an estimated 40 million acres of non-native grass lawns in the United States, covering almost two percent of land, making it the largest irrigated system in the country (Milesi, Running, Elvidge, Dietz, Tuttle, and Nemani 2005; Tallamy 2007). Lawns are often high-input systems, requiring a significant amount of time, monetary, and chemical investments in order to maintain aesthetic property value (Robbins, Polderman, and Birkenholtz 2001). There is growing body of evidence to support the negative impacts that overuse and misuse of chemical pesticides and fertilizers have on overall public and environmental health (Robbins *et al.* 2001).

Some individual consumers and public institutions have adopted alternative lawn management strategies, which have been promoted as a way to prevent potential negative environmental consequences of the overuse and misuse of pesticides (Henderson, Perkins, and Nelischer 1998). The growing interest in lawn management alternatives has led to changes in public policies which ban the use of cosmetic pesticide applications and favor the adoption of lawn alternatives (Vickers 2006), including organically managed green spaces (Alumai, Salminen, Richmond, Cardina, and Grewal 2008).

Although organic management programs are offered as an alternative to traditional lawn care, their impact on arthropod diversity and pest management is poorly understood. A goal of any commercial, integrated pest management (IPM), or organic management regime is to enhance the overall aesthetic quality of the lawn, which includes the suppression of pests that invade turf (Alumai *et al.* 2008). The purpose of this article is to review literature pertinent to organic lawn care, highlighting studies that have assessed the effects of turf variety and management practices on insect communities and their management.

Defining Organic Lawn Management

The USDA defines organic agriculture as “... an ecological production management system that promotes and enhances biodiversity, biological cycles, and soil biological activity. It is based on minimal use of off-farm inputs and on management practices that restore, maintain, and enhance ecological harmony” (USDA National Organic Standards Board 1995). The USDA National Organic Program (NOP) administers and publishes organic regulations with input from the public and the National Organic Standards Board. Before being certified as organic, farms must undergo a three-year transition period in which organic production practices are followed, and documentation must be provided that no unapproved products or practices were used in the production system. Producers must then submit an application and fees to a USDA-accredited certifying agent (state departments of agriculture or private organizations). After an on-site inspection and review of the application indicate the producer is in

compliance with USDA organic regulations, the certifying agent will issue an organic certificate. Producers are required to provide annual updates to the certifying agent, who performs an annual inspection to ensure USDA regulations are still being met.

Except for cases where turf is grown commercially for sod or seed production, lawns are not agricultural commodities and so their management is not regulated other than by local municipal and HOA aesthetic rules. Because there has been no groundswell of support for consistent definitions of organic lawn management and accompanying regulations like for agricultural commodities, there is no national definition or regulation of organic lawn care. This article refers to organic lawn management with the understanding that there are many varying definitions.

Relevant Public Policy in North America

Grassroots organizations throughout North America are pushing institutions as well as local and regional governments to restrict the use of pesticides and adopt organic or similar management policies for public spaces. These changes are being made primarily because of perceived public health concerns, even though the consequences of these policies may not yet be fully understood (e.g. labor requirements, pest management). The following section reviews these policy changes to put the discussion of organic lawn management into context.

Public Policies in Canada

In 1991, the Montreal suburb of Hudson, Quebec was the first municipality to adopt a bylaw prohibiting the nonessential use of pesticide applications in public and private

properties (Pralle 2006a; Robbins and Sharp 2003b). In Canada, national and provincial governments oversee the types and safety of chemicals that can be sold (Pralle 2006a). While this power was not explicitly stated for local municipalities, they did have the power to adopt bylaws that protected the health and well being of the general public (Pralle 2006a). In 1992, Spraytech and Chemlawn filed suit against Hudson, Quebec claiming that municipalities did not have the right to impose bans on chemicals which had been approved for use by national and provincial governments (Pralle 2006a). The two companies brought the case to Quebec's Superior Court, where the decision of Hudson to ban nonessential applications of pesticides was upheld (Pralle 2006a). Eventually, the case went to the Canadian Supreme Court, and in 2001 it upheld Hudson's right to ban nonessential use of chemicals (Pralle 2006a). It also extended its decision, and included the right of all local municipalities throughout Canada to adopt bylaws that banned cosmetic chemical applications in public and privately owned greenspaces (Pralle 2006a). By 2005, there were 70 municipal bylaws which banned the nonessential use of pesticides in Canada (Pralle 2006a).

In 2003 the Province of Quebec adopted a pesticides management code in an attempt to mitigate deleterious effects from the overuse of pesticides in publicly managed greenspaces. The code was revised several years later, and in 2006 extended its guidelines to include commercial as well as privately managed lawns in urban areas (Province of Quebec 2012). Guidelines of the code mandate that all applicators, whether for commercial or private (residential) use, file for an application permit stating just cause and purpose for application of pesticides (Province of Quebec 2012). Following

application of pesticides, signs must be posted notifying the public that pesticides have been applied with the maximum allowable re-entry period, depending on the type of chemical that has been applied (Province of Quebec 2012).

In 2004, the city of Regina in the province of Saskatchewan adopted the cosmetic pesticide policy, which prevents the use of cosmetic pesticide applications in publically managed greenspaces in favor of integrated pest management program (Hjertaas 2007). Unlike the other Canadian provinces, Saskatchewan does not have bylaws or restrictions on cosmetic pesticide use (Hjertaas 2007).

Ontario adopted a ban on the nonessential use of chemical pesticides on lawns in 2008 (Suzuki and Moola 2009). The Ontario Pesticides Act provides legal and regulatory policies that require all commercial pesticide applicators receive proper training in the application and handling of pesticides (Province of Ontario 2009). The cosmetic pesticides ban was added to the Pesticides Act in April 2009 and establishes a clear set of guidelines that commercial pesticide applicators must follow to reduce the nonessential use of pesticides throughout public, residential, and privately owned areas (Province of Ontario 2009). The policy is mandated throughout the entire province of Ontario but, does not include consumer-managed lawns (Province of Ontario 2009).

Alberta mandated a policy similar to Ontario's in 2008 and in 2009 New Brunswick and Prince Edward Island followed suit by adopting pesticide use restrictions in publicly managed greenspaces (Christie 2010). Most recently, Nova Scotia adopted the Nonessential Pesticides Control Act, which restricts the sale and use of nonessential pesticides for lawn care, including residential and publically managed greenspaces

(Government of Nova Scotia 2011). The province of Manitoba is currently considering similar bans on cosmetic pesticide applications throughout the entire province (Winnipeg Free Press 2012). As of 2010 almost 180 municipalities throughout most Canadian provinces have adopted similar bans on pesticide use for cosmetic purposes (Christie 2010).

Public Policies in the U.S.

In the United States, local and state regulations have focused on resident notification by lawn care companies when pesticides were applied (Pralle 2006b). In 1985, Casey, Wisconsin enacted a pesticide ordinance that required permits for pesticide use and placed bans on aerial applications of pesticides (Pralle 2006b). In 1991, the ordinance was challenged by farmers, ranchers, and the timber industry, claiming the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) preempted local regulations. However, the United States Supreme Court ruled that FIFRA did not prevent the regulation of pesticides by local governments and upheld decisions by municipalities to pass pesticide bans (Pralle 2006b). The chemical industry lobbied successfully at the federal level for state preemption laws, which meant that state laws could override stricter pesticide policies adopted at the local level (Pralle 2006b).

Local governments as a result of state preemption laws were therefore slower to adopt pesticide use regulations because of legal conflict with state laws (Pralle 2006b). One of the first nonessential pesticide bans came in 2009, as a response to public and environmental health concerns of the overuse of pesticides in Chicago city parks. The Chicago Park District partnered with the Safer Pest Control Project (<http://spcpweb.org>)

to “naturally” manage public green spaces in the greater Chicago area (Chicago Parks District 2011). The focus of the project was to eliminate the nonessential use of synthetic pesticides and fertilizers, to mitigate public health concerns with the overuse of chemicals (Chicago Park District 2011).

In King County, WA, 102 of the 189 public green spaces, are pesticide free and 87 are pesticide reduced (Enumclaw Courier-Herald 2012). Ogunquit, Rockport, and several other communities throughout Maine currently prohibit chemical-intensive landscaping in public areas (Beyond Pesticides Daily News Blog 2010).

Integrated pest management (IPM) practices and policies have been adopted in publicly managed green spaces throughout the United States. In March of 1999, Carrboro, NC adopted an integrated pest management program for all publically managed properties within the town. The plan was adopted as a result of the growing concern of the public health risks involved with cosmetic applications of chemical pesticides to treat public greenspaces (Town of Carrboro, Dept. of Public Works 1999). The program mandates that each department within the town government have a written IPM plan for the management of municipal property and is written with and reviewed by the IPM coordinator (Town of Carrboro, Dept. of Public Works 1999). The town also adopted the Least Toxic IPM Manual, which provides municipal land managers a protocol for developing and using preventative control measures for pests, using the least toxic form of chemical available (Town of Carrboro, Dept. of Public Works 1999). To date, the IPM policy for Carrboro only applies to publically managed greenspaces, and is not

mandatory for residents living within the town limits (Town of Carrboro, Dept. of Public Works 1999).

Voorhees, NJ requires all public properties and township parks to be managed under an integrated pest management program and requires postage of signs in areas that have been treated with pesticides (Beyond Pesticides 2008). New Jersey is one of 21 states that require homeowners to display postings in lawns where chemicals have been used to treat turf; it is also one of 14 states that require state agencies and individual companies to establish a registry for people to sign up for prior notification when adjacent properties are being treated with chemical sprays (Beyond Pesticides Factsheet 2012). To date, over 30 communities in New Jersey have adopted IPM strategies or have banned cosmetic pesticide use altogether (The Bernardsville News 2012).

The Cuyahoga County Council in Ohio recently approved a policy that limits the use of chemical pesticides on the public green spaces in an attempt to reduce nonessential pesticide applications (Beyond Pesticides Daily News Blog 2012). The policy promotes IPM strategies, emphasizing scouting and proper identification of pest problems, and the judicious use of chemical applications, only when pest pressure poses an immediate threat to public health and when other alternatives to pest control are not available (City Council of Cuyahoga County, OH 2011). The restrictions also require that advanced public notice be given when chemical pesticides are used in public spaces, and enforces the maximum re-entry period following applications (City Council of Cuyahoga County, OH 2011).

In 2007, as a response to public and environmental health concerns of the overuse of pesticides in city parks, Greenbelt, MD assembled an advisory committee to conduct a two-year study that assessed the monetary cost of pesticide usage within the city limits (Greenbelt City Council 2012). Based on their findings, the committee determined that nonessential applications of fertilizers and pesticides were expensive and proposed to eliminate the cosmetic applications of pesticides in publicly managed greenspaces and adopt more sustainable land management practices to alleviate monetary costs as well as public health concerns (Greenbelt City Council 2012). In 2012, Greenbelt, Maryland adopted the

Sustainable Land Care Policy, which bans all cosmetic uses of pesticides in an attempt to phase out the unnecessary use of chemicals for turf treatment (Riddle 2011). Under the law, professional contractors and landscapers must operate under an IPM or completely organic strategy for maintaining turf. Some of these strategies include using plant cultivars resistant to pest pressure, and using manual, mechanical, and biological controls to deal with pest issues, such as weeds and insects (Riddle 2011). IPM programs selectively uses chemical controls as a final option, when pests escape other forms of control (U.S. EPA 2012)

In various states across the country, public schools are adopting IPM programs to manage school grounds. In 2004, New Jersey implemented a statewide New Jersey School IPM Program, which requires that all schools in the state manage their grounds under integrated pest management practices and mandates that a minimum of 72-hour advanced notice be given to parents when pesticide applications are made to school

grounds (New Jersey Dept. of Environmental Protection 2004). Since then, California, Texas, North Carolina and other states have adopted IPM programs for managing school grounds (U.S. EPA nd).

In addition to outright bans on pesticide use or implementing IPM programs, some municipalities have adopted organic management policies for publicly managed areas. In 2001, the town of Marblehead, ME adopted the organic land management policy for turf grass, which was the first implementation of organic policies to reduce and eventually eliminate pesticide use on town-owned land (Town of Marblehead 2001). An organic pest management advisory board was assembled to prioritize the use of cultural, mechanical, and manual controls to reduce pest pressure. The advisory board does allow use of chemical controls in the event of public emergencies (Town of Marblehead 2001). The policy was disputed by professional landscapers as well as the school board, who claimed that implementation of these practices would be more expensive and not as cost effective as a balanced approach for managing turf (Capone 2002).

Camden, ME passed the Pest Management Policy, which emphasizes the use of organic practices to manage public greenspaces (Town of Camden 2008). The ordinance prevents the use of pesticides on publicly managed grounds, and operates under organic practices, using cultural, mechanical, and OMRI approved products to deal with pest issues (Town of Camden 2008). The Healthy Turf and Landscape Policy, adopted by the Village of New Paltz, NY prohibits the application of pesticides for aesthetic purposes on municipal properties and emphasizes the use of organic and cultural management practices as preventative approaches to offsetting pest problems in turfgrass (Village of

New Paltz Board of Trustees 2008). Similarly, the community of Wellfleet, MA limited the amount and types of pesticides used for managing their green spaces (Bragg 2012) and recently adopted the Municipal Organic Land Management Policy, which prohibits the use of synthetic fertilizers on public greenspaces and other municipal properties (Bragg 2012).

In Durango, Colorado, under the citizen initiative petition provision of the Durango City Charter (City of Durango, CO 1986), residents proposed an Organic Land Management Program, which would reduce and eventually eliminate the use of chemical fertilizers and pesticides throughout all city parks (City of Durango, CO 2012). Further, the program planned to implement organic turf management methods such as mechanical and manual strategies to deal with pests (City of Durango, CO 2012), and only allows the use of pesticides in a case of public health emergency, when other methods of control are unsuccessful (City of Durango, CO 2012).

However, opponents to the ordinance estimated substantial increases in cost for the organic management of green spaces, due to an increase in cost of organic fertilizer as well as an increase in labor costs from manual removal of weeds (Chamberlin 2012). Under the charter, ordinances proposed by citizen petitions cannot exceed available monetary funds of the city (City of Durango City Charter 1986). The proposal also allowed any individual citizen the right to sue the city if there was failure to comply with the regulations within the ordinance (City of Durango, CO 2012). On August 21st the proposal was vetoed by the city council (Boardman 2012). In early September 2012, however, the city council reached a compromise with advocates of the citizen group and

voted to develop and evaluate a program that minimized pesticide use and would slowly phase in organic management practices, rather than completely switch from conventional to organic management (Boardman 2012). As an initial step to adopting organic management strategies, the city council allotted a budget of \$36,000 to hire a consultant to develop and estimate the cost of implementation of an organic program for all city parks throughout Durango (Boardman 2012).

Grassroots movements throughout North America are pushing local governments to modify their land management policies to address perceived public health concerns over pesticide applications. If this trend continues, it will become more important to understand the consequences of these new policies. To date, very few studies have assessed the impacts organic land management policies may have on biodiversity, in particular on arthropod diversity and pest management.

Organic Lawn Management Practices

“Organic” or low-input lawns have shown positive correlations with overall soil and water quality and also may reduce stormwater runoff through an accumulation of soil organic matter (Morris and Bagby 2008). Suggestions for low-input turf varieties include fertilizers such as organic composts or teas, and several commercially available products that are available to treat turf pests and are certified by the Organic Materials Review Institute (OMRI; www.omri.org) as acceptable for organic agriculture (Tukey 2007). Bruneau (1997) suggests composting materials such as grass clippings as natural

fertilizers, which can add up to 30% of additional nitrogen into the soil to reduce the overall need for synthetic chemicals and fertilizer applications.

In one study, turf managed with an organic-centered approach needed only approximately 8.1 liters of water for irrigation annually per square meter of lawn, as opposed to 903 liters in a conventionally managed lawn (Morris and Bagby 2008). The direct causes for the reduction in irrigation were not evaluated; however, studies in organic agricultural systems have shown that an increase in soil biomass increases water retention, which ultimately leads to a higher tolerance in drought conditions (Pimental, Hepperly, Hanson, Douds, and Seidel 2005). Increasing organic matter in lawns also can lower the risk for pest damage as buildup of the organic matter in soils support healthier root systems, and thus have a higher tolerance for pest pressure and damage (Bruneau 1997).

Low-input turf management also has the potential to offset respiratory and toxicity impacts to humans by 42% through a reduction in the use of chemical fertilizers and pesticides. Low-input turf programs also may reduce expenses for homeowners (Morris and Bagby 2008). In a comparison of management programs (Alumai *et al.* 2008) found that organic management programs resulted in fewer herbicide and insecticide treatments than conventional programs, and thus a reduction in annual maintenance costs, with comparable aesthetic qualities to a conventionally managed system.

When a neatly manicured lawn is not the ultimate goal, “no-mow” lawns and herbaceous groundcover alternatives are suggested (Tukey 2007). No-mow strategies do

not require the types of chemical and physical inputs associated with traditional turf management, although there are initial startup costs for purchasing and spreading seed for herbaceous ground covers (Tukey 2007).

Organic Lawns on University Campuses

In March of 2008, Harvard University converted a one-acre plot of conventionally managed turfgrass into organic lawn (Raver 2009). The objective was to eliminate use of synthetic chemicals used to manage turf and compare the soil quality, biological activity, and nutrient contents, and overall health of the organically managed turf versus conventionally managed turfgrass. After eight months, the organically managed test plot had more nutrient cycling and supported more root growth, higher nitrogen levels, and reduced need for irrigation than control plots under conventional management practices (Raver 2009). The internal landscape department maintains about 65% (52 acres) of Harvard properties, which have been managed organically since 2008; however, landscape managers hope to convert all 80 acres of Harvard University to organic practices (Raver 2009; W. Carbone, Harvard University, Department of Facilities Maintenance Operations, personal communication). As a result of the switch from conventional to organic landscape practices the university noted a first-year savings of approximately two million gallons of water from reduced irrigation, and \$45,000 in landscape waste removal fees from on-campus composting (Raver 2009).

In 2011, The University of Colorado in Boulder began the first full year of implementation of organic compost tea applications through their irrigation system as a way to increase soil nutrients and soil microbial populations, with the intentions of

minimizing and eventually eliminating the need for synthetic turf inputs (Tukey 2012a; D.Inglis. University of Colorado, Boulder, Department of Facilities Management, personal communication). Any differences in annual costs associated with conventional versus organic programs will be examined by comparing results from soil bioassay tests, including biological soil fauna composition pre- and post- implementation of the organic tea applications (D.Inglis. University of Colorado, Boulder, Department of Facilities Management personal communication).

In 2009, Swarthmore College started managing about 5 acres of their grounds under organic practices to compare the differences, if any, with plots under conventional management strategies (Smith 2011). Root growth increased from about 3.5 to 5.5 inches on average since converting to organic methods; however, weed pressure and visual greenness is not noticeably different between conventional and organically managed plots (N.Selby, Swarthmore College, Department of Facilities Management, personal communication). While synthetic fertilizer and pesticide expense has been eliminated, it has been replaced with compost screening, organic fertilizer and seed purchases, and staff training to monitor soil biology and as a result there have been no savings in cost since converting to organically managed turf (N.Selby, Swarthmore College, Department of Facilities Management, personal communication).

Since March of 2012, the University of Arizona managed 12 acres of open grass in their central mall under organic practices, which includes applications of aerated compost tea and the elimination of pesticides and fertilizer applications (M. Anderson,

University of Arizona, Division of Facilities Development and Management, personal communication). Visual comparisons of organic and conventionally managed areas on Arizona's campus have not yielded any notable differences in the quality of turf between the test plots; however, they are currently awaiting soil analysis results to compare the soil biotic composition between the organic and conventionally managed areas (M. Anderson, University of Arizona, Division of Facilities Development and Management, personal communication; Tukey 2012b). Thus far, widespread adoption has been prevented due mainly to high labor expenditures and lack of adequate equipment required to maintain the 12 acre plot; however, they are seeking alternative, more efficient delivery methods similar to the one at the University of Colorado, Boulder, which utilizes the irrigation system for applications of compost tea (M. Anderson, University of Arizona, Division of Facilities Development and Management, personal communication).

Organic Practices in Golf Courses

There are several examples of golf courses taking organic approaches to managing their greens. A golf course in Lubbock, Texas recently converted 80%-90% of its fairways and greens to organic care (Morris 2011). For more than 50 years prior, the land that the course now occupies was under intensive management as a cotton farm and soil quality was a major concern for the owners. Over a period of five years, the course converted 270 acres of intensively managed greens to low-input practices. The application of compost teas and other organic soil amendments resulted in using almost a quarter of a million less gallons of water used per day than other courses under conventional management, despite being 120 acres larger (Morris 2011).

The Vineyard Golf Club on Martha's Vineyard, thought to be the only completely organic golf course in the country, uses no synthetic pesticides or fertilizers to manage the greens, fairways, and other green spaces throughout the grounds (Pennington 2010). Before construction of the golf course, surrounding subdivisions expressed concern over the potential hazards of using synthetically produced chemicals to control the greens (Pennington 2010). This ultimately resulted in the Martha's Vineyard Commission allowing the course to be constructed under the stipulation that no synthetically produced chemicals could be used to manage the grounds (Pennington 2010).

Arthropod Diversity in Turfgrass Systems

Landscape complexity and vegetative diversity have been well studied in agricultural systems and have been shown to enhance ecological services provided by beneficial arthropods (Marino and Landis 1996; Menalled, Marino, Gage, and Landis 1999). Structurally complex environments increase habitat suitability for beneficial arthropods by providing alternative food resources such as nectar and pollen (Landis, Wratten, and Gurr 2000). Theis, Steffan-Dewenter, and Tscharrntke (2003) demonstrated that the amount of non-crop vegetation in agricultural landscapes was directly correlated with parasitism of agricultural pests, and concluded that landscapes with more than 20% of non-crop vegetation had meaningful reductions in insect herbivore populations and damage to crop

plants. As habitat complexity and surrounding non-crop vegetation increases, the stability of that vegetation community likely will increase (Theis *et al.* 2003). An increase in vegetative complexity may offer sources of refuge, alternative food sources, greater variability in microclimates, or increase the ability to locate prey effectively, and the ability to avoid intraguild predation (Landis *et al.* 2000; Langellotto and Denno 2004).

Habitat complexity has also been studied in urban systems (Raupp, Shrewsbury, and Herms 2010; Shrewsbury and Raupp 2000, 2006). Shrewsbury and Raupp (2006) found that predator efficacy was enhanced and pest populations were more effectively suppressed in an increasingly complex urban environment. Urban systems often involve less frequently disturbed perennial plantings and have higher plant diversity than natural areas (Raupp *et al.* 2010) and provide the opportunity to understand how plant-herbivore-predator interactions work in these habitats (Raupp *et al.* 2010; Shrewsbury and Raupp 2000, 2006).

While the effects of vegetation structure on arthropod communities has been documented in urban systems, few studies have examined effects of lawn plant diversity on arthropod abundance and diversity even though turfgrass habitats have the ability to support diverse arthropod communities including herbivores, natural enemies, and detritivores (Potter 1993). A review by Potter and Braman (1991) highlighted common pests in turfgrass and their management, including the use of IPM programs and biological control agents. They suggested that high intensity management systems may experience more frequent pest outbreaks because of repeated insecticide applications,

which have been shown to negatively affect natural enemies important in IPM and biological control (Potter and Braman 1991). Low intensity turfgrass systems appear to be more stable, as a result of natural enemy predation and parasitism, and as a result, experience fewer pest outbreaks (Potter and Braman 1991).

Braman and Pendley (1993) attempted to catalog ground-dwelling (epigeal) arthropod fauna in centipede grass under high- and low-intensity management conditions. High-intensity systems were based on regular applications of chemical insecticides, while low-intensity sites received no treatment for the two-year duration of the study. They concluded that individual taxonomic families of arthropods responded differently to management practices. For instance, ground beetles (Carabidae) and ants (Formicidae) were found in greater numbers in the low intensity sites, presumably because of the greater number of alternative herbaceous resources available (Braman and Pendley 1993). In the high-intensity plot, parasitic wasps (Hymenoptera) and spiders were adversely affected immediately following insecticidal applications, while rove beetle (Staphylinidae) populations were positively impacted due to the increase in decaying vegetation (Braman and Pendley 1993). Raupp *et al.* (2010) suggested that arthropod communities in high-intensity turf areas could return to original population numbers if those lawns were surrounded by a heterogeneous landscape, due to the fact that structurally complex environments tend to offer sources of refuge in periods of habitat disturbance.

To determine how direct impacts of management programs might impact ground beetles, Blubaugh *et al.* (2011) compared beetle diversity across four lawn management

programs: 1) high input, calendar-based sprays, 2) an IPM program, 3) an organically managed program, and 4) a no-input program. Populations of ground beetles were monitored and the species were categorized as either: predatory, granivorous, or omnivorous (Blubaugh *et al.* 2011). Ground beetle communities were not directly impacted by management regime. Consumer and IPM programs had fewer ground beetle populations than no-input systems. The most prevalent weed species present (white clover, dandelion, and crabgrass) did have a slightly positive impact on weed-feeding beetles, indicating that a reduction of weed species through the use of herbicidal treatments might have a negative, indirect impact on granivorous species of ground beetle communities (Blubaugh *et al.* 2011).

Joseph & Braman (2009) compared the arthropod diversity in four common warm-season turfgrass varieties and concluded that turfgrass type had a significant impact on the relative abundance of most Hemipterans, with the exception of Cicadellidae and Aphididae. Among all arthropod taxa, species evenness and diversity were significantly impacted by turfgrass variety (Joseph and Braman 2009). These authors also reported that relative populations of predatory bugs (Geocoridae and Miridae) were positively impacted by weed density, noting the tendency of these groups to switch feeding habits based on prey availability. Overall plant diversity was not assessed in the study so it remains unclear as to how the diversity of plant communities within lawn systems impact arthropod abundance and diversity.

Discussion

Various interpretations of organic lawn care exist with no clear consensus of what exactly constitutes organic lawn management. Organic lawn care might be considered a *laissez-faire* approach that lets weeds and turfgrass cohabitate the same area, or it could be viewed as active management that uses only OMRI approved products. The common theme in all organic lawn management programs to date is the desire to avoid use of synthetic chemicals, especially pesticides. Because lawns are not consumed, there is no federal agency responsible for their regulation, and there are no marketing advocates demanding consistency in definition or regulation. As a result it is unlikely there will be a consensus any time soon on what, specifically, constitutes organic lawn management.

Interest in organic lawn management throughout North America is growing, and a number of entities have adopted pesticide restrictions, bans, or organic management practices in public spaces. Legal disputes between advocacy groups in some of these cases have progressed all the way to the federal Supreme Courts of both the United States and Canada.

Because the economic and environmental consequences of implementing organic practices are not clear, some of the entities involved are conducting their own assessments prior to full-scale implementation. No studies have examined directly the effects of expected increased plant species diversity in organic lawns on arthropod populations. Studies from agricultural research indicate that increasing vegetative diversity increases beneficial arthropod effectiveness in suppressing pest populations

(Theis *et al.* 2003). This concept has not yet been directly tested in turfgrass systems. Future studies should address this as part of

an effort to understand the consequences of larger scale adoption of organic lawn management.

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THE EFFECTS OF LAWN PLANT DIVERSITY ON ARTHROPOD DIVERSITY

Abstract

The impact of lawn plant diversity on arthropod diversity was assessed in 40 residential lawns in Raleigh, NC. This experiment used a factorial design to examine effects of both lawn plant diversity and vegetative diversity surrounding the yard (vegetative complexity). Arthropods were collected using pitfall and vacuum sampling methods, respectively, identified to the family level, and then assigned to functional groups (pests, beneficials, nonpest herbivores). Diversity, evenness and abundance of functional groups and selected insect families were compared across treatments. Abundances of ground-dwelling granivorous beetles and spiders were not influenced by lawn plant diversity or vegetative yard complexity; however, spider egg parasitoid abundance was greater in diverse lawns with simple yards and cricket abundance was greater in diverse lawns with complex yards. Diverse lawns with complex yards hosted more diverse communities of foliar beneficial insects and the highest diversity and abundance of pest and nonpest insect species. Abundances of selected beneficial families of parasitoid wasps (ichneumonids, mymarids, and scelionids) and selected pest families (membracids and phytophagous mirids) were higher in diverse lawns with complex yards. Increased plant species diversity in lawns influences arthropod species diversity and abundance, however, only when vegetative yard complexity surrounding the lawn is high. Lawns managed with low maintenance or organic practices may not increase herbivore pests considered economically and aesthetically damaging to turf and ornamental plant species unless surrounding vegetation is structurally complex.

Introduction

Turfgrass ecosystems occupy about 40 million acres of total land in the United States (Milesi, Running, Elvidge, Dietz, Tuttle, and Nemani 2005). Because of their ubiquity, turfgrass may represent the largest managed plant system in the United States (Milesi *et al.* 2005) and is therefore a key element in supporting biodiversity throughout urban landscapes (Blubaugh, Caceres, Kaplan, Larson, Sadof, and Richmond 2011). Despite their relative simplicity, turfgrass systems can support diverse arthropod

communities (Potter and Braman 1991), represented predominantly by insects (Cockfield and Potter 1985; Braman and Pendley 1993; Blubaugh *et al.* 2011), some of which may help to suppress pest insect populations (Braman and Pendley 1993) or provide sources of food for insectivorous bird species (Fernandez-Juric and Jokimaki 2001).

At the landscape level, greater vegetative diversity and complexity of habitats can increase beneficial arthropod fauna in agricultural systems (Marino and Landis 1996; Menalled *et al.* 1999; Hendrick, Maelfait, van Wingerden, Scgeiger, Speelmans, Aviron, Augenstein, Billeter, Bailey, Bukacek, Burel, Diekotter, Dirksen, Herzog, Liira, Roubalova, Vandomme, and Bugter 2007) and landscape context depends on the size and dispersal capability of an individual species (Perovic, Gurr, Ramon, and Nichol 2010; Rundlof, Nilsson, and Smith 2008; Theis *et al.* 2003).

Structurally complex environments may increase habitat suitability for beneficial arthropods, and help prevent pest outbreaks, thus increasing the ecological stability of a particular system (Landis, Wratten, and Gurr 2000). Structural complexity is the relative abundance of a habitat based on the percent cover of five vegetational layers: groundcover/turf, annual/perennial layer, shrub layer, understory tree layer, and an overstory (canopy layer) (Shrewsbury and Raupp 2000). Theis, Dewenter, and Tscharrntke (2003) demonstrated that the rate of parasitism of some crop pests increased linearly with the amount of non-crop vegetation in agricultural landscapes, and landscapes with more than 20% non-crop vegetation experienced economically meaningful levels of pest mortality and crop damage reduction as a result.

The effects of vegetative structural complexity on arthropods have also been studied in urban systems. Urban landscapes tend to be more stable than agroecosystems because they usually involve perennial plantings that are less frequently disturbed (Shrewsbury and Raupp 2000; 2006). In urban landscapes, vegetative complexity increases both herbivore and predator abundance (Shrewsbury and Raupp 2000; 2006). While the effects of vegetative complexity landscapes on arthropods have been examined in urban settings, little work has focused on how plant diversity of the groundcover/turf layer within lawns affects arthropod communities. Since structural complexity is based on a relative abundance of vegetative cover and does not measure specific plant species present; however, it may be necessary to determine if the diversity of each layer of vegetative complexity is influential in determining arthropod species diversity, and if those effects are independent of overall structural complexity.

Though the effects of lawn plant diversity on arthropod diversity have not been evaluated, previous studies have examined the impacts of management intensity (Braman and Pendley 1993), type of management program (Blubaugh *et al.* 2011), and turfgrass variety (Joseph and Braman 2009) on predatory arthropods in turfgrass systems. In high maintenance systems insecticide and herbicide treatments had negative consequences for parasitic Hymenoptera and spider communities while rove beetle (Staphylinidae) communities responded favorably to insecticidal and herbicidal treatments, due to increased thatch and decaying vegetative matter (Braman and Pendley 1993). Blubaugh *et al.* (2011) showed that ground beetle communities were not directly impacted by herbicide management regime in a comparison of conventional, IPM, organic, and no-

input turfgrass systems. However, they did find that percent weed cover (primarily white clover, dandelion, and crabgrass) had a small, but statistically significant negative effect on seed-feeding taxa of ground beetle communities (Blubaugh *et al.* 2011).

Joseph and Braman (2009) concluded that warm-season turf variety had a positive impact on arthropod species evenness and diversity as well as relative abundance of hemipterans with the exception of Cicadellidae and Aphididae. Species evenness is how well the abundance among individual species is distributed (Wilsey and Potvin 2000). Although these authors found that geocorid and mirid abundance were positively correlated with relative weed density, overall plant diversity and its effect on arthropod diversity were not assessed.

We determined how lawn plant diversity impacted arthropod populations and whether any observed effects were independent of landscape diversity. Arthropods examined include those that may act as pests of ornamental and turfgrass plants, those that provide important ecological services (i.e. predators and parasites), and non-pest herbivores that provide important sources of food for wildlife, including songbirds.

Materials and Methods

Yard Selection

To assess how diversity affects arthropod abundance and diversity, 40 yards were selected in the Avent West Community in Raleigh, North Carolina. Located in southeastern Raleigh, the Avent West Community is located in southeastern Raleigh and encompasses approximately 1500 acres with 250 residential sites. Site selection was based on preliminary visual estimates of lawn plant diversity and surrounding structural

complexity, hereafter referred to as yard complexity. Property owners were identified using the Wake County GIS software (Wake.gov, iMaps). Letters were mailed to homeowners requesting permission to access their lawns for the duration of the study. Sites were selected regardless of management practices and homeowners were not asked to change or alter their management regimes during this study.

Experimental Design

Ten replications were conducted of a two-factorial design, with two levels for each factor (lawn plant diversity: homogeneous or diverse and surrounding vegetative (yard) structural complexity: simple and complex). Dependent variables for arthropods included abundance, evenness of species distribution, and Simpsons and Shannon-Wiener diversity. Lawn plant dependent variables included Simpsons and Shannon-Wiener diversity index values as well as the structural complexity index of the yard of each site.

In each site, a 100-m² area of representative lawn was selected and subdivided into four 5x5-m plots to ensure equidistant sampling between pitfall traps placed in the center of each plot. A 14.3-m transect was established across the sampling area for vegetative and suction sampling. Because homeowners were not asked to change or stop their management practices, flagging material or obvious markers that might disrupt mowing regimes or aesthetics were not used. A galvanized nail was placed in each corner of the sampling area and beside each pitfall trap location for later location with a metal detector (Bounty Hunter Metal Detectors[®], El Paso, TX). This ensured timely and consistent sampling on each sample date.

Lawn plant diversity and yard complexity of initially selected sites was confirmed using transect samples and plant inventories taken throughout the 2011 and 2012 field seasons. Homogeneous lawns were dominated by one species of grass with little forb ground cover, while diverse lawns had a mix of grass and forb ground cover not dominated by any one type of vegetation. Initial estimates were confirmed by quadrat sampling of vegetative cover taken each time insects were sampled.

Vegetation Samples

Vegetative composition of each lawn was estimated on four dates in 2011 (June 16, July 7, August 8, September 2) and five dates in 2012 (April 12, May 8, June 5, July 7, and July 30). A 1-m² quadrat sampler was randomly thrown across the 14.3-m transect three times to estimate percent cover for each plant species. Individual sample estimates were pooled and divided by three to obtain an overall estimate of percent cover of grass and forb plant specimens present in each lawn. Samples of plants that could not be identified in the field were taken from the lawn, preserved, and later identified with the help of Dr. Alexander Krings, Herbarium Curator at North Carolina State University.

Vegetative complexity of vegetation within a 60-m² radius of the center of each lawn was calculated on May 15, 2011 and on June 12, 2012 using the structural complexity index (SCI) (Shrewsbury and Raupp 2006). This value was recorded to determine effects that vegetation in the yard surrounding individual lawns might have on arthropod populations in the lawns. The SCI is a measure of the structural intricacy of vegetation determined by estimating percent cover of five strata: 1) ground cover (including lawn) 2) annual/perennial layer, 3) shrub layer, 4) understory tree layer, and 5)

canopy layer. Estimates for each vegetative layer are based on a 100 percent maximum so that each study site has the potential to score a maximum SCI of 500. Values less than 125 represent structurally simple surrounding landscapes and those greater than 175 represent structurally complex landscapes (Shrewsbury and Raupp 2000). Moderately complex landscapes, those that scored between 125 and 175 were not included in this study.

Arthropod Sampling

Pitfall traps. To assess activity density of ground-dwelling arthropods, three pitfall traps were assigned to three of the four subdivided quadrats in each experimental plot in each study site on four dates in 2011 (June 3, July 5, August 8, September 9) and five dates in 2012 (April 20, May 21, June 14, July 12, August 8). A 0.95-cm diameter core sampler was used to dig the holes for the pitfall traps. To make the traps permanent, 12.7-cm lengths of 2.5-cm ID schedule 40 PVC pipe was placed into the excavated hole just below the surface of the lawn. A constraint to sampling in residential lawns was that homeowners did not want conspicuous pitfall traps (i.e. one solo cup), which can be used for sampling ground-dwelling arthropods. As a result, three, 50 mL Falcon™ tubes (Fisher Scientific, Waltham MA) measuring approximately 2.7-cm wide were randomly assigned to three of the four subdivided 5x5-m plots in each study site. Total trapping surface area for each plot was approximately 25.4-cm or approximately one solo cup. During sample dates, traps were filled with 40 mL of 50% antifreeze solution and left open for approximately one week. After the one-week period, traps were removed and the open hole was replaced with a cork plug to prevent arthropods from falling into the excavated hole.

Suction Samples. A suction sampler (Husqvarna[®], Model No.125BVX. Charlotte, NC) was used to sample foliar insects in the vegetational layer of each experimental plot. Vacuum samples consisted of walking a 14.3-m diagonal transect through the sample plot. The diameter for the suction sampler measured approximately 0.02-m with a total area of 0.4 m², which resulted in a total area of 5.7-m² being sampled in each experimental plot. Suction samples were taken between 1000 and 1400 hours to account for optimal arthropod activity (Joseph & Braman 2009). Vacuum samples were taken on four dates in 2011 (June 7, July 8, August 8, September 3) and on five dates in 2012 (April 10, May 11, June 8, July 3, August 2). Specimens were placed into plastic bags, labeled, and stored in a freezer at 0 °C until they were processed.

Insect Identification

Insects were identified to family level using keys from the following: Borror, Triplehorn, and Johnson (1989), Goulet and Huber (ed.) (1993), Gibson, Huber, and Wooley (1997), and Balme and Orr (2011). Reference collections were constructed and later confirmed with the assistance of Matthew Bertone, Andrew Ernst, and Bob Blinn at the North Carolina State University Insect Museum. After identification, insects and other arthropods were categorized as pest, beneficial, or herbivore nonpest (Table 1). Groupings were based on confirmation from: Borror *et al.* (1989); Flint and Dreistadt (1998), and Forehand, Orr, and Linker (2006). Groups that had varying life history traits such as Springtails (Order: Collembola) and fungus gnats (Families: Mycetophilidae, Sciaridae) were excluded from this study as they are not considered to be pests or beneficial (Cranshaw and Cloyd 2009). The family Formicidae was not included in the

analysis because fire ants were the main species in pitfall traps in the two-year duration of this study and their presence is dependent on whether homeowners applied measures to control fire ants. Native species of ants were too low to accurately analyze diversity.

Statistical analysis

Vegetation samples were analyzed for species diversity and surrounding structural complexity, while arthropod samples were analyzed for species evenness, diversity, and total overall abundance using statistical analysis software (SAS Version 9.2, SAS Institute, Cary, NC). Effects of lawn plant diversity on arthropod diversity and abundance were tested using an analysis of variance (ANOVA) that was constructed using SAS PROC-GLM procedure (SAS Version 9.2, SAS Institute, Cary, NC). Sampling dates, dates within year, replications, and replications within lawn type were considered fixed effects while arthropod diversity and abundance were the response variables. Means of each functional group and selected individual families in each site were separated using LSmeans.

Simpson's Index, Shannon-Wiener Index, species evenness, and abundance values were analyzed for each functional group (beneficial, pest, and nonpest). Simpson's index is a measure of species diversity and richness and accounts for rare individual species in a particular habitat (CITATION), while Shannon-Wiener accounts for species richness and diversity and does not include rare individuals. Species evenness is the relative abundance with which each species is represented in a habitat and is an overall indication of ecological stability (DeJong 1975; Molles and Cahill 1999). A

habitat that is considered ecologically stable is when species can return to original population numbers following a temporary disturbance event (Grimm and Wissel 1997). Previous studies have reported equal value for both diversity indices and for this reason, we used both to calculate plant and arthropod species diversity. Abundance also was calculated for selected individual families. Abundance values for the nonpest functional group and several individual families of parasitic wasps (Hymenoptera: Ichneumonidae, Figitidae) were transformed using $\log(x+1)$ to normalize frequency distributions and to stabilize the variance resultant from high standard errors.

Simpson's index was used to calculate and compare total species richness and percent of each species present in a site. Simpson's index is based on a scale from 0-1, where zero represents the highest level of habitat diversity (DeJong 1975). Shannon's index gives an account of species richness and the proportion of individual species present, which allows for a calculation of evenness between habitats. Shannon's Index is based on a scale of 0-4, where four represents the highest habitat diversity (Molles and Cahill 1999). Both Simpson's and Shannon's indices allowed comparisons of species richness as well as species evenness across treatment groups.

Special cases were considered for diversity index calculations because not all families of arthropods were observed in every sample date. When there were all zeroes in an observation date, a zero was assigned for Simpson's index and treated as a missing value for Shannon. When there were all zeros and only a single observation, a zero was assigned for both indices. In cases where there were all zeroes and a nonzero integer

greater than one, a value of one was assigned for Simpson and a zero was assigned for Shannon's index.

Results

Lawn plant diversity

Lawn plant diversity was higher in diverse lawns than homogeneous lawns and SCI of complex treatments was higher than simple treatments (Simpson $P < 0.0001$; Shannon $P < 0.0001$; SCI $P < 0.0001$) (Table 2), statistically confirming treatment groups (Table 2). There was no difference in mean diversity values between homogeneous lawns, regardless of surrounding vegetative complexity (Table 2). Diversity values of both homogeneous lawn treatments were lower than both diverse lawns, but the diverse-complex treatment had higher lawn plant diversity than diverse-simple treatments. There was only a 20% difference between diversity index values for both diverse lawn treatments, but an approximately 2-fold difference between Simpson values and a 3-fold difference between Shannon values for diverse compared to homogeneous lawn treatments.

Effects of lawn diversity on beneficial ground-dwelling arthropods

Lawn type did not affect diversity and evenness values of ground-dwelling arthropods (Table 3), but there did appear to be an effect of lawn type on abundance (Table 3). Diverse-simple lawns had lower overall abundance value and differed than the other lawn treatments (Table 3). Abundance of *Baeus spp.* was greater in diverse-simple lawns (Table 4). Field crickets were more abundant in diverse-complex treatments (Table 4). Diversity, evenness, and abundance values for ground-dwelling pest and

nonpest arthropods were not analyzed in this study as the number of pitfall trap captures was too low.

Effects of lawn diversity on foliar arthropods

Beneficial insects. Both diversity indices and evenness values for beneficial insects were influenced by treatment type (Simpson $P = 0.01$; Shannon $P = 0.01$; Evenness $P = 0.01$) (Table 5). Simpson's index values were greater in diverse treatment types than homogeneous regardless of surrounding vegetative complexity (Table 5). Shannon's index was greater in diverse-complex treatments than the other treatment types, but again, values for diverse lawns were greater than for simple treatments (Table 5). Evenness and abundance values were greater in diverse-complex treatments than the others (Table 5).

Abundance of several families of parasitic wasps (Ichneumonidae, Pteromalidae, Mymaridae, and Scelionidae) were influenced by treatment ($P = 0.02$; $P = 0.001$; $P = 0.006$; $P = 0.0006$, respectively) (Table 6). Mymarid and scelionid wasp abundance was higher in the diverse-complex lawn treatment than the other three groups (Table 6). Ichneumonid and pteromalid abundance were greatest in diverse-complex lawn treatments (Table 6).

Pest insects. Lawn type affected Shannon's index, evenness, and abundance values for pest insects (Shannon $P = 0.009$; Evenness $P = 0.009$; Abundance $P = 0.01$) (Table 5). Shannon's index, evenness, and abundance values were greater in diverse-complex lawn treatments (Table 5). Diverse-simple lawn type had greater evenness values than homogeneous-simple and homogeneous-complex treatments (Table 5).

Abundance of pests was highest in diverse-complex treatments than the other three treatments (Table 5). Abundance of the hemipteran families Membracidae and Miridae was greater higher in diverse-complex lawn treatments (Table 6).

Nonpest Insects. Treatment affected Shannon's index and evenness, and abundance values ($P = 0.03$; $P = 0.03$; $P < 0.0001$, respectively) (Table 5). Individual family abundance of nonpest arthropods was too low to accurately analyze and were not included in this study.

Discussion

Ecological theory predicts that an increase in plant diversity should increase the diversity of arthropods. Findings of this study indicate that an increase in lawn plant diversity increases the diversity and abundance of arthropods. This is the first evidence in urban lawns that directly measures how arthropods respond to an increase in lawn plant diversity. Specifically, we found that the diversity of beneficial, pest, and nonpest arthropod functional groups was highest when lawn plant diversity was high, and in some cases, only when surrounding vegetative complexity is high. We found that abundance of selected individual families of beneficial parasitic wasps and pest insects was highest when vegetation of the yard was complex, but only when lawn plant diversity was high, an indication that the diversity of individual layers that make up the SCI are as influential in determining arthropod diversity and abundance as the SCI itself.

Ground-dwelling arthropods.

The effects of lawn plant diversity and the ecological consequences it may have on arthropod diversity are not fully understood (Blubaugh *et al.* 2011). We assessed the

effects of increased lawn plant diversity and surrounding vegetative complexity on ground-dwelling beneficial arthropods over two seasons in a suburban community. Overall, lawn plant diversity and surrounding vegetative complexity did not influence combined beneficial ground-dwelling arthropod populations. Likewise, no effect was found for individual abundant families (Coleoptera: Carabidae: *Harpalus spp.*, *Anisodactylous spp.*) that have demonstrated efficacy as weed-seed predators (Tooley and Brust 2002; White, Renner, Menalled, and Landis 2007).

Previous studies conducted in experimental research plots demonstrated that low maintenance turf programs and increased weed cover in turfgrass had a positive impact on the diversity and abundance of seed-feeding ground beetles (Cockfield and Potter 1985; Blubaugh *et al.* 2011), but was not demonstrated in our study. Increased structural complexity has been shown to offer refuge habitat and increase species abundance of ground beetle populations in disturbed areas in agroecosystems (Lee, Menalled, and Landis 2001) and turfgrass (Frank and Shrewsbury 2004). However, urban areas may present unique challenges to the movement of ground-dwelling arthropods as surrounding impervious structures could impede movement and dispersal of ground dwelling arthropods, increasing the risk and difficulty of dispersal and recolonization of new habitat (McDonnell, Pickett, and Pouyat. 1993; Niemela 2000). Further, frequently disturbed systems such as a lawn may not be readily colonized by arthropods that respond negatively to increased habitat disturbance.

Spiders have demonstrated their importance as predators of arthropods (Riechert and Bishop 1990); however, we found no evidence that lawn diversity influences the

abundance of this particular group. Joseph and Braman (2009) found that spiders did not respond to percent weed cover, most likely because of their generally predaceous habit. However, another possible explanation could be that abundance of *Baeus spp.* (Scelionidae), a spider egg parasitoid, was higher in diverse lawns. To our knowledge, this has not been previously reported in turfgrass, but *Baeus spp.* has demonstrated the ability to disrupt spider populations in agricultural systems (van Baarlen, Sunderland, and Topping 1994). Thus, plant diversity and its effects on spider populations could be constrained if an abundant parasitoid is also present in a more diverse plant community.

Foliar arthropod diversity.

Beneficial species diversity was higher in treatments with diverse plant communities, however diverse-complex treatments had higher arthropod species diversity than diverse-simple lawn treatments. Vegetatively complex environments have been shown to provide refuge habitat for parasitoids (Frankie, Morgan, and Grissell 1992), which could explain higher abundance values for mymarid and scelionid wasps (Lassau and Hochuli 2005). However, these two groups were only higher when lawn plant diversity was high, indicating that plant diversity on at least one level of the SCI is influential in determining family abundance for these two species.

Pteromalid wasps, known parasitoids of filth fly pupae (Diptera: Sarcophagidae), were collected in high numbers on four sampling dates in 2011 and 2012 from two simple-simple lawns and one simple-complex lawn (Marshall, personal observation). Adult sarcophagid flies were also observed in high numbers during the same times. Tooker and Hanks (2000) demonstrated that rates of parasitism was significantly higher

in turfgrass environments and positively correlated with host density, even though species diversity of parasitic wasps was higher in vegetatively complex environments. Although ichneumonid and pteromalid abundances were significantly affected by treatment in the our study, the lack of difference between lawn types may be due to host availability rather than a lack of response to plant diversity.

It has been suggested that increasing surrounding vegetative complexity increases predatory and parasitic insect abundance by offering refuge from predation, enhancing microclimates, and offering a higher concentration of food resources (Raupp, Shrewsbury, and Herms 2010; Shrewsbury and Raupp 2006). An increase in beneficial insect populations has also been shown to suppress specific pest species (Shrewsbury and Raupp 2006; Tooker and Hanks 2000), but their ability to effectively reduce pest populations in urban areas has not been studied (Raupp *et al.* 2010). Beneficial insect diversity and abundance alone are not always accurate predictors for effective pest suppression in other systems (Forehand 2005). If multiple natural enemies are present in a system they could potentially compete with one another for host resources through multiparasitism (Ehler and Hall 1982; Leveque, Monge, Rojas-Rousse, Alebeck, and Huignard 1993) or intraguild predation (Denoth, Frid, and Meyers 2001), which can reduce the efficacy of pest suppression by natural enemies.

Herbivore pest diversity and abundance is increased in structurally diverse sites, but for some individual families, only when lawn plant diversity was high. Laboratory and field studies have demonstrated that diverse plant communities can in some cases intensify pest populations and that concentrated food resources may promote specialist

herbivores (Andow and Risch 1985; Collins and Johnson 1985; Baggen and Gurr 1998; Root 1973). Membracid and mirid abundance in this study was significantly higher in structurally complex yards with diverse lawns. Phytophagous mirids can be economically damaging to a variety of crops (Boivin and Stewart 1983; Stoner and Bottger 1965) and are also considered major pests of garden, ornamental, and grass species (Kelly, Schoelhorn, Deng, and Harbaugh 2003). Cicadellid pests tend to have a large host range (Poos and Wheeler 1943) and as a result are found in a variety of different habitats (Roltsch and Gage 1990; Joseph and Braman 2009), which could explain why lawn diversity did not influence their populations in the current study.

Nonpest herbivorous insects were included in this study because they are potentially an important source of food for various species of wildlife such as birds in urban areas (Falk 1976; McKinney 2002; Horne, Hanula, Ulyshen, and Kilgo 2005). Increased habitat complexity has been shown to positively influence bird species in urban environments (Beissinger and Osborne 1982; Fernandez *et al.* 2001; McKinney 2002). In the current study non-pest herbivorous insect diversity was increased in structurally complex yards where lawn plant diversity was high, indicating that lawn management may be an important consideration for urban wildlife management.

Lawn Diversity and Implications for Management

Results of this study show that vegetatively complex suburban yards increase the diversity and abundance of the three insect functional groups examined. For some individual families, abundance was highest in the most structurally complex yards, but only when lawn plant diversity was high. Since structural complexity index values are

calculated from percent cover of each layer of vegetation, including lawns, this suggests that the species diversity of vegetational strata could be an important consideration when assessing overall landscape complexity.

Specific species of herbaceous ground covers may have more of an impact on beneficial insect populations than diversity alone. For instance, white clover (*Trifolium repens*) has been shown to attract certain parasitoid species that attack pine scale insects (Tooker 1999). In agricultural settings, plant diversity in and of itself may not be an accurate predictor of beneficial insect species diversity as much as the qualitative value of specific plant resources (Landis, Wratten, and Gurr 2000; Wackers 2004).

Increased vegetative complexity in suburban landscapes may facilitate movement of pest insects by increasing connectivity between habitats (Belisle 2005) and subsequently increasing the diversity and abundance of available food resources, which could exacerbate pest problems for homeowners (Raupp *et al.* 2010). The fact that lawn diversity did not change pest populations in our study suggests that conventional, low maintenance, or organically managed lawns may not inherently require more pest management, but that pest management in these situations may be depend on the context of the lawn.

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Table 1. Functional group assignments of insect families collected from lawns of varying diversity and surrounding vegetative structural complexity. Raleigh, North Carolina, 2011 and 2012.

Suction Sampling

Beneficials

Chalcididae	Ichneumonidae	Figitidae
Braconidae	Pteromalidae	Bethylidae
Mymaridae	Scelionidae	Encyrtidae
Halictidae	Diapriidae	Eulophidae
Reduviidae	Crabronidae	Nabidae
Berytidae	Geocoridae	Cydnidae
Tachinidae	Syrphidae	Pipunculidae
Dolichopodidae	Coccinellidae	Cantharidae
Melyridae	Anthocoridae	Coccinellidae

Pests

Cicadellidae	Membracidae	Miridae [†]
Aphididae	Thripidae	Pentatomidae
Tingidae	Culicidae	Chrysomelidae
Curculionidae	Elateridae	Scarabaeidae

Nonpests

Cercopidae	Acrididae	Lepidoptera
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Pitfall Sampling

Beneficials

Tenebrionidae	Carabidae	Cleridae
Staphylinidae	Gryllidae	

Non-Insect Groups from Pitfall Sampling

Aranae (Beneficial)
 Isopoda (Beneficial)
 Chilopoda (Beneficial)
 Diplopoda (Beneficial)

[†]Phytophagous miridae only

Table 2. Diversity and structural complexity index (SCI) values (mean±SE) of vegetation per square meter in lawns of varying diversity and surrounding vegetative structural complexity. Raleigh, North Carolina, 2011 and 2012. Letters in the same column that are the same indicate no significant difference between lawn types.

Lawn Type	Simpson Diversity Index	Shannon Diversity Index	SCI
Homogenous-Simple	0.75±0.014a	0.49±0.029a	118.63±3.75a
Homogeneous-Complex	0.77±0.014a	0.50±0.030a	176.7±3.58b
Diverse-Simple	0.35±0.014b	1.43±0.030b	121.9±3.25a
Diverse-Complex	0.28±0.014c	1.60±0.030c	176.3±2.76b
F	342.8	393.1	54.4
Df	3,36	3,36	3,36
P	<0.0001	<0.0001	<0.0001

Table 3. Diversity, evenness of distribution, and abundance (mean±SE) of beneficial ground-dwelling arthropods collected from pitfall trap samples in lawns of varying diversity and surrounding vegetative structural complexity. Raleigh, North Carolina, 2011 and 2012. Letters in the same column that are the same indicate no significant difference between lawn types.

Lawn Type	Simpson Diversity Index	Shannon Diversity Index	Distribution Evenness	Abundance
Homogeneous-simple	0.55±0.03a	0.81±0.04a	0.33±0.02a	32.3±2.57a
Homogeneous-complex	0.51±0.03a	0.81±0.05a	0.33±0.02a	28.6±2.58a
Diverse-simple	0.49±0.02a	0.9±0.04a	0.36±0.02a	16.3±2.39b
Diverse-complex	0.49±0.03a	0.89±0.05a	0.36±0.02a	24.4±2.9a
F	1.19	0.61	0.60	7.03
Df	3,301	3,301	3,301	3,301
P	0.31	0.60	0.61	0.0001

Table 4. Mean abundance (\pm SE) of selected beneficial ground-dwelling arthropod families collected from pitfall trap samples in lawns of varying diversity and surrounding vegetative structural complexity. Raleigh, North Carolina, 2011 and 2012. Letters in the same column that are the same indicate no significant difference.

Lawn Type	Carabidae*	Araneae**	<i>Baeus spp.</i> †	Gryllidae^{††}
Homogeneous-simple	0.09 \pm 0.77a	11.2 \pm 1.1a	0.76 \pm 0.24a	1.67 \pm 0.54a
Homogeneous-complex	0.09 \pm 0.80a	8.9 \pm 1.1a	0.74 \pm 0.25a	2.10 \pm 0.56a
Diverse-simple	1.11 \pm 0.74a	12.13 \pm 1.02a	1.67 \pm 0.22b	4.22 \pm 0.52b
Diverse-complex	1.32 \pm 0.87a	12.16 \pm 1.21a	1.28 \pm 0.27ab	4.62 \pm 0.61b
F	0.28	1.8	3.38	7.45
Df	3,301	3,301	3,301	3,301
P	0.83	0.15	0.03	<0.0001

*Ground Beetles

**Spiders

†Wingless spider egg parasitoids (Hymenoptera: Scelionidae)

††Gryllidae

Table 5. Diversity, Evenness and abundance (mean±SE) of foliar beneficial, pest, and nonpest arthropods collected from suction sampling in lawns of varying diversity and surrounding vegetative structural complexity. Raleigh, North Carolina, 2011 and 2012. Letters in the same column that are the same indicate no significant difference between lawn types.

Functional Group	Simpson Diversity Index	Shannon Diversity Index	Evenness Index	
<u>Abundance</u>				
Beneficial				
Homogeneous-Simple	0.31±0.02a	1.11±0.064a	0.34±0.02a	18.3±2.2a
Homogeneous-Complex	0.30±0.02a	1.08±0.06a	0.33±0.02a	15.5±2.3a
Diverse-Simple	0.19±0.03b	1.28±0.06b	0.40±0.02a	15.6±2.1a
Diverse-Complex	0.17±0.03b	1.42±0.07c	0.43±0.02b	21.2±2.5b
F	3.75	3.65	3.65	2.03
Df	3,302	3,294	3,294	3,302
P	0.01	0.01	0.01	0.07
Herbivore Pests				
Homogeneous-Simple	0.65±0.04a	0.31±0.04a	0.13±0.02a	25.9±6.4a
Homogeneous-Complex	0.64±0.04a	0.38±0.04a	0.16±0.02a	21.6±6.7a
Diverse-Simple	0.61±0.04a	0.46±0.04a	0.20±0.02b	30.4±6.1a
Diverse-Complex	0.62±0.04a	0.55±0.05b	0.24±0.02c	51.9±7.1b
F	0.15	3.93	3.93	3.75
Df	3,302	3,302	3,289	3,302
P	0.92	0.009	0.009	0.01

Table 5. (continued)

Herbivore Non-Pests					
Homogeneous-Simple	0.04±0.03a	0.08±0.12a	0.05±0.06a	0.20±0.05a	
Homogeneous-Complex	0.02±0.04a	0.04±0.14a	0.02±0.08a	0.17±0.05a	
Diverse-Simple	0.12±0.03a	0.11±0.1a	0.05±0.05a	0.38±0.05b	
Diverse-Complex	0.15±0.04a	0.36±0.1b	0.20±0.04b	0.57±0.06c	
F	1.24	3.14	3.14	11.6	
df	3,302	3,302	3,66	3,302	
P	0.29	0.03	0.03	<0.0001	

Table 6. Mean abundance (\pm SE) per 14.3 m transect sample of selected beneficial and pest insect families collected from suction sampling in lawns of varying diversity and surrounding vegetative structural complexity. Raleigh, North Carolina, 2011 and 2012. Letters in the same column that are the same indicate no significant difference.

<u>Hymenoptera Families</u>						
<u>Beneficial</u>	<u>Ichneumonidae</u>	<u>Figitidae</u>	<u>Braconidae</u>	<u>Pteromalidae</u>	<u>Mymaridae</u>	<u>Scelionidae</u>
Homogeneous-Simple	0.24±0.04ab	0.37±0.05a	2.0±0.35ab	4.74±0.72ab	1.26±0.43a	2.1±0.40a
Homogeneous-Complex	0.2±0.04a	0.33±0.06a	2.1±0.36ab	4.22±0.76ab	1.65±0.45ab	1.8±0.38a
Diverse-Simple	0.2±0.04a	0.41±0.06a	2.4±0.33a	3.32±0.70a	2.80±0.41b	2.0±0.35a
Diverse-Complex	0.36±0.04b	0.44±0.06a	1.4±0.39b	6.0±0.81b	4.0±0.48c	3.60±0.41b
F	3.20	0.61	2.46	3.87	4.21	5.95
Df	3,302	3,302	3,302	3,302	3,302	3,302
P	0.02	0.61	0.06	0.001	0.006	0.0006

Table 6. (continued)

	<u>Hemiptera</u>		<u>Diptera Families</u>	
	<u>Geocoridae</u>		<u>Tachinidae</u>	<u>Dolichopodidae</u>
Homogeneous-Simple	0.12±0.07a		0.29±0.2a	0.012±0.03a
Homogeneous-Complex	0.13±0.07a		0.57±0.2a	0.011±0.03a
Diverse-Simple	0.13±0.07a		0.27±0.2a	0.060±0.03a
Diverse-Complex	0.15±0.08a		0.09±0.2a	0.08±0.04a
F	0.03		0.83	0.84
Df	3,302		3,302	3,302
P	0.99		0.48	0.47

Table 6. (continued)

<u>Pests</u>	<u>Hemiptera Families</u>		
	<u>Cicadellidae</u>	<u>Membracidae</u>	<u>Miridae</u> [†]
Homogeneous-Simple	24.1±4.7a	0.71±3.1a	1.13±2.1a
Homogeneous-Complex	15.1±5.0a	0.22±3.3a	5.0±2.1ab
Diverse-Simple	24.1±4.5a	1.7±3.0a	3.3±2.0a
Diverse-Complex	29.5±5.3a	12.4±3.5b	8.7±2.3b
F	1.59	3.6	2.94
Df	3,302	3,302	3,302
P	0.19	0.013	0.04

[†]Phytophagous miridae only