PLANTING NATIVE PLANTS IN RESIDENTIAL LANDSCAPES INCREASES VISITS BY WILD BEES AND OTHER IMPORTANT POLLINATORS

A Thesis

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ABSTRACT

1. The potential for residential landscapes to support pollinators is of great interest to conservation and agriculture yet little is known of the impacts achieved by adding native plants to residential yards.

2. We implemented landscaping improvements incorporating native flowers, shrubs, and small trees into existing designs of front yards (N = 19) and backyards (N = 11) of private residences in Ithaca, NY and encouraged the homeowners to practice sustainable management practices in their yards. All 30 treatment properties, and an additional 8 quasi-control properties, were monitored for pollinator visits to both the enhanced and unmanipulated front and back yard sections for two years (2016 and 2017). We ran generalized linear mixed effects models in R to estimate the effects of enhancement and other factors on pollinator visits and included environmental and land use data to account for additional variation.

3. Counts of pollinator visits in the most active area ("Most Active Area" method) of the yards revealed that the total N pollinator visits and N wild bee visits were greater in enhanced sections of properties than in unmanipulated sections and that wild bee visits, specifically, increased with backyard enhancements in year two (2017). Enhanced sections of yards also received more pollinator visits than quasi-control yards, but only in the second year (2017).

4. In 2017, we tested for the effect of local enhancement on pollinator visits using an identical, predetermined focal plant (false sunflower). Unlike the Most Active Area method, the Focal Plant method showed no differences in the total number of pollinator visits nor number of wild bee visits between enhanced sections of treatment yards and quasi-control yards. As area enhanced (m^2) tended to be negatively associated with the number of pollinator visits using the Most Active Area method, pollinators are likely more dispersed in enhanced than unenhanced quasi-control yards.

5. *Synthesis and applications.* Our results indicate that modest native plant additions have positive effects on the number of pollinator visits in residential yards and suggest that the "Most Active Area" method may be more powerful for detecting these effects than using a single sunflower as a focal census plant. Our quasi-experimental design allowed for practical implementation of native plant enhancements based on homeowner preferences and local growing capabilities while providing robust results. The rural landscape surrounding the city of Ithaca may have played a large role in our results and more research is needed to examine the extent to which landscape context influences the benefits of habitat enhancements for pollinators in small towns and cities.

BIOGRAPHICAL SKETCH

Jacob Johnston grew up outside, like many in conservation, watching ants and birds, turning over logs and rocks, and saving leaves and pine cones in shoe boxes. An undergrad trip to the tropical forest in Central America helped Jacob understand the connections between vegetation and wildlife diversity and convinced him that the answers to many conservation issues lie in vegetation management. His research seeks to bridge the built and natural environment and return habitat functionality to the vegetated landscape.

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TABLE OF CONTENTS

INTRODUCTION 1

METHODS 4

Site Selection and Enhancement 4

Data Collection 11

2016 and 2017: The Most Active Area method 12

2017: The Focal Plant method 13

2016 and 2017: Pollinator Identification 14

Postsurvey of yard management practices 15

Analysis 16

RESULTS 18

Description of Management Practices 18

Description of Site Enhancements 20

Impacts of native plant enhancements 20

Pollinator response to enhancement, Most Active Area method - 2016 20

Pollinator response to enhancement, Most Active Area method - 2017 24

Pollinator response to enhancement, Focal Plant method - 2017 25

Wild bee response to enhancement, 2017 27

DISCUSSION 29

LIST OF FIGURES

Figure 1. Map of research properties across Ithaca, New York…………..……………………….5

Figure 2. Assessment of enhancements in treatment properties between front and back yard enhanced sections……………………………………………………………………...21

Figure 3. Predicted values for visits by all pollinators based on 2016 pollinator census data using Most Active Area method ……………………………………………………………….23

Figure 4. Predicted values for visits by all pollinators based on 2017 pollinator census data using Most Active Area method and the Focal Plant method ……………………………………26

Figure 5. Predicted values for visits by wild bees based on 2017 pollinator census data using Most Active Area method and the Focal Plant (Heliopsis helianthoides) method…………28

LIST OF TABLES

Table 1. Table of research questions, hypotheses, predictions and results…...…………………..2

Table 2. Descriptive data of research properties, mean total areas and percentage of land cover types….……………………………..…………………………….…………………...8

Table 3. Differences in practices implemented in front vs. back yards of treatment properties based on postsurvey of homeowners…………………………………………………….19

INTRODUCTION

The movement to modify residential landscapes to help pollinators is gaining ground as increased efforts are being made to support a variety of pollinators including birds, butterflies, domesticated honeybees, and even the often-overlooked wild bees. These movements usually focus on the use of regionally native plants (Pardee and Philpott, 2014), but also encourage and promote sustainable practices such as limited pesticide and herbicide use, altered mowing schedules, and leaving, rather than removing, plant debris (litter). Restoring habitat through naturalized landscaping has also been identified as an important strategy to complement conservation efforts on public lands (Cooper et al., 2007; Rudd et al., 2002). In spite of widespread enthusiasm for creating more sustainable urban and suburban landscapes (Butler et al., 2012), little is known about the impacts of recommended practices on pollinator populations.

In many cities, residential property represents a large proportion of urban land. Private gardens can account for approximately 25 percent of that residential landscape (Gaston et al., 2005; Loram et al., 2007). With a growing proportion of land in control of private owners (Eno et al., 2005), the addition of native plants and adoption of sustainable practices in residential landscapes may help mitigate habitat loss (Renauld et al., 2016), population declines (Bartomeus et al., 2013; Goulson et al., 2007) and reduced ecosystem services (Ollerton et al., 2011). We tested the ecological hypothesis that enhancing yards and gardens with native plants for pollinators would lead to greater visitation by pollinators, generally, and greater visitation by native pollinators.

Correlations have been found between native plants, namely trees and shrubs, and the abundance and species richness of pollinating birds and butterflies (Burghardt et al., 2009), pollen- and nectar-feeding bees (Hopwood, 2008), and Lepidopteran diversity (Burghardt et al., 2010; Tallamy and Shropshire, 2009). Furthermore, observational studies in Europe have demonstrated the potential for native vegetation in residential settings to provide habitat resources to a diversity of pollinating insects (Salisbury et al., 2015; Samnegård et al., 2011) and other beneficial invertebrates (Smith et al., 2006). Surveys in the U.S. have also shown that urban gardens and parks, despite their small size, attract more bees, and more species of bees, than similar habitats in larger state parks in more rural areas (McFrederick and LeBuhn, 2006; Samnegård et al., 2011). Although rural areas generally support greater numbers and higher diversity of pollinator assemblages (Bates et al., 2011), studies comparing meadows and urban areas demonstrate that urban sites support a greater diversity of solitary bees, including observations of rare species (Sirohi et al., 2015). On the other hand, traditional gardens planted with non-native exotic species demonstrate relatively poor diversity and abundance of pollinators (Tommasi et al., 2004).

While there is observational support for beneficial effects of enhancing residential habitats, experimental studies of the impacts of landscape enhancements on pollinators and wild bees are few and show mixed results (Matteson and Langellotto, 2010; Simao et al., 2018). Moreover, these studies have often focused on a single genus of bee (Kaluza et al., 2016; Osborne et al., 2008) or included enhancements using a single species of plant (Simao et al., 2018), and most were based in large cities and within existing parks or community gardens (Matteson and Langellotto, 2010, 2009), using potted plants in short-term treatments, which did not consider multi-seasonal needs for wildlife. To our knowledge, this is the first study to investigate the potential importance to pollinators of diverse, multi-resource, native-plant landscaping enhancements permanently applied to residential properties in a small city.

The ability of residential properties to support declining pollinator populations is of great interest to both conservation and agriculture. It is estimated that nearly 90% of flowering trees, shrubs, and other plants, including 35% of all crops, require pollination by bees or other pollinating insects (Ollerton et al., 2011). Butterflies, syrphid flies, and other non-bee pollinators are less effective pollinators of flowers than bees on per visit basis, but together, can provide more total visits, resulting in pollination services on par with bees (Rader et al., 2016).

Agriculture often employs non-native honey bees for pollination services, but wild bees can also meet the pollination requirements for successful field crop production (Morandin and Kremen, 2013, 2012; Winfree et al., 2007). For agriculture alone, the global value, annually, of animal-mediated pollination is estimated at $179 billion (Gallai et al., 2009). The accuracy of these types of estimates is limited, and methods for calculating the values of ecosystem services from pollination vary widely in context and scale (Turner et al., 2003). Although they can be improved upon (Winfree et al., 2011), they do not currently represent the full extent of all benefits. As habitat loss and other factors continue to diminish bee populations and disrupt the networks of native plant resources they rely on, the quantity of pollination services, and the quality of those services, decline as well (Burkle et al., 2013). Efforts to support wild bee populations could provide significant conservation value much in the same way that management of non-native commercial honey bees provides benefits for agriculture.

Increased urbanization and agriculture, including habitat loss and the use of pesticides, are the largest factors contributing declining populations of wild bee species (Biesmeijer et al., 2006; Potts et al., 2010). As the natural environment is fragmented and converted to residential and agricultural land use, the diversity and complexity of native vegetation is reduced (Potts et al., 2010). This landscape homogenization from agriculture and urbanization limits food, shelter, and nesting resources for pollinators like wild bees, affecting growth rates, nesting success, and species diversity (Renauld et al., 2016). Remaining habitat becomes fragmented into a range of patch sizes at varying inter-patch distances, which disrupts ecological networks used for breeding, migration, and ecological services, and results in domination by generalist species and non-native honey bees (Carman and Jenkins, 2016). Maintaining these modified and exotic landscapes requires mechanical and chemical management practices which have a range of negative effects on invertebrate populations from fewer worker bees to lower total biomass and smaller queens in the eusocial bumble bee, as well as the destruction of nesting sites, effectively reducing overall reproductive rates in solitary and communal bees (Bernauer et al., 2015).

While declines in non-native honey bees are well documented and researched (Ellis et al., 2010; Smith et al., 2013; van Engelsdorp et al., 2008), and receive the majority of public attention, a large share of the 4000+ species of wild bees distributed across North America are also experiencing significant population declines (Cameron et al., 2011) as has been observed for most of the insect taxa in Europe (Hallmann et al., 2017). Wild bees are often more specialized (Strickler, 1979) and rely on a close relationship with the lifecycles and morphology of a specific selection of local plant families in order to reproduce. Many require existing cavities, for nesting and roosting, which consist of bores in downed wood or the hollow pith of plant stems and branches, while others require places to excavate small burrows in the soil or sand (Neff, 2008). They can reach their highest rate of brood production when nesting where foraging resources are locally abundant (Neff, 2008). While generalist bees can access pollen and nectar resources available in multiple flower species, specialist bees are more efficient at foraging and harvesting from relatively few or even just one plant species, both by accessing the nectar more efficiently and traveling more quickly between sources (Strickler, 1979). Residential gardens also tend to support more ground-nesting and cavity-nesting wild bee species than communal or hive nesting bees. (Matteson et al., 2008). Given the close proximity of gardens within residential areas, the incorporation of native plants could create important resource networks, allowing for diverse assemblages of butterflies, solitary cavity- or ground-nesting bees, and other specialist pollinators.

Providing homeowners are willing, residential landscapes lend themselves well to experimental manipulations to better understand the role yard practices play in pollinator diversity and abundance. To test the ability of enhancements in residential properties to provide habitat for pollinators, we installed a modest selection of native flowers, shrubs, and small trees into either the front or backyards of private residential properties. We compared these to a set of quasi-control properties representing unmanipulated front yards and backyards. We designed our experiment to answer a set of research questions that would provide insight into important factors that affect pollinator visits, in general, and wild bee visits, specifically, to private yards (Table 1). We generated hypotheses and predictions from these questions and developed response variables, explanatory variables, and covariates to test these predictions.

Treatments to yards were randomly selected from a stratified pool of volunteers and the set of quasi-control properties were selected in a non-random fashion from a list of available seasonal rental properties that fit the stratifying criteria in each subgroup. This quasi-experimental design provided assurance that no property manipulations would take place in quasi-control yards during the course of the study and the flexible planting regimen allowed for treatments that consider homeowners personal landscaping ambitions, furthering the likelihood they would remain in the study, while also maintaining the public service ethos of extension research.

Table 1. Table of research questions, hypotheses, predictions and results. Also given are response variables and predicter variables used in models. Results show findings from measurements relevant to the research question.

Research Question (what we want to know)	**Hypothesis (the test)**	**Prediction (what we expect to see)**	**Response Variable**	**Explanatory Variable**
Do native plants increase pollinator visits to residential gardens?	Enhancing yards and gardens with native plants for pollinators will lead to greater visitation by pollinators, generally.	A census on a plant in the most active area of an enhanced yard section would receive more pollinator visits than a census in the most active area of an unenhanced yard section.	Total Pollinators	Unenhanced=0, Enhanced=1
Do native plants increase wild bee visits to residential gardens?	Enhancing yards and gardens with native plants for pollinators leads to greater visitation by native pollinators	A census on a plant in the most active area of an enhanced yard section would receive more wild bee visits than a census in an unenhanced yard section.	Subset of wild bees	Unenhanced=0, Enhanced=1
Does it matter to pollinators in general if native plant enhancements are made to the front yard or backyard?	Backyards are exposed to fewer roadside effects and city management practices and will have higher pollinator visitation rates than front yards.	A census on a plant in the most active area of an enhanced backyard section would receive more pollinator visits than a census in an enhanced front yard section.	Total Pollinators	Back =0, Front=1
Does it matter to wild bees if native plant enhancements are made to the front yard or backyard?	Backyards are exposed to fewer roadside effects and city management practices and will have higher wild bee visitation rates than front yards.	A census on a plant in the most active area of an enhanced backyard section would receive more wild bee visits than a census in an enhanced front yard section.	Subset of wild bees	Back =0, Front=1

Does the quality of the patch itself affect the number of pollinator visits to a focal plant?	Enhanced yards support a larger number of pollinators that are available to visit a focal plant.	A single focal plant monitored in an enhanced section of a yard would receive more pollinator visits than the same plant grown in an unenhanced section of a yard.	Total Pollinators	Focal Plant=1
Does the quality of the patch itself affect the number of wild bee visits to a focal plant?	Enhanced yards support a larger number of wild bees that are available to visit a focal plant.	A single focal plant monitored in an enhanced section of a yard would receive more wild bee visits than the same plant grown in an unenhanced section of a yard.	Subset of wild bees	Focal Plant=1
Does it matter to pollinators in general how much of the garden plant composition is made of native species?	A higher percent native plant composition will increase pollinator visits.	A census taken on a plant in a patch will receive more pollinator visits than a census taken on a plant in patch with less native composition.	Total Pollinators	Arcsin square-root of proportion native
Does it matter to wild bees how much of the garden plant composition is made of native species?	A higher percent native plant composition will increase wild bee visits.	A census taken on a plant in a patch will receive more wild bee visits than a census taken on a plant in a patch with less native composition.	Subset of wild bees	Arcsin square-root of proportion native
Does the size of the patch matter to the visitation rates of pollinators?	A larger patch size will support a larger population of pollinators	A census taken on a plant in a patch will receive more pollinator visits than a census taken on a plant in a smaller patch.	Total Pollinators	Area measured as Log_{10}(sqft)
Does the size of the patch matter to the visitation rates of wild bees?	A larger patch size will support a larger population of pollinators	A census taken on a plant in a patch will receive more pollinator visits than a census taken on a plant in a smaller patch.	Subset of wild bees	Area measured as Log_{10}(sqft)

METHODS

Site Selection and Enhancement

In the spring of 2016, 30 private residential properties were chosen as research sites throughout the urban and suburban matrix of residential Ithaca, New York, a small city (population ~31,000) surrounded by family-owned agricultural operations and forested lands (Figure 1). The 30 research properties consisted of 27 primary properties and three additional properties chosen to replace any primary properties that may drop from the study. These were selected from a list of 98 homeowners who volunteered their yards by responding to a call for participants through emails to local gardening and conservation group listservs. We also selected nine quasi-control properties, two from the volunteer list and seven from a list of short-term student rental properties, which were owned and managed by a single owner. The rental property owner ensured that no landscaping changes would take place over the course of the study. Using ArcGIS, we accessed county tax-parcel shapefiles to select the subset of volunteered residences that, together, met the sampling criteria: each selected property was located within three houses of the center of a four-block plot area that was separated from other four-block areas in the study by at least two blocks to increase the chances that pollinator visits would be independent among replicates; pollinators often have short foraging ranges (Greenleaf et al., 2007). Outside the city center, four-block plots were not as well defined, but attempts were made to include a similar size area and number of intersections.

We also chose the 30 treatment properties and nine quasi-control properties

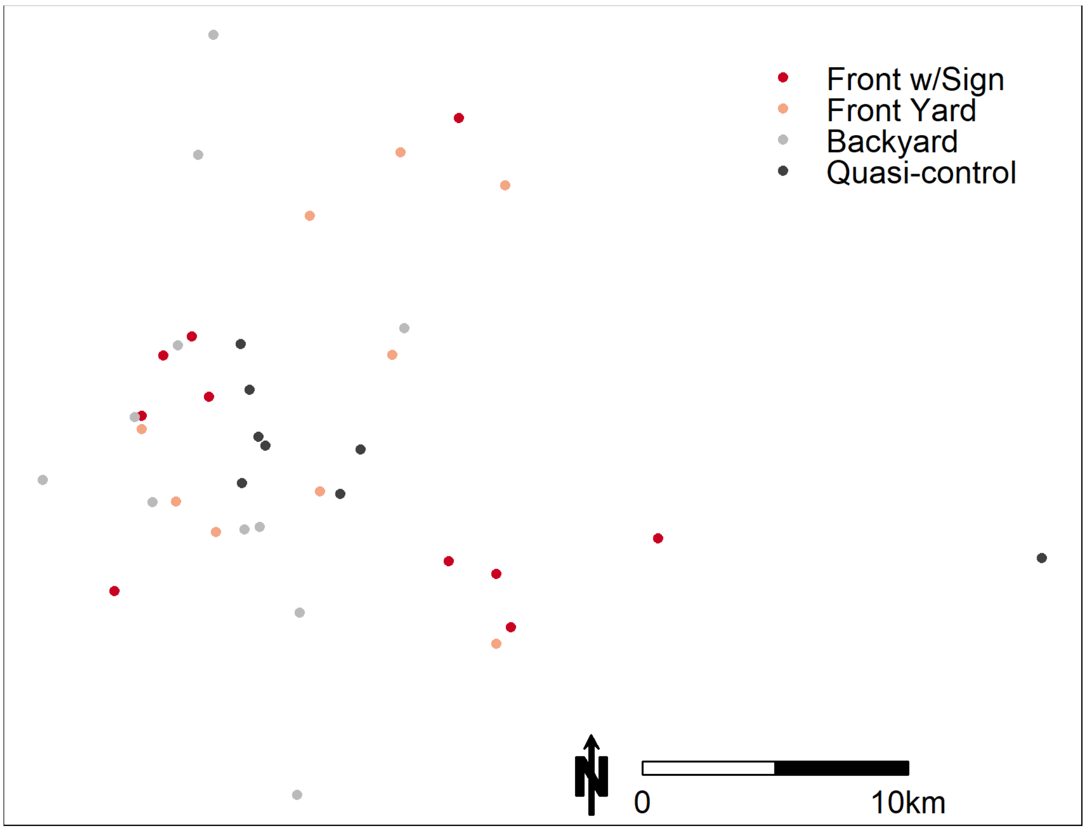

Figure 1. Map of research properties across Ithaca, New York. Distribution of treatment types can be seen but actual locations are concealed for the privacy of the participants.

such that they could be demographically stratified into nine groups of four (plus our three additional properties) for a matched design. Matching was achieved by binning properties into three groups by housing density (in houses per hectare; low = 1-4, medium = 5-10, high = 15-20). Then, each group of housing density was further divided into three groups of property values (low, medium, and high), reported through county tax-parcel data, giving us nine demographic groups, each consisting of one quasi-control property and three treatment properties. The three additional properties represented one of each housing density group. One quasi-control property was dropped from the study early due to extensive construction before data could be collected, leaving eight.

Nine groups of three matched treatment properties (eight of the nine were also matched with a quasi-control) received one of two distinct native plant treatments. Two received front yard treatments, and one was allocated to a backyard treatment. While assignment was random, we assigned twice as many participants to front yard modifications due to a separate visibility experiment designed to examine social contagion effects of front yard modifications with and without promotional yard signs. The three additional properties were scheduled to receive one of each treatment as well but, due to a new installation of solar panels in a front yard where a garden was planned, we allocated one to front yard and two to backyard modifications. The eight quasi-controls retained their traditional landscaping and management practices and received no treatment. Although we did not have a fully matched design for statistical analysis, matching was still of value in reducing random between treatment variance.

Residential properties ranged in size from 310 - 9580 m^2 with a mean area of 2194 ± 341 (SEM) m^2 and landcover proportions consisting of 20.5% impermeable surfaces, like buildings, driveways, and parking lots, with mean area of 117 ± 13.5 (SEM) m^2, and 77.7% vegetated areas with a mean of 185 ± 21.7 (SEM) m^2. Vegetated areas consisted of 32% lawn, with a mean area 258 ± 41 (SEM) m^2, 25.5% forested areas, with a mean area of 576 ± 125 (SEM) m^2, 4.8% shrubs, with a mean area 78 ± 15 (SEM) m^2, 9.3% flower beds, with a mean area 54 ± 9 (SEM) m^2, 4.6% tall grasses, with a mean area 956 ± 338 (SEM) m^2, and 1.2% veggie gardens with a mean area of 148 ± 40.5 (SEM) m^2, all typical for the region. The remaining 1.8% can be attributed to bare ground (0.8%), pools, ponds and other water sources (0.4%), and small gaps in mapping. Areas enhanced in this study represented 6.83% of the total research area. Quasi-controls were larger multiple-residence properties with larger parking areas than treatment sites. See Table 2 for a list of mean areas and landcover types of the research properties.

Each treatment property was prepared and planted in May and June of 2016, using a planting plan guided by the design aspirations of the participant, the research questions, the researcher's suggestions, and the current growing capabilities of the site. Working with the homeowners, a selection of native flowering plants and shrubs was chosen to create new habitat gardens, or to add habitat value to existing gardens, with the goal of providing seasonal access to a diversity of habitat resources for local pollinators. Treatment properties were enhanced with $250-$350 worth of native plants which were purchased from a local native plant nursery or grown in a

Table 2. Mean total areas and percentages of land cover types at research properties. All Properties includes Treatments Properties and Quasi-Control, Treatment Properties includes Front Sign, Front no Sign, and Backyard treatment groups.

	Total Area (m^2)		**Percentage of Land Cover by Type**				
	N	***Mean ± SEM***	**Impermeable**	**Vegetated**	**Lawn**	**Garden**	**Enhanced**
All Properties	38	2194.1 ± 341.4	20.5	77.7	32.1	9.4	6.8
All Treatments	30	1935.6 ± 318.6	12.6	81.0	33.6	12.1	9.8
Front Sign	10	1938.4 ± 615.8	13.5	81.0	47.0	7.1	4.6
Front No Sign	9	2105.8 ± 730.5	18.8	80.6	16.9	13.8	11.5
Backyard	11	1793.8 ± 372.8	17.8	81.3	36.4	15.4	13.3
Quasi-Control	8	3163.3 ± 1085.7	29.2	70.3	28.9	3.2	0.0

greenhouse by the graduate student (Johnston) from locally collected seed. In total, approximately 2,100 plants were installed into the enhanced sections of treatment properties including three species of small trees, seven species of shrubs, eight species of native bunch grasses, and 39 species of flowering forbs. See Appendix I for a complete list of native plants used in enhancements. In seven properties, invasive plants were removed to reduce competition and improve transplant success. Treatment properties were maintained through the summer and fall of 2016 to help new plants become established.

In April and May of 2017, front and backyard treatment properties were revisited to assess health of the previous year's plantings. When plants had been killed by herbivory, we attempted to replace them with species less palatable to local herbivores. Vulnerable plants and habitat gardens were protected with lightweight deer fencing and smaller predation guards which were left in place and maintained for the remainder of the study. Up to $150 worth of replacement plants were selected and replanted in the enhanced yard sections, matching the current size and maturity of the surviving plants' growth from the previous year.

Also, in early June of the second year, we planted a single false sunflower (*Heliopsis helianthoides*) in the garden areas of enhanced sections of treatment properties, as a single common focal plant to conduct censuses on. We also planted this same focal plant at the quasi-control properties, in either the front or back yard, selected at random. Because we were sampling in the most active area of a yard section, we were often counting visits to different plants. Although plant species was accounted for in the analyses, standardizing the census to a single type of plant could help to elucidate whether the quality of the patch itself affected the number of visits to a standard focal plant. Our hypothesis was that enhanced yards supported a large number of pollinators that would be available to visit the focal plant (Table 1). We predicted that a single focal sunflower plant (*Heliopsis helianthoides*) monitored in an enhanced section of a yard would receive more visits than the same plant grown in an unenhanced yard section. We chose this plant for its easy-access morphology and its consistent daily volume of pollen and nectar resources, making it widely attractive to a range of generalist and local specialist species (Holm, 2014). We also used it because it is commonly used in The Great Sunflower Project, a continental-scale citizen-science project (www.greatsunflower.org/).

Over the course of the study, we encouraged homeowners of treatment properties to install habitat materials and implement sustainable practices in their yards, specifically those that promote pollinating insects. Reducing the use of chemical pesticides and herbicides, reduced or delayed mowing practices, and proper management of garden debris were emphasized through workshops and seminars put on by the graduate student (Johnston) in coordination with Cornell Cooperative Extension. Homeowners were also directed to informational and inspirational resources on the Habitat Network website (www.habitat.network). These included articles on ecological concepts and practices that promote wildlife health alongside landscape beautification. Participants were instructed and encouraged to use the mapping tools on Habitat Network to map their properties, log their current management practices, and report changes over time. All participants had email communication access to the graduate student (Johnston) for questions and guidance throughout the course of the study.

Data Collection

Pollinator censuses were conducted in 2016 and 2017 through direct observation in both the front and back yards of all treatment and quasi-control properties, such that each property had two sampling locations, front yard and backyard. We used different census durations and number of censuses in the two years because plants were being installed, censusing was later (missing the first month) and censusing was being optimized; data for the pilot year (2016) and the second year (2017) were analyzed and presented separately. In 2016 we sampled during the last two weeks of July and August, after planting in June. We started with a 20-min stationary count but quickly switched to a 10-min stationary count to achieve the number of counts desired within the season. Our first 6 counts, from the front and back yards of the first 3 properties, were 20-min in duration. The rest (132) were 10-min in duration. 20-min counts were omitted from the analysis. In 2017, 15-min stationary counts were used because we optimized our workflow and our travel times between properties based on the 2016 pilot year. We sampled during the last two weeks of June, July, and August. All stationary counts took place during sunny, partly sunny, or overcast days between the hours of 10am-4pm EDT with temperatures above 70˚F and wind speeds below 12 mph; these are conditions during which pollinators are likely to be the most active (Fussell, 1992; Reddy et al., 2015).

2016 and 2017: The Most Active Area method

For each individual count, the location was selected by first visually scanning a yard section (front or back) for 60 seconds to locate the area with the highest amount of pollinator activity. Within the most active area of a yard section, a flowering plant with the most pollinator activity was selected as the census plant. If there were no pollinators immediately present, an area and a plant likely to be the most active, based on presence of available flowers and sunlight, was chosen. We refer to this method as the “Most Active Area” method. This sampling method was used at all sites in 2016 and 2017 but in 2016 we did two (July and August) 10-min censuses and in 2017 we did three (June, July, August) 15-min censuses (as described above under Data Collection).

After selecting the census plant, we chose a sampling area on the census plant, approximately $0.1m^2$, by placing an imaginary frame around an easily viewable selection of fresh, open blossoms (Hicks et al., 2016). For blossom types comprised of multiple small flowers, the entire inflorescence, regardless of size was included in the sampling area. Similarly, for composites like sunflowers, the entire disc and ray of the selected blossoms was included in the sampling area. We included all the census plant blossoms in the sampling area (5.92 ± 3.38 SEM) for the census. If blossoms from other plants were in the sampling area, we did not include them. The number of selected blossoms being observed, as well as the number of florets on composite flowers or other species with complex inflorescences (e.g., umbels, racemes), were recorded on paper data sheets along with the plant species, the start and stop time, and relevant weather data obtained on site through mobile phone applications. We then used a census protocol similar to that developed for The Great Sunflower Project (www.greatsunflower.org) to record pollinator visits to the selected blossoms. Each landing by an individual pollinator on the observed blossoms was recorded with a tally as a single visit. Multiple landings on the observed blossoms by the same individual pollinator were also counted and tallied as individual visits. This method was used because it was not possible to be certain that repeat visits by unmarked pollinators were not the same individual. Data could then be analyzed as total number of visits by all pollinators as well as comparisons of visitation rates among different kinds of pollinators. All counts included in the analysis were conducted by the same individual (Johnston) for consistency in sampling ability. In 2016 we had a student assistant help set up the enhanced sections. The assistant completed three of the six 20 min censuses before the end of their appointment, but these censuses were among those dropped for the analysis.

2017: The Focal Plant method

In 2017 we continued the Most Active Area method and added a second method of selecting both the census location and the census plant by pre-selecting a focal species, the false sunflower (*Helianthus helianthoides*). We used false sunflowers that had been planted in enhanced sections of treatment properties the previous year (N= 13 yards), and we added a false sunflower in early June of the second year to enhanced sections of treatment properties (N = 5 yards) where there were none to provide focal plants to six of each of the three treatments. We also randomly added this focal species to one section, either the front or back yard, of a subset (N = 6 yards) of the quasi-control properties. We refer to this selection method as the "Focal Plant" method. The Focal Plant method was used in a subset of yards that were also monitored using the Most Active Area method. This subset of yards included the 12 front yard enhanced properties, 6 backyard enhanced properties, and 6 quasi-control properties where the focal plant had been planted. When the Focal Plant was also the Most Active Area in a yard section (64% of the sampling locations), we recorded a single count for both methods.

2016 and 2017: Pollinator Identification

For both years (2016 and 2017), pollinators were identified to general categories: honeybee, bumblebee, wasp, other bee, butterfly, moth, or hummingbird. Beetles, ants, and a few other kinds of insects were counted as "other pollinators". In the second season (2017), each bee visitor was also identified to family, tribe, or genus based on distinct morphotypes (Holm, 2014) (general descriptions of traits common among a group), either on-site or later using photographs taken during the count. Species-level identifications are impossible for most species without collecting. Other categories added to the identification in 2017 included hover fly (Diptera: Syrphidae), bee fly (Diptera: Bombyliidae), and clearwing moth (Lepidoptera: Sphingidae). For the list of pollinators recorded in 2017 see Appendix II.

Our Total Pollinator response variable was the sum of the visits from all pollinator types at each census. Wild bees included all bees except nonnative domestic honey bees and excluded all non-bee visits. While we recognize that some bumble bees are sometimes used domestically in agriculture as are nonnative honey bees, we use the term wild bees to refer to the set of all native bees, including bumble bees, and all introduced bees that are not managed domestically. The majority of wild bees observed were native bees; there are 21 species of introduced wild bees in New York state, which comprise less than 5% of the 425 recognized species in the state.

Postsurvey of yard management practices

To collect data on the front and back yard management practices employed by homeowners at the research properties over the course of the study, we provided a brief postsurvey of 22 questions to score them on the extent to which they had undertaken the nine management practices we recommended. The surveys were created in Qualtrics and distributed via email on September 27th, 2018 under Cornell University IRB # 1601006078. Questions covered homeowners' practices for front yard and backyard pesticide use, mowing frequency, garden management, and providing habitat materials (bee houses, logs, mud, water, bare ground). Ordinal responses were recorded in 3-, 4-, and 5-point Likert scales. The paired differences of the means of the responses, from front and backyard practices, were analyzed in R using a t-test. Responses were also coded as 1 if participants adopted a pollinator-friendly practice and 0 if they had not, and the sum of the nine positive practices was included in the pollinator analysis as an explanatory variable.

Analysis

Data from the two years were analyzed and presented separately due to the differences in sampling methods. Data recorded on paper data sheets in the field were transferred to digital files (.csv) for analysis in R version 3.5.1 -- "Feather Spray" (Development Core Team, 2008). For each response variable, we fit a generalized linear mixed-effects model run in R package lme4 (Bates et al., 2015) with multiple predictors as fixed effects and individual site designations as random effects to account for multiple censusing in each location. Response variables were based on our hypotheses and included the total number of visits by pollinators and by different groupings of pollinators. Fixed effects were included in the model based on a priori predictions (Table 1) and included pollinator-friendly practices as well as measurements for weather conditions and vegetation properties at the census locations. For each analysis we created a correlation matrix of the variables to identify any highly correlated pairs but there were none and all variables were used. We ran each full model once and then removed any non-significant explanatory variables, leaving the remaining variables as the final model.

Explanatory variables available from 2016 censuses included wind speed (mph), temperature in degrees Fahrenheit, overcast conditions to full sun (1-4), census number (1-3) and backyard or front yard location (0,1), and the Log_{10} count of florets in the sampling area, as well as whether the selected census plant was non-native or native (0,1). Additional explanatory variables available from the second season of data collection (2017) included the Log_{10} of the square footage of the census patch, (i.e. the area of similar land use, like a garden, meadow, or hedgerow containing the census plant), and whether the census plant was at the center or edge (0,1) of the census area. Also included was the arcsine square-root of the proportion of native plant composition of the censused area which allowed us to verify whether native plant enhancements to the gardens increased the overall native plant composition at the property.

To test the ecological hypothesis that enhancing yards and gardens with native plants leads to increased visitation by native pollinators, we estimated differences in visits between enhanced yard sections and unmanipulated yard sections for each response variable. We first compared our response variables from the Most Active Area censuses taken in enhanced front yard and enhanced backyard sections of treatment properties with the Most Active Area censuses taken in front and back unenhanced quasi-control properties. Second, we looked at just the treatment properties themselves and compared our response variables between manipulated and unmanipulated sections of the same property and included whether it mattered if enhancements were made to the front yard or the backyard sections of the properties with the idea that these two sections of the yard would experience different levels of roadside effects and city management practices. Third, we compared our response variables from Focal Plant censuses across the set installed at treatment and quasi-control properties.

RESULTS

Description of Management Practices

Of the 30 surveys sent, 23 (72%) were returned, and returned were 100% complete. Gardening practices among homeowners were similar across research properties and remained consistent over the course of the study. Consistent with our research design, practices between front yards and backyards were not statistically different across homeowners but habitat materials for wild bees were measurably more abundant in the backyards (Table 3). Mean responses for chemical pesticide and herbicide use corresponded with "Never" on a Likert scale of 1-4. Leaf litter and garden clean-up practices were almost identical between front and back yards and debris was generally left in place. In yards where leaf litter and garden debris were collected, most (50%-65%) was composted. Lawn mowing took place monthly on average.

Participants provided more types of habitat materials in the backyard than in the front yard (Table 3). Of the five choices of habitat materials available on the survey, bare ground was the most common listed in front yards, provided by 41% of the participants. Logs were the most common in backyards, provided by 33% of the participants. Also, in the backyard, 28% of the participants reported providing bare ground, 19.6% provided a mud source, and 17.3% offered some type of water source. In front yards, only 17% of participants provided downed logs, water, and mud sources. Bee houses were the least common habitat material offered in both the front (5.9%) and back yards (2.2%). Quasi-control property sections, both front and back,

Table 3. Paired differences of practices in front and back yards of treatment properties. Data are from postsurvey of homeowners regarding their management practices over the course of the study. Available responses for Pesticide and Herbicide use are scaled at 1-Often, 2-Sometimes as needed, 3-Rarely, and 4-Never. Garden Tending refers to clean-up timing with 1-Fall, 2-Spring, 3-Do not tend. Debris Removal refers to the disposal method by those that tend with 1-Compost, 2-Bag and dispose, and 3-Leave nearby. Mow Timing is represented by 1-Weekly, 2-Monthly, 3-Less than monthly. Habitat Materials is a count of five possible options participants could provide (bee houses, logs, mud, water, bare ground). Asterisks indicate significance of $p<.05$.

		Front	Back	Paired Differences			
Practice	**N**	**Mean ± SEM**	**Mean ± SEM**	**Estimate**	***df***	***t***	***p***
Pesticide Use	23	1.3 ± 0.1	1.3 ± 0.1	-0.04	22	0.57	0.575
Herbicide Use	23	1.2 ± 0.1	1.2 ± 0.1	0	22	0	1
Garden Tending	23	2.1 ± 0.1	2.1 ± 0.2	0	22	0	1
Debris Removal	16	1.6 ± 0.2	1.9 ± 0.3	-0.43	13	-1.88	0.082
Mow Timing	19	2.3 ± 0.1	2.2 ± 0.1	0.11	19	1.46	0.163
Habitat Materials	23	1.5 ± 0.2	2.0 ± 0.3	-0.52	22	-2.51	0.020*

employed traditional practices of weekly lawnmowing, debris removal, and fall clean up. Fertilizers and pesticides were used as needed (although rare), and no habitat materials were specifically offered to pollinators at quasi-control properties.

Description of Site Enhancements

Enhanced areas represented approximately 8.8% of the total vegetated area within the treatment properties and approximately 12.1% of the vegetated area in just the enhanced sections (front or backyard) of treatment properties. A t-test to compare enhanced areas in front yards *vs.* enhanced areas in backyards showed no measurable difference in the proportion of the vegetated landcover that was enhanced (t = 0.1, df= 10, p = 0.93, Figure 2a). A regression analysis on native plant composition shows that our modest native plant enhancements to the landscaping significantly increased the proportion of native plant composition of the censused areas (0.61 ± 0.003 SEM, t=16.1, $p<.01$, Figure 2b).

Impacts of native plant enhancements

Pollinator response to enhancement, Most Active Area method - 2016

In the first season of data collection, we took 138 pollinator censuses and recorded a total of 1413 visits by pollinating animals, 1188 (84.1%) of which, were visits by bees (Hymenoptera). Of the 1188 visits by bees, 912 (76.8%) were made by unidentified wild bees and 80 (6.7%) were by native bumble bees, *Bombus* spp. (Hymenoptera: Bombidae). Honey bees, *Apis mellifera* (Hymenoptera: Apidae) accounted for 196 (16.5%) of the first season's observed visits. The remaining 225 non-bee visits of the

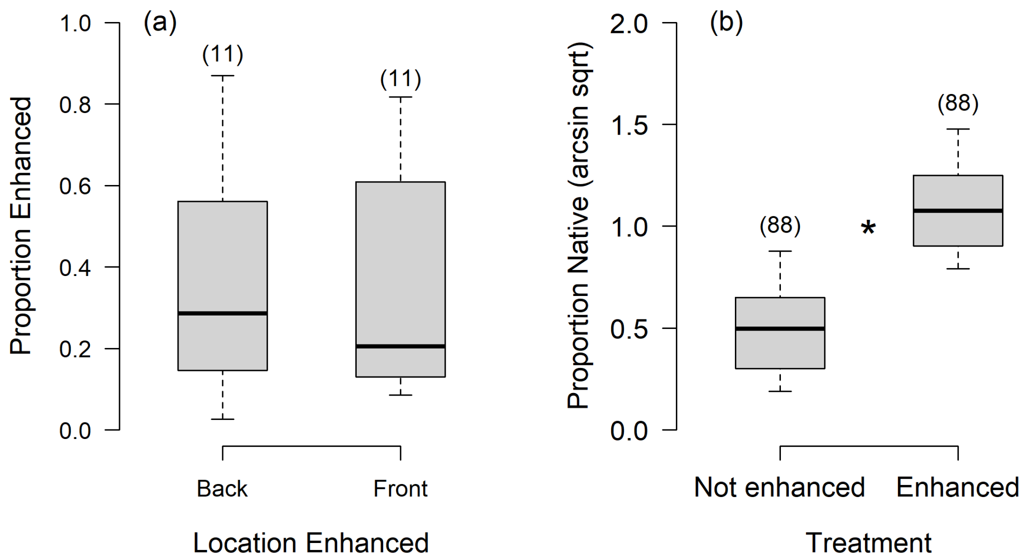

Figure 2. An assessment of enhancements in treatment properties. No measurable difference was found in the mean proportion of vegetated area enhanced (a) between front and back yard enhanced sections. Enhanced treatment sections showed an increased proportion of native plant species composition (b) when compared to the unenhanced section of the same yard, (p<0.001).

total 1413 visits (15.9%) were comprised of 54 from wasps (Hymenoptera: Vespidae) (3.8%), 45 by unidentified flies (Diptera, 3.1%), 56 by hoverflies (Diptera: Syrphidae, 3.9%), 38 by butterflies and moths (Lepidoptera, 2.7%), 29 (2.2%) visits were recorded from a collection of unidentified arthropods, and three visits (.2%) were recorded from one Ruby-throated Hummingbird (*Archilochus colubris*).

In our first analysis, comparing pollinator visits in enhanced sections of treatment properties to our quasi-control properties, the variable for front/back yard section was not statistically significant and was removed (Appendix III). In the resulting model, contrary to our hypothesis, there was no evidence that visitation was greater in enhanced yard sections than in quasi-control yards (0.62 ± 0.51 SEM, df =55, z = 1.22, p>0.1, Figure 3a). Wind was not a significant factor ($p>0.5$) but pollinator visits did increase with the covariates, sun (0.68 ± 0.11 SEM, z = 6.07, p>0.001) and temperature (0.18 ± 0.03 SEM, z = 6.24, p>0.001), as expected, and increased significantly with the number of florets censused (0.61 ± 0.12 SEM, z = 4.90, p>0.001) (Appendix III).

Consistent with the prediction that native plant enhancement increases pollinator visitation, enhanced sections of treatment properties had higher visitation rates than did unmanipulated sections of the same yard (0.42 ± 0.08 SEM, df = 65, z = 5.12, p< 0.001, Figure 3b). The variable for sun was not included in the model, leaving temperature (0.13 ± 0.02 SEM, z = 5.5, p< 0.001), wind (-0.07 ± 0.02 SEM, z = -3.23, p< 0.001) and the number of florets available (0.58 ± 0.07 SEM, z = 8.14, p<0.001) as other significant contributors to pollinator visits. We found no difference

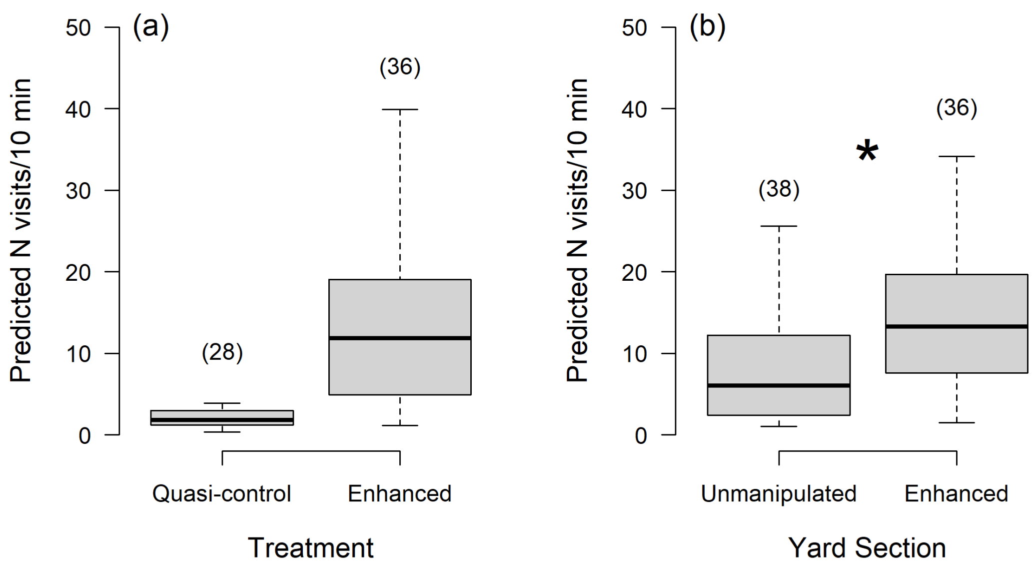

Figure 3. Predicted values based on Generalized Linear Mixed-effects Models representing the comparisons of 2016 pollinator census data between (a) quasi-controls *vs.* front and back enhanced sections and (b) the unmanipulated sections *vs.* enhanced sections of the same yard. Sample sizes are in parenthesis and significance is indicated with an asterisk, (p<0.001).

in pollinator visits to enhanced backyards compared to enhanced front yards (Appendix III).

Pollinator response to enhancement, Most Active Area method - 2017

In 2017, censusing in June, July, and August, including counts on focal plants, and a longer censusing protocol (15 min instead of 10 min), our second field season totaled 235 censuses yielding 4270 visits by over 30 types of pollinating animals. 3515 of those visits were from bees, which accounted for 82.3% all visiting pollinators and consisted of at least 29 genera (Appendix II). Of those 3515 visits, 2114 (60.1%) were by wild, mostly native, bees and 1105 (31.4%) were by native bumble bees (*Bombus* spp.). Honey bees (*Apis mellifera*) accounted for 296 (8.4%) of observed visits by bees 2017. The remaining 755 (17.7% of 4270 total pollinator visits) were comprised of 300 by hover flies (Syrphidae, 40%), 150 by wasps (Hymenoptera, 19.9%), 83 by other flies (Diptera, 11.0%), 71 by butterflies and moths (Lepidoptera, 9.4%), and 44 by sphynx moths (Lepidoptera: Sphyngidae)(5.8%) with the other 107 visits (14.2%) by a collection of unidentified arthropods.

Our first analysis for the 2017 season compared censuses of total pollinators visiting enhanced sections of treatment properties with censuses from quasi-control properties and included in the model the additional variables for the management practices, proportion native composition, and the area in square feet (Appendix III). Non-significant and dropped from the model were temperature data and variables for native census plant and management practices. All other variables in the model remained significant predictors and were included in the final model. Consistent with our hypothesis, the results showed an increase in visitation to enhanced properties by pollinators over the quasi-control properties (0.72 ± 0.27 SEM, *df* = 88, $z = 2.70$, $p < 0.01$, Figure 4a). Interestingly, pollinator visits declined as census area increased (0.49 ± 0.08 SEM, *df* = 88, $z = 6.41$, $p < 0.001$).

When we compared the selected set of censuses taken at enhanced experimental properties, either front or back, with their matched front or back unmanipulated sections from the same property, the variables for area in square feet, proportion native plant composition, sun, wind, and management practices were not statistically significant and were removed (Appendix III). All other variables remained significant to the model. This final model also demonstrated an increase in number of visits by pollinators to native plant enhanced sections of yards over unenhanced sections (0.46 ± 0.05 SEM, *df* = 113, $z = 9.39$, $p < 0.001$, Figure 4b) but, in contrast with our prediction, there was no measurable difference in visits found between enhanced front vs. back yards (Appendix III).

Pollinator response to enhancement, Focal Plant method - 2017

The analysis for our Focal Plant method included censuses from 12 (six front and six backyard) enhanced sections of treatment yards and 6 (three front and three backyard) quasi-control properties. Dropped from the full model for this analysis were variables for sun, wind, area, management practices, and front/back differentiation, all of which were not statistically significant. The resulting model showed that the arcsin square-root of the proportion of native plants in the enhanced patch and census number were not statistically significant with respect to our response variable, pollinator visits.

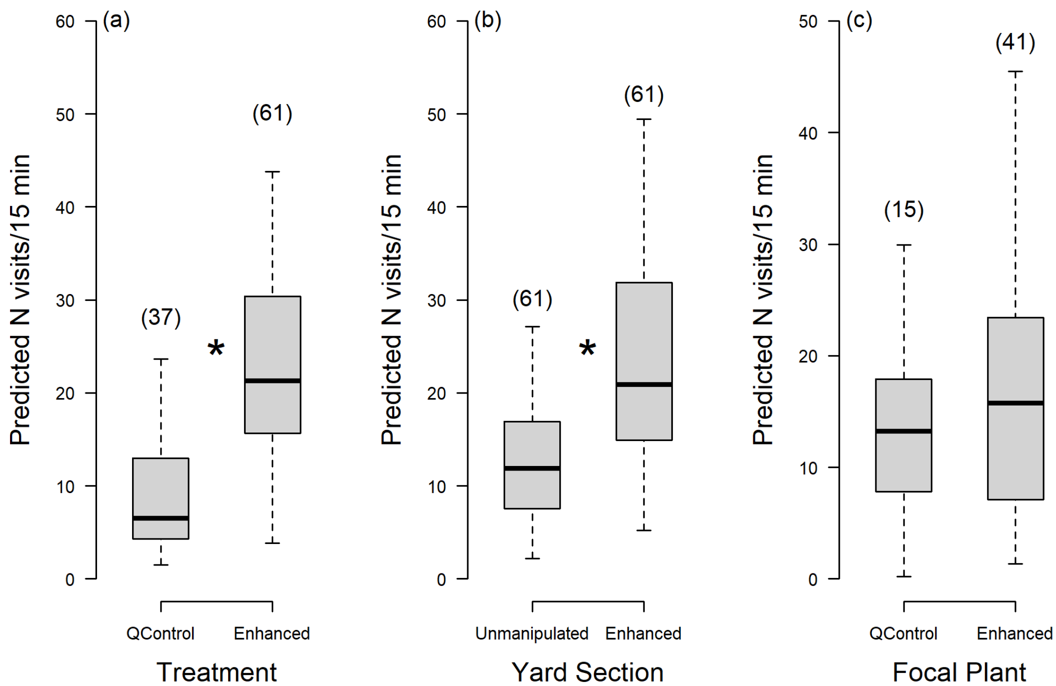

Figure 4. Predicted values for visits by all pollinators based on Most Active Area counts from (a) quasi-controls vs. front and back enhanced sections and (b) unmanipulated sections vs. matched enhanced sections of the same yard. Graph (c) compares number of visits by pollinators in enhanced and quasi-control yards using the Focal Plant method. Sample sizes are in parentheses and significance-level is indicated with an asterisk, (p<0.01).

Visits by pollinators were higher on focal plants located on the edges of garden areas (Appendix III) but the final model did not support the prediction of increased pollinator visits to enhanced sections over the quasi-control yards sections (0.74 ± 0.47 SEM, $df = 48$, $z = 1.58$, $p>0.1$, Figure 4c).

Wild bee response to enhancement, 2017

We identified 19 types of wild bees and recorded 3219 wild bee visits to census areas. *Bombus* spp. made up 26.2% (*Bombidae*, N=846) of all wild bee visits. Halictid bees, including Augochlorini Tribe (Hymenoptera: Halictidae: Halictinae) (15%, N=483) and Halictini Tribe (Hymenoptera: Halictidae: Halictinae) (11%, N=344), along with *Ceratina* spp (Hymenoptera: Apidae: Xylocopinae) (12%, N=390), and bees in the family Megachilidae (10%, N=333) made up most of the wild bee visits.

Most Active Area method. As predicted, we saw a small increase in wild bee visits to enhanced yard sections when analyzing our wild bee response variable across the subset of censuses from enhanced sections of experimental properties, either front or back, compared with the front and back quasi-control properties (0.70 ± 0.33 SEM, $df = 88$, $z = 2.09$, $p<0.05$, Figure 5a). The final model included all variables except temperature, native census plant designation, and management practices. Dropping these non-significant variables from the model did not reduce the significance-level of the remaining variables (Appendix III). Similar to all pollinators, the number of wild bee visits declined with the size of the census patch (-1.20 ± 0.11 SEM, $z = -11.39$, $p<0.001$).

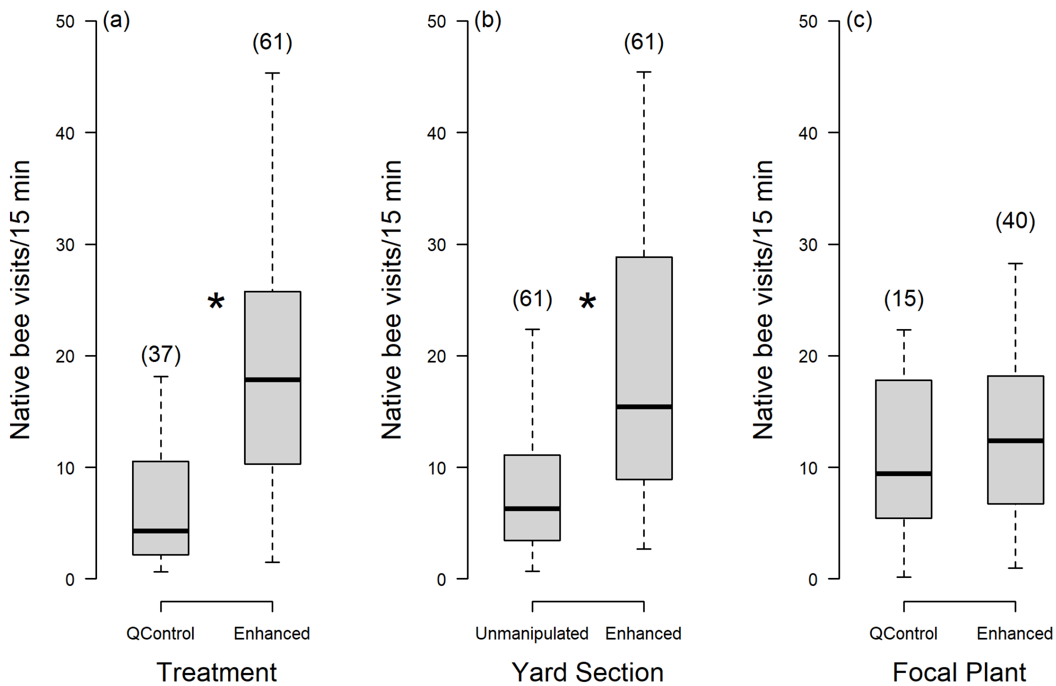

Figure 5. Predicted visits by wild bees only in 2017. These values from Generalized Linear Mixed-effects Models representing 2017 data on wild bee counts and comparing Most Active Area counts from (a) quasi-controls vs. front and back enhanced sections and (b) unmanipulated sections vs. matched enhanced sections of the same yard. Graph (c) compares number of visits by wild bees in enhanced and quasi-control yards using the Focal Plant method. Sample sizes are in parentheses and significance-level is indicated with an asterisk, (p<0.01).

Also as predicted, a similar but even greater effect is shown in the analysis comparing visitation by wild bees in enhanced sections to visitation by wild bees in unmanipulated sections of the same property (0.60 ± 0.1 SEM, *df*=112, $z = 6.11$, $p<0.001$, Figure 5b). Temperature, sun, management practices, and number of florets were non-significant in the full model and were removed for the analysis. Wild bee visits increased with census number and proportional native plant composition (Appendix III). Like all pollinators, the final model supported the hypothesis that enhancement increases native bee use of residential yards and showed that wind and census area have negative effects on wild bee visitation (Appendix III). Consistent with our prediction about roadside effects, backyard enhancement had higher visitation rates by wild bees than did front-yard enhancements (-0.19 ± 0.05 SEM, $z = -3.57$, $p<0.001$).

Focal Plant method. Results on wild bee visits to focal plants were similar to those from our analysis of total pollinators. The final model, in contrast to our prediction, did not indicate an increase in wild bee visits to focal plants in enhanced yards (1.04 ± 0.56 SEM, *df*=48, $z = 1.85$, $p>0.1$, Figure 5c). Wind decreased wild bee visits as did proportion native plant composition and census number (Appendix III).

DISCUSSION

Our main finding using the Most Active Area method is that permanent, native plant additions to residential yards are important contributions to local pollinating insects. Our results in 2017 support the prediction that enhancement of yards with native plants increases visits by pollinators (Table 1). Wild bees, specifically, had a more pronounced response to native plant enhancements, possibly due to their specialist lifestyles (Strickler, 1979), which can benefit from the diverse plantings we provided. In support of this, our main findings also demonstrate an increase in pollinator visits with an increase in the proportion of native plants in the enhanced patches. In the absence of research addressing the optimal percentage of native plants in landscaping enhancements, we cannot rule out the possibility that non-native plants also have benefits, however, our results do show that increasing the percentage of native plants in a patch increases the number of pollinator visits.

We predicted that pollinator visits would be higher in backyard native plant enhancements due to different levels of roadside effects or management practices but found no significant differences in total pollinator counts based on such placement. Wild bees, however, when analyzed separately, did have more visits to backyard enhancements than front yard enhancements. As there were no real differences in management practices of pesticide use or debris clean-up, roadside effects could still play a role, however, increased visits for enhanced backyards is more likely due to the greater number of habitat materials intentionally offered to wild bees, which were preferentially placed in backyards. These resources consisted of bee houses, logs, mud, and other nesting materials. The larger mean garden area in backyards and the higher proportion of enhanced vegetated area in backyards could also offer an explanation.

It is interesting that a single focal plant in our quasi-control sites, many of which were relatively barren of other flowers and consisted mostly of shrubs and mowed grass, yielded a number of visits statistically equivalent to that seen on the identical species of focal plant in enhanced yards. Visits to quasi-control yards were higher using the Focal Plant analysis than the Most Active Area method and the opposite is shown with visits to enhanced yards. Perhaps, in the quasi-control yards, the number of other flowers was low for the number of available pollinators in the area and so they clustered on the one focal plant. If floral resources in enhanced yards were not super-saturated with pollinators waiting to land, then this result could come about because available pollinators in the enhanced yards were more dispersed. We also observed that focal plant visitations declined with an increase in the proportion of the surrounding garden that was composed of native plants, likely due to the greater selection of native plant resources available to pollinators, again, causing greater dispersion of pollinators in yards with a greater coverage of native plants. This suggests that the Focal Plant method is a poor indicator of overall pollinator visitation and instead is subject to a dilution effect in which visitation rates are higher in barren yards and lower in enhanced yards. This makes the Focal Plant method conservative – if it shows that pollinator visits in enhanced yards outperform those in unenhanced yards, then the result is likely very robust, whereas, the dilution effect renders the Focal Plant method less powerful than the Most Active Area method for detecting an increase in visitation rates to an enhanced patch.

There are many factors that can affect pollinator activity and our results confirm known influences. Pollinator visits were consistently higher with an increase in temperature and sun and decreased with higher wind speeds. Pollinator visits also decreased with the size of the census patch, contradictory to our hypothesis. This may be due to a dilution effect (see above), or it may be from difficulties in accounting for the large differences in sizes and types of census patches around the census area, effects that have also been observed in similar studies comparing bee diversity across state parks and city parks (McFrederick and LeBuhn, 2006; Samnegård et al., 2011). Pollinator visits were also consistently and positively influenced by the number of available florets in the census, which also suggests that visitation can be influenced by the density of resources, which may be more condensed in smaller gardens. These differences suggest that patch size and quality are critical to understanding and quantifying pollinator services.

Initially, all sites represented the narrow range of traditional residential landscaping, consisting mostly of lawn and a selection of traditional garden plants and shrubs, non-native cultivars, hybrids, and grafted ornamental trees. After enhancements were made, quasi-control properties and unmanipulated sections of treatment properties maintained this traditional landscaping but enhanced sites were managed in a way that led to variation in the size, conformation, and native plant composition of their gardens. An ideal experiment would install identical native plant gardens, allocating similar treatment sites to the experimental and control conditions to provide true controls. However, participants who engaged in this study did so because of an abiding interest in helping wildlife and because of a desire to have guidance in so doing. To decide whether native plant enhancements to residential landscapes could increase pollinator visits we had to do so in a practical manner that encouraged adoption, participation, and long-term efforts.

As the expanding residential landscape engulfs the natural world, abundant and diverse resource areas for existing wildlife are often transformed into resource barrens, offering little to replace ecological services or mitigate the resulting affected wildlife populations. By adding a selection of garden-quality native plants to provide important, and sometimes essential, resources, shelter, and reproductive materials, residents can encourage pollinators to visit residential landscapes. The benefits of these enhancements include but are not limited to improved pollination in their own gardens for increased fruit production or flower propagation (Matteson and Langellotto, 2009), beautification and increased social capital in the community (Larson et al., 2018), and improved awareness and appreciation for wildlife which can lead to further contributions to conservation (Loss et al., 2015). In this study, the large number of households willing to participate and the fact that all participants remained in the study for three years suggests that these kinds of efforts can take hold with a small amount of extension support and at low costs ($250-$350) per household. If seeding communities with a set of households leads to contagion of the practices, the cost would be further reduced.

This unique quasi-experimental study provides more evidence for the potential importance of incorporating native plant habitat into expanding residential landscapes. Our manipulations instantly and positively affected the number of visits by pollinators and, since a large percent of wild bees forage and nest near available resources we predict that reproductive success would also be enhanced. It is possible that the surrounding landscape, which is largely rural, played an important role in our result, and more research is needed to examine the extent to which landscape context influences the benefits of habitat enhancements for pollinators in small towns and cities. In nature there are thousands of plants that pollinators rely on for resources to complete their lifecycle. Many of those plants, fortunately, possess qualities similar to those we appreciate in our own gardens, and provide other services such as retention of rainwater and reduced need for inputs. Further research is needed to determine how best to incorporate important pollinator habitat and better bridge the built and natural environment.

Appendix I

Appendix I. List of native plants used for enhancements in treatment properties.

Plant Species	**Common Name**	**Family**	**Form**
Achillea millefolium	common yarrow	Asteraceae	forb
Actaea pachypoda	doll's eyes	Ranunculaceae	forb
Actaea rubra	red baneberry	Ranunculaceae	forb
Agastache foeniculum	hyssop	Lamiaceae	forb
Andropogon gerardii	big bluestem	Poaceae	grass
Anemone virginiana	forest anemone	Ranunculaceae	forb
Angelica atropurpurea	purple-stemmed angelica	Apiaceae	forb
Amelanchier canadensis	serviceberry	Rosaceae	tree
Aquilegia canadensis	wild columbine	Ranunculaceae	forb
Asclepias incarnata	swamp milkweed	Asclepiadaceae	forb
Asclepias syriaca	common milkweed	Asclepiadaceae	forb
Asclepias tuberosa	butterfly weed	Asclepiadaceae	forb
Blephilia ciliata	downy wood mint	Lamiaceae	forb
Campanulastrum americana	tall bellflower	Campanulaceae	forb
Campsis radicans	trumpet vine	Bignoniaceae	vine

Carex hystericina	porcupine sedge	Cyperaceae	grass
Carex intumescens	shining bur sedge	Cyperaceae	grass
Carex lupulina	hop sedge	Cyperaceae	grass
Ceanothus americanus	New Jersey tea	Rhamnaceae	shrub
Chelone glabra	white turtlehead	Scrophulariaceae	forb
Cercis canadensis	redbud	Fabaceae	tree
Clematis virginiana	virgin's bower	Ranunculaceae	forb
Coreopsis lanceolata	Lanceleaf tickseed	Asteraceae	forb
Cornus alternifolia	alternate leaved dogwood	Cornaceae	shrub
Cornus amomum	silky dogwood	Cornaceae	shrub
Cornus sericea	red-osier dogwood	Cornaceae	shrub
Echinacea purpurea	coneflower	Asteraceae	forb
Elymus hystrix	bottlebrush grass	Poaceae	grass
Eupatorium sessilifolium	upland boneset	Asteraceae	forb
Eurybia divaricata	white wood aster	Asteraceae	forb
Heliopsis helianthoides	false sunflower	Asteraceae	forb
Lilium canadense	Canada lily	Liliaceae	forb
Lindera benzoin	spicebush	Lauraceae	shrub
Lobelia cardinalis	cardinal flower	Campanulaceae	forb

Lobelia siphilitica	great blue lobelia	Campanulaceae	forb
Lonicera canadensis	honeysuckle	Caprifoliaceae	vine
Lupinus perennis	wild lupine	Fabaceae	forb
Maianthemum racemosum	false Solomon's seal	Liliaceae	forb
Monarda didyma	bee balm	Lamiaceae	forb
Monarda fistulosa	wild bergamot	Lamiaceae	forb
Panicum clandestinum	deer-tongue grass	Poaceae	grass
Penstemon digitalis	foxglove beardtongue	Scrophulariaceae	forb
Penstemon hirsutus	hairy beardtongue	Scrophulariaceae	forb
Physocarpus opulifolius	eastern ninebark	Rosaceae	shrub
Pycnanthemum muticum	mountain mint	Lamiaceae	forb
Rhus typhina	staghorn sumac	Anacardiaceae	tree
Rudbeckia hirta	black-eyed Susan	Asteraceae	forb
Rudbeckia triloba	brown-eyed Susan	Asteraceae	forb
Sambucus nigra	Common elderberry	Caprifoliaceae	shrub
Schizachyrium scoparium	little bluestem	Poaceae	grass
Solidago caesia	blue-stem goldenrod	Asteraceae	grass
Solidago flexicaulis	zig-zag goldenrod	Asteraceae	forb
Solidago sempervirens	seaside goldenrod	Asteraceae	forb

Symphyotrichum cordifolium	blue wood aster	Asteraceae	forb
Symphyotrichum laeve	smooth blue aster	Asteraceae	forb
Symphyotrichum lateriflorum	calico aster	Asteraceae	forb
Symphyotrichum novae-angliae	New England aster	Asteraceae	forb
Tiarella cordifolia	foamflower	Saxifragaceae	forb
Zizia aurea	golden alexanders	Apiaceae	forb

Appendix II

Appendix II. List of pollinator types observed in 2017 identified as close to species as possible.

Pollinator Type	Family	Visits in 2017			
		By Treatment Type			Total
		Enhanced	Unmanipulated	Quasi-Control	
Agapostemon	Halictidae	34	1	4	39
Andrena	Andrenidae	9	21	0	30
Ant	Formicidea	6	18	5	29
Anthidium	Megachilidae	22	22	6	50
Augochlorini	Halictidae	250	189	44	483
Bee Fly	Bombyliidae	0	0	0	0
Bumble Bee	Bombidae	626	374	105	1105
Butterfly	Lepidoptera	23	47	1	71
Ceratina	Apidae	256	101	33	390
Clearwing Moth	Sphingidae	36	7	0	44
Coelioxys	Megachilidae	11	6	0	17
Colletes	Colletidae	76	2	3	81
Halictus	Halictidae	107	48	9	164

Heriades	Megachilidae	71	17	3	91
Honey Bee	Apidae	110	171	15	296
Hoplitis	Megachilidae	2	8	0	10
Hornet	Vespidae	11	5	2	18
House Fly	Muscidae	24	14	16	54
Hylaeus	Colletidae	3	34	7	44
Lasioglossum	Halictidae	97	22	22	141
Leafcutter	Megachilidae	216	22	95	333
Melissodes	Apidae	89	51	1	141
Nomada	Apidae	10	0	0	10
Other Fly	Diptera	13	12	4	29
Other Pollinator	Arthropoda	36	38	5	79
Syrphid Fly	Syrphidae	151	124	25	300
Triepeolus	Apidae	4	11	3	18
Wasp	Vespidae	45	77	10	132
Xylocopa	Apidae	30	42	0	72

Appendix III

Appendix III. Output from all models. Response variable is given in the model name.

Model	Variable	*df*	Estimate ± SEM	Z	*P*
2016 Total Pollinator visits, Most Active Area					
Quasi-control *vs.* Enhanced		55			
	Quasi-control (0) v. Enhanced (1)		0.62 ± 0.51	1.22	0.22
	N florets (Log_{10})		0.61 ± 0.12	4.90	<0.001 ***
	Sun (1,2,3,4)		0.68 ± 0.11	6.07	<0.001 ***
	Temperature °F		0.18 ± 0.03	6.24	<0.001 ***
	Wind speed (mph)		-0.05 ± 0.03	-1.83	0.07
	Native census plant (0,1)		0.34 ± 0.16	2.059	0.034 *
	Census number (1,2)		-1.03 ± 0.12	-8.78	< 0.001 ***
Enhanced *vs.* Unmanipulated		65			
	Unmanipulated (0) v. Enhanced (1)		0.41 ± 0.08	5.116	<0.001 ***
	Front/Back (0,1)		0.05 ± 0.07	0.665	0.51
	N florets (Log_{10})		0.58 ± 0.07	8.140	<0.001 ***
	Temperature °F		0.13 ± 0.02	5.502	<0.001 ***
	Wind speed (mph)		-0.07 ± 0.02	-3.227	0.001 **
	Native census plant (0,1)		0.90 ± 0.11	8.561	<0.001 ***
	Census number (1,2)		-0.76 ± 0.08	-9.862	<0.001 ***
2017 Total Pollinators, Most Active Area					

Quasi-control *vs.* Enhanced	88			
Quasi-control (0) v. Enhanced (1)		0.72 ± 0.27	2.70	<0.01 **
Front/Back (0,1)		0.55 ± 0.12	4.63	<0.001 ***
N florets (Log_{10})		0.58 ± 0.09	6.41	<0.001 ***
Area ($Log_{10}ft^2$)		-0.49 ± 0.08	-6.22	<0.001 ***
Proportion native (arcsin(sqrt))		0.37 ± 0.15	2.48	0.01 *
Sun (1,2,3,4)		0.10 ± 0.03	3.63	<0.001 ***
Wind speed (mph)		0.07 ± 0.02	4.20	<0.001 ***
Census number (1,2,3)		0.18 ± 0.03	5.61	<0.001 ***
Enhanced *vs.* Unmanipulated	113			
Unmanipulated (0) v. Enhanced (1)		0.46 ± 0.05	9.39	<0.001 ***
Back/Front (0,1)		-0.08 ± 0.04	-1.82	0.07
N florets (Log_{10})		0.31 ± 0.07	4.32	<0.001 ***
Edge (0,1)		0.26 ± 0.05	4.83	<0.001 ***
Temperature °F		0.01 ± 0.01	2.46	0.01 *
Native census plant (0,1)		0.24 ± 0.07	3.30	<0.001 ***
Census number (1,2,3)		0.37 ± 0.03	12.57	<0.001 ***
2017 Total Pollinators, Focal Plant				
Quasi-control *vs.* Enhanced	48			
Quasi-control (0) v. Enhanced (1)		0.74 ± 0.47	1.58	0.11
N florets (Log_{10})		3.57 ± 0.31	11.64	<0.001 ***

Proportion native (arcsin(sqrt))		-0.50 ± 0.32	-1.56	0.12
Edge (0,1)		0.55 ± 0.17	3.34	<0.001 ***
Temperature °F		0.06 ± 0.02	3.59	<0.001 ***
Census number (1,2,3)		-0.13 ± 0.07	-1.78	0.08
2017 Wild Bees, Most Active Area				
Quasi-control *vs.* Enhanced	88			
Quasi-control (0) v. Enhanced (1)		0.70 ± 0.33	2.09	0.04*
Back/Front (0,1)		0.59 ± 0.15	3.79	<0.001 ***
N florets (Log_{10})		0.74 ± 0.11	6.81	<0.001 ***
Area ($Log_{10}ft^2$)		-1.20 ± 0.11	-11.39	<0.001 ***
Proportion native (arcsin(sqrt))		0.48 ± 0.18	2.68	<0.01**
Sun (1,2,3,4)		0.20 ± 0.03	5.73	<0.001 ***
Edge (0,1)		-0.62 ± 0.08	-7.94	<0.001 ***
Wind speed (mph)		0.05 ± 0.02	2.46	0.01*
Enhanced *vs.* Unmanipulated	112			
Unmanipulated (0) v. Enhanced (1)		0.60 ± 0.10	6.11	<0.001 ***
Back/Front (0,1)		-0.19 ± 0.05	-3.57	<0.001 ***
Area ($Log_{10}ft^2$)		-0.36 ± 0.07	-4.94	<0.001 ***
Proportion native (arcsin(sqrt))		0.34 ± 0.14	2.36	0.02 *
Wind speed (mph)		-0.07 ± 0.02	-3.31	<0.001 ***
Native census plant (0,1)		0.39 ± 0.09	4.31	<0.001 ***

Edge (0,1)		0.32 ± 0.07	4.81	<0.001 ***
Census number (1,2,3)		0.42 ± 0.03	12.45	<0.001 ***
2017 Wild Bees, Focal Plant				
Quasi-control *vs.* Enhanced	48			
Quasi-control (0) v. Enhanced (1)		1.04 ± 0.56	1.85	0.06
N florets (Log_{10})		3.70 ± 0.32	11.61	<0.001 ***
Proportion native (arcsin(sqrt))		-0.79 ± 0.37	-2.15	0.03*
Edge (0,1)		0.67 ± 0.19	3.54	<0.001 ***
Wind speed (mph)		-0.11 ± 0.03	-3.78	<0.001 ***
Census number (1,2,3)		-0.30 ± 0.08	-3.82	<0.001 ***

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