Local and Landscape-Scale Influences of Bee Abundance and Diversity in Residential Gardens.

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Abstract

Local and Landscape-Scale Influences of Bee Abundance and Diversity in Residential Gardens

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Home gardens are receiving increasing attention from conservation advocacy groups and scientists for their potential ecological value. Gardening for wildlife, including pollinators, is not a new idea but its efficacy and impacts are largely untested. This study evaluated the relative importance of local, garden-scale variables to one another and characteristics of the surrounding landscape for predicting bee abundance and diversity in the mixed rural, suburban and exurban context of Southern Snohomish County Washington. Results indicate that local, garden-scale variables are of greater influence on local bee abundance and diversity than landscape-scale variables, and that floral resource availability is of chief importance. These findings are novel and highlight the potential for actions by individuals to have measurable ecological impacts. However, wildlife gardening in

general does not necessarily benefit bees, and recommendations ascribed specifically for bees such as artificial nest sites and the use of native plants require further investigation.

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Introduction

Among the public gardening community in the United States, there is increasing interest in gardening for wildlife. Conservation advocacy organizations are campaigning to popularize these efforts through private garden recognition programs such as the National Wildlife Federation's Backyard Habitat Certification and the North American Butterfly Association's Certified Butterfly Garden program. Chiefly funded as educational programs, these initiatives are not evaluated for their impact on the wildlife they target, and many of their recommendations are just beginning to be studied. To ensure encouragement of behaviors that have desired effects, advocacy efforts should focus on promotion of evidence-based actions, with an emphasis on evidence that suggests ways that an individual gardener can make a measurable difference to the organisms they care about.

The appreciation of gardens as ecosystems and spaces worthy of scientific consideration is a fairly recent phenomenon, but it has been suggested that a mosaic of gardens with the right characteristics may increase connectivity among populations of organisms negotiating a world of increasing urbanization and decreasing natural habitat (Goddard et al., 2010; Vergnes et al., 2011). But, what are the "right characteristics"? The answer, of course, depends on perspective. This thesis explores the question from the presumed perspective of pollinators and ultimately, bees.

Potential barriers to the study of private gardens are numerous. Permission to access private properties can be difficult to obtain, making systematic sampling difficult. And the nature of gardens as relatively small units displaying great variation within and between properties leads to conundrums with regard to replication and control. Despite these challenges, understanding what happens at the intersection of "natural" and human-made processes is of critical environmental importance. In particular, what can be detected at the scale of individual human activities—can an individual gardener make a measurable difference to the organisms they care about? An answer to this question may give advocacy and education greater credence, and resultant actions may have more desirable results.

Because humans are at the heart of these questions, involving them not only by seeking their permission, but their participation in the scientific process may be an important to overcoming some of the barriers to studying gardens. Citizen Science, also known as Public Participation in Scientific Research (Miller-Rushing et al., 2012), has been particularly successful in the context of issues of local conservation concern (Cooper et al., 2007; Danielson et al., 2007) and has been effectively applied to the study of invertebrates (e.g. Howard et al., 2010; Losey et al., 2007; Silvertown et al., 2011; Matteson et al., 2012; Beasley, 2012; Lye et al., 2012; Oberhauser & LeBuhn, 2012). In a National Research Council Report (NRC, 2007) on the Status of Pollinators in North America, citizen science is suggested as a critical means for achieving scientific data needs, public engagement, education, and outreach. However, a study by Kremen et al. (2011) cautions that data be limited to may be limited to detecting community level differences in abundance and diversity, as species and group-level identification are less reliable.

In light of the widely publicized decline in both honeybee (Charles, 2013; Ranieks & Carreck, 2010) and wild native bee (Lye et al., 2012; Cameron et al., 2011; Colla et al., 2012; Colla & Packer, 2008) populations, there is growing interest in finding causes and solutions to an impending pollination crisis. One proposed solution is a more integrated approach to management of pollinator services where wild bees are encouraged to augment honeybee activity (Garibaldi et al., 2013; Christmann & Aw-Hassan, 2012; Lentini et al., 2012; Calderone, 2012; Kremen et al., 2002; Kremen et al., 2004; Pywell et al., 2012). This potential solution requires an understanding of the needs of wild bees, with a willingness and ability to provide those needs.

How do home gardens fit in? Habitat loss has been proposed as a potential synergistic cause of bee decline (Bommarco et al., 2010; Neame et al., 2013; Dorchin et al., 2013, Haug, 2009; 2013; Winfree et al., 2008), and gardens might be a valuable substitute for natural habitat. Wild plants may benefit from pollinator activity associated with nearby gardens, particularly in highly modified landscapes (Samnegard et al., 2011). And for crops, increased pollination services by wild bee populations associated with residential gardens are detectable at agricultural sites up to 2.5km from such gardens (Kremen et al., 2004). Closer to home, personal food gardens also rely on pollination services provided by bees also. Recent interest in urban and residential agriculture has seen an associated attention to pollinator services; see for instance, the Urban Pollinator Project (http://nwpollination.org/).

Conservation advocacy groups suggest a variety of practices for gardeners who want to increase the overall wildlife habitat value of their properties. These generally include a mix of natural habitat mimicry and garden supplements: native plants, water features, woody debris, and artificial nests and feeders. Suggestions specifically for pollinators often add native and non-native nectar plants, specific host plants, bare soil for ground nesting bees, and mason bee or bumblebee nest boxes (Xerces, 2011).

Of the practices that have been studied, plant diversity and floral resource abundance appear most influential for both insect and avian pollinators (Smith et al., 2006; Sperling, 2009; French et al., 2004) with respect to both abundance and diversity. There is also increasing support for the importance of native plants in a variety of systems. Native plants are positive correlates of larval lepidopteron abundance and richness (Burghardt, 2009), nectivorous birds (French et al., 2004), honeybees (Morandin & Kremen, 2012), and native bees (Frankie et al., 2005; 2010), including rare ones (Hostetler & McIntyre, 2001). Artificial nests, however, may be more valuable as educational tools than as useful habitat (Gaston, 2005; Xerces, 2011). Woody debris and water sources are known to be important to some pollinators during various parts of their lifecycles (Xerces, 2011), but their value at individual sites may be dependent on their overall availability. Nectar feeders do attract hummingbirds, but may alter their visitation to flowers, thereby impacting pollination services (French et al., 2004). Other trends appear to be even more taxon specific; for instance bumblebee, but not solitary bee richness is correlated with heterogeneity within gardens (Smith et al., 2006).

Human property boundaries are irrelevant to wild organisms, unless stewardship of these properties varies drastically. At what scale is heterogeneity of benefit, and when is it a detriment to pollinator richness and abundance? Evidence suggests that at broad scales, human populations correspond to greater overall biodiversity, because humans tend to colonize bio-diverse places, but at small scales the impacts of human presence result in a decrease in diversity (Pautasso, 2006). Sattler et al. (2010) found that bee richness is positively correlated with habitat heterogeneity within a 50m area surrounding a sample site. Effective pollinator conservation will require an understanding of how pollinator species respond to variations in landscape and resource patterns at both local (such as the garden level) and broader scales.

The impact of human activities on pollinators and the value of gardens specifically have been studied with mixed results. A review by McKinney (2006) found that richness and abundance of arthropods are almost always negatively affected by urbanization, but the effect is most extreme where anthropogenic impacts are most intense (Winfree et al., 2009). Studies in specific cities, however, have found pollinator assemblages in gardens that are comparable to that found in natural habitat (Fetridge et al., 2008; Hostetler & McIntyre, 2001; Frankie et al., 2005; 2010; Hinners et al., 2012). Effects may be taxa and land-use specific, for instance certain ground nesting bees appear to respond negatively to intense human activity (Xie et al., 2013), but nest sites for bumblebees in the UK are higher in gardens compared to semi-natural countryside habitats (Osborne et al., 2008). Honey bees in particular show the most adaptability to fragmentation and disturbance resulting from anthropogenic activity, and appear to thrive when native pollinators struggle (Aizen & Feinsinger, 1994; Ricketts, 2004; Brosi et al., 2008), possibly due to differences in foraging habits (Leonhardt et al., 2012).

The studies that measure pollinator responses to land use generally either compare different types of land-use (e.g. natural vs. agriculture or garden vs natural) or similar types in a gradient of anthropogenic effect (e.g. agriculture with varying amounts of natural habitat nearby). Overall, landscapes with higher floral resources show an increase in pollinators (Winfree et al., 2011), even if these resources are anthropogenic in origin. For instance, syrphid flies in some gardens are more abundant than in grasslands or forests, and halictidae and apidae bee species share similar numbers between gardens and grasslands (Sperling, 2009). In systems where native habitat has been depleted or is limited in floral resources, gardens provide increased or different pollinator assemblages (Sattler et al., 2010; Gotlieb et al., 2011).

We know from agricultural studies that pollination services by wild bees in agricultural settings benefit from large, nearby natural habitat (Ricketts, 2004; Greenleaf & Kremen, 2006; 2008; Aizen & Feinsinger,1994; Klein et al., 2012; Watson et al., 2011; Kremen, 2012) and gardens (Goulson et al., 2010). Landscape effects on pollinator services have been documented for up to 2.5km surrounding a site of interest (Kremen et al., 2004), with increased influences at shorter distances (Samnegard et al., 2011; Osborne et al., 2007; Ricketts et al., 2001), though these studies were primarily conducted in tropical or deciduous dominated ecosystems.

Landscape effects may be different in the Pacific Northwest, where the dominant forest type is defined by evergreen conifers.

There has been limited exploration of how local-scale characteristics and the surrounding landscape compare or interact in their influence on pollinators (Goddard et al., 2010; Winfree et al., 2011), though there are a growing number of examples. Davis et al. (2007) found that butterfly abundance and richness in prairies were explained almost equally by landscape and local variables. The largest extent of landscape studied (2km surrounding a sample site), gave the same amount of explanation compared to 0.5km, suggesting that for butterflies, the scale of landscape influence is likely larger than that for bees. There is evidence that bees are more sensitive to local-scale characteristics of nest site and forage availability than landscape or regional factors (Murray et al., 2012). In a garden framework, Sattler et al. (2010) looked at bee response to local and landscape factors with insignificant, inconclusive results but Schwartz et al. (2013) found that local characteristics are more predictive of pollinating invertebrates than the landscape-scale.

This study aims to understand the influences on bee diversity and abundance in residential gardens. Specifically:

- Are local garden-scale or surrounding landscape-scale variables more important for predicting bee abundance and diversity within residential gardens?
- Which variables overall are most important and do these variables match recommendations from conservation advocacy organizations?
- Do these patterns differ between bumblebees and honeybees?

Methods

Study Area

Southern Snohomish County, considered to be south of the town of Snohomish and west of the Cascade mountain range was the general study area. It is comprised of less than 1% wildland and 60% "extreme" anthropogenic footprint (Leu, 2008). The area includes a broad mix of landcover types, from intense development to agriculture to mixed conifer, deciduous forest and wetland fragments of varying sizes. There are no known previous studies of bees in this area.

Sample Sites

Sample sites were chosen based on volunteer interest. Forty sites were originally identified and thirty were retained until the end of the study. The sites that dropped out of the study contributed little or no data. Eligible volunteers were homeowners in southern Snohomish County with gardens and a willingness to commit to data collection requirements for the duration of the study. Gardens were defined as vegetated spaces surrounding a home that were planted and maintained by people for aesthetic or recreational purposes. Volunteers were recruited through outreach targeted to National Wildlife Federation habitat gardeners, Washington Department of Fish and Wildlife backyard sanctuary stewards, the Washington Butterfly Association, Snohomish Audubon Society, University of Washington Botanic Garden newsletter subscribers, the SCARABS: The Bug Society, Snohomish Master Gardeners, and Northwest Horticultural Society members of southern Snohomish County. Because these groups are self-selective for garden and wildlife enthusiasts, I expanded outreach via word of mouth, volunteermatch.com and personal relationships to try to capture a broad spectrum of both local and landscape variables. Ultimately, twenty of the thirty sites were Certified Wildlife Habitats.

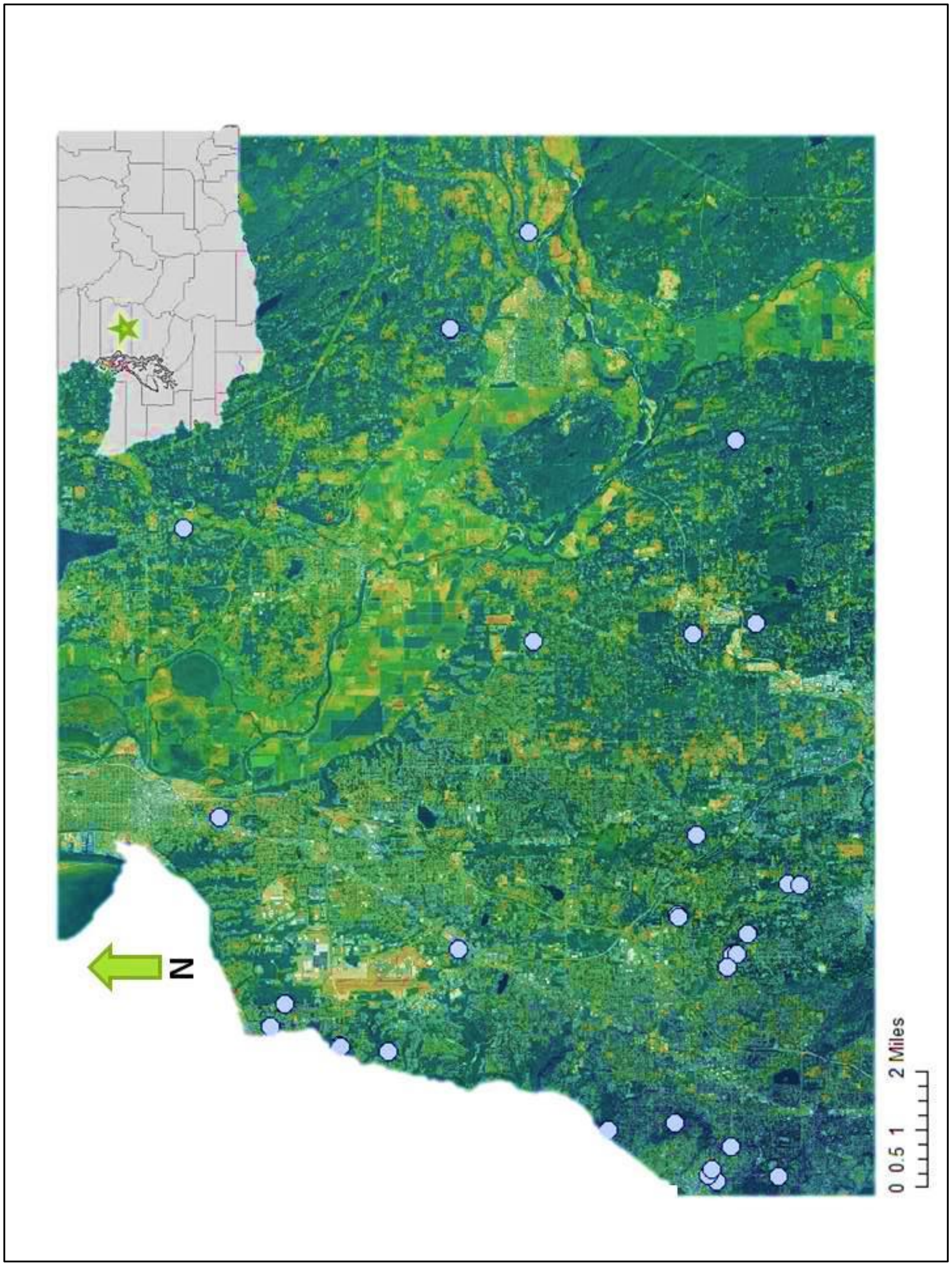


Figure 1. Location of 30 sample sites distributed throughout Southern Snohomish County, WA

Volunteer Training

A half-day volunteer training was held on March 17th, 2012 at the Snohomish Public Utilities District meeting space in Edmonds. Twenty-three of the 40 initial volunteers attended the training, and 19 of these participated throughout the entire study. Volunteers who were not able to attend the training were prioritized for in-person site visits and received training during our meeting.

The training included three parts: an overview of the study rationale and goals, an explanation of the requirements of data collection including a step by step walk-through of survey protocol and how to fill out the data sheets, and a workshop on local pollinator ecology and identification with emphasis on distinctions required for data collection. Based on feedback during the training, datasheets were slightly modified for ease of use and clarity (see Appendix A). Rob Sandelin, a local entomologist and high school teacher, contributed to the bee and bee-mimic identification portion and assisted with the development of additional training materials that were distributed to each volunteer via e-mail and the project website. These materials included data collection instructions and an identification guide (viewable at https://sites.google.com/site/pollinatorsingardens/ and Appendix B).

During each site visit, I conducted a pollinator survey with the volunteers in an effort to reinforce data collection protocol and identification skills. In May, I created a web-based self-test (appendix C) with images of commonly encountered bees and bee-mimics and multiple-choice answers corresponding to the options on the data sheets. The results are reported in Table 1.

Characterization of local, garden-scale, variables

I visited each site at least once during the 2012 season to characterize garden-scale variables of interest. The following variables were chosen based on literature review of pollinator ecology and common recommendations for wildlife gardening, specifically for pollinators:

- Floral area: Area of each animal-pollinated angiosperm taxa present was calculated based on the most specific taxonomic unit possible (either genus, species or variety). This information was later used to quantify abundance, diversity of angiosperms, proportions of native and non-native plants and total garden area as the sum of area of all animal-pollinated angiosperms present. Samples or photographs of unknown plants were compared to virtual herbarium and web-based gardening resources for identification.
- Layered vegetation: Vegetation structure was measured on a scale of 0-3, with zero corresponding to no variation in vegetation height, 1 denoting two layers, 2 denoting 3 layers, and 3 denoting four or more layers. Layers were defined in the following strata: groundcovers or herbaceous plants, woody shrubs less than 3 feet, shrubs greater than 3 feet, mature deciduous trees, and mature conifers.
- Water: Water features were counted and included both man-made and natural bodies of water such as bird baths, fountains, ponds and streams.
- Woody debris: Woody debris was measured on a scale of 0-3 with 0 being no woody debris, 1 constituting a small, less than 2x2sqft area or a single snag, 2 included woody debris between 2x2 and 4x4sqft or 2-3 snags, and a designation of 3 including everything with woody debris covering more than 4x4sqft or 4 or more snags. Woody debris were defined as wood piles, green waste compost

piles, sticks and logs larger than four inches in diameter and snags. Mulch was not included.

- Pesticide use: Volunteers were asked if they used any pesticides and if so, which ones.
- Bare soil: Area of bare, exposed soil was estimated in square feet.
- Lawn: Area of lawn was estimated in square feet.
- Artificial nest sites: Man-made nesting sites were counted and included mason bee tubes and boxes and bumble bee boxes.
- Hummingbird feeders: Hummingbird feeders were counted.
- Adjacency: To get a sense of local heterogeneity, the four edges of each garden were categorized as garden, lawn, forest or impervious surface (roads or buildings). For instance, a garden could be surrounded completely by neighboring gardens, or a garden on one side, forest on two sides, and a road on the fourth, etc.

Characterization of landscape scale variables

Landscape-level characteristics were measured using ESRI ArcGIS 10 within a series of buffers at 50km, 300km and 2.5km surrounding each garden sampled. These radii were chosen to capture the scales described in previous studies of landscape effects, as well as known foraging distances for the variety of pollinators of interest. The USGS GAP landcover dataset (US Geological Survey, 2011) was chosen because it was conducted at a finer resolution (30m) than other datasets available. Within each buffer, the proportion of agriculture, forest, forbs, recent anthropogenic disturbance, high development, low development, open space, and wetland were calculated. See Figure 2 for an example.

Pollinator sampling

Volunteer garden owners were asked to collect data from March through August of 2012. They were instructed to take surveys of pollinators at least two times during the last two weeks of each month, at varied times of the day, during mostly sunny weather. A survey constituted walking the same route through their garden while counting the number of pollinators encountered. Specifically, they counted the number of total individual live honey bees, bumble bees, and “other” bees, the number of different kinds of bees (defined as unique types of bees seen during each survey), total hummingbirds, total butterflies and total flies encountered in flight, resting, or feeding. They recorded the start and stop time of each survey, temperature in degrees Fahrenheit, sky conditions and the types of plants that were in bloom. Plants in bloom were later used to calculate estimates of area in bloom based on areas quantified for each plant. Sky conditions were either sunny or partly sunny, and in a few cases where directions weren’t followed, mostly cloudy and overcast were recorded. For analysis, three categories were created: sunny, partly sunny or not sunny.

Data analysis

After initial data exploration a few modifications were made to the dataset to assist with analysis. All continuous garden-scale variables tended to be heavily left-skewed with the majority of data points falling at the lower end of the range and a few outliers toward the upper end. These variables, which included bloom area, native plant area, garden size, lawn area, and soil area, were log transformed. One site was removed from the dataset due to its misleading influence. It was uniquely characterized by many tall fruit trees, which made achieving accurate pollinator counts unlikely. I had originally intended to replicate the model selection process for all groups of pollinators (not just bees), but the scope of response variables was reduced based on my confidence of accuracy and the limited availability of data for butterflies, hummingbirds and flies.

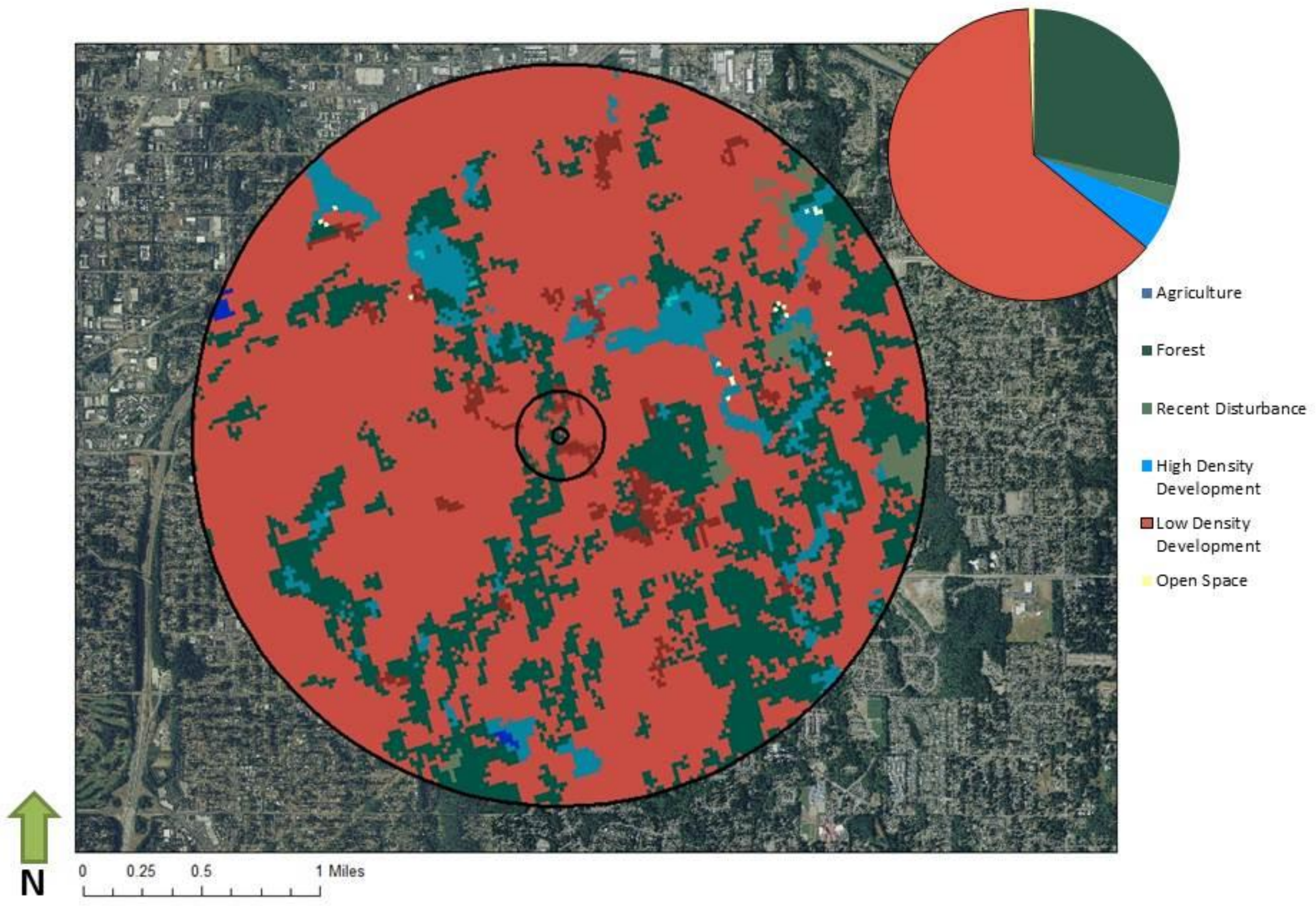


Figure 2. Example land-cover within 2.5km, 300m, and 50m radii surrounding a site. The pie chart displays the proportion of landcover types within a radius of 2.5km.

A model selection approach was used to determine which variables of interest may be most influential for the following response variables: number of kinds of bees (defined by each data collector as unique types of bees seen during each survey), total individual bees of all kinds, total bumble bees, and total honey bees. Because repeated measures were taken at each site, lack of independence was accounted for by employing generalized linear mixed effects, with site being treated as a random effect using the R package lme4 (Bates, 2011).

I evaluated the effects of temporal autocorrelation on the model selection process by conducting a sensitivity analysis for the set of models predicting total bees present, wherein for any group of two or more surveys conducted on the same or consecutive days at the same site, surveys were removed at random to leave only one survey for that site. Results of the model selection process were compared between the full dataset and this reduced dataset. Because the final models included the same variables and the parameters were nearly identical (within 0.1 units), I chose to include all data points for the rest of the analysis.

Model selection process

Total Bees

Akaike's Information Criterion, corrected for small sample size, was used to compare candidate models via backwards selection (Mazerolle, 2013).

The process began with an initial examination of correlation matrices and scatterplots to reduce the number of variables included in the full models.

Temperature and amount of sun were highly correlated, so only temperature was included. Many of the landscape-scale variables were highly correlated (correlation coefficient ≥ 0.5) with one another. Only proportion of forest within 300m and agriculture within 2.5km were chosen for inclusion in the final full models because I thought that large quantities of nearby evergreen-dominant forest might be negatively correlated with floral resources (and thereby bees) and that a signal from agriculture-associated apiculture within the flight range of honeybees might be detectible (Beekman and Ranieks, 2000). National Wildlife Certification status was removed because it correlated with many characteristics required for the certification and many of those characteristics were not included because the scatterplots and correlation coefficients did not suggest a clear pattern. A separate model was run to evaluate the significance of NWF certification on its own.

Bumblebees

For bumblebees, the full model was a slight modification from the one chosen for total bees. It included the same predictor variables, with the addition of woody debris and logSoil area. Although data exploration did not indicate that these might be of importance, they are of specific interest for bumblebees as they are associated with known nesting habits. The proportion of agriculture within 2.5km was removed.

Honeybees

For honeybees, three versions of the same full model that was used for total bees were first compared. These versions contained the proportion of agriculture surrounding each site at the three different scales of 50m, 300m and 2.5km because I was interested in finding the most appropriate potential scale of influence from agriculturally associated apiculture. Artificial nest sites were excluded from the full model. Apiaries were not included in the study and sites with apiaries were disqualified from participating; other artificial nest sites are not applicable. The model with the lowest AICc was chosen for the rest of the selection process.

Different Kinds of Bees

For different kinds of bees, the same full model that was used for total bees was chosen as the starting point for model selection, with the additional inclusion of woody debris and logSoil area. Although data exploration did not indicate that these might be of importance, they are associated known lifecycle habits, particularly for nesting, of a variety of bees.

Results

Data Quantity and Quality

A total of 324 surveys were recorded at thirty sites from March through August of 2012. There was variation in the number of surveys contributed by each study site. Participants made 0-12 surveys per month, averaging 1.8 (Figure 3). There was considerable variation in the number of bees counted both between and within sites (Figure 4).

Overall, my experiences working on-site with volunteers gave me confidence in their ability to correctly distinguish bees from flies, and honeybees from bumblebees. Flies however, were occasionally misidentified as either bees or neither flies nor bees. The results of the training quiz, summarized in Table 1, suggest that participants had greater success correctly identifying bees than flies and that there may be a small proportion of false positive bee identifications, so I only included bee data in my analysis.

	Honeybee	Bumblebee	Other Bee	Fly	Neither
Honeybee	17	4	3	8	0
Bumblebee	2	84	5	4	0
Other Bee	0	4	24	23	0
Fly	0	0	2	61	0
Not a Fly or a Bee	0	0	4	14	0
Proportion Correct	89.5	91.3	63.2	55.5	

Table 1. Confusion matrix of responses to the identification training quiz. The top row corresponds to the correct answer and the side column corresponds to the test takers' responses, ie. in column one, row two, the 2 represents the number of times that honeybee was the correct answer when the respondent selected bumblebee.

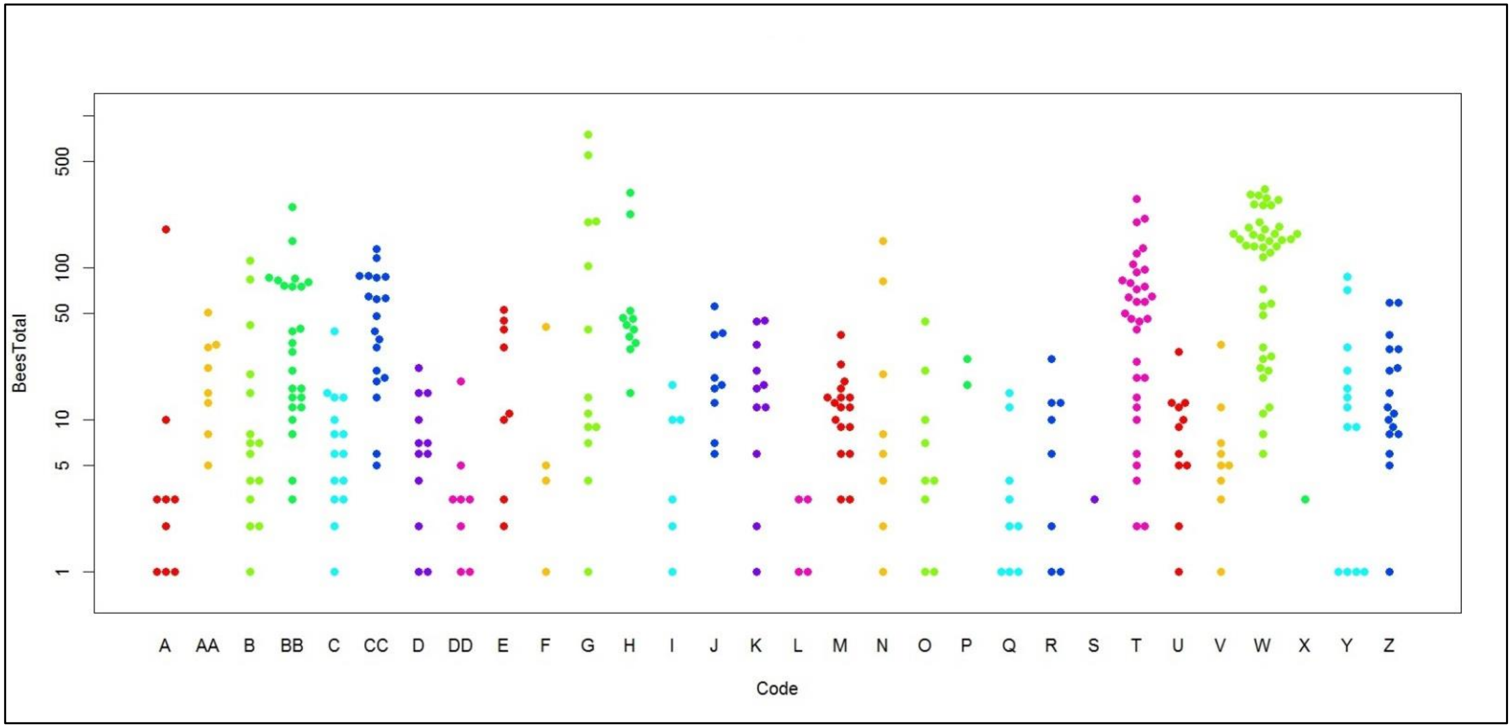


Figure 3. Beeswarm plot displaying total number of bees counted during each survey at each site (Code). Each dot represents a single survey, colors denote unique sites.

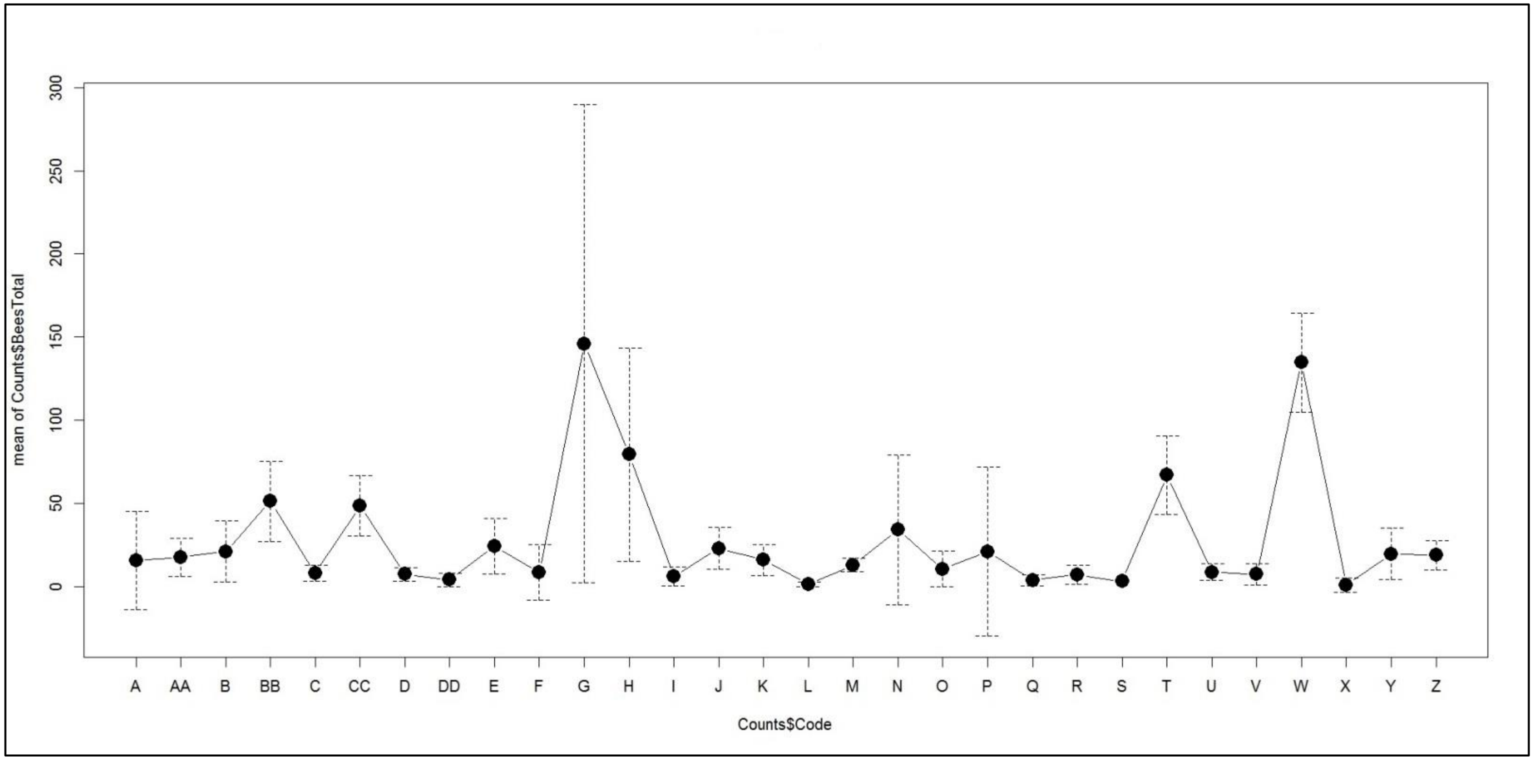


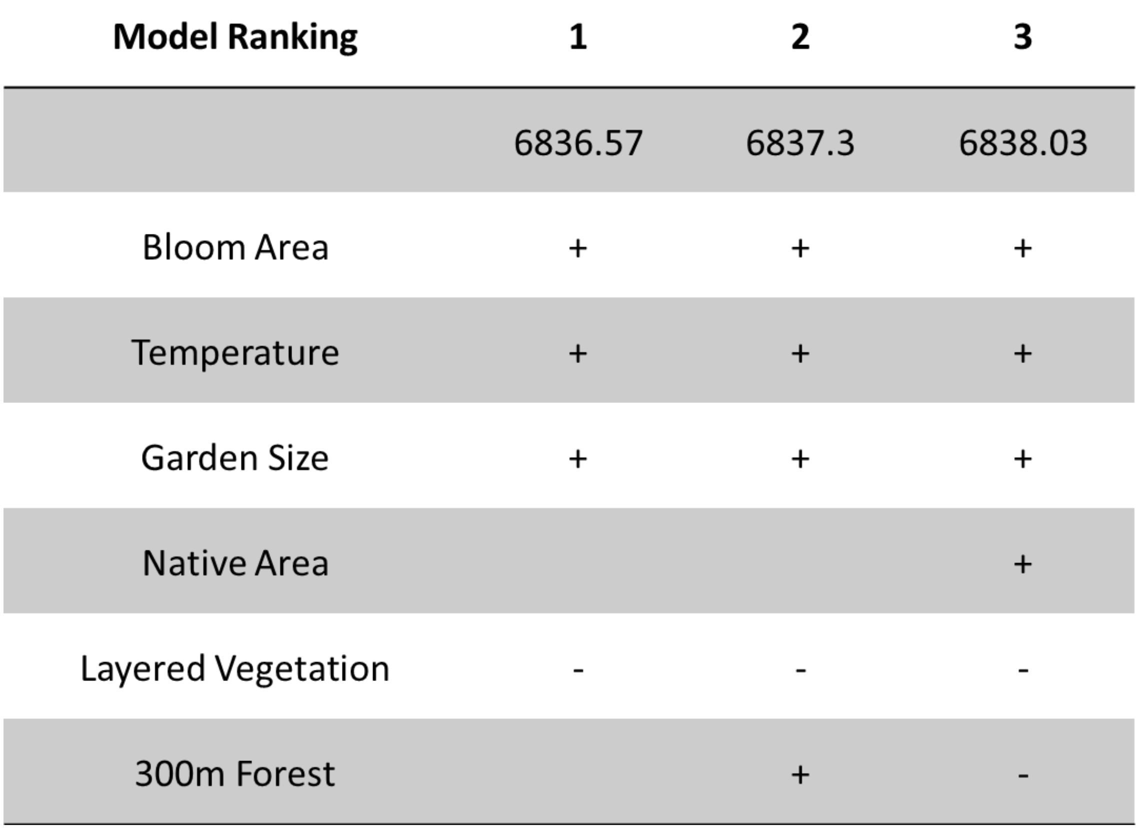
Figure 4. Means and 95% confidence intervals of total bees counted at each site (Code) throughout the study.

Total Bees

The “best model” predicting the total number of all bees includes only garden-scale variables--all landscape-scale variables dropped out during the selection process. Bloom area, garden size, and temperature are all positively correlated with the total number of bees at each site, while layered vegetation is negatively correlated. Overall, Certified Wildlife Habitat criteria (aside from providing floral resources) that were in the full model did not contribute much explanation to bee presence. Layered vegetation however, was determined to be of importance but with a negative correlation.

Other models with AICc values within a range of 1-2 units of the “best model,” included proportion of forest within 300m of each site and area of flowering Pacific Northwest native plants (see Table 2). Inclusion of forest gave unenlightening results (parameter estimates fluctuating between slightly above and below 1). The area of native plants had a slightly positive influence, however. These results are summarized in Appendix D.

Table 2. AICc values and variables included in the best supported models predicting total number of bees. -/+ denote positive/negative correlations.



Model Ranking	**1**	**2**	**3**
	6836.57	6837.3	6838.03
Bloom Area	+	+	+
Temperature	+	+	+
Garden Size	+	+	+
Native Area			+
Layered Vegetation	-	-	-
300m Forest		+	-

Bumblebees

The best predictive model for bumblebees includes the same variables as that for total bees, minus garden size (Table 6). However, models with AICc values within the range of 1-2 units of the best model included garden size and woody debris, with woody debris being associated with lower numbers of bumblebees (Table 3 & Appendix E).

Table 3. AICc values and variables included in the three best supported models predicting bumblebees. -/+ denote positive/negative correlations.

Model Ranking	**1**	**2**	**3**
	4904.95	4905.19	4906.72
Bloom Area	+	+	+
Temperature	+	+	+
Garden Size			+
Layered Vegetation	-	-	-
Woody	-	-	-

Honeybees

The best model for honeybees includes different variables than that for bumblebees (Table 6). Models for all bees, bumblebees and honeybees give evidence that total bloom area and temperature are of importance, but honeybees uniquely showed a negative correlation with the area of native plants at a given site, and a positive correlation with increased diversity of flowering plants, while layered vegetation, which was present in the best models for all bees and bumblebees, dropped out early in the model selection process for honeybees. Models with AICc values within 1 unit of the best model either added agriculture via a slight negative association or removed the area of native plants (Table 4 & Appendix F).

Table 4. AICc values and variables included in the three best supported models predicting honeybees. -/+ denote positive/negative correlations.

Model Ranking	**1**	**2**	**3**
	2619.82	2619.83	2620.96
Bloom Area	+	+	+
Temperature	+	+	+
Garden Size	+	+	+
Count Angiosperm	+	+	+
Native Area	-		-
2.5km Ag			-

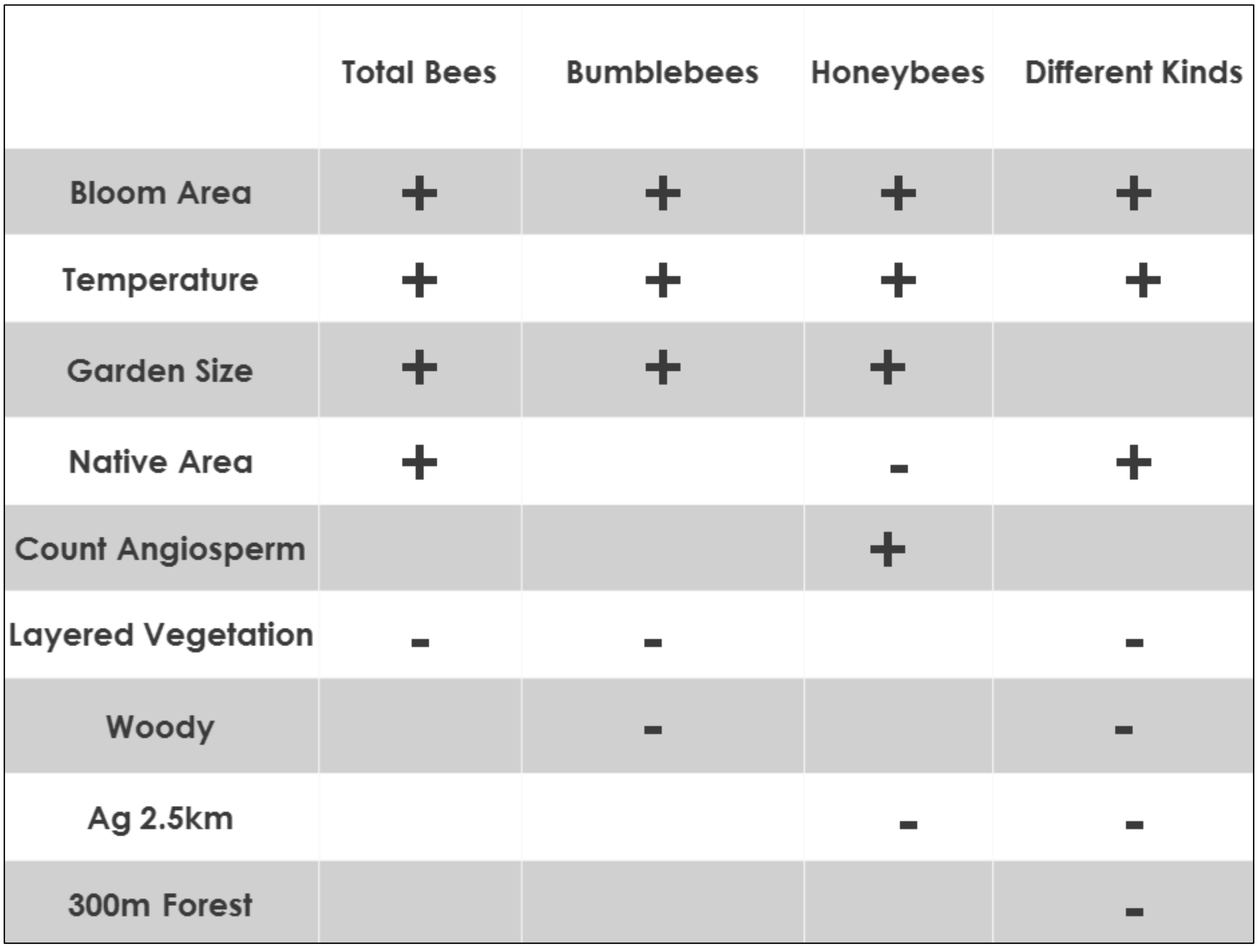
Different Kinds of Bees

Diversity of bees, as measured by the number of different kinds of bees distinguishable to the observer, had unique results compared to bee abundance (Table 6). The best predictive model included total bloom area and temperature, as the other models do, but with the addition of native plant area, woody debris, and proportion of forest within the 300m surrounding a given site (Table 5). Woody debris, and forest, potential correlates of shade showed negative correlations while proportion of native plants was positive. Models with AICc values within 1-2 units of the best model included agriculture within 2.5km surrounding a given site and layered vegetation, both with negative correlations (Appendix G).

Table 5. AICc values and variables included in the three best supported models predicting the number of different kinds of bees. -/+ denote positive/negative correlations.

Model Ranking	**1**	**2**	**3**	**4**
	392.08	392.1	392.55	392.99
Bloom Area	+	+	+	+
Temperature	+	+	+	+
Native Area	+		+	+
Layered Vegetation				-
Woody	-	-	-	-
x300Forest	-	-	-	-
2.5km Ag			-	-

Table 6. Summary of model selection. Response variables are listed across the top, and variables included in the best models are along the left. (+)/(-) denote a positive/negative correlation.



	Total Bees	Bumblebees	Honeybees	Different Kinds
Bloom Area	+	+	+	+
Temperature	+	+	+	+
Garden Size	+	+	+	
Native Area	+		-	+
Count Angiosperm			+	
Layered Vegetation	-	-		-
Woody		-		-
Ag 2.5km			-	-
300m Forest				-

Discussion

The model selection process suggests that in Southern Snohomish County Washington, local garden-scale variables are more influential to the presence of bees than landscape-scale variables. These findings are consistent with Silvertown et al (2013) who explored similar questions by evaluating biodiversity in Parisian public gardens. It appears that in a variety of contexts, from rural and suburban Pacific Northwest to densely urban European metropolis, the notion that local variables tend to prescribe local bee abundance and diversity is gaining credence. Small-scale actions undertaken by an individual or individual(s) can have a measurable impact on pollinating insects.

Unsurprisingly, total bloom area and temperature appear to be overall most important for observation of both bee abundance and diversity. It is sensible that areas with abundant food resources host more bees than those with fewer resources. Similarly, temperature is a widely accepted control of bee activity. Because bees are more visible when active and their activity depends on temperature, one would expect greater numbers would to be counted on warmer days. Other variables, though less influential, are of greater relevance to the study questions and will be discussed below.

Floral diversity, as measured by the number of angiosperm taxa at a site, only appeared in the best supported model for honeybees. In retrospect, a measurement that takes into account relative diversity and resource density, rather than a simple count of the different kinds of plants present, might be a more useful metric for understanding how bees respond to floral resource diversity. Assuming that findings from large-scale agricultural studies that underpin the benefits of mixed hedgerows and flower plantings translate to urban and backyard environments, ornamental gardens can likely play a positive role in home food production by attracting and sustaining a variety of pollinators. Other research suggests that bumblebees in particular are attracted to within-patch plant diversity rather than a single widespread resource pulse, but prefer some patch-to patch consistency (Jha & Kremen, 2013).

I found no evidence to support the importance of artificial nest sites or bare soil, which are both often recommended specifically for attracting and sustaining bees. Because this study measured observations of bees, which are most likely to occur when bees are active, it is not a complete evaluation of the value of artificial nests and bare soil with respect to bees' entire lifecycle. Bees may or may not nest in the same properties that they forage. The value of these garden attributes could be further evaluated by directly quantifying their use by bees, or by comparing the abundance of particular taxa, such as mason bees, at sites with and without artificial nests.

Interestingly, layered vegetation and woody debris, both recommended for wildlife gardening in general, were negatively correlated with bee abundance and diversity. Layered vegetation and woody debris tend to be associated with shadier spaces and are thought to be valuable garden additions specifically for birds. Advocacy programs targeted at bees should consider this distinction. Gardeners wanting to appeal to both birds and bees could partition their gardens with separate open, floral-rich and layered canopy-covered areas with woody debris.

Pesticide use did not appear in any of the best models, but very few sites reported using pesticides, and those that did cited RoundUp and or Sluggo, neither of which are known to harm flying insects such as bees. Given that volunteers for this study are likely more “environmental” in their practices than the general population, I don’t feel that this sample adequately addresses the issue of pesticides. While future research could get a more representative sample of site-level pesticide use, accounting for the behavior of neighbors with the potential for drift etc. would be very difficult. So far, studies of the impacts of pesticides on bees have been experimental rather than observational and targeted toward agricultural rates and applications. This research indicates that certain pesticides, specifically neonicotinoids, are harmful to bees (Hopwood et al., 2012) can be harmful to bees and may be a synergistic component of bee decline. These pesticides are readily available to homeowners and can be applied at much higher rates than is legally permitted in agricultural applications. A combination of surveys, sampling for pesticide residue in plant tissue, soil and bees with comparison to bee abundance and diversity would help shed light on the patterns of homeowner pesticide use and its impacts on pollinators.

Garden size was positively correlated with bee abundance, but not bee diversity, suggesting that compared to the qualities of a garden, perhaps size doesn’t matter. No matter how much space an individual has with which to garden, they can have a positive influence on local biodiversity. However, Sperling and Lortie (2010) found that an increase in garden area, regardless of how big, corresponded to increased numbers and diversity of winged invertebrates, even if that new area only included soil. This raises the question of the value of resource density versus total area: both results hint that the former is of greater consequence to bees, though the issue deserves further investigation. It seems logical that larger areas dense with resources would be better for bees, at least with respect to abundance, but gardeners and land managers would benefit from knowing whether smaller spaces dense in resources are more or less valuable than large areas with dispersed resources.

Evidence is mixed for the importance of native plants, which are recommended in general for wildlife gardening and specifically for pollinators. Work by other ecologists, (eg. Zuefle et al., 2008; Tallamy, 2009), has suggested that co-evolutionary associations point to the importance of native plants for native bees, so it is not surprising that for honeybees, which are non-native, there was not a positive correlation, in fact the correlation was negative. Following that logic, a positive correlation with native bee species would be expected. Native plants appeared in the best models for both total bees and kinds of bees, but not bumblebees, which suggest that they may be of greatest importance to bees other than bumblebees which are generalists, perhaps other wild, native bees that are more discriminating in their food choices.

Beyond the individual garden, I expected to see some signal from adjacent land uses, either an overall increase due to greater local floral resources, or a decrease due to floral competition. The lack of a predictive pattern may not mean that adjacent land management is not important; it is possible that the effects of parcel to parcel homo- versus heterogeneity may be so complex that a pattern could not be detected at this sample size. It is likely that what happens in the immediate and surrounding landscape do play a role in driving the presence or absence of bees locally, but in this case the influence amounts to “noise.” Future research could improve the detectability of influential factors by capturing finer resolution information about neighboring properties. Recent advancements in the use of aerial photography (Taylor & Lovell, 2011) and satellite imagery (Mathieu et al, 2007) could aid this effort.

Interestingly forest within 300m of a site was negatively correlated with bee diversity. This is in contrast to agricultural studies where nearby natural areas, including forests, are associated with greater pollinator diversity at crop sites. These other investigations have been restricted to the eastern United States and the tropics, where forests may have greater numbers of animal-pollinated angiosperms and therefore naturally support a greater number and diversity of bees. A better understanding of the interaction between forested, natural habitats in Western Washington and human modifications would be of value.

We have evidence that local-scale variables are most important for predicting local-scale bee abundance and diversity in gardens, but is the reverse true? To what extent does the presence of gardens influence bee abundance, diversity and associated services in the surrounding landscape? If there are different or increased pollinator assemblages associated with gardens, nearby natural areas may benefit from an increase in pollination services, as has been shown for crop sites, or potentially, there could be competition. Comparison of bee communities and services of gardens to natural areas at various proximities in our region could be explored to better understand the impacts of land management. Ideal future research could employ a nested block design in which groupings of adjacent gardens with similar or different management practices would be replicated across varying landscape contexts. Site-scale abundance and diversity could be compared to block-scale abundance and diversity, as well as between different blocks and sites.

We are gaining a sense of how individual people can steward their land for both beauty and a healthy ecology by employing educated gardening practices. The next step is to discover the impact of collective actions on the ecosystem services associated with bee abundance and diversity. In human-dominated landscapes, gardens that are rich in number and variety of plant resources but share a similar plant palette with neighboring gardens may optimize benefits to wild bees. Scaling-up from individual gardens, as Goddard et al (2010) suggest, will require coordinated effort and continued examination of how bees respond to the world around them.

On Citizen Science

While not directly related to the questions posed by this study, there are several outcomes from this study that are worth documenting. Citizen involvement in this process provided an opportunity for unexpected observations of value for science and conservation or less tangible results such as inspiring a sense of wonder at natural curiosities, and fostering human-human and human-nature connections.

Many volunteers became curious about the behaviors of their bees and sent pictures and inquiries about intriguing activities that included bumblebees sleeping in flowers and honeybees blowing bubbles in fountains. Nearly one year later, I receive messages about how bee numbers compare to last year and a lot of interest in continuing the study.

One volunteer and her adult daughter bonded over making pollinator observations and became enthralled with the variety of bees and flies in their backyard and went above and beyond the requirements of the study in an effort to identify and know them all. Originally gardening for butterflies and birds, they were excited to discover that bees are also drawn to their efforts and that they are at least as interesting to learn about and watch. One day they noticed an unfamiliar bee and suspected it might be the Western bumble bee, *Bombus occidentalis*, an imperiled bee that was once common on the West coast and now is nearly extirpated. They sent the image to the Xerces Society for Invertebrate Conservation, who confirmed and were excited to document the siting as part of their citizen science monitoring effort. Story of this siting spread and the mother was invited to speak at a North American Butterfly Association meeting about her experience observing bees. Her enthusiasm about pollinators has continued to grow and she is now leading efforts to organize the development of pollinator gardens in her community.

Surveys at several sites uncovered the ubiquity of the European carder bee, *Anthidium manicatum*, which is thought to have spread to Washington as recently as 2009. Communications with local entomologists at the University of Washington and WSU Extension revealed that this bee has not been studied, but there is a lot of interest in its potential impacts and interactions with native bees.

There are a few lessons-learned that I would like to acknowledge also. Anyone interested in conducting a similar study that relies on the public to identify pollinators should distinguish pollinating flies and bee mimics from other flies. I initially asked participants to count all flies encountered, which included many that are not relevant, including house flies. To better capture the personal and unintended scientific results, I recommend that future research employ pre-and post-participation tests of knowledge and surveys about the experience. I also add that in-person contact and training is helpful both for adequate training and for volunteer motivation. Citizen science is growing as a field, becoming more self-aware, and leaders are developing best practices, and new resources and tools are becoming available.

Although not all participants were equally dedicated and inspired by this project, I was impressed overall with the minimal attrition. In general, it seemed that retired people with an interest in gardening made the most committed volunteers. Engaging this growing demographic holds immense potential. With the participation of an educated and active public, the possibilities are endless for documentation, discovery, connection and conservation.

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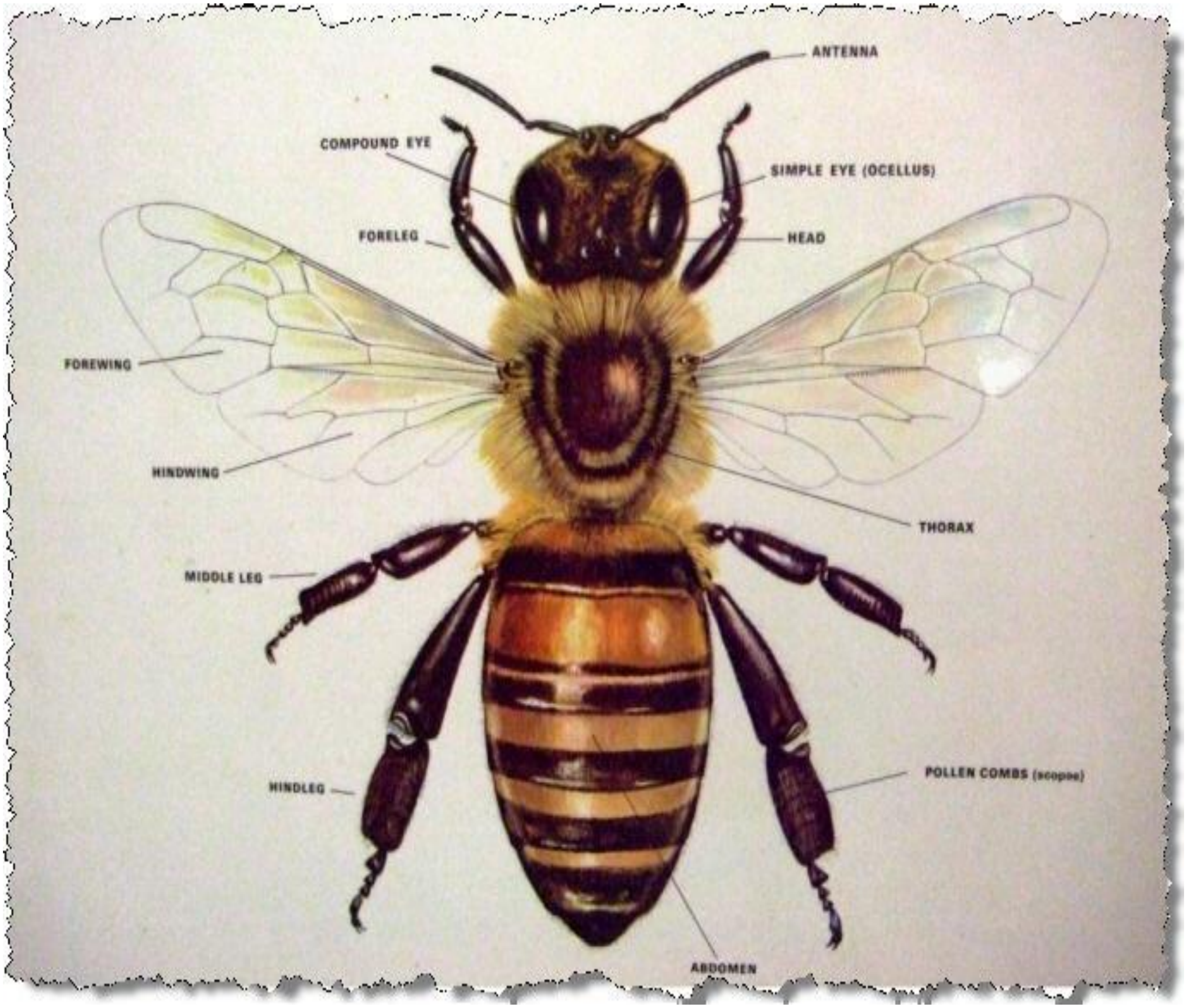
Appendix A. Pollinator observation data collection sheet.

	Observer (Full Name)	
Site #:		**Sunny or partly cloudy?:**
Start time:		**Windspeed:**
Observation end time:		**Temperature:**
Pollinator	**Count**	**Notes (**What flowers are in bloom? What flowers are pollinators using?**)**
Number of Different Kinds Bees		
Total Bumble Bees		
Total Honey Bees		
Total Individuals (All Bees)		
Number of Different Kinds Butterflies		
Total Individuals Butterflies		
Total Individuals Hummingbirds		
Number of Different Kinds Flies		
Total Individuals Flies		
Additional comments:		

Appendix B. Typical garden pollinators of Snohomish County Prepared by Rob Sandelin



Bees

Red-bottomed Bumblebee *Bombus spp.*
Densely hairy with last two abdominal segments red.

Yellow-faced Bumblebee *Bombus spp.*
Mostly black with last abdominal segment yellow, yellow on top of thorax and head.

Honey Bee *Apis spp.*
Yellow with black and white abdominal bands, densely hairy thorax

Mining Bee *Adrena spp.*
Very small, about half the size of a honey bee, very densely hairy, oval head, with mostly black abdomen with small white bands. Long hairs on upper part of hind leg.

Dark Sweat Bee *Lagioglossum spp.*
Similar to Mining bee only with short white hair on abdomen, smaller head.

Sweat bee *Halictus spp.*
Small bee, similar to mining bee black abdomen with white markings, dense golden fur on abdoment, lacks leg hair

Leaf cutter bee *Megachile spp.*
Abdomen is blunt and somewhat flattened, thorax hairy especially underneath.

Orchard Mason Bee *Osmia spp.*
Black shiny bee, large round head.

Green Metallic Bee *Agapostemon spp*
Shiny green bee, big gray eyes, legs often covered with pollen.

Bald Faced Hornet *Dolichovespula spp*.
Mostly black abdomen with last two asdominal segments white.

YellowJacket *Vespula spp*.
Abdomen with yellow and black markings, yellow legs.

Paper Wasp *Polistes spp*.
Similar to yellow jacket but longer abdomen and legs, yellow antennae.

Flies found on flowers

Flower Fly *Syrpidae*
Big eyes, not hairy, shiny, very small antennae.

Drone fly *Eristalis spp.*
Similar to honey bee, larger eyes and black hourglass markings instead of stripes, hairless, tiny antennae

Greater Bee Fly *Bombylius spp.*
Very hairy, similar to bumblebee only it hovers in front of flowers and has a large needle like beak.

Narcissus Bulb Fly *Merodon spp.*
Large fly, very hairy with shiny black abdomen and antennae with knobs on them. Similar to bumblebee.

A few common butterflies

Cabbage White

Margined White

Blue Azure

Woodland Skipper

Tiger Swallowtail

Mourning Cloak

Painted Lady

Lorquins Admiral

California Tortiseshell

Appendix C. Training Quiz

◉ Select one...
○ Honeybee
✓ ○ Bumblebee
○ Other bee
○ Fly
○ Not a bee or a fly

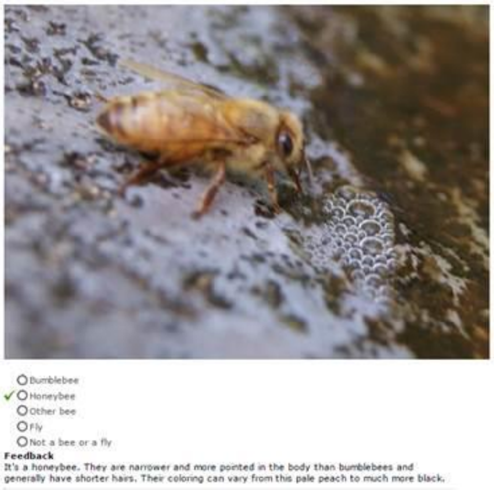
Feedback
This is a bumblebee! Notice the longish antennae and fuzzy round body.

○ Bumblebee
○ Honeybee
○ Other bee
✓ ○ Fly
○ Not a bee or a fly

Feedback
This is a fly! A drone fly to be exact. Notice its fat body, short antennae, round eyes at the front of its head and not-so hairiness.

○ Bumblebee
○ Honeybee
○ Other bee
✓ ○ Fly
○ Not a bee or a fly

Feedback
It's a fly! Short antennae, big round eyes at front of head, shiny, 1 pair of wings.



○ Bumblebee
✓ ○ Honeybee
○ Other bee
○ Fly
○ Not a bee or a fly

Feedback
It's a honeybee. They are narrower and more pointed in the body than bumblebees and generally have shorter hairs. Their coloring can vary from this pale peach to much more black.

○ Bumblebee
○ Honeybee
○ Other bee
✓ ○ Fly
○ Not a bee or a fly

Feedback
Narcissus Bulb Fly. Large fly, very hairy with shiny black abdomen and short antennae with knobs on them. Similar to bumblebee.

○ Bumblebee
○ Honeybee
✓ ○ Other bee
○ Fly
○ Not a bee or a fly

Feedback
It has long antennae and a decent amount of fuzziness.

○ Bumblebee
○ Honeybee
○ Other bee
✓ ○ Fly
○ Not a bee or a fly

Feedback
It's a fly! Short antennae, not much hair, one pair of wings.

✓ ○ Bumblebee
○ Honeybee
○ Other bee
○ Fly
○ Not a bee or a fly

Feedback
Bumblebee! Long antennae, super fuzzy, eyes on side of head.

○ Bumblebee
○ Honeybee
○ Other bee
✓ ○ Fly
○ Not a bee or a fly

Feedback
Whoa! Fly. Short antennae, large eyes toward front of head.

✓ ○ Bumblebee
○ Honeybee
○ Other bee
○ Fly
○ Not a bee or a fly

Feedback
It's a bumblebee!

✓ ○ Bumblebee
○ Honeybee
○ Other bee
○ Fly
○ Not a bee or a fly

Feedback
It's a bumblebee!

○ Bumblebee
○ Honeybee
✓ ○ Other bee
○ Fly
○ Not a bee or a fly

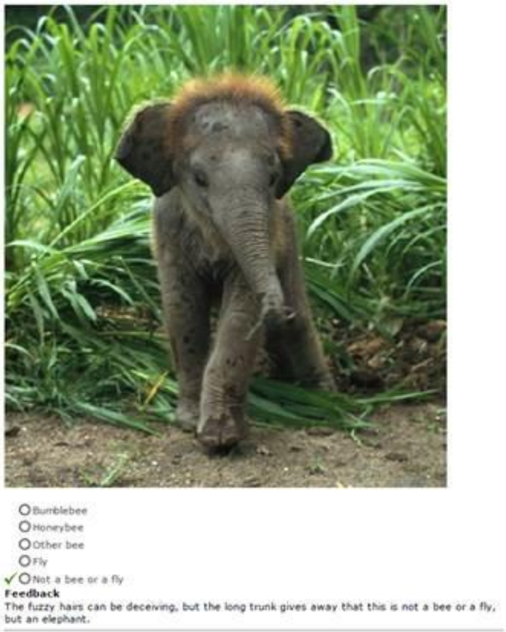
Feedback
This is a mason bee. It has a shiny body and long antennae.

✓ ○ Bumblebee
○ Honeybee
○ Other bee
○ Fly
○ Not a bee or a fly

Feedback
It's a bumblebee!

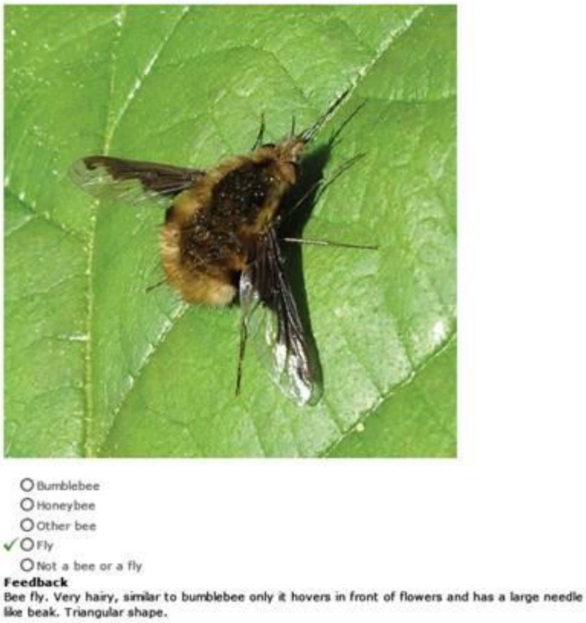
✓ ○ Bumblebee
○ Honeybee
○ Other bee
○ Fly
○ Not a bee or a fly

Feedback
This is the bumblebee that most of us think of.



○ Bumblebee
○ Honeybee
○ Other bee
○ Fly
✓ ○ Not a bee or a fly

Feedback
The fuzzy hairs can be deceiving, but the long trunk gives away that this is not a bee or a fly, but an elephant.

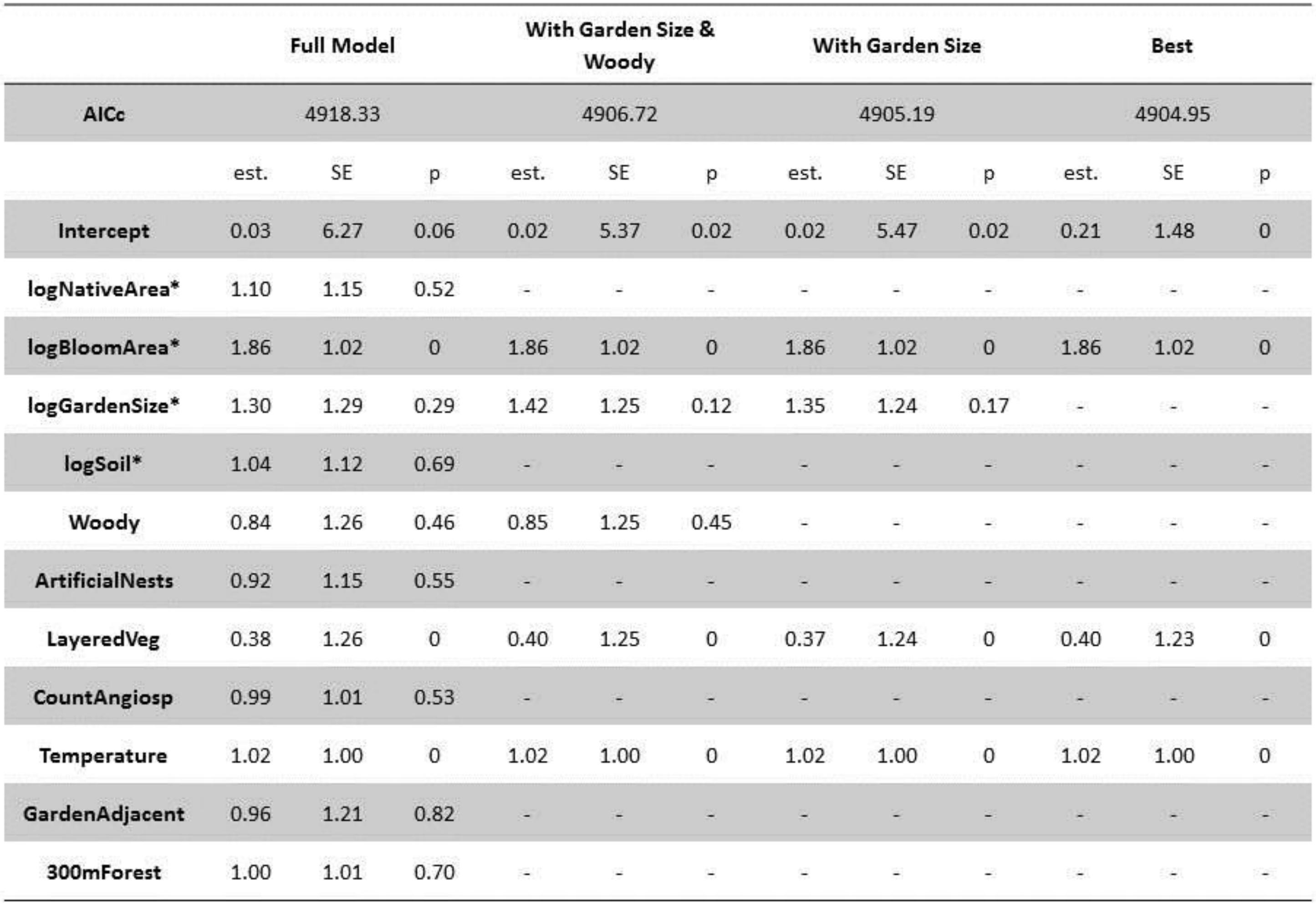


○ Bumblebee
○ Honeybee
○ Other bee
✓ ○ Fly
○ Not a bee or a fly

Feedback
Bee fly. Very hairy, similar to bumblebee only it hovers in front of flowers and has a large needle like beak. Triangular shape.

	Full Model			With Native and Forest			With Forest			Best		
AICc	6845.66			6838.03			6837.3			6836.57		
	est.	SE	p	est.	SE	p	est.	SE	p	est.	SE	p
Intercept	0	3.56	0	0	3.10	0	0	3.06	0	0	3.13	0
logNativeArea*	1.11	1.09	0.27	1.09	1.08	0.23	-	-	-	-	-	-
logBloomArea*	1.45	1.01	0	1.45	1.01	0	1.45	1.01	0	1.45	1.01	0
logGardenSize*	1.54	1.19	0.01	1.49	1.16	0.01	1.63	1.15	0	1.65	1.15	0
ArtificialNests	0.98	1.08	0.77	-	-	-	-	-	-	-	-	-
LayeredVeg	0.58	1.16	0	0.01	1.15	0	0.60	1.15	0	0.58	1.16	0
CountAngiosp	1.00	1.01	0.87	-	-	-	-	-	-	-	-	-
Temperature	1.06	1.00	0	1.06	1.00	0	1.06	1.00	0	1.06	1.00	0
GardenAdjacent	0.95	1.12	0.65	-	-	-	-	-	-	-	-	-
2.5kmAG	0.96	1.06	0.52	-	-	-	-	-	-	-	-	-
300mForest	0.99	1.01	0.15	0.99	1.01	0.1	1.01	1.00	0.24	-	-	-

Appendix D. Results of GLMM selection for total bees. The full model and top three models are summarized. Parameter estimates (est.) for the variables included in each model are displayed with their associated standard error (SE) and p values. Lower AICc values favor the “more likely” model with the fewest number of variables. * denotes that estimates correspond to a one unit change on the log scale of that parameter. – denotes when a variable was not included in a given model.

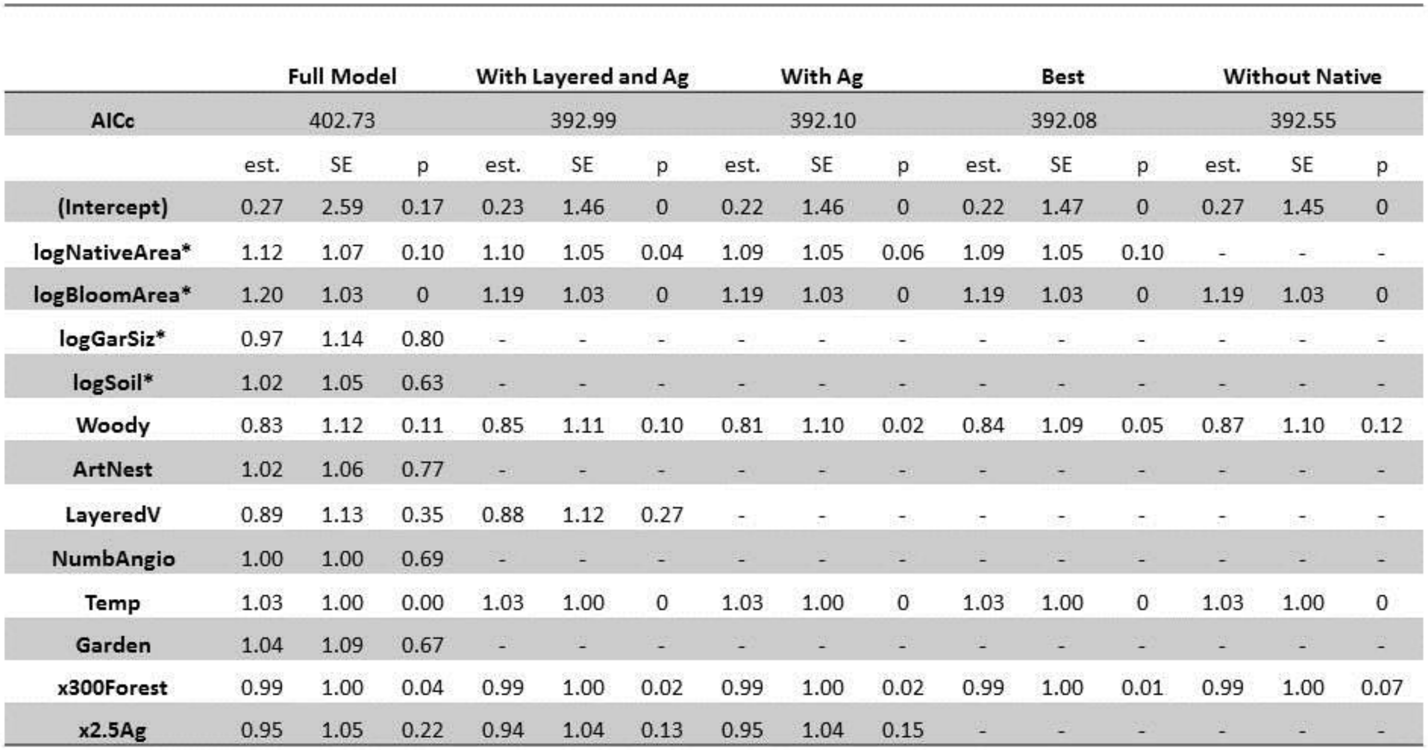


	Full Model			With Garden Size & Woody			With Garden Size			Best		
AICc	4918.33			4906.72			4905.19			4904.95		
	est.	SE	p	est.	SE	p	est.	SE	p	est.	SE	p
Intercept	0.03	6.27	0.06	0.02	5.37	0.02	0.02	5.47	0.02	0.21	1.48	0
logNativeArea*	1.10	1.15	0.52	-	-	-	-	-	-	-	-	-
logBloomArea*	1.86	1.02	0	1.86	1.02	0	1.86	1.02	0	1.86	1.02	0
logGardenSize*	1.30	1.29	0.29	1.42	1.25	0.12	1.35	1.24	0.17	-	-	-
logSoil*	1.04	1.12	0.69	-	-	-	-	-	-	-	-	-
Woody	0.84	1.26	0.46	0.85	1.25	0.45	-	-	-	-	-	-
ArtificialNests	0.92	1.15	0.55	-	-	-	-	-	-	-	-	-
LayeredVeg	0.38	1.26	0	0.40	1.25	0	0.37	1.24	0	0.40	1.23	0
CountAngiosp	0.99	1.01	0.53	-	-	-	-	-	-	-	-	-
Temperature	1.02	1.00	0	1.02	1.00	0	1.02	1.00	0	1.02	1.00	0
GardenAdjacent	0.96	1.21	0.82	-	-	-	-	-	-	-	-	-
300mForest	1.00	1.01	0.70	-	-	-	-	-	-	-	-	-

Appendix E. Results of GLMM selection for bumblebees. The full model and top three models are summarized. Parameter estimates (est.) for the variables included in each model are displayed with their associated standard error (SE) and p values. Lower AICc values favor the “more likely” model with the fewest number of variables. * denotes that estimates correspond to a one unit change on the log scale of that parameter. - denotes when a variable was not included in a given model.

	Full Model			With Ag			Best			Without Native Proportion		
AICc	2626.443			2620.96			2619.818			2619.827		
	est.	SE	p	est.	SE	p	est.	SE	p	est.	SE	p
Intercept	0.00	13.36	0.00	0.00	9.72	0.00	0.00	8.82	0.00	0.00	9.18	0.00
logNativeArea*	0.87	1.20	0.47	0.80	1.16	0.12	0.81	1.16	0.14	-	-	-
logBloomArea*	1.09	1.03	0.00	1.09	1.03	0.00	1.10	1.03	0.00	1.10	1.03	0.00
logGardenSize*	1.84	1.42	0.08	1.82	1.36	0.05	1.64	1.34	0.09	1.42	1.32	0.00
LayeredVeg	0.83	1.35	0.53	-	-	-	-	-	-	-	-	-
CountAngiosp	1.01	1.01	0.28	1.02	1.01	0.11	1.02	1.01	0.12	1.01	1.01	0.21
Temperature	1.08	1.00	0.00	1.07	1.00	0.00	1.08	1.00	0.00	1.08	1.00	0.31
GardenAdjacent	0.96	1.24	0.85	-	-	-	-	-	-	-	-	-
2.5kmAG	0.88	1.13	0.33	0.89	1.13	0.33	-	-	-	-	-	-
300mForest	0.99	1.01	0.56	-	-		-	-	-	-	-	-

Appendix F. Results of GLMM selection for honeybees. The full model and top three models are summarized. Parameter estimates (est.) for the variables included in each model are displayed with their associated standard error (SE) and p values. Lower AICc values favor the “more likely” model with the fewest number of variables. * denotes that estimates correspond to a one unit change on the log scale of that parameter. - denotes when a variable was not included in a given model.



	Full Model			With Layered and Ag			With Ag			Best			Without Native		
AICc	402.73			392.99			392.10			392.08			392.55		
	est.	SE	p	est.	SE	p	est.	SE	p	est.	SE	p	est.	SE	p
(Intercept)	0.27	2.59	0.17	0.23	1.46	0	0.22	1.46	0	0.22	1.47	0	0.27	1.45	0
logNativeArea*	1.12	1.07	0.10	1.10	1.05	0.04	1.09	1.05	0.06	1.09	1.05	0.10	-	-	-
logBloomArea*	1.20	1.03	0	1.19	1.03	0	1.19	1.03	0	1.19	1.03	0	1.19	1.03	0
logGarSiz*	0.97	1.14	0.80	-	-	-	-	-	-	-	-	-	-	-	-
logSoil*	1.02	1.05	0.63	-	-	-	-	-	-	-	-	-	-	-	-
Woody	0.83	1.12	0.11	0.85	1.11	0.10	0.81	1.10	0.02	0.84	1.09	0.05	0.87	1.10	0.12
ArtNest	1.02	1.06	0.77	-	-	-	-	-	-	-	-	-	-	-	-
LayeredV	0.89	1.13	0.35	0.88	1.12	0.27	-	-	-	-	-	-	-	-	-
NumbAngio	1.00	1.00	0.69	-	-	-	-	-	-	-	-	-	-	-	-
Temp	1.03	1.00	0.00	1.03	1.00	0	1.03	1.00	0	1.03	1.00	0	1.03	1.00	0
Garden	1.04	1.09	0.67	-	-	-	-	-	-	-	-	-	-	-	-
x300Forest	0.99	1.00	0.04	0.99	1.00	0.02	0.99	1.00	0.02	0.99	1.00	0.01	0.99	1.00	0.07
x2.5Ag	0.95	1.05	0.22	0.94	1.04	0.13	0.95	1.04	0.15	-	-	-	-	-	-

Appendix G. Results of GLMM selection for different kinds of bees. The full model and top four models are summarized. Parameter estimates (est.) for the variables included in each model are displayed with their associated standard error (SE) and p values. Lower AICc values favor the “more likely” model with the fewest number of variables. * denotes that estimates correspond to a one unit change on the log scale of that parameter. – denotes when a variable was not included in a given model.