

The effects of local and landscape-level characteristics on the abundance and diversity of solitary-nesting Hymenoptera in urban family gardens.



Sarah D. Pellkofer
Institute of Evolutionary Biology and Environmental Studies
University of Zurich
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Supervisors: Dr. Lindsay Ann Turnbull & Dr. Gabriela Schaepman-Strub



University of Zurich

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1 Abstract

Urbanization has been increasingly transforming natural areas into city landscapes dominated by man-made infrastructure. Family gardens (*Areas*) are one component of this urban landscape that could act as essential habitat to species of solitary-nesting Hymenoptera that still remain within the city, however, many of these gardens have been facing increased pressure to be closed and developed. As the ecosystem services of pollination and pest control that these Hymenoptera provide are extremely valuable to humans, this study sought to determine if these gardens are truly a habitat for solitary-nesting Hymenoptera within the city of Zurich and also what features of these gardens on the local and landscape scale make them more suitable as such a habitat. Using trap-nests this study analyzed how strongly a) abundance, b) richness and c) evenness were predicted by three landscape-level variables and three local-level variables. The landscape-level variables examined were 1) Area size, 2) the greenness of the Area surroundings and 3) the Area's daily potential solar radiation and the local-level variables were 4) the use of pesticides, 5) the number of existing nesting sites, and 6) the ground cover diversity within individually managed garden plots in each Area. The results of this study showed that on the landscape-level Areas that were smaller with greener surroundings had increased abundance and richness of hymenopteran genera. Areas that were smaller also had increased evenness among those genera. Daily potential solar radiation was not an effective predictor of the abundance, richness and evenness of solitary-nesting Hymenoptera. On the local-level, garden plots with lower ground cover diversity had a higher abundance of hymenopteran genera; however, it was not a predictor the richness and evenness of the genera. Furthermore, the number of existing nesting sites and the use of pesticides were not effective predictors of the abundance, richness and evenness of solitary-nesting Hymenoptera. Although the findings of this study were not in line with many of the original hypotheses, the larger finding that there are a great number of hymenopteran individuals and moreover a wide variety of genera utilizing these family gardens within all varieties of gardens analyzed, it can be said that these family gardens are an important habitat for these species. Therefore, the value of the ecosystem services provided by the species utilizing these gardens should be taken into account when determining the best future use for the urban land currently occupied by family gardens in the city of Zurich.

2 Introduction

2.1 Urbanization

Urbanization: the physical growth of urban areas as a result of global change. An increasing concentration of the human population in cities and a transformation of land use to an urban pattern of organization (McGraw-Hill).

Urbanization is an increasingly prominent modern global trend that has transformed natural habitats into landscapes dominated by man and manmade infrastructure (United Nations Population Fund, 2007). Currently, little is known about the effects urban ecosystems have on the species that live within them (McIntyre, 2000). It is recognized that urbanization disturbs the habitats of many species through pollution (noise, chemical substances, light and heat) (Connor, Hafernik, Levy, Moore, & Rickman, 2003; Niemela et al., 2002; Rebele, 1994), fragmentation (McIntyre, 2000) and by facilitating the introduction of invasive species (McKinney, 2002; Mckinney, 2006). However, more recent studies show that some species have adapted to these urban landscapes and are successfully living in the microclimatic conditions that they provide (Frankie et al., 2005; Saure, 1996). But, overall there is a large gap in understanding of the ultimate impacts that urban landscapes have on local biodiversity and ecosystem functioning (Frankie et al., 2005; Hernandez, Frankie, & Thorp, 2009).

2.2 Family Gardens

Family gardens are one component of urban environments that are currently poorly studied. These family gardens, locally called 'Familiengärten', 'Kleingärten', 'Schrebergärten' or 'Pünten' are rentable satellite gardens that consist of a conglomerate of fenced-in individually cultivatable parcels, grouped together and managed by various garden associations, although they are owned by the municipality. There are over 6,000 independently managed plots in the city of Zurich, many of which were founded over a century ago (Verbund Lebensraum Zürich, Grün Stadt Zürich, & Stadt Zürich, 2008). Since their establishment a large number of these family gardens have gradually been engulfed by dense urban development and they now make up a large fraction of the remaining green space within the city limits (Zürich Familie, 2007) (Figure 1-a). Moreover, because they are centrally located, they have been under increasing threat from developers who feel that the land could be transformed into spaces that provide benefits to a larger proportion of the population as well as bring in greater direct revenue to the city (Kawagishi & Malterre-Barthes) (Figure 1-b). Currently the tangible outflows of these gardens (harvested fruits, vegetables and flowers, recreational and educational space, and exposure to nature in an urban setting) (Matteson, Ascher, & Langellotto, 2008; Miller, 2005; Pyle, 1978) are viewed as

benefits limited to the people who rent the plots. However, they may actually be providing a currently unrecognized value to larger sections of the city if they are acting as an important habitat for species that provide humans with ecosystem services.

2.3 Solitary-Nesting Hymenoptera

Solitary-nesting Hymenoptera (Apidae, Sphecidae, Eumenidae, Pompilidae), also called trap-nesting Hymenoptera, are one order that could plausibly be utilizing family gardens and providing such ecosystem benefits (Goddard, Dougill, & Benton, 2009; Matteson et al., 2008). Hymenoptera provide the important ecosystem services of pest control and pollination (Cane & Tepedino, 2001; Giles & Ascher, 2009; Gowdy, 1994; Williams, Minckley, & Silveira., 2001) and they also contribute to ecosystem functioning and biological diversity (Kevan, 1991; LaSalle & Gauld, 1993). Their trophic position and interactions with other trophic levels add not only to the integrity of the ecological communities in which they live, but also contribute to human well-being. Pollination alone is a valuable service as 60-90% of plant species require an animal pollinator to successfully reproduce (Burd, 1994; Kearns, Inouye, & Waser, 1998). Monetary quantification of this service from a single Hymenoptera species, the honey bee, has been estimated at \$2–8 billion USD a year (Nabhan & Buchman., 1997), however many smaller species also provide this service.

Populations of solitary-nesting Hymenoptera have been found to exist in urban areas, although our understanding of how the structure of urban areas affects their populations is limited (Cane, 2001; Cane, Minckley, Kervin, Roulston, & Williams, 2006; McIntyre, 2000). It is known that the presence of species depends on foraging and nesting resources (Westrich, 1996) and these opportunities are different in urban habitats as compared to surrounding natural areas. Urban habitats are characterized by high fragmentation and high frequency of disturbance, including construction, ground tilling, and foliage modifications (Matteson et al., 2008). Urban landscapes also feature more compacted soils (Cane et al.,

Figure 1



a) Family garden Area Vulkan



b)The view overlooking the city of Zurich from family garden Area Waidburg.

2006) as well as a host of non-native flowers, all of which can significantly impact where hymenopteran species nest and forage (Frankie et al., 2005; Thompson et al., 2003).

2.4 Study Objectives

The objective of this study was to gain a better understanding of how the structure of suitable urban areas affects the abundance and diversity of solitary-nesting Hymenoptera populations. Family gardens in the city of Zurich offer an excellent study system because 1) they are all owned by the city of Zurich, and hence the ground rules are shared throughout the family gardens, and 2) as each garden is individually managed, the differences in management at a very local level can also be examined. Although Hymenoptera are small in size and range as compared to many other species, previous studies on agricultural areas have found that, due to the effect of habitat connectivity, features of the landscape are just as important as local characteristics for predicting species diversity (Ahrné, 2008; Rundölf & Smith, 2006; Thies & Tschardtke, 1999; Weibull, Bengtsson, & Nohlgren, 2000). This is a concept founded in landscape ecology (Turner, Gardner, & O’Neill, 2001) and metacommunity theory (Leibold & Miller, 2004). To account for both levels of analysis, this study looked at three local-level and three landscape-level characteristics as predictors of the abundance and diversity of populations of solitary-nesting Hymenoptera in the different garden sites in the city of Zurich. The three local-level explanatory variables quantified variation differing within the individually rented spaces (*Gardens*) inside each family garden. And three landscape-level variables quantified the features corresponding with the larger family garden site as a whole (*Areas*), consisting of several independently rented *Gardens* (Table 1).

Table 1
Study variables of analysis

| Explanatory Variables | |
|------------------------------------|--------------------------------------|
| Local-Level (<i>Garden</i>) | Landscape-Level (<i>Area</i>) |
| Pesticide Use | Size |
| Existing Nests | Surrounding Greenness |
| Garden Ground Cover Diversity | Potential Solar Radiation |
| Response Variables | |
| Abundance | |
| Richness | |
| Evenness | |

The local variables examined within each *Garden* were 1) the use of pesticides, 2) the number of existing nests and 3) the diversity of the ground cover of each of the *Gardens*. Pesticide use has been found in a multitude of studies to lower the abundance of most species of insects (Johansen, 1977; Morandin, Winston, Franklin, & Abbott, 2005) because of its direct toxicity to insects. Therefore, in this study pesticide use was expected to lead to reduced diversity and abundance of solitary-nesting Hymenoptera.

In the natural world Hymenoptera utilize holes in dead wood or grass stems for construction of their nests (Tscharntke, Gathmann, & Steffan-Dewenter, 1998). Studies have shown that manmade structures can also provide nest sites and can attract and maintain populations of solitary-nesting species (Roubik, 1989). This study therefore quantified the number of existing natural or manmade nesting sites in each *Garden*. They were expected to have a positive correlation with the abundance and diversity of solitary-nesting Hymenoptera.

Studies have shown that increased floral diversity and vegetation complexity are important predictors of invertebrate abundance (Goddard et al., 2009; Smith, Gaston, Warren, & Thompson, 2006; Smith, Warren, Thompson, & Gaston, 2006). This is especially true in the case of solitary-nesting Hymenoptera because many of the adult species forage for pollen and nectar from a variety of flowers or they feed on other species that utilize a diverse array of foliage types (Tscharntke et al., 1998). Human management and planting is the main determinant of this diversity in urban gardens (Goddard et al., 2009; Loram, Thompson, Warren, & Gaston, 2008), which is particularly apparent among the independently managed *Garden* plots in family gardens. Therefore, this study included the diversity of ground cover of the gardens as an explanatory variable with the prediction that a greater diversity of land cover types should lead to greater abundance and diversity of solitary-nesting Hymenoptera.

The three landscape-level variables considered for each *Area* were 1) the *Area* size, 2) the greenness of the *Area* surroundings and 3) the average potential daily solar radiation for each *Area*. Landscape structure has proven to be a reliable indicator of species composition in past studies (Dauber, 2003; Tilman & Kareiva, 1997). It is known that in a habitat where suitable habitat space is limited, such as in an urban environment, the size of a habitat patch, its connectivity to other patches and the quality of that patch (Gathmann & Tscharntke, 2002; Tilman & Kareiva, 1997) have a significant impact on the number and diversity of species. This size and the greenness were predicted to have a positive effect on solitary-nesting Hymenoptera abundance and diversity.

Finally, incoming solar radiation was included as an explanatory variable as it has been found to be strong contributor to understanding the overall amount of life that an area can support (The Center for Earth Observation Yale University, 2008). The amount of solar energy input into a system is correlated with the productivity of that system, or net primary productivity (NPP) which therefore provides more resources to species living in the system (Connell & Orias, 1964; Hutchinson, 1959; Paine, 1966). Moreover, if a system has increased solar radiation over a set time period, there is a general trend of many of the plant resources in that system being a more favorable to pollinators (Comba et al., 2000) because numerous pollinators are attracted to increased temperatures in floral resources independent of the nutritional value that the resources may offer (Dyer, Whitney, Arnold, Beverley, Glover, & Chittka, 2006).

We analyzed the numbers of individuals present at each site (abundance), and also the number of different genera represented in each trap (richness) and the balance among those genera numbers (evenness). Each response variable was analyzed as a function of the three landscape-level and the three local-level explanatory variables. The aim of the study is to test fundamental ecological ideas but also to provide information and advice to Grün Stadt Zürich (Goddard et al., 2009). Based on the range of variables tested this study was designed to contribute to an increased knowledge of the true value of these *Gardens* so that more well-informed decisions can be made about the future of their existence in the city of Zurich.

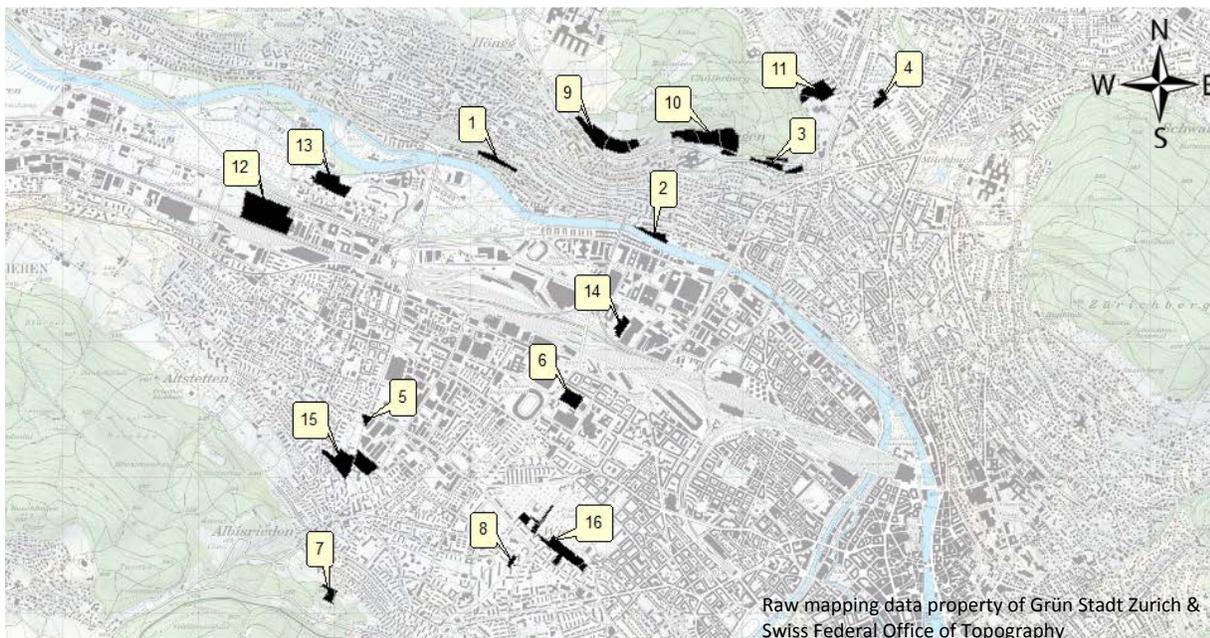


Figure 2

The final 16 *Areas* (black polygons) in the city of Zurich used in this study with site numbering.

3 Methods

3.1 Site Selection

Sixteen *Areas* within the city limits of Zurich were obtained for this experiment in cooperation with the city of Zurich and several garden associations across the city. In order to make monitoring and monthly testing of all study sites more feasible, the selection area was limited to the older and generally more intensely urbanized part of the city north of Lake Zurich. Areas with a range of sizes and intensity of urban surroundings were originally targeted for use in the study; however, as the utilization of the sites for the experiment was limited by the unanimous agreement of the city, the garden managers and the garden renters to participate, selection was limited. Within each of the selected 16 *Areas* trap poles were placed in two individually managed *Gardens*, giving a total of 32 test sites in the city of Zurich (Figure 2). Each trap pole at the 32 study sites held 2 trap tubes (see Section 3.2 - Trap Design) that were occupiable from either side of the pole, providing 4 possible nesting opportunities (*Traps*). This gave a total of 128 data points for this study. Study Areas and the selected *Gardens* contained within them were assigned numerical titles for organizational purposes (Table 2).

Table 2

Names, latitude/longitude coordinates, size (in hectares), elevation (in meters above sea level), and the study's numerical nomenclature of the study's 16 family garden *Areas* and *Gardens*.

| <i>Area Number</i> | <i>Area Name</i> | <i>Latitude</i> | <i>Longitude</i> | <i>Garden Numbers</i> | | <i>Size</i> | <i>Elevation</i> |
|--------------------|-----------------------------|-----------------|------------------|-----------------------|----|-------------|------------------|
| 1 | Tobelegg-Halden | 47°23'56" | 008°30'03" | 21 | 22 | 1.01 | 409 |
| 2 | Breitenstein | 47°23'38" | 008°31'00" | 15 | 16 | 0.82 | 408 |
| 3 | Waidburg I & II | 47°23'56" | 008°31'38" | 27 | 28 | 1.96 | 501 |
| 4 | Steinkluppe | 47°24'11" | 008°32'19" | 31 | 32 | 0.78 | 452 |
| 5 | Bachwiesen | 47°22'55" | 008°29'15" | 3 | 4 | 0.31 | 407 |
| 6 | Hard | 47°23'00" | 008°30'26" | 11 | 12 | 1.44 | 446 |
| 7 | Hagenbuchrain | 47°22'13" | 008°29'03" | 5 | 6 | 0.67 | 469 |
| 8 | Triemlifussweg | 47°22'22" | 008°30'07" | 7 | 8 | 0.27 | 432 |
| 9 | Emil-Klöti & Müseli | 47°23'59" | 008°30'47" | 23 | 24 | 4.19 | 506 |
| 10 | Käferberg | 47°24'01" | 008°31'14" | 25 | 26 | 5.01 | 509 |
| 11 | Brunnenhof | 47°24'12" | 008°31'57" | 29 | 30 | 2.57 | 460 |
| 12 | Vulkan | 47°23'45" | 008°28'40" | 19 | 20 | 7.15 | 404 |
| 13 | Juckhof | 47°23'53" | 008°29'02" | 17 | 18 | 2.67 | 397 |
| 14 | Pfingstweid | 47°23'17" | 008°30'45" | 13 | 14 | 0.94 | 422 |
| 15 | Areal Freilger (Ost & West) | 47°22'44" | 008°29'13" | 1 | 2 | 4.12 | 469 |
| 16 | Areal Friedhof (Ost & West) | 47°22'31" | 008°30'13" | 9 | 10 | 3.86 | 447 |

Additionally, two traps poles (8 *Traps*) were placed in an agricultural research facility of the Swiss Federal Office of Agriculture (Agroscope Reckenholz-Tänikon) just outside of the city of Zurich. Another study used a similar methodology on agricultural land in 2004. My additional traps were intended to provide a comparison of the relative presence of solitary-nesting Hymenoptera in agricultural sites with the data collected in previous years.

3.2 Trap Design

The specifications of the trap design were based on the known behavioral characteristics and preferences of solitary-nesting Hymenoptera (Tscharntke et al., 1998). At the beginning of April the trap poles were positioned 1.5 meters off the ground in each *Garden*. The traps consisted of two replicate 11 centimeter plastic tubes each holding approximately 300 cuttings of common reed *Phragmites australis* (Cav.) (Tscharntke et al., 1998). As the reeds were cut to have a natural closure in the middle, allowing separate nesting to occur from either side of the tube, each tube provided approximately 600 possible nesting internodes.

The reeds measured between 2 and 10mm in diameter and approximately 23 cm long (Tscharntke et al., 1998). It is known that most solitary-nesting bees prefer nests with a diameter of 5-8mm and solitary-nesting wasps generally prefer 3-8mm (Albrecht, Duelli, Schmid, & Müller, 2007). Wooden roofs (50x50 cm) were constructed over every trap pole in an effort to shield the traps from weathering and damage (Figure 3). There were several storms with strong winds during the field season and the roofs were not able to protect the traps from lateral wind and rain. Some reeds were also displaced during the nesting season.

Traps were checked several times a month during the experimental period to assess initial occupancy, note plot composition proportions, and ensure trap and reed stability. During the checks any displaced reeds were put back into the traps.

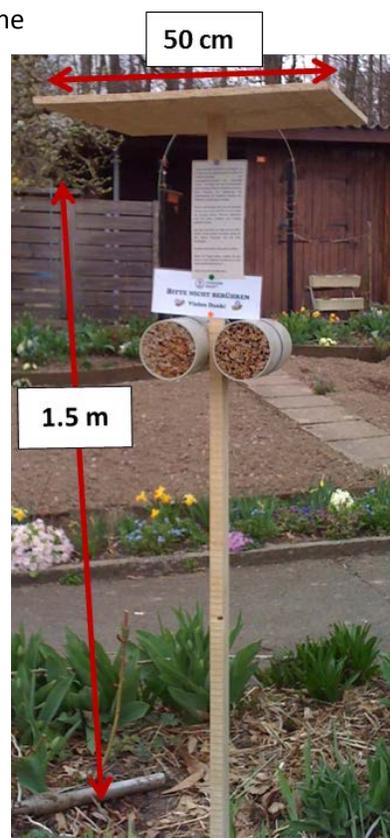


Figure 3
Study trap-nest design.

3.3 Trap Placement

Over a two-day period in the first week of April 2011 traps were positioned in the family gardens. The timing of the placement of the traps was designed to accommodate species of solitary-nesting Hymenoptera that nest early in the spring season (Albrecht et al., 2007; Jenkins & Matthews, 2004). As the gardens were donated on a volunteer basis, locations for placement of the traps within each *Garden* were limited to the gardener's specifications. In an effort to standardize the experiment as much as possible, all traps were positioned with the trap openings having a north-south orientation (Calabuig, 2000). However, during the nesting season several of the traps were slightly repositioned by the *Garden* renters contrary to the anti-tampering instructions that were given to them, so this strategic orientation was lost.

3.4 Explanatory Variables Analysis

The six explanatory variables of interest in this study were quantified for each test site once the trap poles were placed in each of the *Gardens*.

3.4.1 Local Level

The three local-level characteristics quantified for each *Garden* were pesticide use, existing nests and garden ground cover diversity (Table 3).

3.4.1.1 Pesticides

Pesticide use was quantified as a binomial explanatory variable by surveying the 32 renters of the *Garden* study sites. The gardeners were asked to check a *Yes* or *No* box indicating whether they used any kind of pesticide within their *Garden*. If they checked *Yes* the respondents were asked to list which kinds of pesticide they used (example form in Appendix A). Of the 32 *Gardens* in the study, only 9 said that they did not use any kind of pesticides in their plot.

3.4.1.2 Existing Nests

During the study period the area in a 10 meter radius of each trap was searched for the presence of existing man-made trap nests and trees, both live and dead. Final numbers for this variable were quantified as continuous values. Half of the gardens (16) were found to have existing nest opportunities within 10 meters of the traps.

3.4.1.3 Garden Ground Cover Diversity

The local garden ground cover diversity was calculated through a series of site surveys where the percent composition of various vegetation and structural elements of each plot was noted. Ground cover categories included flowers, vegetables, berry vines, bushes, wild grass, manicured grass, bare soil, or man-made infrastructure. As the composition of the ground cover of the gardens varied significantly during the five-month period that the traps were in the *Gardens*, surveys were conducted once a month. At the end of the period the mean value for each possible category of garden ground cover was calculated and those values were used to compute a single overall Shannon Diversity Index for each *Garden* (see formula in Section 3.6). These indices ranged from 1.17 to 1.84 with the mean garden ground cover diversity being 1.61 ± 0.19 .

3.4.2 Landscape Level

The three landscape-level characteristics quantified for each *Area* were the size, the greenness of the surroundings and the average potential sunlight during the nesting season (Table 4). Each of these three explanatory variables was calculated using Esri's ArcGIS 10.x.

Table 3

Local Level (*Garden*) explanatory variables values of pesticide use (a), number of existing nests (b) and ground cover diversity (c).

a) a binomial count, 1 = pesticides used, 0 = no pesticides used. b) a count of man-made nests and trees within 10 meters of trap. c) The average Shannon Index of the ground cover of each *Garden* over the study period.

| Garden | Area | Pesticide Use ^a | Existing Nests ^b | Garden Diversity ^c | Garden | Area | Pesticide Use | Existing Nests | Garden Diversity |
|--------|------|----------------------------|-----------------------------|-------------------------------|--------|------|---------------|----------------|------------------|
| 1 | 15 | 1 | 0 | 1.798 | 17 | 13 | 1 | 2 | 1.833 |
| 2 | 15 | 1 | 0 | 1.420 | 18 | 13 | 0 | 1 | 1.510 |
| 3 | 5 | 1 | 0 | 1.651 | 19 | 12 | 1 | 1 | 1.841 |
| 4 | 5 | 1 | 1 | 1.393 | 20 | 12 | 0 | 0 | 1.645 |
| 5 | 7 | 0 | 2 | 1.210 | 21 | 1 | 1 | 0 | 1.724 |
| 6 | 7 | 1 | 0 | 1.747 | 22 | 1 | 0 | 1 | 1.580 |
| 7 | 8 | 1 | 0 | 1.171 | 23 | 9 | 0 | 2 | 1.763 |
| 8 | 8 | 1 | 2 | 1.617 | 24 | 9 | 0 | 1 | 1.813 |
| 9 | 16 | 0 | 0 | 1.447 | 25 | 10 | 1 | 4 | 1.762 |
| 10 | 16 | 1 | 0 | 1.630 | 26 | 10 | 0 | 2 | 1.675 |
| 11 | 6 | 1 | 0 | 1.260 | 27 | 3 | 1 | 2 | 1.734 |
| 12 | 6 | 1 | 0 | 1.267 | 28 | 3 | 1 | 1 | 1.774 |
| 13 | 14 | 1 | 1 | 1.704 | 29 | 11 | 1 | 0 | 1.500 |
| 14 | 14 | 1 | 1 | 1.795 | 30 | 11 | 1 | 0 | 1.616 |
| 15 | 2 | 0 | 0 | 1.548 | 31 | 4 | 1 | 1 | 1.559 |
| 16 | 2 | 1 | 0 | 1.732 | 32 | 4 | 1 | 0 | 1.715 |

Table 4

Landscape-level (*Area*) explanatory variables of (a) size (in hectares), (b) surrounding greenness (in NDVI), and (c) potential daily solar radiation (in average watt-hours per day during the study period).

| Area Number | Garden Numbers | | Size | Surrounding Greenness | Daily Potential Solar Radiation |
|-------------|----------------|----|------|-----------------------|---------------------------------|
| 1 | 21 | 22 | 1.01 | 0.146 | 5158 |
| 2 | 15 | 16 | 0.82 | 0.029 | 4697 |
| 3 | 27 | 28 | 1.96 | 0.397 | 5075 |
| 4 | 31 | 32 | 0.78 | 0.199 | 4941 |
| 5 | 3 | 4 | 0.31 | 0.082 | 4935 |
| 6 | 11 | 12 | 1.44 | -0.042 | 4932 |
| 7 | 5 | 6 | 0.67 | 0.446 | 4534 |
| 8 | 7 | 8 | 0.27 | 0.228 | 4781 |
| 9 | 23 | 24 | 4.19 | 0.334 | 5028 |
| 10 | 25 | 26 | 5.01 | 0.449 | 5185 |
| 11 | 29 | 30 | 2.57 | 0.352 | 4846 |
| 12 | 19 | 20 | 7.15 | 0.090 | 4920 |
| 13 | 17 | 18 | 2.67 | 0.044 | 4934 |
| 14 | 13 | 14 | 0.94 | -0.195 | 4916 |
| 15 | 1 | 2 | 4.12 | 0.211 | 4793 |
| 16 | 9 | 10 | 3.86 | 0.347 | 4924 |

3.4.2.1 Area Size

Size was derived in ArcGIS using mapping information from Grün Stadt Zürich, a department of the city of Zurich. *Areas* in the study ranged from 0.27 to 7.15 hectares (mean \pm sd = 2.36 \pm 1.94).

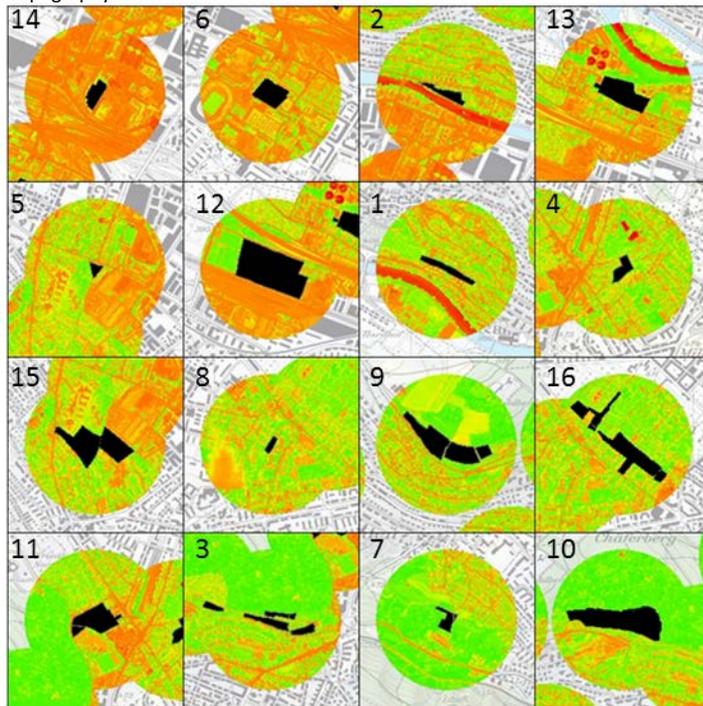
3.4.2.2 Greenness of Area Surroundings

Although all *Areas* were within the boundaries of the city, the surroundings of each *Area* ranged from highly urban to those with more natural or green surroundings. The Normalized Difference Vegetation Index (NDVI) was used to quantify those differences. NDVI is a normalized ratio of near infrared (NIR) and red (red) spectral reflectance.

$$NDVI = \frac{NIR - red}{NIR + red}$$

Plants absorb red light through chlorophyll but reflect most infrared light, so the normalized difference of the reflected light is a proxy for the photosynthetic activity or greenness of an area. The NDVI was calculated for a circle with a 375 meter radius centered on each *Area* (Figure 4) using mapping and remote sensing data from Grün Stadt Zürich, the Swiss Federal Office of Topography (SwissTopo) and

Raw mapping data property of Grün Stadt Zurich & Swiss Federal Office of Topography



Source: Bundesamt für Landestopografie



Figure 4

16 study Areas (with Area number) with mapped NDVI values for 375 meter radius from center of Area, ordered (left to right, top to bottom) from least green to most green.

the Swiss Federal Institute for Forest, Snow and Landscape Research (WSL). These NDVI values were averaged to create a single mean NDVI quantity for each of the 16 Areas. A 375 meter radius was chosen as it is the mean maximum foraging distance for most solitary-nesting Hymenoptera (Abrol & Kapil, 1994; Gathmann & Tschardt, 2002; Guédot, Bosch, & Kemp, 2009; van Nieuwstadt & Ruano Iraheta, 1996). Final NDVI values for the 16 Areas ranged from -0.195 to 0.449 with a mean value of 0.195 ± 0.181 .

3.4.2.3 Average Potential Daily Sunlight

The daily potential sunlight was calculated for each Area for the period that the traps were in the Gardens (Figure 5). This can be determined for any particular place based

on its elevation, slope, aspect, latitude, distance from the sun, and the time of year (The Center for Earth Observation Yale University, 2008). For this study this information, including a Digital Elevation Model (DEM), was obtained from SwissTopo and input into a set of algorithms in the spatial analysis tool, Area Solar Radiation in ArcGIS (Fu & Rich, 2000; Fu & Rich, 2002; Rich, Dubayah, Hetrick, & Saving, 1994; Rich & Fu, 2000). Daily potential sunlight values were calculated in watt-hours for each Area for each day of year that the traps were in the Gardens and those numbers were averaged to create a mean daily potential sunlight factor for each Area during the study period. Final potential daily sunlight values for the 16 Areas ranged from 4,534 to 5,185 watt-hours with a mean value of $4,912 \pm 159$ watt-hours.

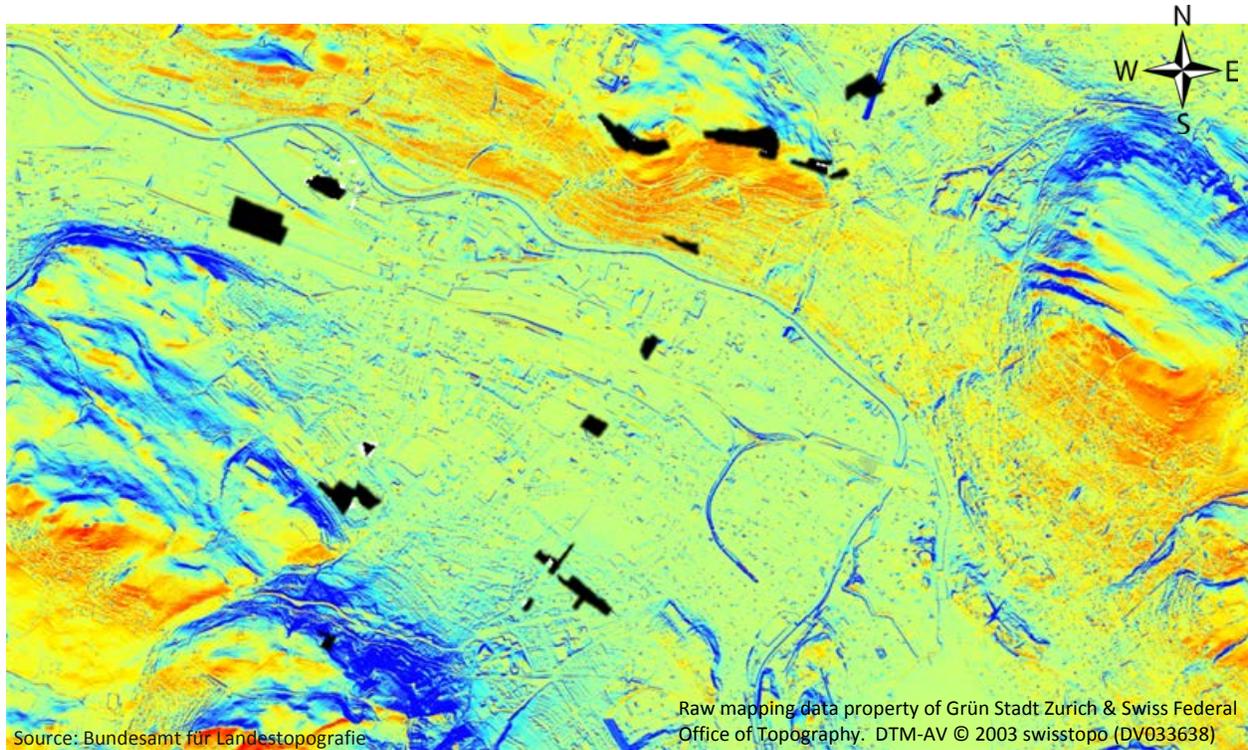


Figure 5
Calculated daily potential sunlight estimates for the city of Zurich.

3.5 Trap Collection & Analysis

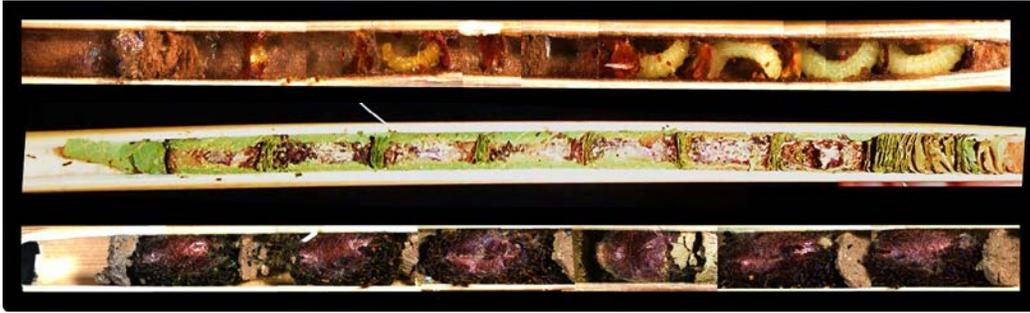
The traps were collected from the study sites over a two day period during the second week of September 2011 and brought into the laboratory for extraction and analysis. In the laboratory each reed was removed individually from the traps and carefully sliced open in order to view any possible brood cells inside without damaging the larvae contained within them. Those reeds showing any sign of occupancy, such as constructed walls, cocoon remnants, food supplies or dung, were placed whole in 16 ml polystyrene round-bottom tubes and closed with cotton stuffing for further examination.

3.6 Response Variable Quantification

Samples containing larvae were identified to genus level based on the materials used to fill and close the brood cells, the food supply in the reed, as well as the traits of the larvae and cocoons of the occupants. This is possible because different species of Hymenoptera stock specific food supplies such as pollen, beetle larvae, aphids, caterpillars or spiders in their brood cells for their larvae growing inside (Budriené,

Figure 6

Specimens of brood cell occupants. From top to bottom, Hylaeus, Megachile & Osmia



2003; Tschardt et al., 1998) (Figure 6). Classification to a genus level was based on a key by A. Gathmann and T. Tschardt (1999). During the identification process it was also noted when parasites were present in the nests (rather than the original species) or if there were signs that the original species had been parasitized. Abundance of solitary-nesting Hymenoptera was quantified as a single value normalized to account for the different number of nest sites (reeds) in each *Trap*. It was calculated as for each *Trap* as the number of occupied reeds (O) per number of total reeds (P) in that trap i (from $i=1$ to 32).

$$A_i = \frac{O_i}{P_i}$$

This number was multiplied by 100 to give the final values as percentage of occupied reeds in each *Trap*. In the case where there were no larvae present but there were empty cocoons, or when there were holes in a reed closure characteristic of hymenopteran species, or other signs of previous occupancy by a solitary-nesting Hymenoptera, those reeds were counted as being occupied. Diversity of the trap nests was quantified by using richness and evenness for each trap. Richness (R) was determined as the total number of genera (G) observed in each trap.

$$R_i = \sum G_i$$

Evenness (E) is an expression of how evenly-distributed individuals are among genera. It was calculated using the Shannon index (S) for each trap, with S_{max} being the largest Shannon index value of all traps:

$$E^i = \frac{S_i}{S_{i_{max}}}$$

$$S_i = - \sum_{i=1}^G \frac{1}{G} \ln \frac{1}{G} = \ln G$$

Due to time constraints during the extraction period a small number of brood cells that were indistinguishable using the key were termed *Genus X*. Following the initial extraction and identification process, the larvae were placed into a refrigeration chamber to allow for other teams to do species-level identification on all imago emerging from the collected brood cells following a required hibernation and maturation period. The results of that work are not included in this study.

3.7 Secondary Analysis of Response Variables

A secondary analysis was performed to test the response variables for correlation among each other.

3.8 Spatial Analysis of Response Variables

To test the spatial structure of the three response variables the final values were input into a Mantel test statistic to determine if they were at all spatially correlated. This test is founded in Spearman’s rank correlation with 1,000 permutations and Euclidian distances as similarity indices (Legendre & Legendre, 1998).

Table 5
Partitioning of variance among levels of the random effects.

| | Abundance | Richness | Evenness |
|-------------------|----------------|---------------|---------------|
| Area | 0.562 (30.5 %) | 0.441 (27.7%) | 0.325 (27.1%) |
| Garden | 0.475 (25.8 %) | 0.444 (27.9%) | 0.331 (27.6%) |
| Residual variance | 0.805 (43.7 %) | 0.709 (44.5%) | 0.542 (45.2%) |

3.9 Statistical Analysis

Data was analyzed by mixed-effects models using the function `lme` and the statistical software R (version 2.12.2)(R Development Core Team, 2011). The random effect structure was chosen to be *Garden* nested within *Area* to account for the nested experimental design for all models. Each level of the random effects explained approximately a quarter of the total variance (Table 5), leaving half of the total variance in the data unexplained. All fixed effects were measured either at the *Area* or the *Garden* scale. Fixed effects at the *Area*-level were size of the *Area*, surrounding greenness (NDVI), and daily potential solar radiation. Fixed effects at the *Garden*-level were a binomial factor of pesticide use, number of existing nests and ground cover diversity of gardens. *Area* size was log-transformed to improve model fit and meet assumptions of normality. All fixed effects variables were tested for

correlations among each other, revealing that *Area* size and NDVI were positively correlated ($r = 0.252$, $p < 0.01$), possibly due to fewer large garden *Areas* in highly urbanized parts of the city (Figure 7). If explanatory variables are correlated, order of fitting can potentially affect significance; hence variables were fitted to a model in the order of their explanatory power. All possible orderings of explanatory variables were fitted to the response variable and the order which maximized F-ratios at each position was chosen. Non-significant explanatory variables were discarded.

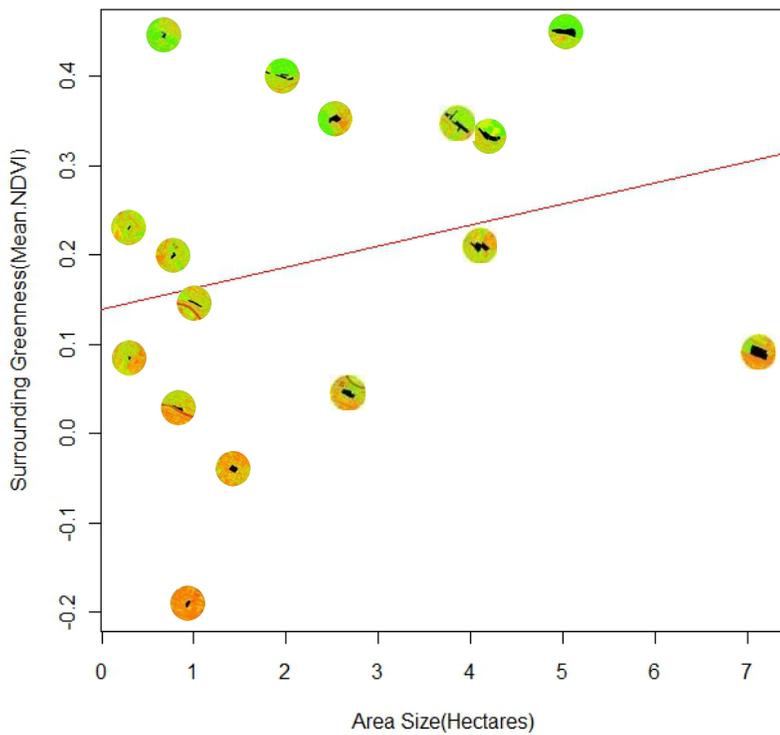


Figure 7
The relationship between surrounding greenness and size of the final *Areas* selected for this study

Three response variables were analyzed using these models: the abundance of hymenopterans in each trap, expressed as the logarithm of the ratio of occupied vs. total number of reeds; and the logarithm of evenness and richness of hymenopteran genera in each trap. Six traps had zero occupancy; hence 0.1 was added to all values to achieve positive response variables for all traps.

Study sites that had data points, either as response or explanatory variables, that could be considered outliers to the rest of the data

points were removed from the model during a secondary analysis. This did not have significant effects on the trends of the results of the models, so the outliers were included in the final analysis.

4 Results

A total of 3,935 larvae in 1,439 nests of 21 genera were identified within the experiment trap-nests on the 32 study sites (Table 6). The abundance per trap ranged from 0 to 29.9 with the average value of 4.10 ± 4.38 (Figure 8). Genus richness in the study site ranged from 0 to 11 with an average of 3.82 ± 2.13 (Figure 9). Evenness ranged from 0 to 1 with a mean of 0.50 ± 0.27 (Figure 10).

Table 6
Genus composition of traps.

| Family | Genus | Genera Totals | Percentage of Genera Composition | Percentage of Garden Sites Where Found |
|-------------|--------------|---------------|----------------------------------|--|
| Apidae | Chelostoma | 48 | 3.52% | 50% |
| Apidae | Heriades | 30 | 2.25% | 50% |
| Apidae | Hylaeus | 257 | 19.05% | 100% |
| Apidae | Megachile | 2 | 0.14% | 6% |
| Apidae | Osmia | 562 | 41.84% | 100% |
| Chrysididae | Chrysis | 4 | 0.30% | 6% |
| Crabronidae | Nitela | 1 | 0.07% | 6% |
| Crabronidae | Passaloecus | 117 | 8.61% | 81% |
| Crabronidae | Pemphredon | 23 | 1.72% | 69% |
| Crabronidae | Trypoxylon | 132 | 9.77% | 100% |
| Vespidae | Eumenidae | 48 | 3.52% | 63% |
| Pompilidae | Dipogon | 27 | 1.95% | 81% |
| X | Unidentified | 96 | 7.19% | 81% |

4.1 Abundance

For the abundance of solitary-nesting Hymenoptera two *Area* -level variables were significant, size ($F_{1,13} = 16.929$, $p = 0.001$) and greenness of the surroundings ($F_{1,13} = 4.858$, $p = 0.046$). Larger *Areas* generally had lower abundance (Figure 11-a) whereas *Areas* with greener surroundings had higher abundance (Figure 11-b & 11-g). The third landscape variable, daily average potential sunlight, was not significant ($F_{1,12} = 0.499$, $p = 0.494$). Of the three analyzed local-level explanatory variables only garden ground cover diversity was significant ($F_{1,14} = 1.835$, $p = 0.014$) (Figure 11-c). *Gardens* that had higher groundcover diversity generally had lower numbers of occupants in their *Traps*. Pesticide use ($F_{1,13} = 3.644$, $p = 0.079$) and the number of existing nests ($F_{1,13} = 1.812$, $p = 0.201$) in the *Gardens* were not significant.

4.2 Richness

For the genus-richness analysis both *Area* size ($F_{1,13} = 8.973$, $p = 0.012$) and the greenness of the *Area* surroundings ($F_{1,13} = 7.119$, $p = 0.019$) were significant. As for abundance, larger gardens had fewer

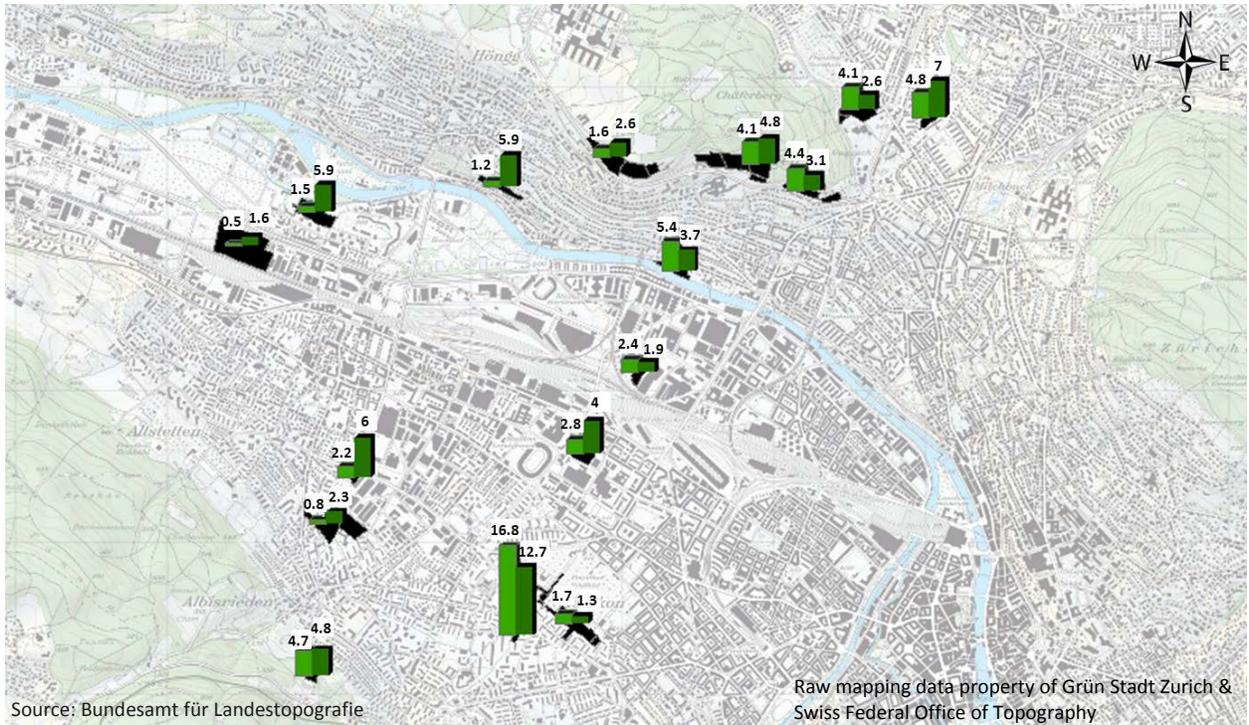


Figure 8
Trap-nesting Hymenoptera abundance (as the mean percentage of reeds occupied in the four *Traps* in each *Garden*).

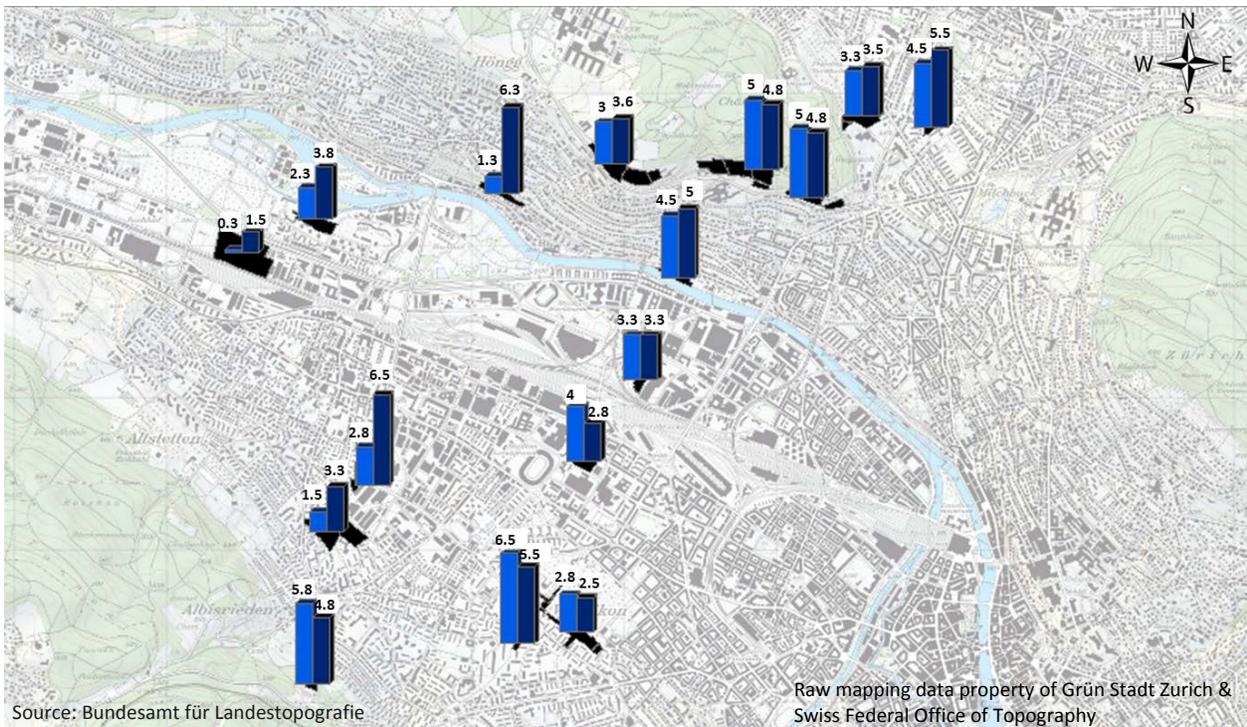


Figure 9
Trap-nesting Hymenoptera richness (as the mean total number of genera present in the four *Traps* in each *Garden*).

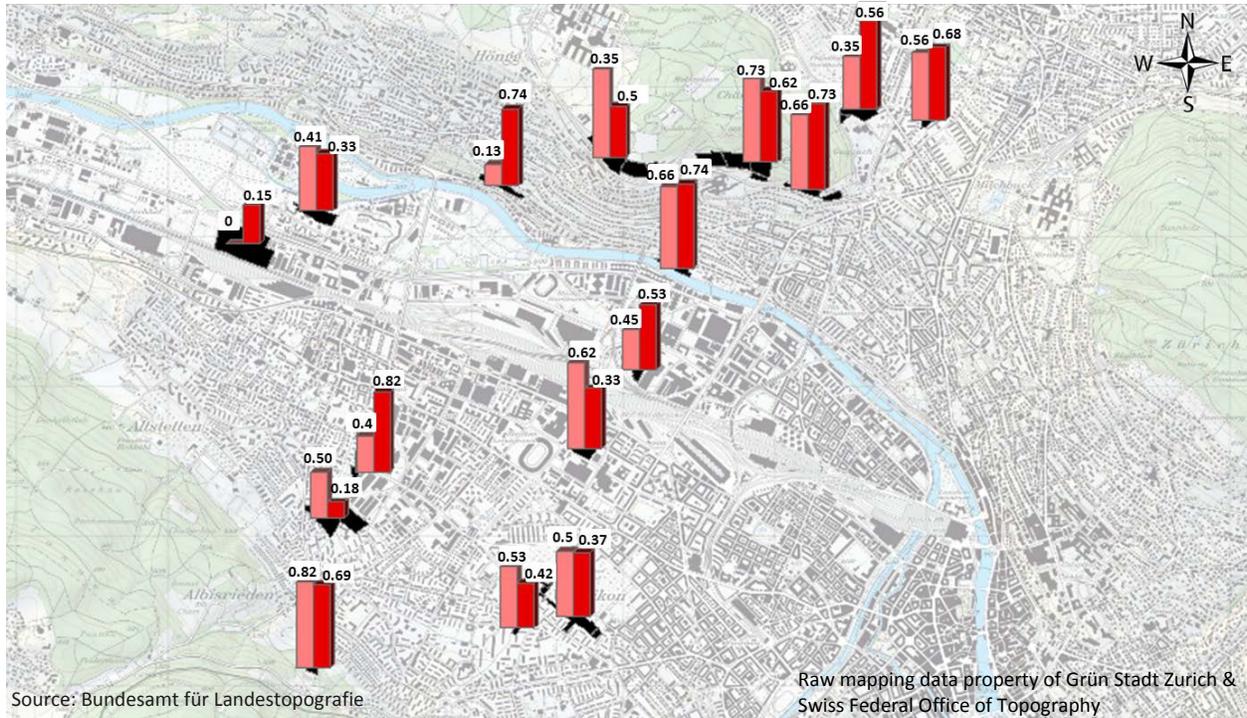


Figure 10

Trap-nesting Hymenoptera evenness (as the mean evenness of the four *Traps* in each *Garden*).

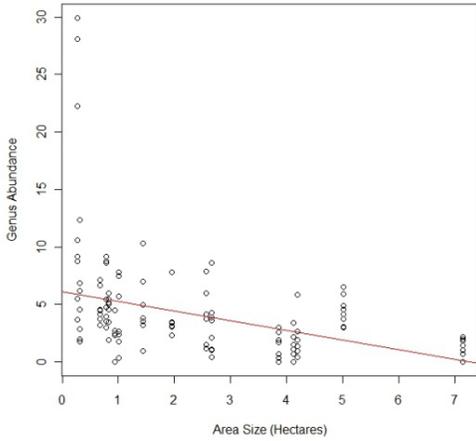
genera present and so did those where the *Area* surroundings were less green (Figures 11-d, 11-e & 11-h). Daily potential solar radiation ($F_{1,12} = 0.114$, $p = 0.741$), garden ground cover diversity ($F_{1,13} = 3.631$, $p = 0.079$), pesticide use ($F_{1,13} = 2.845$, $p = 0.116$), and the number of existing nests ($F_{1,13} = 0.948$, $p = 0.348$) were not found to be significant within a 95% confidence interval.

4.3 Evenness

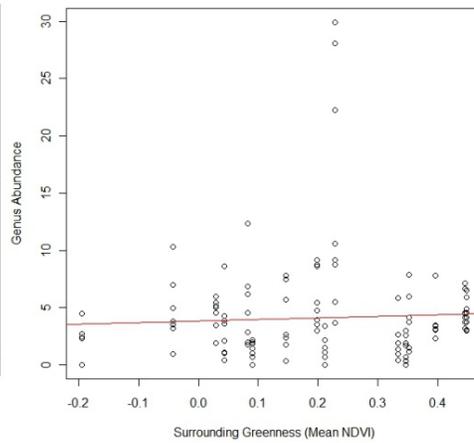
For genus-level evenness *Area* size was the only significant explanatory variable ($F_{1,13} = 6.225$, $p = 0.0268$). As for richness, larger areas had lower genus-level evenness than smaller gardens (Figure 11-f). Surrounding greenness ($F_{1,12} = 3.978$, $p = 0.069$), daily potential solar radiation ($F_{1,12} = 0.005$, $p = 0.942$), garden ground cover diversity ($F_{1,13} = 2.822$, $p = 0.117$), pesticide use ($F_{1,13} = 1.843$, $p = 0.198$), and the number of existing nests ($F_{1,13} = 2.017$, $p = 0.179$) were not found to have significant correlation with evenness.

Figure 11

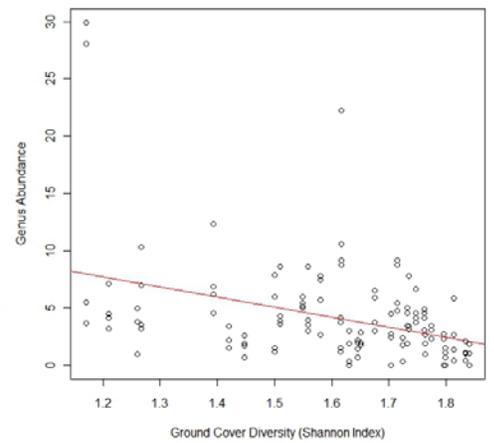
a) The effect of *Area* size on genus abundance.



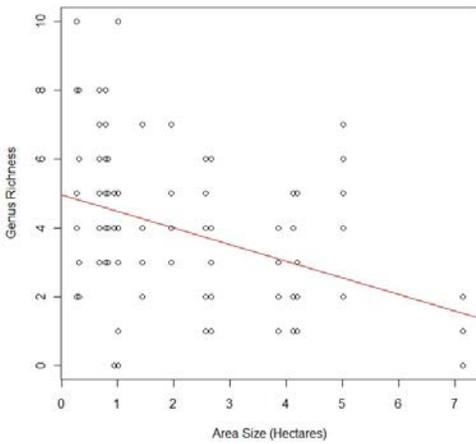
b) The effect of *Area* surrounding greenness on genus abundance.



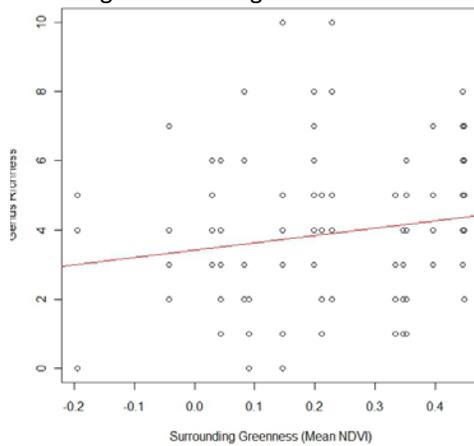
c) The effect of *Garden* ground cover diversity on genus abundance.



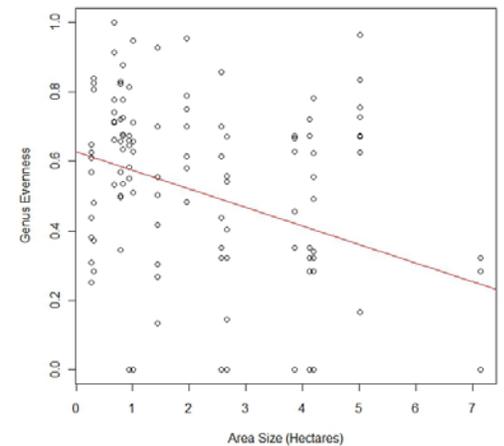
d) The effect of *Area* size on genus richness.



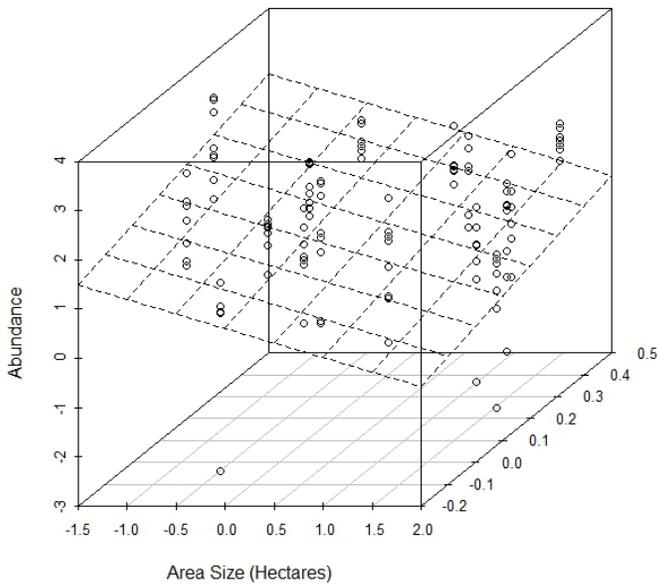
e) The effect of *Area* surrounding greenness on genus richness.



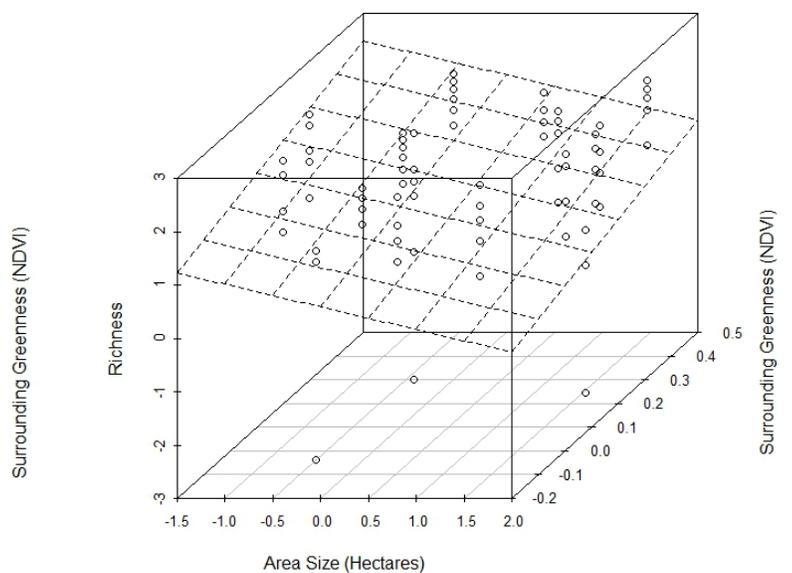
f) The effect of *Area* size on genus evenness.



g) The effects of *Area* size and *Area* surrounding greenness on genus abundance.



h) The effects of *Area* size and *Area* surrounding greenness on genus richness.

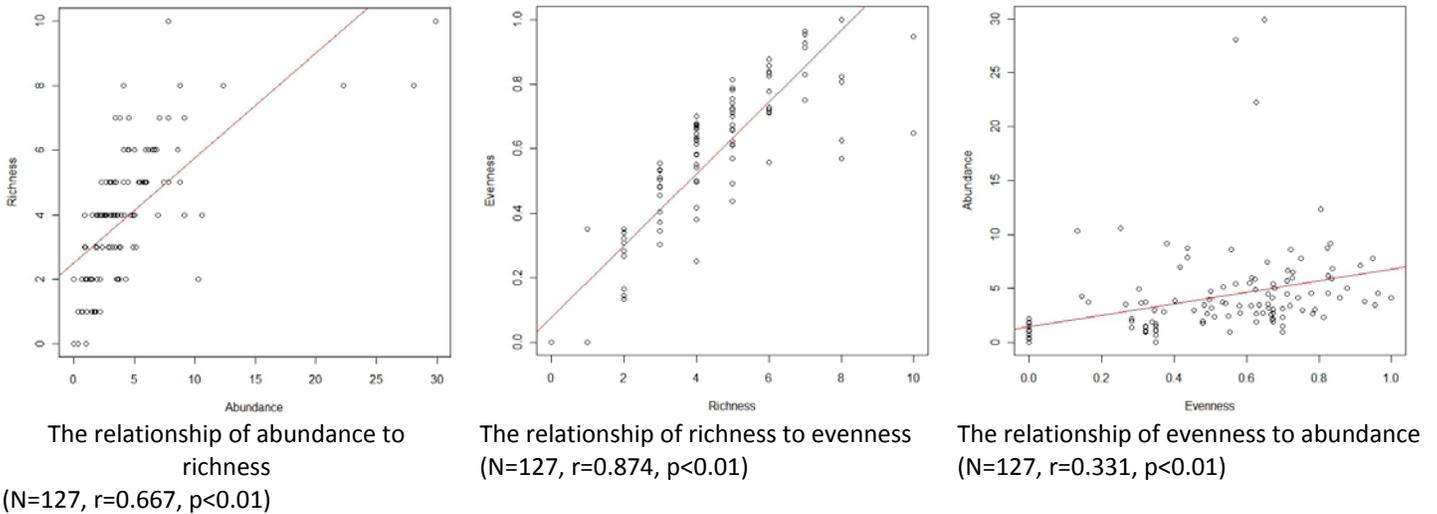


4.4 Secondary Analysis of Response Variables

The secondary analysis of the response variables found that all relationships were highly correlated ($p < 0.05$, Figure 12). This correlation is most likely due to the similarities that these variables hold in expressing the health of a community's structure. Their comparability in this situation strengthens the conclusions that can be drawn about the state of the hymenopteran populations in these family gardens as they all have the same trend.

Figure 12

Correlation analysis of response variables.



4.5 Spatial Analysis of Response Variables

The secondary analysis using the Mantel test statistic found the spatial relatedness of the abundance ($r = 0.011$; $P = 0.387$), richness ($r = 0.152$; $P = 0.075$), and evenness ($r = 0.174$; $P = 0.067$) of solitary-nesting Hymenoptera to be uncorrelated.

4.6 Comparison with Previous Study Data

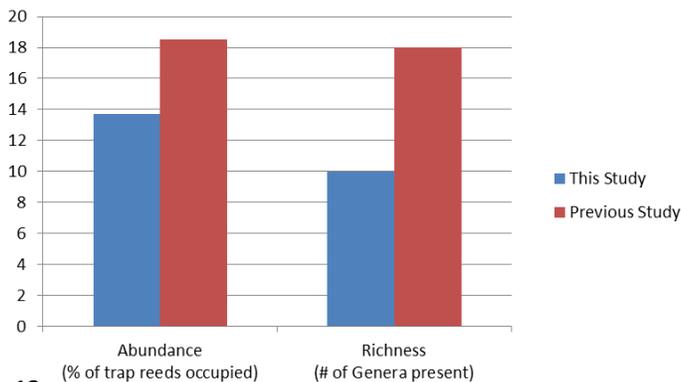


Figure 13

Average abundance and richness of the additional traps at the agricultural sites compared to those from the 2004 agricultural sites study (Albrecht et al., 2007)

The traps placed at the agricultural sites were found to have comparable numbers of solitary-nesting Hymenoptera to those from the similar trap-nest study completed in 2004 (Albrecht et al., 2007) (Figure 13). These numbers were also similar to the mean abundance and diversity found in the *Gardens* of this study (Figure 14).

5 Discussion

This experimental study attempted to isolate and analyze the effects that local and landscape-level attributes of family gardens have on the abundance and diversity of solitary-nesting Hymenoptera. The results of this work show that on the landscape-level, *Areas* that are smaller with greener surroundings have a greater abundance and richness of hymenopteran genera than *Areas* that are larger and less green. *Areas* that are smaller also have a greater evenness among those genera than larger *Areas*. Daily potential solar radiation is not an effective predictor of the abundance, richness and evenness of solitary-nesting Hymenoptera. The results also show that on a local-level, *Gardens* with lower ground cover diversity have a higher abundance of hymenopteran genera; however, it is not able to predict the richness and evenness of the genera. Moreover, the number of existing nests and the use of pesticides are not effective predictors of the abundance, richness and evenness of solitary-nesting Hymenoptera.

The conclusion that *Area* size in family gardens is a significant determinant of the abundance, richness and evenness of solitary-nesting Hymenoptera is in line with the original hypothesis of this study; however, the finding that smaller areas have higher values of all response variables is contrary to the original prediction. This occurrence could be attributed to a phenomenon known as the crowding effect, where the population density of a species is found to be higher in the smaller patches of habitat remaining in an altered landscape (Debinski & Holt, 2000). This is believed to occur because when surrounding habitats are removed, species are forced into the small areas where their food and nesting resources still remain. Results similar to these were found by experiments done on the habitat structure of honey bees (Steffan-Dewenter, 2002) so the concept could hold particular

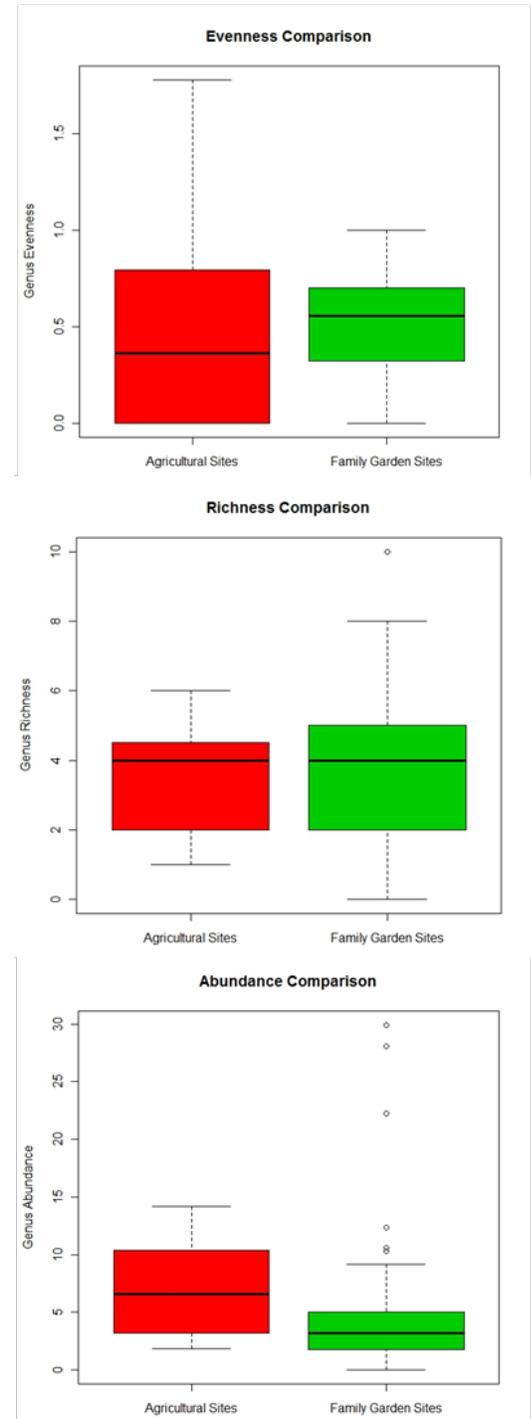


Figure 14
Average evenness, richness and abundance found in the additional agricultural site traps as compared to the traps in the family gardens.

weight in the case of Hymenoptera in general. It is suggested that this idea be further tested. It could also be that larger *Areas* represent a space that contains more possible nesting resources throughout therefore causing the genera of interest to not be as attracted to using the traps set up in the study. In this study, limiting the identification of existing nesting sites to a ten meter radius from the test trap may have limited the power to isolate and truly identify the predicting weight that existing nesting sites have on the abundance and diversity of hymenopteran genera. Although expanding this aspect of the analysis to a larger level entails much more work, it is suggested that it be considered for future studies in order to get a more accurate depiction of the effects of existing nests.

As mentioned in the 'Methods' section, size and the greenness of the *Area* surroundings were positively correlated, possibly due to fewer large *Areas* being in the more urban parts of the city. It could be that if there were more of these larger and less green sights available for testing in this study, the correlation of the results could be different. It seems there has been a wide spread on the results found on this relationship, as many related studies have also found positive, negative or no correlation between abundance and the size of the available habitat (Connor, Courtney, & Yoder, 2000; Debinski & Holt, 2000; Matter, 2000). So it seems that there is still a gap in the understanding of the matter, therefore it should be studied further by future experiments.

The positive relationship between the greenness of the surroundings of the *Areas* and the abundance and richness of Hymenoptera in the study traps is in line with what was originally hypothesized at the beginning of this study. This confirms that there is a positive link between the family gardens and the potential habitat that the surrounding area provides to the solitary-nesting Hymenoptera found within the gardens. This link is something that should be considered when areas surrounding family gardens are modified because it could affect the populations of these species, as well as the ecosystem services that they provide.

Gardens with low ground cover diversity had a higher abundance of solitary-nesting Hymenoptera. This relationship could be explained by the different structure that a highly diverse garden environment presents as compared to a highly diverse natural landscape. The structures of family gardens are controlled by man so they tend to be made up of components that have high ornamental or food supply values. So increases in diversity due to greater variety in components high in these values do not necessarily correspond to increases in nesting and foraging opportunities for solitary-nesting

Hymenoptera. This contraction to the original hypothesis could also be attributed to the weakness of this explanatory variable. As time restraints prevented more detailed analyses of the composition of the species making up the various ground covers, it could be that the simple categorization that was done does not truly represent the diversity of nesting and foraging resources available to the hymenopteran species in each *Garden*. It is suggested that future work do more detailed analyses on the composition of the ground cover in order to gain a more representative result on the effects that it has on the abundance and diversity of hymenopteran species.

Although three of the examined explanatory variables were found to be significant, they do not explain the full breadth of patterns in the abundance and diversity of solitary-nesting hymenopteran species around the city. The way that the abundance and diversity numbers differ around the city suggest that there are elements related to foraging and nesting that vary between the locations around the city and are causing this variation in the structure of the populations. The nature of these predicting variables warrants further examination. Supplementary work should be done to analyze different explanatory variables within a similar experimental design to better pinpoint what local or landscape environmental conditions are better predictors of the abundance, richness and evenness of solitary-nesting Hymenoptera.

Another striking result of this study is that gardens located within the same *Area*, even ones that are quite close in terms of the known foraging distances of hymenopteran species, had different abundance and richness and evenness. This is likely an indicator that some of the characteristics of this urban habitat that are strong predictors of the abundance and diversity of solitary-nesting Hymenoptera exist on the local-scale. This notion was confirmed by another study published soon after the completion of this experiment that found that the urban foraging and nesting preferences of the red mason bee (*Osmia bicornis* L.), a species of solitary-nesting Hymenoptera, can be better predicted by microsite or local conditions rather than landscape ones (Everaars, Strohbach, Gruber, & Dormann, 2011).

As the traps in this study that were placed in the agricultural sites boasted occupancy numbers analogous to those in the similar Hymenoptera study performed in 2003 and 2004, it is reasonable to say that the general Hymenopteran populations for this season were not abnormal. Therefore, the numbers can be viewed as comparable to results from previous studies as well as applicable to future studies.

And finally, the results of this study show is that solitary-nesting Hymenoptera are in fact using family gardens in the city of Zurich as a foraging and nesting habitat. It is unknown whether the population differences observed among the different gardens are representative of several independent populations that are isolated in the *Garden* patches by the fragmentation caused by urbanization. Or rather, if the numbers are a reflection of a larger population of solitary-nesting Hymenoptera that are using these gardens as a network allowing them to forage and nest across the city. The quality of the connectivity between the patches (Vandermeer & Perfecto, 2007) would have to be further examined to come to a reputable conclusion on this matter. Nonetheless, solitary-nesting Hymenoptera are present within the urban environment that is Zurich, and they are using foraging and nesting resources within even the smallest of these family gardens. The ecosystem services that hymenopteran species provide to the larger population of the city should be factored in to the worth of these gardens, as they represent an increasingly scarce form of green space within an urban habitat. And as increasing pressure is being put onto these areas to be developed it is important for policymakers and city officials to acknowledge these more unseen but extremely valuable services and recognize that there is much more at stake to be lost than a few families' vegetables.

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Garden Renter Volunteers:

| | | |
|------------------------------|----------------------|--------------------|
| Felix Bosshart-Nijman | Alfred Grieser | Angelika Strobel |
| Bernadette & Werner Boxler | Irmgard Hardegger | Paulo Ten Caten |
| Ruth Brandalise | Bruno Helg | C & J Trudel |
| Hans Bucher | Gerber Herner | Jacques Vergères |
| Marianma & Max Dell'Ava | Rahel Jenz | Sandro Wermelinger |
| Hans Egli | Bettina Knellwolf | Robert Widmer |
| Edith Eigenmann | Ruth & Robert Kümmin | Susanne Zandonella |
| Christina Gabrielli-Kaufmann | Hans Nägeli | Walter Zbinden |
| Jacqueline Graüb | Bruno Oberholzer | Walter Zehnder |
| Albert Gretschi | Karin Ritzmann | |

Garden Club Managers:

| | | |
|------------------------|------------------|----------------|
| Alfred Grieser, | Markus Peer | Stefan Wigger |
| Rose-Marie Nietlisbach | Hanspeter Tobler | Walter Zbinden |

IEU PhD students, technicians, personnel & professors:

| | | |
|--------------------------|-------------------|-----------------|
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| René Husi | Dr. Michel Nakano | Theres Zwimpfer |
| Matthias Furler | | |

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