The Impact of Urban Development on Wild Bee Populations in the Washington, DC Area

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Abstract

In recent years, a number of studies have been conducted to determine the extent to which urbanization may be contributing to the suspected decline of bee populations. The results of such studies have been inconsistent across different regions, suggesting that the effects of urbanization on wild bee populations cannot readily be generalized and that geographic regions must be considered individually. To this end, this paper examines the extent to which different degrees of urban development in the Washington, D.C. metropolitan area appear to impact the abundance and diversity of the region's wild bee populations. It was hypothesized that urbanization would correlate negatively with bee abundance and bee species richness. Data was compiled from seven years' worth of bee population samples collected via pan trapping by biologists and student interns working for the United States Geological Survey. The sampling locations were grouped into four levels of urban development: less than 10% developed, 10-60% developed, 60-90% developed, and more than 90% developed ("development" was characterized as the proportion of pavement and/or buildings). A bees-per-trap capture rate was calculated for each location as an indicator of abundance, and the differences between the capture rates at the four levels of urbanization were tested for statistical significance. Additionally, a statistical program was used to estimate the bee species richness at each level of urbanization, and to calculate diversity indices. While the two moderate levels of urbanization had the highest mean capture rates, the lowest level of urbanization performed best with regard to diversity. Hence, although moderate urban and suburban development does not appear to be wholly incompatible with the conservation of wild bee populations, it remains advisable to encourage the preservation and spread of gardens and parks with native habitats as a conservation tactic in urban areas.

Acknowledgement

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Introduction

In recent years, the suspected decline of bee populations has become an increasingly pressing worldwide ecological concern. It is widely recognized that bees and other pollinators are essential both to wild ecosystems and to agriculture; in fact, 60-70% of flowering plants cannot reproduce successfully without the aid of pollinators (Richards 1986, as cited in Kearns and Oliveras 2009). Bees perform critical functions in urban settings as well, facilitating park land vegetation as well as fruit and vegetable gardens (Cane 2005, p. 109). At the same time, however, urban development poses a threat to wild bee populations, as natural habitats are taken over by pavement and buildings, and as the remaining habitat fragments become increasingly small and isolated. In order to thrive, bees require appropriate foraging resources and nesting materials, and while many bee species exhibit foraging versatility, nesting requirements are more specific and vary greatly among different species (Cane, p. 112 and 114). When suitable foraging and nesting materials become too widely separated by habitat fragmentation, the urban environment can no longer support a thriving bee population, and species may be driven to local extinction (Cane, p. 114).

That being said, however, the impact of urbanization on wild bee communities remains imperfectly understood. A German study found that decreasing size of habitat fragments correlated with lesser diversity and abundance of wild bees (Steffan-Dewenter 2002), yet a recent study in Boulder, Colorado (U.S.A.), found no correlation between measures of urbanization (such as square meters of pavement) and bee species richness (Kearns and Olivares 2009). Such mixed results indicate that urbanization is a complex issue, the effects of which cannot be easily generalized; instead, different locales must be individually examined. Accordingly, this study investigates the extent to which different degrees of urban development in the Washington, D.C. metropolitan area appear to impact the abundance and diversity of the corresponding wild bee populations. It was hypothesized that more intensive urbanization would correlate with lower numbers of bees and fewer represented species.

Methods

The investigation was based on analyzing data compiled from bee population samples collected by biologists and student interns working for the United States Geological Survey (USGS). The data entry for each bee specimen indicated its species name and sex, as well as the latitude and longitude coordinates of the location of collection, the date and time of collection, an identification code for the experimental trial in which the specimen was collected, and notes about the method of collection, the weather, and the habitat. The samples were collected from 2002 through 2007, all in the month of September, from 99 locations within the Washington, D.C. metropolitan area. 12 of the locations were in the District of Columbia itself, while the remaining 87 were scattered throughout the adjacent Prince George's County, which is largely suburban but includes rural areas as well.

To provide a standardized basis for comparisons across different locations, the data set was restricted to the 116 samples (totaling 2561 specimens) collected using pan traps; for the purposes of this investigation, "sample" refers to all specimens collected at one location at a particular time. The use of pan traps (colored plastic bowls or cups filled with soapy water) is a widely accepted method of sampling wild bee populations. Pan traps have been shown to generally capture larger samples than net collections, and they have the additional advantage of eliminating collector bias; however, some species tend to be consistently underrepresented (Wilson et al. 2008). The latter point was not a significant concern in this investigation, because

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the focus was on the relative abundance and diversity of bees across different locations, not on creating an exhaustive survey of each population.

The basic procedure of pan trapping is as follows: A few teaspoons of a liquid soap are mixed with a gallon of water, and the mixture is distributed among small, colored plastic bowls or cups deployed at the desired location of collection. The colors of the bowls attract bees, which fly into the water and drown; the soap acts as a surfactant. The bowls are left in the field for a period that includes the peak activity hours of most bee species, i.e. from before 9:00 a.m. to after 3:00 p.m. at the least (Carboni and LeBuhn 2002). Afterwards, the trapped specimens are removed from the bowls either by hand or by using a fine-mesh strainer. The bees are then washed in a mixture of water and dishwashing detergent, gently rinsed with tap water, and blotted with a paper towel. Once all excess water has been removed, the bees are briefly treated with 95% alcohol, placed onto a paper towel and separated from each other (gently by hand, or using tweezers), and blotted again. To further dry the bees, the corners of the paper towel are folded towards each other, enclosing the bees, and the bees are shaken around inside the towel. Drying is complete when the wings are separated and the bee hair appears fluffy. The bees are then pinned and labeled.

Because many of the samples used in this investigation were collected in experiments originally designed to test the efficacy of different pan trapping protocols, the data set included minor variations in the method of collection. However, all variations previously found to affect the bee catch had been removed; only those that had been shown not to affect results were deemed acceptable. For example, although the majority of the pan traps had been set out for a 23- to 24-hour period, several trials had deployed pan traps for only a 10- to 12-hour period. Samples from both protocols were included in the data set because a previous study found no statistically significant difference between the number of bees collected in pan traps set out for 24 hours and those set out for 8 hours (Carboni and LeBuhn 2002). Four other variations in the method of collection were also noted but accepted: 1) white, fluorescent yellow, and fluorescent blue bowls were sometimes used in combination at a site and sometimes used separately; 2) a few trials utilized 12 oz. bowls, while the vast majority utilized 3.25 oz. bowls; 3) a few trials utilized laboratory detergent instead of Dawn® dishwashing liquid as a surfactant; and 4) several trials were conducted with salt added to the soap water. Wilson (2008) found that bowl color does not affect capture rate. Likewise, bowl size does not affect the number of bees caught (Droege 2002a), nor does the use of laboratory detergent as opposed to Dawn® dishwashing liquid (Droege 2002b). The addition of salt has also been found not to affect bee catch (Droege, unpublished data).

Analysis

To manage the large number of locations included in the data set, the locations were grouped into four categories representing four levels of urbanization. To do so, the latitude and longitude coordinates of each location were first inputted to Google Earth 5.0, in which the "historical imagery" function was used to view the locations as they were in the year that the bee population samples were collected; since many samples were collected as far back as 2002, this step ensured that any subsequent development at a location would not affect the analysis of the data. The "add polygon" function was then used to outline one square kilometer centered on the exact location point.

The level of urbanization at each location was determined by visually estimating the percentage of the square kilometer that was covered by pavement and/or buildings (see Appendix B for sample screenshots). Although the location assessments were more qualitative than quantitative in nature, frequent cross-checking between locations helped to ensure that the standards for each category remained consistent in practice. "Category A" locations were those at which less than 10% of the surrounding square kilometer was covered by pavement and/or buildings. "Category B" locations were those at which 10 – 60% of the land within a square kilometer was covered by pavement and/or buildings. These locations generally included at least one residential neighborhood, but sometimes included a major highway or a few large industrial-type buildings instead. "Category C" locations were 60 – 90% covered by pavement and/or buildings; these were generally areas of significant suburban residential development, with relatively small patches of woods or fields. One location in central Washington, D.C., was also placed into this category (rather than the highest level of urbanization) because a significant portion of the square kilometer consisted of the National Mall (an open, grassy area) and the lawns in front of the U.S. Capitol. Lastly, "Category D" locations were those that were at least 90% covered by pavement and/or buildings; these were areas of intense residential development with no significant fields or patches of forest. 35 locations were classified as Category A, 36 were classified as Category B, 23 were classified as Category C, and 5 were classified as Category D.

Once all the locations were categorized, they were analyzed for abundance of bees and for species richness (i.e. total number of species, as one measure of diversity). Total specimen counts for each location were not a reliable indicator of relative abundance, since different numbers of pan traps had been set out at different locations. Consequently, relative abundance was instead determined by dividing the total number of specimens collected at each location by the number of pan traps at that location, to obtain the bees-per-bowl capture rate. For twelve of the locations (four in Category A, six in Category B, and two in Category C), the capture rate could not be calculated because the number of pan traps had not been recorded by the collector. Once the capture rates had been determined for each of the other 87 locations, univariate statistical analysis and tests of normality were performed for each location category using the PAST (**Pa**leontological **St**atistics) software package (Hammer et al. 2001). PAST was also used to conduct a Kruskal-Wallis test and Mann-Whitney pairwise comparisons to compare the median capture rates of the four location categories.

Regarding species richness, it was not appropriate simply to compare the total number of species represented at each location. One factor that ruled out this approach was the variation in the number of bowls deployed in different sampling trials; even dividing the number of species at each location by the corresponding number of bowls would not have solved this problem, since species richness is not a per-bowl phenomenon. Furthermore, given that capture probabilities necessarily vary across species, it could not be assumed that the empirical data would, in itself, accurately indicate the actual number of bee species frequenting each location.

Despite these complications, however, statistical techniques made it possible to usefully compare the species richness of the different levels of urbanization, as statistical techniques can be used to obtain robust estimates of actual species richness based on empirical species abundance distribution data. Two such species richness predictors, ACE (Abundance-based Coverage Estimator) and Chao1, were calculated using EstimateS 8.2 (Colwell 2009). Because of the mobile nature of insects, and consequently varying capture probabilities, these statistics (based on distribution data) were more appropriate than those based on incidence (i.e. presence / absence) data (Kearns and Oliveras 2009). Furthermore, Chao (1984) found that the Chao1 estimator performed well on test data sets; Chao1 extrapolates species richness from the number of singletons (observed species represented by exactly one individual in a sample) and doubletons (observed species represented by exactly two individuals). ACE and Chao1 were used to estimate total species richness across all locations within each category, rather than for each location individually.

In addition to ACE and Chao1 estimates of species richness, diversity was also represented by Shannon's index (which accounts for both abundance and evenness of the represented species) and Simpson's reciprocal index (the reciprocal of the probability that two randomly selected individuals in the sample would belong to the same species; it likewise accounts for both abundance and evenness) (Magurran 2004, cited in Colwell 2009).

Results

Capture rates were calculated as a measure of abundance for 32 Category A locations, 29 Category B locations, 21 Category C locations, and 5 Category D locations (see Table 1 and Figure 1). Among the Category A (<10% developed) locations, the minimum capture rate was 0.12 bees per bowl, and the maximum capture rate was 2.00 bees per bowl; the mean capture rate was 0.64 bees per bowl; the standard deviation was 0.48; and the data was moderately skewed right (skewness = 1.27).

Among the Category B (10-60% developed) locations, the minimum capture rate was 0.20 bees per bowl, and the maximum capture rate was 2.80 bees per bowls; the mean capture rate was 1.02 bees per bowl; the standard deviation was 0.71; and the data was moderately skewed right (skewness = 1.09).

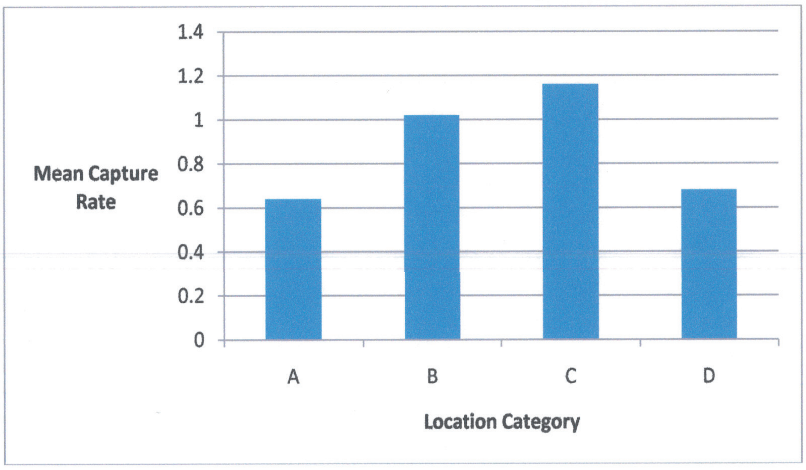
Among the Category C (60-90% developed) locations, the minimum capture rate was 0.29 bees per bowl, and the maximum was 2.33 bees per bowl; the mean capture rate was 1.16 bees per bowl; the standard deviation was 0.62; and the data was somewhat skewed right (skewness = 0.41).

Among the Category D (>90% developed) locations, the minimum capture rate was 0.20 bees per bowl, and the maximum was 1.32 bees per bowl; the mean capture rate was 0.68 bees per bowl; the standard deviation was 0.44; and the data was somewhat skewed right (skewness = 0.61).

Table 1: Univariate Statistical Analysis of Bees-per-Bowl Capture Rates at Locations in Four Levels of Urban Development

	Category A (<10% Developed)	Category B (10-60% Developed)	Category C (60-90% Developed)	Category D (>90% Developed)
Number of Samples Analyzed	32	29	21	5
Minimum	0.12	0.20	0.29	0.20
Maximum	2.00	2.80	2.33	1.32
Sum	20.49	29.72	23.24	3.39
Mean	0.64	1.02	1.16	0.68
Standard Error	0.08	0.13	0.14	0.20
Variance	0.23	0.50	0.39	0.19
Standard Dev.	0.48	0.71	0.62	0.44
Median	0.55	0.89	1.10	0.73
25th Percentile	0.24	0.48	0.58	0.28
75th Percentile	0.90	1.27	1.69	1.06
Skewness	1.27	1.09	0.41	0.61

Figure 1: Mean Capture Rates at Category A, Category B, Category C, and Category D Locations



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Normal probability plots were also created for Category A, Category B, Category C, and Category D in turn (see Appendix A). The plots revealed that the capture rate data were not normally distributed in Categories A and B, as those data points did not follow a straight line. Consequently, one-way analysis of variance (which assumes normal distribution) could not be used to compare the mean capture rates of the four location categories. Instead, the non-parametric Kruskal-Wallis test, which does not assume normal distribution, was used to compare the medians. The Kruskal-Wallis test indicated that at least one of the four median capture rates was significantly different from the others ($H = 11.7$, $p = 0.008472$). Subsequently, Mann-Whitney pairwise comparisons more specifically revealed that the median capture rate of Category A was significantly different from those of Categories B and C, but not Category D (likely due to the low number of samples in Category D). The median capture rates were not significantly different between Categories B and C, B and D, or C and D.

Regarding species diversity (see Table 2), the cumulative number of observed species across all Category A locations was 52. EstimateS yielded species richness predictors of 68.32 (ACE) and 77.6 (Chao1; 59.43 – 140.17; 95% confidence interval; Table 2) for Category A locations. Note that for Category A, as well as for Category B and Category C, the Chao1 classic equation was used instead of the bias-corrected equation (at the recommendation of the EstimateS program) because Chao's estimated coefficient of variance was greater than 0.5 in these cases. The Shannon diversity index for Category A was 3.25, and the Simpson reciprocal index was 18.98.

The cumulative number of observed species across all Category B locations was 63, and the species richness predictors were 107.31 (ACE) and 115.08 (Chao1; 95% confidence interval was 80.89 – 214.57; Table 2). The Shannon diversity index was 3.19, and the Simpson reciprocal index was 17.75.

The cumulative number of observed species across Category C locations was 45, and the species richness predictors were 57.42 (ACE) and 69 (Chao1; 95% confidence interval was 50.71 – 145.72; Table 2). The Shannon diversity index was 2.93, and the Simpson reciprocal index was 13.14.

The cumulative number of observed species across Category D locations was 27, and the species richness predictors were 33.90 (ACE) and 33.42 (Chao1; 95% confidence interval was 28.51 – 54.30; Table 2). The Shannon diversity index was 3.00, and the Simpson reciprocal index was 19.25.

Table 2: Comparison of Diversity Indicators for Category A, Category B, Category C, and Category D Locations

	Category A (<10% developed)	Category B (10-60% developed)	Category C (60-90% developed)	Category D (>90% developed)
Number of observed species (S_{obs})	52	63	45	27
ACE	68.32	107.31	57.42	33.90
Chao1	77.6	115.08	69	33.42
Shannon index	3.25	3.19	2.93	3
Simpson reciprocal index	18.98	17.75	13.14	19.25

Discussion and Evaluation

Neither aspect of the hypothesis was supported by the results of the data analysis; that is, neither abundance nor diversity strictly decreased in correlation with increasing urbanization. Category A (i.e. the most "rural" locations) had the lowest mean capture rate and the lowest median capture rate, while Category D (i.e. the most "urban" locations) had the second lowest of both mean and median capture rates. Furthermore, the differences in median capture rate between Categories B, C, and D were not statistically significant; the median capture rate of Category D was also not significantly different from that of Category A.

In retrospect, however, the hypothesis was based on rather simplistic assumptions about the effects of urbanization; it did not take into consideration the fact that vegetation characteristics, not just vegetation coverage, are often affected by land development. For example, agricultural fields and woods in the Washington, D.C. metropolitan area typically do not offer floral resources in September, so at this time of year, bee habitats in rural places are effectively limited to grassy areas next to roads, in between agricultural fields, and so on. These habitable areas tend to be relatively small; moreover, in early autumn they typically contain predominantly cool-season grasses, with very limited numbers of flowers (Droege, personal communication, Sept. 1, 2009). In more developed landscapes, on the other hand, watered and fertilized lawns and gardens can offer more abundant early autumn floral resources; despite being interspersed with roads and housing, such bee-friendly habitat fragments are usually located in relatively close proximity to each other, allowing bees to travel between them and make use of their resources. In this context, the relatively low capture rates (indicating relatively low abundance) among the most rural locations, as compared to the capture rates of the two categories of moderately-urbanized locations (Categories B and C), are less confounding. It must be pointed out, however, that the data did not show a complete reverse of the expected trend of decreasing abundance with increasing urbanization, because the most urban locations (Category D) had a low median capture rate not significantly different from that of the most rural locations. Possibly the bees in the moderately-urbanized locations had ready access both to floral resources (in lawns and gardens) and nesting resources (in unmanaged fields and forest fragments), whereas bees in highly urbanized areas may have had access to floral resources in gardens, but extremely limited access to nesting resources – mowed lawns, for example, are not a suitable habitat for ground-nesting bees.

The values of the species richness estimates and species diversity indices suggest that there is likewise no consistent correlation, whether positive or negative, between diversity and urbanization. For example, as compared to Category A (S_{obs} = 52; ACE = 68.32; Chao1 = 77.6), Category B displayed a higher number of observed species (S_{obs} = 63) and higher predicted species richness (ACE = 107.31; Chao1 = 115.08). However, the Shannon diversity index and Simpson reciprocal index were both higher for Category A (3.25 and 18.98 respectively) than for Category B (3.19 and 17.75 respectively), indicating that Category A had greater diversity when the abundance of each observed species was taken into account. In other words, the diversity indices reveal that while Category B locations yielded a greater number of species overall, relatively few species dominated those communities, whereas the communities at "rural" Category A locations tended have more equitable species representation. Category C had a lower number of observed species (S_{obs} = 45) compared to Category A, as well as lower predicted species richness (ACE = 57.42; Chao1 = 69); it also had a lower Shannon diversity index (2.93) and Simpson reciprocal index (13.14). Meanwhile, Category D had the lowest number of observed species (S_{obs} = 27), the lowest predicted species richness (ACE = 33.90; Chao1 = 33.42), and the second-lowest value for the Shannon diversity index (3), though it also had the highest value for the Simpson reciprocal index (19.25). The fact that there were only five Category D locations may have limited the efficacy of these statistical analyses. Nevertheless, the low Shannon diversity index highlights the low number of captured species in Category D, although the high value for the Simpson reciprocal index reveals that those species were relatively evenly represented (since the Simpson reciprocal index gives the reciprocal of the probability that two randomly selected individuals in the sample will belong to the same species).

Overall, only Category A had both relatively high predicted species richness and relatively high values for the species diversity indices. In comparison, the three more-urbanized location categories displayed compromised diversity, whether in terms of species richness or in terms of significantly uneven representation of the species. It is possible that rural areas offer a more diverse selection of nesting substrates than do more urbanized locations, thus supporting greater species diversity.

It should be noted that locations at which bees were collected using multiple colors of bowls, as opposed to a single color, may have been somewhat biased towards a greater variety of captured species; bowl color does not significantly affect capture rate, but some species are caught more often in one color than in other colors. However, species rarely display an absolute preference for a single color, and the vast majority of the collections were carried out with multiple bowl colors, so the species richness estimates remain a valid basis of comparison (S. Droege, personal communication, Sept. 1, 2009). Another complication in this investigation was that within each level of urban development, the undeveloped land varied from woods to agricultural fields to apparently unmanaged fields. Bee populations likely vary across the different habitat types, but the fairly even representation of each type of undeveloped land helped to compensate for this possibility.

The findings of this investigation are largely consistent with those of similar recent studies in other metropolitan regions. For example, Kearns and Oliveras (2009) found that in Boulder, Colorado (U.S.A.), bee diversity and the abundance of the observed species did not differ significantly among locations with different levels of urbanization; abundance was instead most affected by whether the land was grazed and by the number of flowering plant species. Also, Winfree et al. (2006) found that in southern New Jersey (U.S.A.), bee abundance and species richness was greater in suburban and urban areas than in less-developed areas with natural forest cover.

Conclusion

Moderate urban and suburban development appears to be compatible in some respects with the conservation of wild bee populations in the Washington, D.C. metropolitan area. Bee abundance, as measured by capture rates, was greatest overall in those locations that were more than 10% developed but at least 10% covered by vegetation. In terms of diversity, however, the most rural locations constituted the only category with both relatively high predicted species richness and relatively high diversity indices. Hence, rural landscapes may be the most conducive to maintaining diverse bee communities, even during seasons with fewer floral resources. Since this study was limited in scope to the Washington, D.C. area and the month of September, further surveys of bee populations in other metropolitan areas and at other times of year are needed in order to more fully understand the impacts of urban development. It would also be worthwhile to conduct another such investigation in the Washington, D.C. area with a revised experimental design. In particular, although the variations in the collection protocols used in the present investigation were previously demonstrated not to significantly affect bee catch, it would be preferable to eliminate the question altogether by using a single, consistent protocol; in addition, quantification of landscape features could be improved by using geographical information systems (GIS) software applications. Even in advance of more complete understanding of the consequences of urbanization, however, the fact that the most developed locations yielded relatively low bee numbers and species richness makes it imperative for conservationists to continue advocating for urban gardens and the preservation of park lands. By providing floral and nesting resources, such landscape features may serve as oases of relatively bee-friendly habitats in the midst of ever-increasing urban sprawl.

Appendix A

Figure 2: Normal Probability Plot of Capture Rates at Category A (<10% developed) Locations

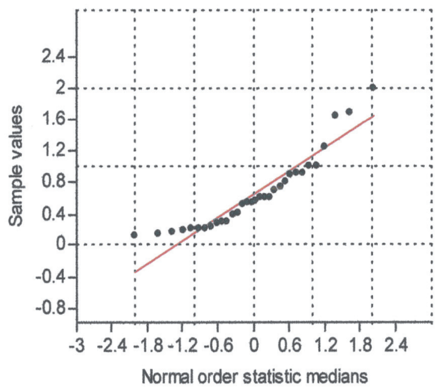

Figure 3: Normal Probability Plot of Capture Rates at Category B (10 – 60% developed) Locations

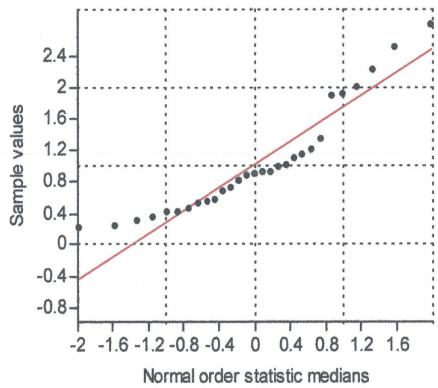

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Figure 4: Normal Probability Plot of Capture Rates at Category C (60 – 90% developed) Locations

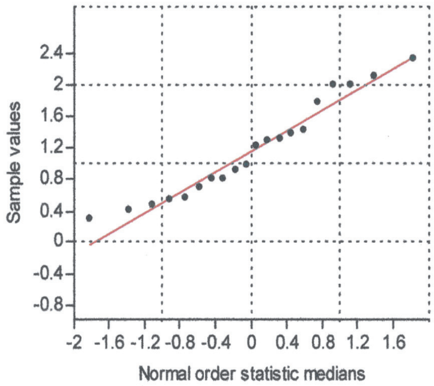
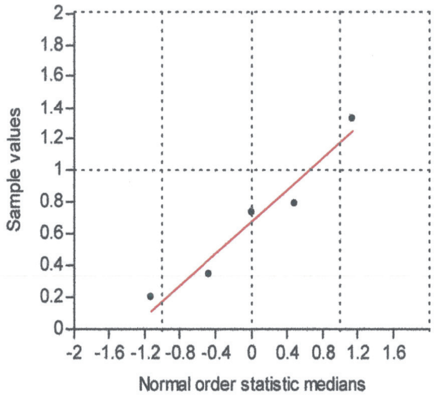


Figure 5: Normal Probability Plot of Capture Rates at Category D (>90% developed) Locations



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Appendix B

Figure 6: Representative Category A Location

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Figure 7: Representative Category B Location

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Figure 8: Representative Category C Location

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Figure 9: Representative Category D Location

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Appendix C

Table 3: Specimens Captured at Category A (<10% developed) Locations

Species Name	**Number of Specimens**
Agapostemon splendens	5
Agapostemon texanus	6
Agapostemon virescens	46
Andrena simplex	1
Anthidiellum notatum	1
Anthidium manicatum	1
Anthidium oblongatum	1
Apis mellifera	31
Augochlora pura	4
Augochlorella aurata	14
Augochlorella near gratiosa	1
Augochloropsis metallica	1
Bombus impatiens	2
Calliopsis andreniformis	8
Ceratina calcarata	62
Ceratina calcarata/dupla	14
Ceratina dupla	34
Ceratina strenua	40
Ceratina unknown	1
Coelioxys sayi	1
Halictus confusus	8
Halictus ligatus	16
Halictus ligatus/poeyi	10
Hylaeus affinis	10
Hylaeus affinis/modestus	3
Lasioglossum admirandum	5
Lasioglossum atlanticum	5
Lasioglossum bruneri	14
Lasioglossum coreopsis	7
Lasioglossum coriaceum	4
Lasioglossum cressonii	5
Lasioglossum illinoense	2
Lasioglossum macoupinense	1
Lasioglossum male	2
Lasioglossum nelumbonis	14
Lasioglossum nonfit	1
Lasioglossum oblongum	1
Lasioglossum pectorale	1

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Table 3 continued

Lasioglossum pilosum	26
Lasioglossum platyparium	1
Lasioglossum quebecense	4
Lasioglossum rohweri	39
Lasioglossum tegulare	5
Lasioglossum unknown	19
Lasioglossum versatum	38
Megachile brevis	7
Megachile mendica	3
Megachile rotundata	2
Melissodes desponsa	1
Melissodes species	1
Pseudopanurgus unknown	1
Ptilothrix bombiformis	2

Table 4: Specimens Captured at Category B (10 – 60% developed) Locations

Species Name	Number of Specimens
Agapostemon texanus	9
Agapostemon virescens	103
Andrena placata	1
Anthidium oblongatum	6
Apis mellifera	34
Augochlora pura	4
Augochlorella aurata	34
Augochlorella near gratiosa	1
Augochloropsis sumptuosa	1
Bombus fervidus	2
Bombus impatiens	38
Calliopsis andreniformis	46
Ceratina calcarata	57
Ceratina calcarata/dupla	72
Ceratina dupla	74
Ceratina strenua	104
Ceratina unknown	1
Coelioxys coturnix	1
Coelioxys octodentata	2
Coelioxys sayi	1
Halictus confusus	24
Halictus ligatus	18

Table 4 continued

Halictus ligatus/poeyi	21
Halictus rubicundus	1
Hylaeus affinis	24
Hylaeus mesillae	1
Hylaeus modestus	1
Lasioglossum	2
Lasioglossum admirandum	26
Lasioglossum bruneri	18
Lasioglossum coreaceum	3
Lasioglossum coreopsis	14
Lasioglossum coriaceum	1
Lasioglossum cressonii	4
Lasioglossum illinoense	4
Lasioglossum imitatum	1
Lasioglossum male	3
Lasioglossum nelumbonis	1
Lasioglossum pectorale	2
Lasioglossum pilosum	88
Lasioglossum platyparium	9
Lasioglossum rohweri	56
Lasioglossum tegulare	27
Lasioglossum unknown	6
Lasioglossum versatum	8
Lasioglossum zephyrum	1
Megachile brevis	7
Megachile campanulae	1
Megachile mendica	9
Megachile rotundata	2
Megachile unknown	1
Melissodes dentiventris	1
Melissodes desponsa	2
Melissodes druriella	1
Melissodes illata/subillata	1
Melissodes rustica	1
Melissodes subillata	1
Peponapis pruinosa	1
Perdita boltoniae	1
Pseudopanurgus compositarum	1
Ptilothrix bombiformis	3
Sphecodes	1
Sphecodes C	1
Xylocopa virginica	4

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Table 5: Specimens Captured at Category C (60 – 90% developed) Locations

Species Name	Number of Specimens
Agapostemon texanus	8
Agapostemon virescens	31
Andrena asteroides	4
Andrena simplex	2
Anthidium manicatum	4
Anthidium oblongatum	33
Apis mellifera	8
Augochlora pura	6
Augochlorella aurata	69
Bombus bimaculatus	1
Bombus impatiens	5
Calliopsis andreniformis	64
Ceratina calcarata	18
Ceratina calcarata/dupla	20
Ceratina dupla	16
Ceratina strenua	167
Ceratina unknown	3
Halictus confusus	56
Halictus ligatus	16
Halictus ligatus/poeyi	90
Halictus rubicundus	1
Hylaeus affinis	8
Lasioglossum admirandum	25
Lasioglossum anomalum	1
Lasioglossum bruneri	50
Lasioglossum coreopsis	1
Lasioglossum cressonii	6
Lasioglossum illinoense	12
Lasioglossum imitatum	4
Lasioglossum male	10
Lasioglossum oenotherae	1
Lasioglossum pilosum	53
Lasioglossum platyparium	1
Lasioglossum rohweri	105
Lasioglossum species	1
Lasioglossum tegulare	41
Lasioglossum unknown	4
Lasioglossum versatum	1
Megachile brevis	1
Megachile rotundata	1

Table 5 continued

Melissodes desponsa	3
Melissodes druriella	2
Sphecodes illinoensis	1
Sphecodes species	1
Xylocopa virginica	2

Table 6: Specimens Captured at Category D (>90% developed) Locations

Species Name	Number of Specimens
Agapostemon texanus	2
Agapostemon virescens	4
Augochlorella aurata	2
Calliopsis andreniformis	4
Ceratina calcarata	2
Ceratina calcarata/dupla	1
Ceratina dupla	2
Ceratina strenua	6
Ceratina unknown	1
Halictus confusus	7
Halictus ligatus	2
Halictus ligatus/poeyi	1
Hylaeus affinis	3
Lasioglossum admirandum	3
Lasioglossum bruneri	1
Lasioglossum cressonii	1
Lasioglossum illinoense	2
Lasioglossum imitatum	3
Lasioglossum male	1
Lasioglossum nelumbonis	1
Lasioglossum oblongum	1
Lasioglossum pilosum	12
Lasioglossum quebecense	1
Lasioglossum rohweri	4
Lasioglossum tegulare	6
Lasioglossum unknown	1
Sphecodes	4

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