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"BEE CITY": USING CITIZEN SCIENCE TO MONITOR POLLINATOR ABUNDANCE IN CULTIVATED AND UNCULTIVATED GREEN SPACES IN KAMLOOPS, BC

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"BEE CITY": USING CITIZEN SCIENCE TO MONITOR POLLINATOR ABUNDANCE IN CULTIVATED AND UNCULTIVATED GREEN SPACES IN KAMLOOPS, BC

by

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ABSTRACT

Pollinators provide critical ecosystem services, and are facing worldwide declines, caused in part by habitat loss due to urbanization. With the collaboration of the Thompson-Shuswap Master Gardeners Association's pollinator monitoring citizen science project, this project surveyed pollinators in both cultivated and uncultivated green spaces within Kamloops, BC. Pollinators were identified into functional groups or guilds based morphological characteristics that could be distinguished in the field by citizen scientists. The purpose of this project was threefold: (1) to characterize the consistency of citizen science surveys of pollinators over the course of a growing season, (2) to compare the floral resources for pollinators in cultivated and uncultivated green spaces within the city of Kamloops, and (3) to compare the abundance of pollinator guilds observed in cultivated and uncultivated green spaces over the growing season and determine if observed differences were correlated with observed differences in floral resources. The results indicated that citizen science was effective in monitoring bee abundance and diversity in Kamloops. There were drastic differences in flowering plant genera between cultivated and uncultivated green spaces, and significantly higher abundances of flowering plants in cultivated green spaces than uncultivated green spaces. This project also demonstrated that cultivated green spaces within Kamloops supported a greater numerical abundance of pollinators, especially during the month of August, than uncultivated natural areas within the city. This suggests that cultivated green spaces may have served as a refuge from seasonal drought for some native bees. All bee groups and flies were positively associated with bee flower abundance, and specific flowering plant genera were associated with high pollinator abundance. Because of this, it is important to advocate for the planting of native and exotic plants in cultivated green spaces, such as home gardens and city parks, and to support the restoration of native plant communities in uncultivated green spaces. Given the increasing urbanization faced by many landscapes, the

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results of my research provide preliminary evidence identifying that while not necessarily supporting all native pollinators, appropriately planted urban landscapes may play an important role mitigating urbanization's negative impact.

Thesis Supervisor: Lyn Baldwin (Ph.D.), Dept. Biological Sciences

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INTRODUCTION

In many areas of the world, including Canada, urbanization is concentrating global change within discrete spatial locations (Harrison and Winfree 2015). Through its influence on habitats, biogeochemistry, hydrology, land cover, and surface energy balance (d'Amour et al. 2017), urbanization can alter existing pollinator diversity, which in turn will influence the sustainability of urban areas. Given that more than 40% of the world's invertebrate pollinator species (predominantly bees and butterflies) are facing extinction (Potts et al. 2016), and urban land expansion is expected to continue (Seto et al. 2011), it is important to understand the ability of urban green space to support pollinator diversity.

To date, the relationship between bee diversity and urbanization has not been consistent across studies (Geslin et al. 2013, Fortel et al. 2014, Martens et al. 2017). Although several studies indicate that native bee diversity declines with increasing urbanization (Geslin et al. 2013, Fortel et al. 2014), other researchers have shown that diverse communities of wild bees persist in cities across the world (see review in Hall et al. 2017) and that conservationists should perceive the "city as a refuge for insect pollinators." The capacity (or lack thereof) of urban green spaces to support pollinators arises from the interaction between pollinator biology (which can differ in social structure, dietary specificity and nesting resources) and dominant drivers of urbanization within a given location. Given pollinator dependency upon plants, Harrison and Winfree (2015) identified four major drivers known to influence plant-pollinator interactions: habitat loss and fragmentation, the introduction of non-native plant species, urban microclimates, and the introduction of environmental contaminants.

Habitat loss and fragmentation can influence pollinator access to resources and their mobility within landscapes (Garibaldi et al. 2011; M'Gonigle et al. 2015; McKechnie et al. 2017; Leston & Koper 2017). Pollinator access to floral resources can become limited when small, isolated plant patches experience fewer pollinator visits than larger, less isolated patches (Pyke 1980). This may pose a particular problem for dietary specialists, which rely upon specific species of plants for forage. However, the ability to move across fragmented, urban landscapes may vary by pollinator group. Small solitary bees, such as those in the genus Andrena, have limited foraging distances, often travelling no more than 130 m from their nesting site (Franzén et al. 2009). In comparison, larger bees such as bumble bees and honey bees regularly make flights of 0.2 km to 9.5 km (Beekman & Ratnieks 2000; Osborne et al. 1999). The ability of pollinators to navigate urban environments may also depend upon the habitats of the plants they are pollinating. By using fluorescent dye as a pollen analogue, Van Rossum (2010) demonstrated that pollinators effectively moved pollen from a meadow plant (Centaurea jucea) more than 2 km between unconnected urban parks. However, in a parallel study, pollinators exhibited little ability to move pollen from a forest understory plant (*Primula elatior*) between parks unless the parks were connected with corridors (Van Rossum and Triest 2012).

Compared to surrounding natural areas, urban areas may experience different microclimates due to the urban heat island effect and summer sprinkling. In cities, the urban heat island effect is caused by impervious surfaces, such as concrete, absorbing and reradiating solar radiation (Yuan & Bauer 2007). In northern regions, such as BC, where pollinator activity is often limited by low temperatures, gardeners are often encouraged to create local hot spots in their yard to help support bees (Environmental Youth Alliance 2013). However, in warmer climates, the warming associated with urbanization can be associated with decreased bee abundance and/or fitness (Williams, Hahs & Vesk 2015). In North Carolina, when bees were

sampled in an urban warming mosaic, their abundance declined by about 41% per 1°C of urban warming (Hamblin, Youngsteadt & Frank 2018). Overwintering adult bees have been shown to exhibit reduced fitness at warmer winter temperatures, likely due to increased metabolic activity (Fründ et al. 2013). Finally, thermal changes may also cause asynchronous shifts in pollinator-plant phenology. If thermal shifts cause pollinators and plants to be active at different times over a season, pollinators could become temporally isolated from needed floral resources (Harrison & Winfree 2015).

In addition to shifts in microclimate, increasing urbanization is also associated with a reduction of native plant cover (McKinney 2006) and an increase of exotic plant cover. This shift in species composition can lead to higher plant diversity in cities (Loram et al. 2007; Pickett et al. 2011), and/or biotic homogenization (McKinney 2006). The effects of changing plant composition on pollinators will depend on the resources that urbanized floras provide pollinators. If these species provide nectar and pollen, they could help support native pollinators, especially if pollen is limited in the surrounding rural areas through extensive land use changes. Chrobock et al. (2011) surveyed pollinator visitation to native, invasive alien, and non-invasive alien plant species in semi-natural and urbanized habitats in Switzerland and found pollinator visitation was higher for native plants than for alien species, however pollinators did not distinguish between invasive and non-invasive alien plants.

Drivers of urbanization, of course, do not act independently. Combined, the shift in microclimate and plant species composition can change the seasonal availability of pollinator foraging resources (Harrison & Winfree 2015). Many non-native or cultivated species have extended or altered blooming periods. Even within the controlled environment of a greenhouse, seed collected from Siberian elm populations outside of the species' native range germinated earlier than seed collected from within the species' native range, presumably because earlier

germination facilitated spread (Chrocock et al. 2011). In addition, the warmer temperatures or altered hydrology (from sprinkling) of urban habitats may cause plants to bloom at different times in the season or for longer durations (Harrison & Winfree 2015). Such changes in plant phenology can impact pollinator phenology. In the deserts of the Jordan Rift Valley of Israel, bee species richness and abundance varied seasonally between gardens and adjacent natural habitats. Bees in the natural desert habitat displayed short phases of activity, peaking early in the season then decreasing, corresponding with the phenology of natural blooms. Bees in gardens (dominated by non-native, exotic plant species) displayed longer phases of activity, with a slow start early in the season and peaked towards the end of the season, presumably taking advantage of the longer growing season a garden environment provided (Gotlieb, Hollender & Mandelik 2011).

As a vehicle for pollen transport from flower to flower, pollinators play a large role in the reproductive ecology of many angiosperms and aid in the maintenance of biodiversity (Villalobos & Vamosi 2018). In North America, the ecosystem services provided by pollinators, including both native bees and honey bees, is worth approximately \$15 billion CAD. Globally, more than 75% of the world's food crops depend on pollination (Potts et al. 2016; Villalobos & Vamosi 2018). Pollinators are not only responsible for the majority of the food that people consume, but they are also vital to the production of biofuels, fibers, medicine, and construction materials.

Given the predicted increase in urbanization, some biologists have argued that pollinator conservation within urban landscapes is both necessary and possible (Hall et al. 2017); many municipalities, however, lack baseline data on existing bee abundance or diversity within their landscapes. In order to provide such baseline data, a growing number of citizen science projects have begun to monitor pollinator populations. For two years, the Vancouver based non-profit charity, The Environmental Youth Alliance, trained youth to monitor bumble bees within local

neighborhoods (Environmental Youth Alliance 2018). Provincially, within the Nature Kids BC program, youth have been collecting data on the abundance and diversity of bees, wasps, and butterflies, which is then analyzed by professional biologists (Nature Kids BC 2019). At a continental scale, Wildlife Preservation Canada helps organize BumbleBeeWatch.org in order to track and conserve North America's bumble bees. Within this project, citizen scientists upload photos of bumble bees, use an interactive guide to identify bumble bees, have their identifications verified by experts, help determine the status and conservation needs of bumble bees, aid in the location of rare or endangered populations of bumble bees, and much more (Wildlife Preservation Canada 2014).

There are obvious limitations to data collected with citizen science: observational biases may be present as variation exists among citizen scientists and incorrect detection of organisms may result from volunteers' differing expertise (Hochachka et al. 2012). However, in one of the few studies to analyze the effectiveness of bee monitoring with citizen scientists, Mason and Arathi (2019) compared the data collected by citizen scientists with that collected by a researcher in gardens from May-September in Fort Collins, Colorado. As with many citizen science projects, volunteers recorded the abundance of "morphospecies" based on morphological characteristics to differentiate bee groups, wasps, and flies, rather than individual species. The results of this study indicated that with adequate training in morphospecies identification and data collection, the citizen scientist volunteers in this project collected data that was as accurate as that collected by a scientific researcher (Mason & Arathi 2019).

Because taxonomic identification of pollinators is labour-intensive, time-consuming and expensive, citizen science projects may be the only monitoring option available. Moreover, although morphospecies or pollinator guilds (i.e., honey bee, bumble bee, hairy belly bee, pollen pants bee, wasps, flies) are not taxonomic distinctions, pollinator guilds can reflect differences in

pollinator biology that may influence their response to urbanization. For instance, although both honey bees and bumble bees are both social bees with mature females living together in colonies, these two morphospecies depend on very different resources. Both bumble bee and honey bee colonies consist of worker bees who do most of the foraging, brood care, and guarding and one queen who is responsible for all of the egg laying. However, honey bees live in large colonies (up to 50,000 individuals) that must be actively maintained by humans. In comparison, bumble bees live in much smaller colonies (10- 800 individuals) independently of humans. These bees often recycle old mice or bird nests for their colonies (Michener 2007). Thus, extensively cleaning and/or continuous disturbance of urban green spaces may have a greater impact on bumble bees as compared to honey bees.

However, bumble bee and honey bees depend upon similar floral resources and have similar foraging distances. Both have foraging distances ranging from 0.2 km to 9.5 km (Beekman & Ratnieks 2000; Osborne et al. 1999). In addition, both bumble bees and honey bees can be dietary generalists, foraging on a wide variety of plants. Such generalist pollinators tend to have long active seasons and can take advantage of many different floral resources (Michener 2007).

In contrast to the social habits of honey bees and bumble bees, hairy belly bees and pollen pants bees are solitary bees (Thompson Shuswap Master Gardeners Association 2017). Solitary females do everything on their own; they construct their own nest and provide food for their offspring, usually dying or leaving the nest before their offspring mature (Michener 2007). Pollen pants bees (named for the pollen carried along their hind legs) nest in the ground and are the most diverse group of bees; more than 70% of all bee species in British Columbia belong to this pollinator guild. In comparison, hairy belly bees carry their pollen on the underside of their abdomen and build nests in vertical wood with either mud or leaf material. As solitary bees, both

pollen pants and hairy belly bees have short foraging ranges, often travelling no more than 100-200 meters from their nesting sites (Thompson Shuswap Master Gardeners Association 2016). Many solitary bees are dietary specialists with only short seasons of adult flight activity.

Thus, the four bee guilds commonly included in citizen science pollinator monitoring projects (honey bees, bumble bees, hairy belly bees, and pollen pants bees) represent different pollinator requirements in terms of both floral and nesting resources. Specialist pollinators such as pollen pants and hairy belly bees may be especially vulnerable to urbanization as they rely on particular floral species that may bloom for a limited time (Michener 2007) and have specific nesting requirements. Bumble bees are predicted to be more vulnerable than honey bees, but their larger flight distances and dietary generalization may make them less vulnerable than the solitary bees (Harrison and Winfree 2015).

In 2017, Kamloops became the first designated "Bee City" in British Columbia indicating the City Council's desire to "protect pollinators and their habitats through action and education" (City of Kamloops 2017). The southern interior of British Columbia is believed to support more than 350 species of native bees (L. Best, personal communication); however, little is known about the native bee diversity or abundance within the urban landscapes of Kamloops. Shortly thereafter, the Thompson Shuswap Master Gardeners Association (TSMGA) developed a citizen science monitoring project to monitor the abundance of pollinator "guilds" in home gardens (hereafter referred to as cultivated green space). This citizen science project, combined with independent sampling in uncultivated green space in the city, created a unique opportunity to assess the pollinator (particularly that of bees) abundance and diversity of within Kamloops green spaces. Thus, the purpose of this project was three-fold:

 To characterize the consistency of citizen science surveys of pollinators over the course of a growing season.

- (2) To compare the floral resources for pollinators in cultivated and uncultivated green spaces within the city of Kamloops.
- (3) To compare abundance of pollinator guilds observed in cultivated and uncultivated green spaces over the growing season and determine if observed differences were correlated with observed differences in floral resources.

MATERIALS AND METHODS

Study Area

The city of Kamloops is situated in the southern interior of British Columbia at the confluence of the North and South Thompson rivers. Influenced by the rain shadow of the Coast Mountains, precipitation ranges from 10-12 inches annually (van Ryswyk & McLean 1989). Historically, the native vegetation of this landscape was a mosaic of sagebrush-steppe, grassland, riparian cottonwood forest, and higher elevation conifer (Ponderosa Pine and Douglas-Fir) forests. Within this ecosystem, important native pollinator forage plants include shrubs such as Rabbit Brush (*Chrysothamnus nauseosus*), Wax Currant (*Ribes cereum*), Prickly Pear Cactus (*Opuntia fragilis*), Snowberry (*Symphoricarpus* spp.), Choke cherry (*Prunus virginiana*), and many forbs. However, Kamloops also experiences a pronounced summer drought in which few forb and shrub species are found flowering from late July through August (there are, however, important exceptions such as Rabbit Brush which flowers in late August).

As a city, Kamloops encompasses 299.25 km² of inter-mixed neighborhoods and green spaces (Statistics Canada 2016). Kamloops has faced and will continue to face increasing urbanization. From 2011 to 2016, the population increased by 5.4% with a growth rate 0.4% greater than the average national growth rate (Kilpatrick 2017). A recent community plan by the City of Kamloops predicted that the population of Kamloops will grow from 90,000 to 120,000

in the next 22 years, and that the limited available and developable land will need to strategically be used to support this population growth (City of Kamloops 2017).

Citizen Scientist Training

In collaboration with the Thompson-Shuswap Master Gardeners Association, local citizens (hereafter referred to as citizen scientists) and I attended a weekend-long workshop in May 2017 to order to learn how to identify and monitor pollinator guilds. This workshop was designed to train citizen scientists to classify pollinators into one of seven pollinator guild types (bumble bees, honey bees, pollen pants bees, hairy belly bees, flies, wasps, and others (e.g., spiders, and butterflies)) based on relatively easy-to-observe morphological differences. For example, honey bees carry pollen in a pollen basket or corbicula on the top of their legs, pollen pants bees carry pollen all over their legs, and hairy belly bees carry pollen on the underside of their abdomen (their "belly") on tiny hairs called scopa. Flies can be distinguished from bees as flies have one pair of wings and very short antennae, whereas bees have two pairs of wings and longer antennae. The training workshop also gave participants hands-on experience counting pollinators in the field.

Pollinator and Vegetation Monitoring

Following a protocol developed by Wray and Udal et al. (2016), I surveyed pollinators in both cultivated and uncultivated green spaces within Kamloops, BC, during the first two weeks of June, July, August, and September of 2017. Each cultivated green space was paired with an uncultivated green space within 1 kilometer of the cultivated green space (Figure 1). Eight citizen scientists monitored their home gardens, while I monitored all uncultivated green spaces. In order to increase sample size, I also monitored three additional cultivated green spaces and their paired uncultivated green spaces.

At all sites, pollinator surveys consisted of a 20-minute observation period conducted under optimal weather conditions (between 15°C - 35°C and with wind speed no more than 5km/h), during the hours of 7am to 5pm. In order to standardize the areal extent surveyed in uncultivated green spaces, observation in uncultivated green spaces was limited to an area with a length of 40m (north to south) and a width of 17m (east to west), as this is the size of an average lot in downtown Kamloops. During each survey, all pollinators landing on open flowers were assigned to one of seven guilds of pollinating insects and recorded on a standardized data sheet (Appendix, Figure A-1). Elevation and GPS coordinates were recorded at each site once during the summer.



Figure 1. Locations of survey sites in Kamloops, BC. Grey pins represent cultivated green spaces, and red pins represent uncultivated green spaces.

2017 was an extreme fire season and the average fine particulate matter (PM_{2.5}) observed during each 20-minute survey period was compiled from PurpleAir.com. The Purple Air sensor closest to the survey site was used and the average PM_{2.5} levels for the entire 20-minute survey were recorded. In order to characterize the consistency of citizen-science surveys, the temperature, Julian day, survey time, and PM_{2.5} recorded during each survey period were compared between locations (cultivated versus uncultivated) and across months (June-September).

Finally, in order to assess the floral resources available at each monitoring site, the areal extent (m²) of all flowering plant genera present in each sampled green space was recorded once during the summer (Elzinga and Salzer 1998). Within cultivated green spaces, plant surveys occurred during the weeks of August 14th to September 14th and all uncultivated green space plant surveys occurred during the month of June. The areal extent of all flowering plant genera was recorded within the survey area. Cultivated green space surveys were completed with the homeowner in order to ensure as complete a list as possible and typically took 1-3 hours to complete. Once compiled, flowering plant genera were scored (1-3) for their value as bee forage based on local master gardener advice (E. Sedgeman, pers. communication) and published references (Xerces Society 2016; Weidenhammer 2016). All plant genera that were scored 2 or higher were lumped together as "bee flowers."

Statistical Analysis

Minitab was used to perform paired t-tests to determine if there were differences in temperature, Julian date, survey time, and PM_{2.5}, between cultivated and uncultivated green space surveys during each month.

All generalized linear models were conducted in R version 3.5.3 (R Core Team 2019). For monthly sampling data, pollinator counts were modeled in relation to location (cultivated and uncultivated green space), month, temperature, average fine particulate matter $< 2.5 \,\mu\text{m}$ (PM_{2.5}), and the interaction between location and month as fixed population-level effects and site as a random group-level intercept using generalized linear mixed models with the glmmTMB package (Brooks et al. 2017). Temperature and PM_{2.5} were centred on their mean values and scaled by dividing by their standard deviations. Specific pollinator groups (bumble bees, honey bees, hairy belly bees, pollen pants bees, flies, wasps, and other pollinators) were modeled separately. Observations for all pollinator groups were patchy, with many zero observations, and for some groups the prevalence of zeros appeared to differ by location (Appendix, Figure A-2). Variancemean ratios were substantially greater than 1 for all groups and also varied by location (Appendix, Figure A-3). This indicated that pollinator observations were overdispersed, relative to a Poisson process (where the variance-mean ratio = 1).

Biologically, overdispersion can occur if pollinators are patchily distributed and have clustered foraging behavior (Alexandre et al. 2018). To evaluate which error distribution would provide the best model fit, I compared models with Poisson and negative binomial error distributions. For negative binomial distributions, I compared both linear (where variance increases linearly with the mean (variance = $\mu(1 + \phi)$, where ϕ = dispersion parameter) and quadratic (where variance increases quadratically with the mean (variance = $\mu(1 + \mu/\phi)$) variance structures (Hardin and Hilbe 2007). Within these distributions, I modeled zero-inflation, both as a single parameter (hairy belly bees, flies, wasps, and other pollinators) and as a function of location (bumble, honey, and pollen pants bees). I also modeled the negative binomial dispersion parameter as a function of location, with and without accounting for zero inflation for bumble, honey, and pollen pants bees. Error distribution models were compared using the small-sample

corrected Akaike Information Criterion (AICc, Burnham and Anderson 2002). Model comparisons were run with the full model described above. After the best fitting error model was selected, I used AICc to compare fixed terms (Appendix, Tables A-2 and A-3). Model diagnostics (tests for uniformity and overdispersion, plots of standardized residuals vs. predicted values) were evaluated using the DHARMa package (Hartig 2019).

I used a similar approach to model the effect of bee flowers abundance on pollinators. Because flower abundance was estimated once, pollinator abundance was summed by site over the sampling season. Pollinator counts were modeled in relation to log-transformed bee flower abundance. Error distributions (Poisson, negative binomial with both linear and quadratic variance structures) with and without zero inflation were compared using AICc based on the full model. After selecting the best fitting error model, the effect of bee flower abundance on pollinator numbers was evaluated using AICc (Appendix, Tables A-4 and A-5). The effect of location on plant genera richness, total flower abundance, and bee flower abundance was evaluated using linear models, based on log-transformed response variables.

RESULTS

During Summer 2017, 10 citizen scientists counted a total of 2938 pollinators in 85 surveys in 22 cultivated and 22 uncultivated green spaces within the urban landscape of Kamloops, BC. Across all surveys, the most abundant pollinator guild observed was honey bees, followed by pollen pants bees (Tables 1 and 2).

Table 1. Summary of cultivated green space survey effort from June-September 2017, including
number of surveys conducted during each month, average number of pollinators observed,
average temperature, and PM _{2.5} during surveys.

Survey Month	Number of Surveys completed	Average pollinators observed (per survey)	Average weather conditions
June	10	23 ±12	22°C, PM _{2.5} 3.2 μg/m ³
July	10	47 ±24	28°C, PM _{2.5} 96.7 μg/m ³
August	11	80 ±51	26°C, PM _{2.5} 148.7 µg/m ³
September	10	48 ±35	24°C, PM _{2.5} 64.7 μg/m ³

Table 2. Summary of uncultivated green space survey effort from June-September 2017, including number of surveys conducted during each month, total number of pollinators observed, average temperature, and $PM_{2.5}$ during each survey.

Survey Month	Number of Surveys completed	Average pollinators observed (per survey)	Average weather conditions
June	11	21 ±11	24°C, PM _{2.5} 2.1 μg/m ³
July	11	22 ±9	28°C, PM _{2.5} 13.0 μg/m ³
August	11	9 ±11	23°C, PM _{2.5} 86.3 µg/m ³
September	11	28 ±40	30°C, PM _{2.5} 62.1 µg/m ³

Variability in citizen-science surveys

In this project, citizen scientists independently chose when to survey pollinators within the first two weeks of June, July, August and September. In doing so, participants were balancing optimal weather conditions for surveying pollinators with their own availability. As Kamloops experienced prolonged periods of forest fire smoke during late July, August and early September 2017, optimal sampling conditions became increasingly rare. In addition, due to the severity of the fire season, the City of Kamloops closed city parks for much of July and August. During this time, I was able to survey uncultivated green spaces only when accompanied by city staff, further constraining survey time and dates in uncultivated green spaces.

However, even with these constraints, all but one survey occurred within the recommended temperature range (Figure 2A). As might be expected, the temperatures recorded during surveys increased from June to July (Figure 2A). Surveys conducted in August, however, recorded the greatest variation in temperature. Temperatures recorded between cultivated and uncultivated surveys did not differ except for the month of September, with significantly warmer temperatures recorded during surveys in uncultivated green spaces than in cultivated green spaces (p=0.009, paired t-test; Figure 2A). The average Julian date of surveys conducted in cultivated and uncultivated sites did not differ in July and August, but did in June (p<0.001, paired t-test) and September (p<0.001, paired t-test). However, the difference in Julian date between surveys in these sample locations was not consistent: in June uncultivated green spaces were sampled earlier than cultivated and in September, this was reversed (Figure 2B). Time of day for surveys in cultivated did not differ significantly from July-September (no data was collected for time in uncultivated green spaces during the month of June; Figure 2C). Across the season, surveys in July and August were conducted earlier than in June and September.

Compared to surveys conducted in June, those conducted in July and August had significantly higher recorded PM_{2.5} values (Figure 2C). The PM_{2.5} recorded for cultivated and uncultivated surveys were significantly different only during August surveys (p=0.031, paired t-test), with higher PM_{2.5} recorded for surveys in cultivated green spaces (Figure 2D).



Figure 2. Comparison of sampling temperature (A), Julian date (B), sampling time (C), and average fine particulate matter $(PM_{2.5})$ (D) for surveys in cultivated and uncultivated green spaces in June, July, August, and September.

Floral resources in cultivated and uncultivated green spaces

Floral resources differed in richness, abundance and composition in cultivated and uncultivated green spaces in Kamloops. Plant genera richness, total flower abundance, and bee flower abundance in cultivated green spaces far exceeded that found in uncultivated green spaces (plant genera richness: $\overline{x}_{cultivated} = 77.7$, SD = 31.5, $\overline{x}_{uncultivated} = 16.4$, SD = 7.2, total flower abundance: $\overline{x}_{cultivated} = 237.2$, SD = 157.1, $\overline{x}_{uncultivated} = 29.7$, SD = 10.5, bee flower abundance: $\overline{x}_{cultivated} = 155.3$, SD = 67.4, $\overline{x}_{uncultivated} = 25.6$, SD = 10.0, Figure 3). These differences are supported by the strong response of linear models based on log-transformed vegetation variables to location (plant genera richness: R² = 0.71. F_{1, 20} = 51.4, P < 0.001, total flower abundance: R² = 0.68. F_{1, 20} = 44.8, P < 0.001, bee flower abundance: R² = 0.53. F_{1, 20} = 24.3, P < 0.001).



Figure 3. Effect of location (cultivated and uncultivated green space) on plant genera richness, flower abundance, and bee flower abundance. Dark points are mean values. Error bars represent 95% confidence intervals. Light points are observations. Response variables were log transformed in models, but are shown on their original scale.

An ordination of flowering plant genera displayed a drastic difference in the composition of flowering plant genera found in cultivated and uncultivated green spaces (Figure 4) when all genera are included and when only genera occurring in 2 or more sites were included (Figure 4).



Figure 4. Graphical representation of unconstrained ordinations (nonmetric multidimensional scaling) of all sites. Points represent genera abundance and composition at each location. Distance between points is proportional to dissimilarity between sites (i.e., sites with similar genera composition are plotted closer together). The left graph shows sites with all genera included while the right graph shows all sites with genera that occurred at only one site removed. In both cases ordinations have been rotated so that the first axis (NMDS 1) explains the greatest amount of variation.

There was very little overlap in the common bee-friendly genera in cultivated and uncultivated green spaces (Table 3). Of the 23 genera that occurred in 60% of either cultivated or uncultivated green spaces, only one, *Achillea*, was common to both lists. Of these bee friendly plants, the families that were recorded most frequently were Apiaceae, Asteraeae, Brassicaceae, Lamiaceae, and Rosaceae in cultivated green spaces and Asteraceae, Brassicaceae, and Fabaceae in uncultivated green spaces (Appendix, Table A-1). Of the bee friendly plants recorded, 88% were exotic species and 51% were native species (37% of bee friendly plant genera recorded contained both native and exotic species) (Appendix, Table A-1).

	Cultivated Si	tes	Uncultivated Sites				
Plant Genera	# of Sites	Family	Plant Genera	# of Sites	Family		
Prunus	10	Rosaceae	Artemisia	10	Asteraceae		
Helianthus	9	Asteraceae	Tragopogon	10	Asteraceae		
Achillea	8	Asteraceae	Sisymbrium	9	Brassicaceae		
Allium	8	Amaryllidaceae	Achillea	8	Asteraceae		
Aster	8	Asteraceae	Medicago	8	Fabaceae		
Fragaria	8	Rosaceae	Erigeron	8	Asteraceae		
Lavandula	8	Lamiaceae	Crepis	7	Asteraceae		
Perovskia	8	Lamiaceae					
Rudbeckia	8	Asteraceae					
Alyssum	7	Brassicaceae					
Anethum	7	Apiaceae					
Echinacea	7	Asteraceae					
Mentha	7	Lamiaceae					
Nepeta	7	Lamiaceae					
Rosa	7	Rosaceae					
Sedum	7	Crassulaceae					

Table 3. Flowering plant genera occurring in 60% or more of sampled cultivated and uncultivated green spaces in Kamloops, BC during Summer 2017.

Abundance of pollinator guilds observed in cultivated and uncultivated green spaces

The total number of pollinators observed in cultivated green spaces was 2060 pollinators over 41 surveys, whereas the total number of pollinators observed in uncultivated green spaces was 878 pollinators over 44 surveys. In cultivated green spaces, the most common pollinator guild observed over the season was honey bees and in uncultivated green spaces pollen pants bees was the most common pollinator guild observed.

Pollinator trends over the season varied depending on guild type and month. The most obvious trend was that bumble bees, honey bees, and pollen pants bees all increased drastically in cultivated green spaces in August. Pollen pants bees, other, hairy belly bees, and honey bees all decreased during the month of August in uncultivated green spaces (Figure 5).



Figure 5. Average abundance of pollinators belonging to each pollinator guild from cultivated and uncultivated green spaces in June, July, August, and September. Bees are separated from 'others' (wasps, flies, and other) to improve readability.

For monthly sampling data, selected candidate models for all pollinator groups used a negative binomial error distribution without a zero-inflation parameter. For bumble and honey bees, dispersion parameters were estimated separately for cultivated and uncultivated green space. For most pollinator groups, the top model included the interaction between month and location. Exceptions were flies, where the location-only model was selected, and wasps, where no fixed terms were selected (Table 4). For models where pollinator abundance varied by both month and location, the number of pollinators was often higher in cultivated than uncultivated green spaces, especially in the month of August (Figure 6).

					Random, Dispersion	
Family*	Fixed Terms [†]	χ^2	df	Р	Terms [‡]	Coefficients§
			Bum	ble Bees		
NB1	L	28.86	1	< 0.001	Site	0.73
	М	12.17	3	0.007	<i>φ</i> cultivated	3.32
	L:M	19.52	3	< 0.001	<i>Φ</i> uncultivated	0.62
			Hon	ey Bees		
NB2	L	18.51	1	< 0.001	Site	0.17
	М	13.62	3	0.003	<i>φ</i> cultivated	0.73
	L:M	12.00	3	0.007	Quncultivated	0.35
			Hairy	Belly Bees		
NB1	L	1.72	1	0.189	Site	0.45
	М	9.76	3	0.021	φ	5.42
	L:M	7.28	3	0.063		
			Pollen	Pants Bees		
NB1	L	3.77	1	0.052	Site	0.39
	М	8.15	3	0.043	φ	8.61
	Т	4.59	1	0.032		
	L:M	11.57	3	0.009		
				Flies		
NB2	L	5.98	1	0.014	Site	0.55
					φ	2.67
			V	Vasps		
NB1	Intercept-only				Site	0.45
					φ	4.46
			Other	Pollinators		
NB1	L	0.01	1	0.905	Site	0.28
	М	16.79	3	< 0.001	φ	1.62
	L:M	13.79	3	0.003		

Table 4. Best fitting models based on monthly sampling data for each pollinator group, as selected by small-sample corrected Akaike Information Criterion and model diagnostics.

* NB1 = negative binomial, variance increases linearly with mean, NB2 = negative binomial, variance increases quadratically with mean

[†] L = location (cultivated and uncultivated green space), M = month (June, July, August, September), T = temperature, L:M = interaction between location and month

[‡] Site = group-level random intercept, φ = dispersion parameter (either global or locationspecific)

[§]Random effect estimates are given on the standard deviation scale, dispersion parameter estimates are given on the data scale

P-values were estimated using Type II Wald χ^2 tests, df = degrees of freedom



Figure 6. Effect of the interaction between month and location on the abundance of bumble, honey, hairy belly, and pollen pants bees and other pollinators and the effect of location on the abundance of flies based on monthly data. Dark points are mean values. Error bars represent 95% confidence intervals. Light points are observations.

Association between floral resources and pollinator guild abundance

For aggregate data, selected candidate models for all pollinator groups used a negative binomial error distribution without a zero-inflation parameter, except for hairy belly bees, where a global zero-inflation parameter was estimated. For all bee groups and flies, the selected model included the effect of bee flower abundance and the number of pollinators was positively associated with bee flower abundance (Table 5, Figure 7).

					Dispersion, Zero-	
Family*	Fixed Terms [†]	χ^2	df	Р	Inflation Terms [‡]	Coefficients§
			Bum	ble Bees		
NB1	F	28.74	1	< 0.001	φ	12.35
			Hon	ey Bees		
NB1	F	9.65	1	0.002	φ	33.65
			Hairy I	Belly Bees		
NB1	F	6.36	1	0.012	φ	3.57
					π	0.17
			Pollen	Pants Bees	5	
NB1	F	4.63	1	0.031	φ	13.80
				Flies		
NB1	F	4.45	1	0.035	φ	5.09
			V	Vasps		
NB1	Intercept-only				φ	8.24
			Other 1	Pollinators		
NB1	Intercept-only				φ	3.10
* 1 1 1				1. 1 .	· 1	

Table 5. Best fitting models based on aggregated sampling data for each pollinator group, as selected by small-sample corrected Akaike Information Criterion and model diagnostics.

* NB1 = negative binomial, variance increases linearly with mean

[†] $F = \log(\text{bee flower abundance})$

[‡] φ = global dispersion parameter, π = global zero-inflation parameter

[§] Dispersion parameter estimates are given on the data scale, zero-inflation estimate is given on the probability scale [0-1]

P-values were estimated using Wald χ^2 tests, df = degrees of freedom



Figure 7. Effect of bee flower abundance on the number of bumble, honey, hairy belly, and pollen pants bees and flies based on aggregated data. Dark lines show the fitted relationship and shaded areas represent 95% confidence bands. Light points are observations differentiated by location (cultivated and uncultivated green space).

DISCUSSION

In this study, citizen science monitoring detected significant differences in pollinator guild abundance in cultivated and uncultivated green spaces in the city of Kamloops. Even with the additional constraints of sampling during an extreme forest fire season, survey conditions remained relatively consistent across types of green space (cultivated and uncultivated) and encompassed expected variation throughout the season. A unique aspect of this citizen science project, however, is that the one habitat type (uncultivated green spaces) was surveyed by an undergraduate student (myself) while the other habitat type (cultivated green space) was primarily surveyed by master gardeners. It may be expected that sampling constraints on these two populations would differ and factors such as returning to school in early September resulted in the variation in survey conditions (i.e., the earlier Julian date of September uncultivated green space surveys). This earlier Julian date of sampling may have also resulted in the significantly warmer temperatures recorded during September uncultivated green space surveys as compared to the temperatures of September cultivated green space surveys.

Perhaps the most surprising difference between environmental conditions of cultivated and uncultivated surveys was the significant difference in PM_{2.5} recorded during the August surveys. As time of day and Julian date did not differ for the cultivated and uncultivated surveys, I have little explanation for this difference except that air quality was known to change rapidly during the month of August 2017. Overall, differences in survey conditions were minimal; however, the observed variation in citizen science survey conditions highlight the importance of validating data collected by citizen scientists (Mason & Arathi 2019).

I also documented a shift in plant species composition commonly associated with urbanization (McKinney 2006). Driven by an increase in exotic species, plant genera richness and abundance were far higher in cultivated green spaces than uncultivated green spaces, supporting

previous studies finding high species diversity in cities (Loram et al. 2007; Pickett et al. 2011). This increase in richness did not occur through the addition of exotic genera to the existing native flora, but rather a whole-scale replacement of one flora for another, as indicated by the little overlap in the ordination diagrams (Figure 4).

It is also important to note that the flora of the uncultivated green spaces sampled in this study does not represent the diversity of intact natural areas in the Kamloops region. Previous studies of native plant communities within the Kamloops region have shown that plant genera richness typically ranges from 30-40 genera (L. Baldwin, pers. comm) whereas the mean richness for uncultivated sites was only 16.4 genera. Furthermore, although representative of many uncultivated green spaces in the city, numerous uncultivated sites showed signs of disturbance and included weedy genera such as *Sisymbrium*, *Centaurea*, *Tragopogon* and *Medicago*. My sampling protocol required selecting uncultivated sites within 1 km of cultivated home gardens which meant that I did not monitor pollinators found within larger nature parks found in Kamloops. Thus, the cultivated and uncultivated sites sampled in this study do not reflect a wide gradient of urbanization, but instead reflect the diversity of green spaces commonly found in residential neighborhoods of Kamloops. This is especially important to note as the relative value of urban landscapes for pollinators has been shown to vary with what they are being compared to (Winfree et al. 2011).

Unsurprisingly, when cultivated and uncultivated areas were analyzed collectively, the abundance of all bee guilds and flies were positively associated with bee flower abundance (Figure 7). Floral resources have been previously shown to be a limiting factor for bee populations (Roulston & Goodell 2011). It should be noted that due to the little overlap observed in floral composition in cultivated and uncultivated sampling sites, I was not able to distinguish if the relationship between bee guild abundance and floral abundance varied between green space

type. However, in a meta-analysis Winfree et al. 2011 concluded that pollinators track the availability of resources more than they track land-use changes.

Within the urban green spaces sampled, the results of this study demonstrate that pollinator guild abundance over the growing season differed between cultivated and uncultivated green spaces. The total number of pollinators observed was generally higher in cultivated compared to uncultivated green spaces, with the most dramatic shift observed in August (Figures 5 & 6). The August peak in pollinator abundance was driven by an increased abundance of bumble bees, honey bees, and pollen pants bees in cultivated green spaces and was accompanied by a decline in pollen pants bees, hairy belly bees, and honey bees in uncultivated green spaces.

Given that they are strong fliers, the observed shift in honey bee and bumble bee abundance may have resulted from the bees' response to declining floral resources in uncultivated areas. Summer drought is prominent in Kamloops, especially during the month of August. Many plants in uncultivated areas go dormant or have already gone to seed from blooming earlier in the season, thus the availability of floral resources diminishes drastically. In comparison, many genera grown in cultivated green spaces such as *Echinacea*, *Rudbeckia*, *Borago*, and *Eupatorium*, will, with watering, bloom throughout August. Thus, it is likely that the change in seasonal availability of pollinator foraging resources (Harrison & Winfree 2015) was at least partially responsible for the August peak in honey bee and bumble bee abundance in cultivated areas. For native bumble bees, cultivated green spaces may serve as a refuge from seasonal drought.

In comparison with social bees, solitary bees like pollen pants bees are floral specialists with short seasons of adult flight activity and rarely travel long distances from their nests. These bees can afford to only visit their preferred flower (Michener 2007). Given the dormant stage of vegetation in uncultivated green spaces in August, it is not surprising that the abundance of

pollen pants bees and hairy belly bees diminished. However, given their short flight distance and dietary specialization, it is unlikely that the increased abundance of pollen pant bees observed in cultivated green spaces in August resulted from these solitary bees migrating from uncultivated areas. Instead, this increased abundance may have resulted from an increased abundance of pollen pant generalists such as *Agapostemon* spp. which were regularly observed foraging on *Scabiosa* and *Coreopsis* flowers throughout the summer (L. Baldwin, pers. comm).

The increased abundance of pollen pants bees in cultivated gardens in August also suggests the possibility that at least some portion of the pollen pant bee population is flying later in the season. Such differentiation of flight seasons has been previously found for bee species in fragmented or urbanized environments (Gotlieb, Hollender and Mandelik 2011; Wray, Neame and Elle 2014). In comparison with pollen pant bees, hairy belly bees showed no associated increase in cultivated sites in August. Nesting resources are difficult to quantify and this study, like most pollinator surveys (Winfree et al. 2011), did not assess nesting resources available in urban green spaces. Yet, bee species nesting in cavities above ground (e.g., hairy belly bees) have been shown to decrease with increasing land-use changes while those nesting below ground (pollen pants bees) increased with land-use change (Williams et al. 2010). This suggests that the lack of hairy belly bees in cultivated areas may be associated with limited nesting sites and will be an important factor to consider in future studies.

CONCLUSION

Citizen science is an effective tool in monitoring bee abundance and diversity in Kamloops. The results of this study indicated that all bee groups and flies were positively associated with bee flower abundance. This suggests that in Kamloops, planting bee friendly flowers, such as the genera listed in Appendix Table A-1, in cultivated gardens could be

beneficial to many pollinator guilds. In addition, it may be especially important to provide native floral resources to pollinators for those specialist pollinators that rely on specific native plant species. This citizen science project has provided Kamloops with baseline data on bee diversity and abundance in our landscape. It is also apparent that specific flowering plant genera are associated with high pollinator abundance, and that cultivated and uncultivated green spaces differ greatly in their floral composition. Because of this, it is important to advocate for the planting of native and exotic plants in cultivated green spaces such as home gardens and city parks, and to support the restoration of native plant communities in uncultivated green spaces. As many solitary, specialist bees do not travel far from their nesting site and are dependent upon native plants, it is crucial that the city of Kamloops protect bee habitat within its natural parks.

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APPENDIX

Name: Date: Location: Km/h) (°C) Apollinator monitoring event sects present at a given loc participants. The goal is to re- nitube timeframe. The Individ Jolinators are supported by t	CLOUD COVER: (scale 0-5. 0= clear, 5 = full haze) t with citizen scientists is an opportunistic survey of the cation, observed in a shart time frame by a number of	Other Observations? (nesting spots, local climate differences, landscape	e features, special sightings)
Date:	CLOUD COVER: (scale 0.5. 0= clear, 5 = full haze) t with citizen scientists is an apportunistic survey of the cation, observed in a short time frame by a number of		
Location:	CLOUD COVER:		
AIND: TEMP: A pollinator monitoring event sects present at a given loc sarticipants. The goal is to rec ninute timeframe. The individ solinators are supported by t	CLOUD COVER: (scale D.S. Or clear, 5 = full haze) t with clitzen scientists is an apportunistic survey of the cation, observed in a short time frame by a number of		
A pollinator monitoring event nsects present at a given loc outricipants. The goal is to rec minute timeframe. The individ sollinators are supported by t	t with citizen scientists is an opportunistic survey of the cation, observed in a short time frame by a number of		
community can make decision nay want to include in their g	card as much accurate data da possible, within a 20 dual data will be totaled to assess what kinds of this location, and what is lacking. From this, the ions on what kind of lowers and nesting provisions they green space plans on site.	Plant Observations:	
Survey spor		Types of plants. Common names ok, include shape (may also include colour, smell, estimate of # of flow	and diameter of flower: wers in patch)
Hairy belly bees			
Mining bees			
Honeybees			
Flies			
Wasps			
Other			
Pollinator Photos taken? Yes	- N-		
	s NO	•	

Figure A-1. Sample data sheet to be filled out for each pollinator survey (Wray and Udal 2016).

Plant Genera	Species	Species	Cultivated	Unultivated	Family
Abelmoschus	Yes	No	1	0	Malvaceae
Acer	Yes	Yes	3	0	Sapindaceae
Achillea	Yes	Yes	8	8	Asteraceae
Actinidia	Yes	No	2	0	Actinidiaceae
Agastache	Yes	Yes	2	0	Lamiaceae
Allium	Yes	Yes	8	0	Amaryllidaceae
Alyssum	Yes	No	7	0	Brassicaceae
Amelanchier	No	Yes	4	4	Rosaceae
Ammi	Yes	No	1	0	Apiaceae
Anemone	Yes	Yes	3	0	Ranunculaceae
Anethum	Yes	No	7	0	Apiaceae
Antennaria	No	Yes	2	4	Asteraceae
Arabis	No	Yes	2	4	Brassicaceae
Arnica	No	Yes	0	1	Asteraceae
Artemisia	Yes	Yes	4	10	Asteraceae
Artirrhinum	Yes	No	1	0	Plantaginaceae
Asclepias	Yes	Yes	2	0	Apocynaceae
Aster	Yes	Yes	8	0	Asteraceae
Astragalus	Yes	Yes	0	5	Fabaceae
Aurinia	Yes	No	2	0	Brassicaceae
Balsamorhiza	No	Yes	0	1	Asteraceae
Baptisia	Yes	No	1	0	Fabaceae
Bellis	Yes	No	1	0	Asteraceae
Berberis	Yes	No	5	0	Berberidaceae
Borago	Yes	No	2	0	Boraginaceae
Brassica	Yes	No	6	0	Brassicaceae
Calendula	Yes	No	3	0	Asteraceae
Calluna	Yes	No	1	0	Ericaceae
Calochortus	No	Yes	0	4	Liliaceae
Capsicum	Yes	No	5	0	Solanaceae
Castanea	Yes	No	1	0	Fagaceae
Castilleja	No	Yes	0	3	Orobanchaceae
Centaurea	Yes	No	2	5	Asteraceae
Chrysothamnus	No	Yes	1	5	Asteraceae
Circium	Yes	No	1	0	Asteraceae
Clematis	Yes	Yes	5	0	Ranunculaceae
Coriandrum	Yes	No	4	0	Apiaceae
Cosmos	Yes	No	5	0	Asteraceae

 Table A-1. Origin status, occurrence in location type, and family of all bee-friendly plant genera.

 Exotic
 Native

Plant Genera	Exotic Species	Native Species	Cultivated	Unultivated	Family
Crepis	Yes	Yes	0	7	Asteraceae
Crocus	Yes	No	2	0	Iridaceae
Cynara	Yes	No	1	0	Asteraceae
Descurainia	Yes	Yes	0	4	Brassicaceae
Digitalis	Yes	No	1	0	Plantaginaceae
Echibeckia	Yes	No	1	0	Asteraceae
Echinacea	Yes	No	7	0	Asteraceae
Echinops	Yes	No	5	0	Asteraceae
Elaeagnus	Yes	Yes	1	0	Elaeagnaceae
Epilobium	Yes	Yes	1	0	Onagraceae
Erigeron	Yes	Yes	0	8	Asteraceae
Eriogonum	No	Yes	0	2	Polygonaceae
Eruca	Yes	No	1	0	Brassicaceae
Eryngium	Yes	No	4	0	Apiaceae
Eupatorium	Yes	No	1	0	Asteraceae
Eutrochium	No	Yes	1	0	Asteraceae
Fragaria	Yes	Yes	8	0	Rosaceae
Fritillaria	Yes	No	0	4	Liliaceae
Fuchsia	Yes	No	5	0	Onagraceae
Gaillardia	Yes	Yes	5	1	Asteraceae
Galium	Yes	Yes	1	0	Rubiaceae
Geum	No	Yes	1	2	Rosaceae
Grindelia	Yes	Yes	0	3	Asteraceae
Helianthus	Yes	Yes	9	0	Asteraceae
Heliopsis	Yes	No	3	0	Asteraceae
Heuchera	Yes	Yes	4	2	Saxifragaceae
Hyssopus	Yes	No	2	0	Lamiaceae
Iberis	Yes	No	1	0	Brassicaceae
Ilex	Yes	No	1	0	Aquifoliaceae
Lamium	Yes	No	4	0	Lamiaceae
Lappula	Yes	Yes	0	1	Boraginaceae
Lathyrus	Yes	Yes	2	0	Fabaceae
Lavandula	Yes	No	8	0	Lamiaceae
Lavatera	Yes	No	1	0	Malvaceae
Levisticum	Yes	No	3	0	Apiaceae
Liatris	Yes	No	4	0	Asteraceae
Linum	Yes	Yes	1	0	Linaceae
Lithospermum	Yes	Yes	1	4	Boraginaceae
Lobelia	Yes	Yes	3	0	Campanulacea

Plant Genera	Exotic Species	Native Species	Cultivated	Unultivated	Family
Lonicera	Yes	Yes	5	0	Caprifoliaceae
Lupinus	Yes	Yes	3	0	Fabaceae
Mahonia	N/A	N/A	3	1	Berberidaceae
Malus	Yes	Yes	5	0	Rosaceae
Malva	Yes	No	2	0	Malvaceae
Medicago	Yes	No	1	8	Fabaceae
Melilotus	Yes	No	3	2	Fabaceae
Melissa	Yes	No	2	0	Lamiaceae
Mentha	Yes	Yes	7	0	Lamiaceae
Monarda	Yes	Yes	4	0	Lamiaceae
Nasturtium	Yes	No	4	0	Brassicaceae
Nepeta	Yes	No	7	0	Lamiaceae
Ocimum	Yes	No	6	0	Lamiaceae
Opuntia	No	Yes	3	0	Cactaceae
Origanum	Yes	No	5	0	Lamiaceae
Papaver	Yes	Yes	5	0	Papaveraceae
Perovskia	Yes	No	8	0	Lamiaceae
Petroselinum	Yes	No	3	0	Apiaceae
Phacelia	No	Yes	2	0	Hydrophyllaceae
Philadelphus	Yes	Yes	4	0	Hydrangeaceae
Phlomis	Yes	No	1	0	Lamiaceae
Physocarpus	No	Yes	5	0	Rosaceae
Polemonium	No	Yes	2	0	Polemoniaceae
Polygonum	Yes	Yes	1	0	Polygonaceae
Prunus	Yes	Yes	10	0	Rosaceae
Pyrus	Yes	No	2	0	Rosaceae
Raphanus	Yes	No	1	0	Brassicaceae
Rhododendron	Yes	Yes	1	0	Ericaceae
Ribes	Yes	Yes	5	0	Grossulariaceae
Robinia	Yes	No	1	0	Fabaceae
Rosa	Yes	Yes	7	2	Rosaceae
Rosmarinus	Yes	No	4	0	Lamiaceae
Rubus	Yes	Yes	6	0	Rosaceae
Rudbeckia	Yes	No	8	0	Asteraceae
Salix	No	Yes	1	0	Salicaceae
Salvia	Yes	No	6	0	Lamiaceae
Sambucus	Yes	Yes	2	0	Adoxaceae
Saxifraga	Yes	Yes	1	0	Saxifragaceae

Plant Genera	Exotic Species	Native Species	Cultivated	Unultivated	Family
Scabiosa	Yes	No	2	0	Dipsacaceae
Sedum	Yes	Yes	7	0	Crassulaceae
Silene	Yes	Yes	1	2	Caryophyllaceae
Sisymbrium	Yes	No	2	9	Brassicaceae
Solidago	Yes	Yes	4	2	Asteraceae
Spiraea	Yes	Yes	6	0	Rosaceae
Stachys	Yes	Yes	4	0	Lamiaceae
Symphoricarpos	Yes	Yes	3	0	Caprifoliaceae
Tanacetum	Yes	Yes	1	0	Asteraceae
Taraxacum	Yes	Yes	4	2	Asteraceae
Thymus	Yes	No	4	0	Lamiaceae
Tilia	Yes	No	3	0	Malvaceae
Tragopogon	Yes	No	1	10	Asteraceae
Trifolium	Yes	Yes	1	0	Fabaceae
Tropaeolum	Yes	No	1	0	Tropaeolaceae
Verbena	Yes	Yes	2	0	Verbenaceae
Veronicastrum	Yes	No	1	0	Plantaginaceae
Viola	Yes	Yes	4	0	Violaceae
Zigadenus	N/A	N/A	0	2	Melanthiaceae



Figure A-2. Distribution of pollinator groups in cultivated and uncultivated green space across n = 22 sites, based on monthly sampling data.



Figure A-3. Variance/mean ratios for pollinator groups in cultivated and uncultivated green space across n = 22 sites, based on monthly sampling data. Dashed line indicates variance = mean (Poisson distributional assumption).

Table A-2. Models for different pollinator groups using monthly sampling data ranked by smallsample corrected Akaike Information Criterion (AICc). Model selection was based on Poisson and negative binomial (NB) error distributions with and without accounting for zero inflation (π). Models for bumble, honey, and pollen pants bees also accounted for global and location-specific dispersion (φ) and location-specific zero-inflation.

ΔAICc	df	Family*	π^\dagger	$NB \phi^{\dagger}$	ΔAICc	df	Family*	π^\dagger	$NB \phi^{\dagger}$
Bumble Bees						Ро	llen Pants Bees		
0.0	13	NB1	0	2	0.0	12	NB1	0	1
0.9	12	NB1	0	1	2.8	13	NB1	0	2
2.3	13	NB1	1	1	2.8	13	NB1	1	1
3.4	12	NB2	0	1	2.8	15	NB2	2	2
5.0	14	NB1	2	1	3.2	14	NB2	2	1
5.1	13	NB2	1	1	4.7	12	NB2	0	1
6.2	13	NB2	0	2	5.3	15	NB1	2	2
8.0	14	NB2	2	1	5.8	13	NB2	0	2
8.0	14	NB2	1	2	6.1	14	NB1	2	1
10.9	15	NB2	2	2	6.6	13	NB2	1	1
32.0	12	Poisson	1	_	9.3	14	NB2	1	2
33.9	13	Poisson	2	_	11.8	14	NB1	1	2
44.0	11	Poisson	0	_	150.3	13	Poisson	2	_
NA [‡]	14	NB1	1	2	156.2	12	Poisson	1	_
NA [‡]	15	NB1	2	2	259.3	11	Poisson	0	_
		Honey Bees					Flies		
0.0	14	NB2	2	1	0.0	12	NB2	0	1
0.1	13	NB2	0	2	0.4	12	NB1	0	1
1.7	12	NB2	0	1	2.8	13	NB2	1	1
2.5	15	NB2	2	2	3.2	13	NB1	1	1
2.6	13	NB2	1	1	9.8	12	Poisson	1	_
2.7	14	NB2	1	2	10.7	11	Poisson	0	_
6.9	12	NB1	0	1			Wasps		
9.7	13	NB1	0	2	0.0	12	NB1	0	1
9.7	13	NB1	1	1	0.1	13	NB2	1	1
12.6	14	NB1	2	1	0.2	13	NB1	1	1
14.6	15	NB1	2	2	1.9	12	NB2	0	1
23.2	14	NB1	1	2	3.0	12	Poisson	1	_
200.0	13	Poisson	2	_	47.3	11	Poisson	0	_
205.2	12	Poisson	1	_		0	ther Pollinators		
290.3	11	Poisson	0	_	0.0	12	NB1	0	1
	H	airy Belly Bees			2.8	13	NB1	1	1
0.0	12	NB1	0	1	5.1	12	NB2	0	1
2.6	13	NB1	1	1	7.9	13	NB2	1	1
4.2	12	NB2	0	1	18.3	12	Poisson	1	_
6.0	13	NB2	1	1	27.7	11	Poisson	0	_
7.8	12	Poisson	1	_		-			
33.5	11	Poisson	0	_					

* NB1 = negative binomial, variance increases linearly with mean, NB2 = negative binomial, variance increases quadratically with mean

 † 0 = not estimated, 1 = single global parameter, 2 = location-specific parameters, – = not applicable

[‡] NA = models did not converge

df = degrees of freedom

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Terms*	ΔAICc	df	Terms*	ΔAICc	df
Bumble Bees			Flies		
L + M + L:M	0.0	11	L	0.0	4
L + M + P + L:M	1.9	12	Intercept-only	2.4	3
L + M + T + L:M	2.5	12	L + M	3.6	7
L + M + T + P + L:M	4.6	13	Μ	6.1	6
L + M	9.1	8	L + M + L:M	6.8	10
L	9.2	5	L + M + T + L:M	8.8	11
М	31.0	7	L + M + P + L:M	9.2	11
Intercept-only	36.6	4	L + M + T + P + L:M	11.4	12
Honey Bees			Wasps		
L + M + L:M	0.0	11	М	0.0	6
L + M + T + L:M	2.0	12	Intercept-only	0.6	3
L + M + P + L:M	2.5	12	L + M + L:M	0.9	10
L + M + T + P + L:M	4.6	13	L + M	2.2	7
L + M	5.4	8	L	2.5	4
L	9.7	5	L + M + T + L:M	3.4	11
Μ	12.0	7	L + M + P + L:M	3.4	11
Intercept-only	15.9	3	L + M + T + P + L:M	6.0	12
Hairy Belly Bees			Other Pollinators		
L + M + L:M	0.0	10	L + M + L:M	0.0	10
L + M + T + L:M	0.1	11	L + M + T + L:M	1.6	11
L + M + P + L:M	1.0	11	L + M + P + L:M	2.6	11
L + M + T + P + L:M	1.9	12	L + M + T + P + L:M	4.3	12
L + M	7.3	7	М	5.5	6
Μ	10.3	6	L + M	7.8	7
L	15.2	4	Intercept-only	16.5	3
Intercept-only	16.5	3	М	18.7	4
Pollen Pants Bees					
L + M + T + L:M	0.0	11			
L + M + T + P + L:M	1.5	12			
L + M + L:M	1.9	10			
L + M + P + L:M	4.1	11			
L + M	8.4	7			
L	8.4	4			
М	9.6	6			
Intercept-only	9.6	3			

Table A-3. Models for different pollinator groups using monthly sampling data ranked by smallsample corrected Akaike Information Criterion (AICc). Model selection was based on fixed terms.

* L = location (cultivated and uncultivated green space), M = month (June, July, August, September), T = temperature, P = atmospheric particulate matter < 2.5 μ m (pm2.5), and L:M = interaction between location and month

df = degrees of freedom

Table A-4. Models for different pollinator groups using aggregated sampling data ranked by small-sample corrected Akaike Information Criterion (AICc). Model selection was based on Poisson and negative binomial (NB) error distributions with and without accounting for zero inflation (π).

ΔAICc	df F	amily*	π^{\dagger}	ΔAICc	df	Family*	π^\dagger
Bu	mble Bees				Flies		
0.0	3 N	IB1	0	0.0	3	NB1	0
3.0	4 N	IB1	1	0.2	3	NB2	0
7.6	3 N	IB2	0	3.0	4	NB1	1
10.6	4 N	IB2	1	3.2	4	NB2	1
234.6	2 P	oisson	0	63.7	2	Poisson	0
237.3	3 P	oisson	1	66.4	3	Poisson	1
He	oney Bees			I	Vasps		
0.0	3 N	IB1	0	0.0	3	NB2	0
3.0	3 N	IB2	0	0.1	3	NB1	0
3.0	4 N	IB1	1	3.0	4	NB2	1
6.0	4 N	IB2	1	3.1	4	NB1	1
599.4	2 P	oisson	0	141.3	2	Poisson	0
602.1	3 P	oisson	1	144.0	3	Poisson	1
Hairy	y Belly Bees			Other	Pollinato	ors	
0.0	3 N	IB1	0	0.0	3	NB1	0
0.0	3 N	IB2	0	0.2	3	NB2	0
0.6	4 N	IB1	1	3.0	4	NB1	1
0.8	4 N	IB2	1	3.3	4	NB2	1
20.7	3 P	oisson	1	24.4	2	Poisson	0
57.1	2 P	oisson	0	27.1	3	Poisson	1
Polle	n Pants Bees	5					
0.0	3 N	IB1	0				
0.4	3 N	IB2	0				
3.0	4 N	IB1	1				
3.4	4 N	JB2	1				
218.3	2 P	oisson	0				
221.0	3 P	oisson	1				

* NB1 = negative binomial, variance increases linearly with mean, NB2 = negative binomial, variance increases quadratically with mean

 $^{\dagger}0$ = not estimated, 1 = single global parameter

df = degrees of freedom

with and without bee nower at	Junuanee.					
Terms*	ΔAICc	df	Terms [*]		ΔAICc	df
Bumble Bees				Flies		
F	0.0	3	F		0.0	3
Intercept-only	16.3	2	Intercept-only		1.2	2
Honey Bees				Wasps		
F	0.0	3	Intercept-only	-	0.0	2
Intercept-only	5.0	2	F		2.6	3
Hairy Belly Bees	S			Other Pollinators		
F	0.0	4	Intercept-only		0.0	2
Intercept-only	2.5	3	F		0.9	3
Pollen Pants Bee	S					
F	0.0	3				
Intercept-only	1.4	2				
$* \Gamma = \log(\log f \log \log$						

Table A-5. Models for different pollinator groups using aggregated sampling data ranked by small-sample corrected Akaike Information Criterion (AICc). Selection was based on models with and without bee flower abundance.

 $F = \log(\text{bee flower abundance})$

df = degrees of freedom