ORIGINAL RESEARCH ARTICLE

Apple flower-visiting insects' diversity and abundance in selected central Kenya orchards

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Abstract
Flower-visiting insects are essential in maintaining a healthy and productive agricultural landscape through ecosystem services such as pollination. Fruits are important sources of vitamins and micronutrients, and several fruit crops depend on animal pollination, which enhances their nutritional content. Besides honey bees, apple orchards can sustain a large number of arthropod species that also aid in pollination. In this present study, we assessed the diversity and abundance of insect flower visitors in six apple orchards in Nyeri and Laikipia East. Six plots, each with more than 20 apple trees, were purposefully selected. Data were collected through timed visual searches and sweep netting. Sampling was done from 0900 hours to 1700 hours, six days a week, for five months consecutively in 2019. Diversity indices were computed using the Shannon-Wiener diversity index, while abundance patterns were displayed using species abundance curves. Differences in species diversity and abundance between sites were compared using a one-way analysis of variance. A total of 1,221 insects belonging to 23 families, 82 species, and 4 orders (Hymenoptera, Lepidoptera, Coleoptera, and Diptera) were recorded. The order Hymenoptera (bees, wasps, and ants) was the most abundant, with 1,176 individuals, and had the most species-rich taxa, with 56 species in 9 families. The order Coleoptera (beetles) was second, with 26 individuals and 12 species in 6 families. Lepidoptera were the least abundant with 10 individuals and the least species-rich taxa with 7 species in 5 families, followed closely by Diptera with 7 individuals and 7 species in 3 families. There were significant differences in flower visitors' composition among the six sites. The study provides important information on the status of key apple flower visitors, which can guide orchard management practises to increase apple yield through pollinator conservation. Conserving apple pollinators will enhance fruit production, promote the livelihoods of farmers, and contribute to the national economy.

Keywords Apple flower visitors, Diversity, Abundance, *Malus domestica*, ecosystem services

1.0 Introduction
Approximately 87% of plant species on a global scale are pollinator-dependent (Ollerton et al., 2011), and this percentage may increase to 94% in the tropics. Pollinators contribute an

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estimated $220 billion per year to food security (Gallai et al., 2009), accounting for 9.5 percent of global agricultural food production. The presence of insect pollinators in agroecosystems significantly enhances the quality and quantity of yields (Kasina et al., 2007), as well as an agroecosystem's resilience. Several studies have shown that insects are important providers of pollination services globally, with the main pollinators being bees and some flies (Potts et al., 2016). In the past, most of the credit was given to manage honeybees. However, recent studies have recognized the more vital role wild bees and other pollinators play in contributing to global crop pollination than previously assumed (Breeze et al., 2011). Varied ecosystems show diverse groups of pollinators that ensure pollination happens even when climatic conditions are unpredictable (Vamosi et al., 2006).

Similarly, studies have reported gradual declines in both pollination services and pollinators globally due to habitat destruction and land use intensification (Potts et al., 2010). However, the decline is tentative, considering the lack of comprehensive data (LeBuhn et al., 2013). The quantification of pollinator diversity and abundance in natural and agricultural ecosystems is crucial. Continued land-use change, pest and disease emergence, and other human-induced phenomena pose threats to pollinator populations globally (Vanbergen et al., 2013). Globally, apples are an important fruit crop that benefits from pollination services. It is important to document apple pollinators and their status nationally to inform orchard management practises that will enhance pollinator diversity during the blooming period.

Apple, *Malus domestica,* is among the most important fruits in temperate regions, with the highest economic impact of the Rosaceae family (FAO, 2015). Apple farming is expanding into tropical and subtropical areas. China is the leading producer of apples, followed by the USA. The main producers in Africa are South Africa, Morocco, and Egypt, with a few cases in Kenya and Uganda (FAOSTAT, 2017). In Kenya, apples are grown by small- to medium-scale farmers mainly for the domestic market and a few for exports. Generally, apples have a gametophytically self-incompatible (SI) system, which tends to prevent inbreeding and promotes outcrossing (Stern et al., 2001). Therefore, most of the known apple varieties, being self-incompatible, rely on cross-pollination for fruit set (Delaney & Tarpy, 2008).

In Kenya, the supply of locally produced temperate fruits is limited in quantity, quality, and seasonality. Therefore, there is a need to maintain and promote pollination services as a key and inseparable component of regular and consistent apple production (Sharma et al., 2004). Insufficient pollination of apple trees may lead to poor or low fertilization rates, uneven fruit sets, and high rates of fruit drop. In addition, it leads to a long maturing period in comparison to adequately pollinated fruits, which usually assure uniform quality and maturity (Fell, 2005). Despite the importance of insect pollinators in *M. domestica* production, information on the diversity and abundance of insect pollinators of *M. domestica* in Kenya is scarce. Previous studies have focused on other fruit trees, but none have been done on locally grown temperate fruits, despite their health and economic benefits. Data on arthropod diversity is important as it gives an indication of the diversity of pollinators in agricultural ecosystems and may serve as an indicator of the quality of a particular habitat (Klein et al., 2006).

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Given the scarcity of information on *Malus domestica* insect flower visitors in Kenya, this study bridges the data gap by providing information on the status of pollinators in apple orchards with the aim of promoting pollinator conservation in orchards and ultimately increasing apple yields, food security, and nutrition security. The study identified the key pollinators of apples in each region and within orchards. This is vital when implementing effective pollination service management.

2.0 Materials and methods

2.1 Study sites

The study was done in six apple orchards: three in Laikipia East (Ngobit Ward) and three in Nyeri (Ihwa, Mweiga, and Giakanja), the two main apple production areas in Central Kenya. The study sites were purposefully selected based on the number of apple trees present, acreage, apple varieties grown, and management regimes. Farmers mainly grew two varieties of apples, with the 'Wambugu' semi-arid apple variety being the main one. The apples have two flowering seasons in a year, with the main season between September and December.

2.1.1 Nyeri County orchards

In Nyeri orchards, farmers practised mixed farming, and farm sizes ranged from 0.75 to 1.75 acres. The soils are loam or red soils. The monthly mean temperature in the county is about 12.8–20.8 ^{o}C (GoK, 2013). There are two rain seasons: March to May, with long rains of 1200–1600 mm, and October to December, with short rains of 500–1500 mm. Three orchards were selected as study sites and labelled Farms A, B, and C**.** Farm A was 0.75 acres with 21 apple trees, lying at an elevation of 2104 m with GPS coordinates S-0.347042 E 36.870781. Other crops on-site were *Solanum tuberosum*, *Phaseolus vulgaris*, *Citrus limon*, *Passiflora edulis*, and *Persea americana*. Farm B was 1.75 acres with 130 apple trees lying at an elevation of 2107 m; GPS coordinates were S-0.43117 E-36.88498. Farm B was situated in a tea-growing area. Other crops grown included *Solanum muricatum*, *Solanum betaceum*, *Brassica oleracea*, *Brassica oleracea* var. capitata, *Cucurbita pepo*, *Prunus persica*, *Persea americana*, *Diospyros texana, and Solanum tuberosum*, intercropped with *Phaseolus vulgaris* and *Zea mays*. Farm C was 0.75 acres with 29 apple trees, lying at an elevation of 2129m; GPS coordinates were S -0.46698 E 36.94111. Other food crops grown on-site were *Coffea arabica*, *Zea mays*, *Mangifera indica*, *Phaseolus vulgaris*, *Ipomoea batatas*, *Solanum tuberosum*, and *Musa acuminata*.

2.1.2 Laikipia East orchards

Laikipia orchards were large farms surrounded by a savannah landscape characterised by grasses and small, dispersed Acacia and Grevillea tree species. The annual mean temperature in the county ranges between 16^{0} C and 26^{0} C. The county receives relief rainfall of between 400 and 750mm annually. The farms had artificial dams as sources of water for farming activities. The soils were black cotton soils that support varied farming activities. Three orchards were selected as study sites and labelled Farms D, E, and F. Farm D was 6 acres with over 200 apple trees, located at an elevation of 2086m (GPS coordinates: S-0.05274 E-36.66971) on a relatively gently sloping area. Other crops on site were *Phaseolus vulgaris*, *Solanum muricatum*, *Lens culinaris*, *Vitis vinifera*, *Solanum tuberosum*, *Coriandrum sativum*, *Cucumis metuliferus*, *Opuntia ficus*, *Ipomoea batatas*, *Amaranthus viridis, Cleome gynandra*, *Prunus persica*,

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Saccharum officinarum, *Punica granatum,* etc. Farm E lay at an elevation of 1865m, S-0.06202, E 36.68145, with 133 apple trees. Other crops on site were *Allium cepa*, *Brassica oleracea*, *Beta vulgaris*, *Prunus persica*, *Saccharum officinarum,* and rows of apple grafting beds. Farm F lies at an elevation of 1963m, S-0.06200 E 36.67699, with over 90 apple trees. Other crops on site were *Allium cepa*, *Brassica oleracea*, *Citrus limon*, *Cleome gynandra*, *Amaranthus viridis, Beta vulgaris*, *Saccharum officinarum*, and *Cucumis metuliferus*.

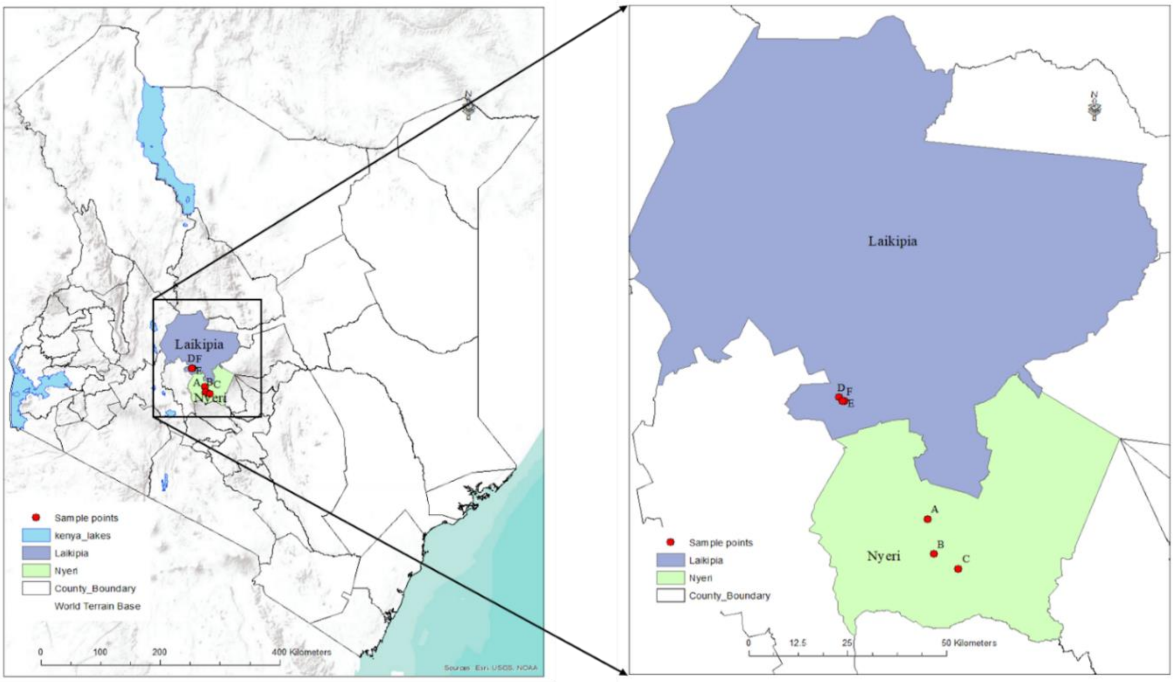

Figure 1: A map of Kenya showing the six study sites in Nyeri and Laikipia East, Central Kenya region

2.2. Sampling methods

The pollinator surveys were conducted from June to December 2019. A daily census of flower visitors was done using two standardised protocols, i.e., aerial netting and timed visual searches.

2.3 Data collection methodology

At least 20 plants that were flowering during the study period were selected and marked. Each farm was sampled for four full days each month during the blossom period. Aerial netting was done in the morning, midday, and afternoon sessions (0900–1100 hours, 1200–1400 hours, and 1500–1700 hours) during the short and long flowering seasons. Surveying was done through visual checks and walking slowly around each selected tree for 5 minutes while observing flowers on branches from ground level up to 3 m to ensure that the observer could easily observe and catch flower-visiting insects. These selected sites were all sampled in a similar order for uniformity during apple bloom in season one (June–July 2019) and season two (Oct–Dec 2019).

The number of flower visitors collected during each sampling session at a particular site was considered an estimate of the species richness and abundance. Captured insect specimens in

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aerial nets were immobilised in killing jars containing ethyl acetate. The captured flower visitors were well labelled and pinned in insect collection boxes using entomological pins. Identification was done at the National Museum of Kenya (NMK) with the assistance of the resident entomologists and taxonomists. Morphological features, standard identification manuals, and a reference specimen at the NMK were used to confirm the identity of the specimen.
Voucher specimens were deposited at the National Museums of Kenya Centre for Bee Biology and Pollination Ecology.

2.4 Data analysis

The data collected was both qualitative and quantitative. For a detailed comparison of species composition among the six farms, a comprehensive list of insect flower visitors was maintained, showing composition percentages on the basis of their abundance. Diversity indices were computed using the Shannon-Wiener diversity index, while abundance was computed using species abundance curves. Differences in species richness and abundance between sites were compared using a one-way analysis of variance (ANOVA). A post hoc analysis following an analysis of variance (ANOVA) was performed using Tukey's multiple comparisons of means at a 95% family-wise confidence level. All statistical analysis was performed using R version 4.1.0 (R Core Team, 2018). The data was presented using tables and graphs.

3.0 Results

3.1. Apple flower visitors' abundance and species composition in Nyeri and Laikipia East orchards

In all the farms, 82 species, totaling 1221 insects, belonging to 23 families and 4 orders, namely, Hymenoptera (96%), Coleoptera (2%), Lepidoptera (1%), and Diptera (1%) were recorded. The most abundant and species-rich order was Hymenoptera (bees, wasps, and ants), while the least abundant were Diptera and Lepidoptera with 10, and 9 individuals, respectively (table 1). Honey bee *Apis mellifera* L. was the most abundant with 850 individuals (69.6%), followed by *Lasioglossum* sp. i with 74 individuals (6.06%), and thirdly *Lasioglossum* sp. ii with 31 individuals (2.5%) (Appendix A, table A1).

Table 1. Insect Orders of apple flower visitors, number of; Families, Species, and their relative abundance in Nyeri and Laikipia East Orchards

Insect Order	No. of families	No. of species	No.of individual insects (abundance)	Percentage (%) representation
Hymenoptera	9	56	1176	96
Coleoptera	6	12	26	2
Lepidoptera	5	7	9	1
Diptera	3	7	10	1

The species accumulation curves (Figure 1) show the rate at which new species were recorded on the farms for the five months. Although the accumulation curve did not flatten in the five months, the data provided a good estimate of the species richness and their abundance in the

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apple farms in Nyeri and Laikipia Orchards. The highest number of species was recorded in Farm E, and the least number of species was recorded in Farm A. Farm D had the highest abundance, while Farm A had the least abundance (Figure 1). There were no significant differences in species abundance between study sites in Nyeri and Laikipia East (p = 0.0534).

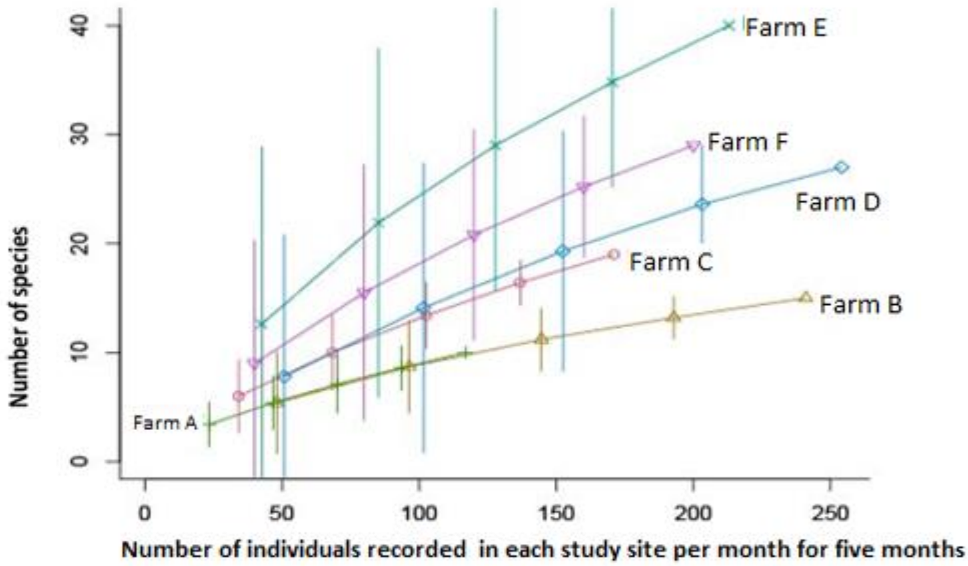

Figure1: Apple flower visitor's species accumulation curves for farmlands A, B, C, D, E and F in Nyeri and Laikipia Orchards

The species accumulation curve (Figure 1) shows the rate at which new species were recorded on the farms for five months. The five-month data provided a good estimate of the species richness and abundance in the apple farms in Nyeri and Laikipia Orchards. Higher species richness was recorded in Farm E, with the least species richness in Farm A.

During apple bloom season one (June-July 2019) and season two (Oct-Dec 2019), the flower visitors diversity varied among farmlands A, B, C, D, E, and F, with farm E having the highest diversity and farm A having the lowest diversity (table 2). However, even after pooling the data, the differences in diversity were not significant (p = 0.0523).

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Table 2: A comparison of Shannon-Weiner Diversity Indices for the Nyeri and Laikipia East Farms

Farm	Elevation	Total TVS abundance (N)	Species richness (n)	Shannon-Weiner Diversity Index (H) Season 1	Shannon-Weiner Diversity Index (H) Season 2	Pooled H
A (Mweiga)	2104m	136	13	0.66	0.57	0.64
B (Ihwa)	2107m	243	16	0.60	0.92	0.93
C (Giakanja)	2129m	171	19	0.59	1.51	1.35
D (Sam's)	2086m	255	28	0.66	1.13	1.13
E (Nyokabi's)	1865m	216	40	0.89	2.49	2.15
F (Wambugu)	1963m	200	30	1.17	1.94	1.94

Using pooled data from all the farms in Nyeri and data from all the farms in Laikipia Orchards, a comparison of species diversity was done (table 3). There was no significant difference in species diversity between Nyeri and Laikipia Orchards ($p = 0.32$).

Table 3: A comparison of Shannon-Weiner Diversity indices for Nyeri and Laikipia Orchards

Region	Shannon-Weiner Diversity Index (H) Season 1	Shannon-Weiner Diversity Index (H) Season 2	Pooled H
Nyeri	0.73	1.13	1.16
Laikipia East	1.14	1.97	1.89

4.0 Discussion

The study of pollinators in orchards has mainly been focused on Hymenoptera; however, pollination in apple orchards includes a wider range of wild insects such as Coleoptera, Diptera, and Lepidoptera (Földesi et al., 2021). The findings from this study show that the order Hymenoptera was the most abundant (96%), but non-Hymenoptera pollinators (4%) were also present in the apple orchards. *Apis mellifera*, the common honey bee, was the most abundant with 850 individuals (69.6%), followed by native bees such as the Lasioglossum species. (Supplementary material, Appendix A, Table A1), an indicator that native bees are also important and that their conservation and management in orchards are crucial.

The high abundance of honey bees could be attributed to bee hives being placed within or near apple orchards to increase the success rate of pollination (Corbet et al., 1991). These findings are in line with the findings of Raj and Mattu (2014), who found hymenopterans to be the most important insect visitors to apple blossoms in the Himachal-Himalaya region. Mattu (2015) also reported that honey bees comprised a major proportion of insect pollinators on the apple crop in Shimla Hills.

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In a study by Pielou (1975), the author categorized species diversity into low, intermediate, and high based on their Shannon-Wiener index values. The range of low diversity was typically defined as values below 1.0; intermediate diversity ranged between 1.0 and 2.0; and high diversity corresponded to values above 2.0. In this study, the total number of species recorded in Nyeri and Laikipia was 82 (table 1), but the six farms A, B, C, D, E, and F had low to intermediate diversity of insects in season one (table 2). However, in season two, a high species diversity (H = 2.49) was recorded in farm E. There is therefore a need for further research on the influence of adjacent crops on apple pollination, especially competition for pollinators.

The presence of a large number of bees on the farms is a good sign; however, the low diversity of insects in the ecosystem is a cause for concern, as it suggests that the ecosystem is not as resilient as it should be. A diverse ecosystem is better able to withstand changes such as climate change or invasive species. One possible cause for the low species diversity in the apple orchards may be competition for flowers with other plant species, as the apple farms were adjacent to other flowering crops. Besides, the Nyeri and Laikipia regions are characterised by agricultural land use and are subjected to human-induced disturbances. These disturbances pose significant threats to pollinator populations, as highlighted by Potts et al. (2016). Also, pollinator foraging and nesting resources are directly impacted by farm management in terms of their availability and quality in agricultural fields (Requier et al., 2015). Farm practises such as weeding and pest management using pesticides and agrochemicals may have influenced visitation to the apple if done when pollinator activity is heightened. All the farms practised intercropping; therefore, frequency and time of weeding may affect flora composition, nesting site availability, and pollen resources, thus indirectly affecting pollinator diversity and abundance (Rasmont et al., 2005).

Therefore, the study of flower visitors was an important step towards preserving agricultural systems (Klein et al., 2007). Knowledge of apple flower visitors richness, abundance, and diversity is crucial for improving management techniques (Hambäck et al., 2021). The data presented in this study can be valuable for farmers as it enables them to make informed decisions when choosing more targeted and effective pest control methods. Additionally, it can guide farmers in enhancing the surrounding landscape to attract beneficial arthropods that are known to visit their orchards.

5.0 Conclusion

The current study provides a starting point and a baseline survey of species composition in six apple orchards in the central part ~~o~~f Kenya. Across the six farms, the results depict that *Apis mellifera* was the most abundant flower visitor in both seasons. Species richness was higher in Laikipia compared to Nyeri Orchards. The order Hymenoptera had the highest abundance and species richness. The study also points out that the likely pollinators of apple flowers are hymenopterans. By documenting the diversity and abundance of flower visitors on the apple farms, the information can be used to develop management and conservation strategies to protect and enhance the habitats of the species, promoting their survival and function in ecosystems. Overall, this baseline study serves as an important foundation for future research

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and conservation efforts aimed at understanding and protecting the important ecological interactions between plants and their pollinators.

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6.3 Conflict of interest

None.

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Appendix A. Supplementary data

Table A1: Apple Flower visitors composition and abundance in Orchards in Nyeri and Laikipia County

Species	Farm A	Farm B	Farm C	Farm D	Farm E	Farm F	Frequency	% Abundance
Bees								
Apis mellifera	117	187	114	200	117	115	850	69.61507
Seladonia sp.i	0	0	1	0	3	1	5	0.4095
Sphecodes sp.i	0	0	0	1	0	0	1	0.0819
Steganomus sp.i	0	0	0	0	1	0	1	0.0819
Megachile sp.ii	1	0	0	2	0	0	3	0.2457
Xylocopa caffra	0	3	1	0	0	0	4	0.3276
Xylocopa calens	0	0	0	1	0	0	1	0.0819
Xylocopa flavorufa	1	5	0	0	1	0	7	0.573301
Macrogalea candida	0	0	0	1	8	5	14	1.146601
Xylocopa scioensis	0	0	0	1	0	0	1	0.0819
Megachile sp.iii	0	0	0	0	2	0	2	0.1638
Lasioglossum sp.i	4	28	22	2	7	11	74	6.061
Lasioglossum sp.ii	2	5	12	2	3	7	31	2.538903
Lasioglossum sp.iii	1	0	0	5	3	1	10	0.819001
Lasioglossum sp.iv	0	1	3	0	0	2	6	0.4914
Lasioglossum sp.v	1	0	1	2	3	0	7	0.573301
Lasioglossum sp.vi	0	1	0	0	1	0	2	0.1638
Lipotriches sp.i	0	5	0	3	4	1	13	1.064701
Lipotriches sp.iii	0	0	0	0	0	1	1	0.0819
Nomia sp.i	0	0	0	2	4	7	13	1.064701
Unidentified species	0	2	0	1	0	0	3	0.2457
Colletes sp.i	0	0	0	1	1	1	3	0.246
Ceratina ericia	1	0	0	0	0	1	2	0.1638
Ceratina sp.i	3	1	0	0	2	4	10	0.819001
Compsomelissa sp.i	0	0	2	0	0	0	2	0.1638
Ceratina viridis	0	0	0	0	1	4	5	0.4095
Patellapis sp.i	0	2	1	7	0	0	10	0.819
Patellapis sp.ii	0	0	0	4	0	2	6	0.4914
Patellapis sp.iii	0	0	0	0	0	1	1	0.0819
Pseudapis sp.i	0	1	0	1	0	0	2	0.1638
Braunsapis bouyssoui	0	0	0	0	0	5	5	0.4095
Braunsapis leptozonia	1	0	0	4	4	11	20	1.638002
Braunsapis sp.i	0	0	0	2	0	1	3	0.2457
Braunsapis sp.ii	1	0	2	0	0	0	3	0.2457
Wasps								
Micromeriella aureola	0	0	0	0	1	0	1	0.0819
Micromeriella spee	0	0	0	0	1	0	1	0.0819
Ammophila sp.	0	0	0	0	4	0	4	0.3276
Sceliphron sp.	0	0	0	0	0	1	1	0.0819
Tachytes panzeri	0	0	0	0	1	0	1	0.0819
Tiphia sp.	0	0	0	0	0	1	1	0.0819
Polistes sp.	0	1	0	0	0	0	1	0.0819
Scolia sp.	0	0	0	2	7	2	11	0.900901
Synagris analis	1	0	0	0	0	0	1	0.0819
Belonogaster grisecious	0	0	2	0	0	2	4	0.3276
Campsomeriella coelebs	0	0	1	0	3	3	7	0.573301
Campsomeriella madonensis	0	0	0	0	1	0	1	0.0819
Campsomeriella sp.	0	0	3	0	14	0	17	1.392301
Campsomeris sp.	0	0	0	0	1	0	1	0.0819

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Campsomeris sp.i	0	0	0	0	1	0	1	0.0819
Eumenes xanthaspis	0	0	0	0	0	1	1	0.0819
Cathimeris clotheo	0	0	0	0	1	0	1	0.0819
Cathimeris hymenaea	0	0	1	0	1	0	2	0.1638
Butterflies								
Vanessa cardui	0	0	0	1	0	0	1	0.0819
Borbo detecta	0	0	1	0	0	0	1	0.0819
Zizula hylax	2	0	0	0	0	0	2	0.1638
Belenois aurota	0	0	0	1	0	0	1	0.0819
Catopsilia florella	0	0	0	1	0	0	1	0.0819
Beetles								
Pachnoda ephippiata	0	0	0	1	4	6	11	0.900901
Cheilomones lunata	0	0	0	1	0	0	1	0.0819
Megalognatha reflecta	0	0	1	0	0	0	1	0.0819
Megalognatha reflecta Lab	0	0	1	0	0	0	1	0.0819
Micrelaphinis adupersula	0	0	0	0	1	0	1	0.0819
Cheilomones propinqua	0	0	1	0	0	0	1	0.0819
Hapalochrus amplipennis	0	0	0	0	1	0	1	0.0819
Hedybius sp.	0	0	0	0	0	1	1	0.0819
Lagria cyanicollis	0	0	0	3	2	0	5	0.4095
Lidalia intermedia	0	0	0	1	0	0	1	0.0819
Lycus sp.	0	0	0	0	1	0	1	0.0819
Moths								
Macroglossum rotundata	0	1	0	0	1	0	2	0.1638
Flies								
Musca domestica	0	0	0	1	1	0	2	0.1638
Eumerus sp.	0	0	0	0	1	0	1	0.0819
Allograpta nasuta	0	0	0	0	0	1	1	0.0819
Allograpta varipes	0	0	0	0	1	0	1	0.0819
Ischiodon aegyptius	0	0	0	0	1	0	1	0.0819
Aprosterna sp.	0	0	0	0	1	0	1	0.0819
Eristalinus taeniops	0	0	1	1	0	0	2	0.1638
Oplodontha sp.	0	0	0	0	0	1	1	0.0819
Grand Total	136	243	171	255	216	200	1221	

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