What You Don't Know Won't Hurt You: A Survey of Cryptic Insect Biodiversity on Duke University's Campus

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Abstract

We surveyed soil-dwelling insects and other arthropods across eight sites on Duke University's West Campus, collecting and identifying specimens to the taxonomic order. Results revealed Acari (mites and ticks) and Collembola (springtails) as the dominant groups, reflecting their adaptability to varied microhabitats and reliance on moist, organically rich soils. Site-specific diversity highlighted the influence of vegetation, microclimate, and habitat structure on insect and arthropod populations. Based on site-specific data, Duke's campus supports millions of arthropods, underscoring the ecological significance of urban green spaces. These findings emphasize the importance of biodiversity conservation in urban ecosystems and call for further research on the critical ecological roles of soil arthropods.

Keywords: insects | cryptic biodiversity

Introduction

Insects, class Insecta, are a principal group of phylum Arthropoda and comprise up to 80% of known animal species [1]. There are as many as 30 million estimated insect species, of which over three-quarters are yet undiscovered [1]. Despite this prolific biodiversity, insects face global declines [1]. On average, terrestrial insect abundance is declining at a rate of 9% each decade [2]. Climate change, habitat loss, pesticides, and pollution are principal factors causing these declines [1]. Additionally, urbanization has significant effects on insect populations [3]. Urbanization—associated with human-induced stressors such as habitat loss, deforestation, artificial lighting, and land use—results in, on average, approximately a 40% decrease in both insect abundance and richness compared to conserved areas [3].

Soil-dwelling arthropods, in particular, have experienced declines. Soil arthropods in temperate forests demonstrate declines in abundance, with increased precipitation as a key explanatory factor [4]. Climate change is predicted to increase extreme precipitation events [5], thus the effects of increased precipitation on the abundance of these organisms will likely increase over time. However, climate change is simultaneously predicted to increase drought and decrease soil moisture [6]. Dry conditions likewise threaten soil arthropods, with desiccation-prone species experiencing declines in abundance with lower average rainfall [7]. Declines in soil arthropod species are ecologically important, as these organisms are crucial ecosystem engineers due to their contributions to soil fertility and nutrient cycling [8].

Informed by these threats facing insects, we sought to reveal, identify, and measure cryptic soil-dwelling urban insect biodiversity on Duke University's West Campus in Durham, North Carolina, U.S. We collected and assessed data as a semester-long class project for Entomology (Biology 349L), an upper-level undergraduate biology course. Our goals in conducting this study were to A) assess and quantify the cryptic insect biodiversity present on Duke's campus and B) provide information to raise awareness about the importance of insects and their declines.

2 | Methods

2.1 | *Sample Collection*

To establish a representative survey of Duke University's West campus, leaf litter and topsoil samples were collected from eight regions across campus (Figure 1). These eight regions were strategically selected to ensure an even distribution across the area Duke's campus occupies and to highlight variations in insect population density within campus hotspots. We collected ten samples from each area using haphazard sample site selection. The dimensions of the collection area were demarcated using a sheet of standard 8.5 by 11 inch letter paper, either full size or folded in half. Sampling was conducted during September and November of 2024 to ensure consistent environmental conditions between the regions, as well as to ensure that insects had not begun overwintering, thus drastically changing sample makeup. After clearing dry surface debris, we collected the moist leaf litter (~2 inches) and approximately the first inch of moist topsoil at each of the ten sample sites for each area. The samples were stored in labeled, airtight plastic bags to preserve moisture and prevent contamination during transportation to the laboratory.

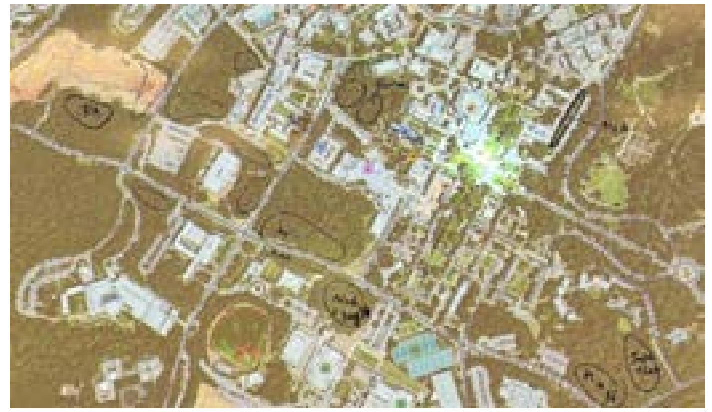

Figure 1. Project sample sites on Duke University's West Campus.

Berlese funnels were used to extract insects from the soil samples. Our Berlese funnels were categorized into "small" or "big" sizes, either holding one or five samples, respectively. The "small" Berlese funnels were constructed using a 25.4 cm diameter plastic funnel to hold each sample and an approximately 38.7 cm2 metal mesh sheet (each hole of the small mesh measured 0.2286 cm2) placed at the base of the funnel to prevent the sample soil from passing through while allowing small insects and other arthropods to pass through. The "small" Berlese funnels were placed over mason jars containing a 1.2 cm depth of 70% ethanol to collect and preserve the insect specimens that fell through the mesh. The "big" Berlese funnel was constructed using a 12 in diameter plastic funnel and a 930 cm2 metal mesh sheet (each hole of the big mesh measured 0.635 cm2). In the same way as the "small" Berlese funnels, the "big" Berlese funnels were placed over 5-gallon buckets containing a 1.2 cm depth of 70% ethanol to collect and preserve the insect specimens from the sets of five samples. After 24-48 hours of extraction time in the funnels, the ethanol-preserved specimens were transferred to petri dishes for long-term storage and examination.

2.2 | *Identification & Estimation*

We used microscopes to identify and count insects and other arthropods—identified to taxonomic order—in each petri dish. Using these counts, we summed the number of insects in each order for all samples of each sampled region to get a total count of insects per order for each survey region. Based on these survey area totals, we found the mean

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count for each insect order for each sample collected by dividing these totals by the number of samples collected in each region. To estimate the total number of insects per order for each sample region—beyond the limited sample sites within the area that we surveyed—we multiplied the mean insect order count per sample by the area (meters2) of the sample region. We then extrapolated these estimates to Duke University's West Campus and Durham. For these calculations, we multiplied the total count estimate for each order across all site areas by the area of Duke's campus divided by the total site area, and by the area of Durham [9] divided by the total site area, respectively:

Total insects (by order) in a set of regional samples =

$$N_{order,\, sample\ set} = \sum_{i=1}^{10} n_{sample,\, i}$$

Mean insects (by order) per regional sample =

$$X_{sample,\, region} = \frac{N_{order,\, sample\ set}}{10\ samples}$$

Insect (by order) per unit area in a region =

$$\rho_{region} = \frac{X_{sample, region}}{A_{region}}$$

Total insects in a region =

$$N_{order,\, region} = \rho_{region} * A_{region}$$

3 | Results

The following tables present a detailed breakdown of the insect counts observed in each sample region on Duke University's West Campus. These tables summarize raw counts by taxonomic order, mean counts across samples, and extrapolated estimates to represent total insect populations within each region and across larger areas (West Campus and Durham). For each table, insect orders and other arthropod orders are listed in black and gray font, respectively.

3.1 | *Site 1*

Sample 1 is located in the forested area behind Duke University's chapel, specifically on the side closest to the chapel. The total area of this site measures 8,154.84 m², with a sampling area of 0.604 m² (10 samples of approximately 8.5 × 11 inches). Samples were collected across multiple dates between September and November 2024 to capture a representative survey of the insect and arthropod population under consistent environmental conditions. The distance of the site from a central reference point is 460.88 m.

Total Count	n =	Mean per Sample	n =	Total Estimate for Area	n =
Blattodea	1	Blattodea	0.1	Blattodea	1350.14
Coleoptera	13	Coleoptera	1.3	Coleoptera	17551.81
Collembola	73	Collembola	7.3	Collembola	98560.15
Dermaptera	1	Dermaptera	0.1	Dermaptera	1350.14
Diplura	1	Diplura	0.1	Diplura	1350.14
Hymenoptera	18	Hymenoptera	1.8	Hymenoptera	24302.50
Protura	1	Protura	0.1	Protura	1350.14
Psocoptera	14	Psocoptera	1.4	Psocoptera	18901.95
Thysanura	22	Thysanura	2.2	Thysanura	29703.06
Acari	820	Acari	82	Acari	1107114.04
Araneae	32	Araneae	3.2	Araneae	43204.45
Isopoda	12	Isopoda	1.2	Isopoda	16201.67
Myriapoda	11	Myriapoda	1.1	Myriapoda	14851.53

Table 1.

Acari (mites and ticks) emerged as the most abundant group, comprising over 82% of the total arthropod count. Other frequently observed orders included Coleoptera (beetles) and Collembola (springtails), which varied significantly across individual samples. Less abundant orders, such as Diplura, Protura, and Dermaptera, were represented by only a single individual each. Additionally, the data revealed that Hymenoptera (ants, bees, wasps) exhibited notable activity during mid-October. Extrapolated estimates indicated that the site supports approximately 1,107,114 individuals of Acari and 29,703 individuals of Thysanura (silverfish).

3.2 | *Site 2*

Sample 2 was collected from the lawn behind the Biological Sciences Building on Duke University's campus. This site encompasses an area of 439.9 m^2, with sampling conducted across 0.604 m^2 (approximately 8.5 × 11 inches for each of the 10 samples). The samples were taken on various dates, primarily during November 2024, to ensure representative data under consistent environmental conditions.

Total Count	n =	Mean per Sample	n =	Total Estimate for Area	n ≈
Blatteria	3	Blatteria	0.3	Blatteria	55.569
Coleoptera	28	Coleoptera	2.8	Coleoptera	518.644
Collembola	9	Collembola	0.9	Collembola	166.707
Diplura	3	Diplura	0.3	Diplura	55.569
Diptera	7	Diptera	0.7	Diptera	129.661
Hemiptera	1	Hemiptera	0.1	Hemiptera	18.523
Homoptera	1	Homoptera	0.1	Homoptera	18.523
Hymenoptera	3	Hymenoptera	0.3	Hymenoptera	55.569
Acari	79	Acari	7.9	Acari	1463.317
Araneae	6	Araneae	0.6	Araneae	111.138
Myriapoda	4	Myriapoda	0.4	Myriapoda	74.092

Table 2.

Acari (mites and ticks) emerged as the most abundant, accounting for approximately 53.5% of the total arthropod count. Other prominent orders included Coleoptera (beetles) and Collembola (springtails), which reflected the presence of organic debris in the grassy terrain. Some orders, such as Hemiptera (true bugs) and Homoptera (leafhoppers), were observed in very low numbers, with only one individual each recorded across all samples. Moderate representation was noted for Diplura (two-pronged bristletails) and Blattodea (cockroaches), though they were not dominant. Extrapolated data suggests a total population of approximately 1,463 individuals of Acari and 519 individuals of Coleoptera within the entire sampling area.

3.3 | *Site 3*

Sample 3 was collected from the area adjacent to the Campus Pharmacy on Duke University’s campus. The total site area measures 5,673.01 m^2, with a perimeter of 322.93 m. Samples were collected on various dates between late September and early November 2024, ensuring representative data under consistent environmental conditions. The sampling area consisted of a combination of compacted soil and limited vegetation, characteristic of a semi-urbanized campus location. Each sample measured approximately 8.5 × 11 inches, with the total sampled area amounting to 0.604 m^2.

Total Count	n =	Mean per Sample	n =	Total Estimate for Area	n ≈
Acari	103	Acari	10.3	Acari	96741.72682
Collembola	7	Collembola	0.7	Collembola	6574.680464
Hymenoptera	4	Hymenoptera	0.4	Hymenoptera	3756.960265
Thysanoptera	23	Thysanoptera	2.3	Thysanoptera	21602.52152
Blattodea	1	Blattodea	0.1	Blattodea	939.2400662
Diptera	4	Diptera	0.4	Diptera	3756.960265
Coleoptera	3	Coleoptera	0.3	Coleoptera	2817.720199
Araneae	4	Araneae	0.4	Araneae	3756.960265
Isopoda	3	Isopoda	0.3	Isopoda	2817.720199
Total	152				

Table 3.

Sample 3, collected near the Campus Pharmacy, exhibited diverse arthropod populations, with Acari (mites and ticks) being the most abundant order. Acari accounted for a total of 103 individuals across all samples, representing a mean count of 10.3 per sample. Extrapolated estimates suggest that this site supports approximately 96,742 individual Acari, indicating a high density of microarthropods in this area. Thysanoptera (thrips) was the second most abundant order, with a total of 23 individuals and an extrapolated estimate of 21,603 individuals.

Less abundant orders included Collembola (springtails), Hymenoptera (ants, bees, wasps), and Diptera (flies), each with fewer than 10 individuals observed. Notably, rarer arthropods, such as Blattodea (cockroaches) and Coleoptera (beetles), were represented by a single individual each, while Isopoda (roly-polies) and Araneae (spiders) were observed in moderate numbers but were not dominant.

3.4 | *Site 4*

Sample 4 was collected from the Card Lot area on Duke University’s campus, an expansive open site covering 10,862.16 m^2 with a perimeter of 399.78 m. Sampling focused on a total area of 0.302 m^2, with samples measuring approximately 8.5 × 11 inches each. The samples were collected on multiple dates, ensuring data reliability under consistent environmental conditions. This area, characterized by a mix of hard surfaces and nearby vegetation, was

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characteristic of a semi-urban habitat.

Total Count	n =	Mean per Sample	n =	Total Estimate for Area	n ≈
Acari	153	Acari	15.3	Acari	183433.83
Araneae	51	Araneae	5.1	Araneae	61144.61
Coleoptera	24	Coleoptera	2.4	Coleoptera	86321.80
Collembola	106	Collembola	10.6	Collembola	381254.62
Diplura	4	Diplura	0.4	Diplura	14386.97
Diptera	2	Diptera	0.2	Diptera	7193.48
Ephemeroptera	3	Ephemeroptera	0.3	Ephemeroptera	10790.23
Hymenoptera	29	Hymenoptera	2.9	Hymenoptera	104305.51
Isopoda	4	Isopoda	0.4	Isopoda	14386.97
Lepidoptera	6	Lepidoptera	0.6	Lepidoptera	21580.45
Myriapoda	6	Myriapoda	0.6	Myriapoda	21580.45
Protura	7	Protura	0.7	Protura	25177.19
Psocoptera	2	Psocoptera	0.2	Psocoptera	7193.48
Scorpiones	4	Scorpiones	0.4	Scorpiones	14386.97
Thysanoptera	28	Thysanoptera	2.8	Thysanoptera	100708.77

Table 4.

Sample 4 revealed a rich diversity of arthropods, with Acari (mites and ticks) being the most abundant order, comprising a total of 153 individuals across all samples. The mean count of Acari was 15.3 per sample, and extrapolated estimates suggest a total population of approximately 183,434 Acari in the entire site. Collembola (springtails) were the second most prevalent, with a total of 106 individuals observed and an estimated population of 381,255 individuals.

The site also featured notable numbers of Araneae (spiders) and Coleoptera (beetles), with total counts of 51 and 24, respectively. Rarer orders, such as Diplura, Scorpiones (scorpions), and Psocoptera (booklice), were represented by only a few individuals each. Additionally, Hymenoptera (ants, bees, wasps) were moderately abundant, with 29 individuals recorded and an estimated total of 104,306 individuals.

Other arthropods, including Isopoda (roly-polies), Myriapoda (millipedes and centipedes), and Lepidoptera (moth and butterfly larvae), were observed, albeit at a lower rate. Extrapolated population estimates for these orders ranged from 14,387 to 21,580 individuals, reflecting their presence in the site’s mixed terrain. Protura (tiny soil arthropods), typically rare in other sites, were observed at a count of 7 individuals, with an estimated population of 25,177 individuals.

3.5 | *Site 5*

Sample 5 was collected from the Edens “backyard” area on Duke University’s campus. The total site area spans 1,250.72 m^2, with a perimeter of 108.72 m. Sampling focused on a total area of 0.302 m^2, with individual samples measuring approximately 8.5 × 11 inches each. The samples were collected on multiple dates from late September to late November 2024, ensuring comprehensive coverage of seasonal arthropod activity. The site features a mix of natural and landscaped environments, providing an opportunity to observe arthropod diversity in semi-controlled conditions.

Total Count	n =	Mean per Sample	n =	Total Estimate for Area	n ≈
Acari	74	Acari	7.4	Acari	30646.78
Araneae	36	Araneae	3.6	Araneae	14909.25
Coleoptera	5	Coleoptera	0.5	Coleoptera	2070.73
Collembola	70	Collembola	7	Collembola	28990.20
Diplura	4	Diplura	0.4	Diplura	1656.58
Diptera	2	Diptera	0.2	Diptera	828.29
Hymenoptera	2	Hymenoptera	0.2	Hymenoptera	828.29
Thysanoptera	9	Thysanoptera	0.9	Thysanoptera	3727.31

Table 5.

Sample 5 revealed substantial arthropod diversity, with Acari (mites and ticks) being the dominant order, representing a total of 74 individuals across all samples. The mean count of Acari was 7.4 per sample, with extrapolated estimates indicating a population of approximately 30,647 Acari within the site. Collembola (springtails) were the second most abundant order, with a total of 70 individuals observed and an estimated population of 28,990 individuals, reflecting their prevalence in the moist and shaded microhabitats within the area.

Moderate counts of Araneae (spiders) were observed, totaling 36 individuals and an extrapolated population of 14,909 individuals. Other arthropods, including Coleoptera (beetles), Diplura (two-pronged bristletails), and Thysanoptera (thrips), were present in smaller numbers but remained ecologically significant. Orders such as Diptera (flies) and Hymenoptera (ants, bees, wasps) were rare, with only two individuals recorded for each, resulting in extrapolated populations of approximately 828 individuals for each order.

3.6 | *Site 6*

Sample 6 was collected from the forested area behind Duke University's chapel, specifically on the side closest to the Biological Sciences Building. The total site area spans 5,669.36 m^2, with a perimeter of 339.85 m. Sampling was conducted across a total area of 0.604 m^2, with individual samples measuring 0.0603 m^2 each. Collections occurred on three different dates: September 23, October 10, and October 25, 2024 to capture seasonal variations in arthropod activity. This site is characterized by dense tree coverage and moist leaf litter, creating an environment conducive to diverse arthropod populations.

Total Count	n =	Mean per Sample	n =	Total Estimate for Area	n ≈
Collembola	50	Collembola	5	Collembola	46931.79
Coleoptera	9	Coleoptera	0.9	Coleoptera	8447.72
Diplura	1	Diplura	0.1	Diplura	938.64
Diptera	3	Diptera	0.3	Diptera	2815.91
Hymenoptera	8	Hymenoptera	0.8	Hymenoptera	7509.09
Protura	9	Protura	0.9	Protura	8447.72
Thysanoptera	22	Thysanoptera	2.2	Thysanoptera	20649.99
Acari	405	Acari	40.5	Acari	380147.48
Araneae	26	Araneae	2.6	Araneae	24404.53
Myriapoda	4	Myriapoda	0.4	Myriapoda	3754.54

Table 6.

Sample 6 demonstrated high arthropod diversity, with Acari (mites and ticks) being the most abundant order. A total of 405 Acari individuals were observed, with a mean of 40.5 per sample and an extrapolated population of approximately 380,147 individuals across the entire site. Collembola (springtails) were the second most prevalent, with a total count of 50 individuals, a mean of 5 per sample, and an estimated population of 46,932 individuals, reflecting the suitability of this site's moist microhabitats for these organisms.

Other frequently observed orders included Araneae (spiders), with 26 individuals and an estimated population of 24,405 individuals, and Thysanoptera (thrips), which accounted for 22 individuals and an extrapolated population of 20,650 individuals. Moderate populations of Coleoptera (beetles), Hymenoptera (ants, bees, wasps), and Protura (tiny soil arthropods) were also noted, with estimated populations ranges of 7,509 to 8,448 individuals.

Rarer orders, such as Diplura (two-pronged bristletails), Myriapoda (millipedes and centipedes), and Diptera (flies), were represented by fewer individuals. Notably, Protura populations were slightly elevated compared to other sample sites.

3.7 | *Site 7*

Sample 7 was collected from the Hollows residential and Towerview road area on Duke University's campus. This site spans a total area of 11,348.89 m^2, with sampling conducted over 0.603 m^2, divided into multiple smaller samples (each approximately 0.060 m^2). The samples were collected on two dates, September 29 and October 6, 2024, ensuring that the data represents a range of early autumn arthropod activity. This site features a mix of landscaped grounds and surrounding natural vegetation.

Total Count	n =	Mean per Sample	n =	Total Estimate for Area	n ≈
Collembola	28	Collembola	2.8	Collembola	52610.75
Coleoptera	23	Coleoptera	2.3	Coleoptera	43215.97
Hymenoptera	8	Hymenoptera	0.8	Hymenoptera	15031.64
Blattodea	7	Blattodea	0.7	Blattodea	13152.69
Araneae	4	Araneae	0.4	Araneae	7515.82
Diptera	2	Diptera	0.2	Diptera	3757.91

Table 7.

The Hollows and Towerview site demonstrated moderate arthropod diversity, with Collembola (springtails) being the most dominant order, totaling 28 individuals across all samples. The mean count of Collembola per sample was 2.8, and the extrapolated population for the entire site was estimated to be 52,611 individuals, highlighting the prevalence of springtails in this area.

Coleoptera (beetles) was the second most abundant order, with 23 individuals observed. The mean count was 2.3 per sample, leading to an extrapolated population estimate of 43,216 individuals. Other notable but less abundant orders included Hymenoptera (ants, bees, wasps), Blattodea (cockroaches), and Araneae (spiders), which had estimated site populations of 15,032, 13,153, and 7,516 individuals, respectively. These arthropods were present in varying quantities across the different sampling periods, with higher concentrations observed during the October 6 collections.

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Diptera (flies) were the least abundant, with only two individuals observed, resulting in a site-wide extrapolated population of 3,758 individuals.

3.8 | *Site 8*

Sample 8 was collected from the area in front of the Sarah P. Gardens on Duke University campus. The total site area covers 3,995.64 m^2, with sampling conducted over 0.603 m^2 in total, divided into 10 smaller samples of 0.0603 m^2 each. All samples were collected on October 10, 2024, ensuring consistency in environmental conditions during the collection period. The area is characterized by landscaped grounds, open spaces, and nearby shaded regions.

Total Count	n =	Mean per Sample	n =	Total Estimate for Area	n ≈
Acari	422	Acari	42.2	Acari	279165.58
Collembola	119	Collembola	11.9	Collembola	78722.05
Hymenoptera	16	Hymenoptera	1.6	Hymenoptera	10584.48
Araneae	22	Araneae	2.2	Araneae	14553.66
Coleoptera	6	Coleoptera	0.6	Coleoptera	3969.18
Thysanopteaa	4	Thysanoptera	0.4	Thysanoptera	2646.12
Diptera	6	Diptera	0.6	Diptera	3969.18
Blattodea	5	Blattodea	0.5	Blattodea	3307.65
Protura	2	Protura	0.2	Protura	1323.06
Isopoda	1	Isopoda	0.1	Isopoda	661.53
Myriapoda	4	Myriapoda	0.4	Myriapoda	2646.12

Table 8.

The most abundant arthropod order observed was Acari (mites and ticks), with a total count of 422 individuals across all samples, resulting in a mean count of 42.2 per sample. The extrapolated population for Acari across the entire site is estimated at 279,166 individuals, reflecting the site's suitability for mite populations, likely due to its combination of soil and vegetation.

Collembola (springtails) were the second most abundant, with a total count of 119 individuals, a mean of 11.9 per sample, and an extrapolated population estimate of 78,722 individuals.

Other notable arthropod orders include Hymenoptera (ants, bees, wasps), with 16 individuals and an estimated site population of 10,584 individuals, and Araneae (spiders), with 22 individuals and an extrapolated population of 14,554 individuals. Orders such as Coleoptera (beetles), Blattodea (cockroaches), and Diptera (flies) were observed in smaller numbers, each with an estimated site population ranging from 3,969 to 3,307 individuals.

Rarer orders, including Thysanoptera (thrips), Protura, Isopoda (roly-polies), and Myriapoda (millipedes and centipedes), contributed to the overall biodiversity but were represented by fewer than 5 individuals each.

3.9 | *Site 9*

Sample 9 was collected from the Duke Pond area on Duke University's campus, a large and diverse habitat covering 37,808.38 m^2 with a perimeter of 865.09 m. Sampling was conducted over a total area of 0.302 m^2, with each individual sample measuring approximately 8.5 × 5.5 inches. All samples were collected on October 10, 2024, under consistent environmental conditions to capture a snapshot of arthropod diversity in this aquatic and semi-aquatic ecosystem. This site includes areas of water, riparian zones, and surrounding vegetation.

Total Count	n =	Mean per Sample	n =	Total Estimate for Area	n ≈
Coleoptera	1	Coleoptera	0.1	Coleoptera	2700.28
Collembola	11	Collembola	1.1	Collembola	29703.06
Diptera	5	Diptera	0.5	Diptera	13501.39
Hymenoptera	3	Hymenoptera	0.3	Hymenoptera	8100.83
Thysanoptera	3	Thysanoptera	0.3	Thysanoptera	8100.83
Acari	67	Acari	6.7	Acari	180918.64

Table 9.

The Duke Pond site displayed moderate arthropod diversity, with Acari (mites and ticks) being the dominant order. A total of 67 Acari individuals were observed across all samples, resulting in a mean count of 6.7 per sample. The extrapolated population estimate for Acari at this site is approximately 180,919 individuals, reflecting their high prevalence in this environment. Collembola (springtails) were the second most abundant order, with 11 individuals recorded, a mean count of 1.1 per sample, and an extrapolated population estimate of 29,703 individuals. Diptera (fly larvae) were also prominent, with 5 individuals observed, translating to a mean of 0.5 per sample and an estimated population of 13,501 individuals.

Other notable orders include Hymenoptera (ants, bees, wasps) and Thysanoptera (thrips), each represented by 3 individuals, with a mean count of 0.3 per sample and an extrapolated population of 8,101 individuals per order. Coleoptera (beetles) was the least abundant order, with just one individual recorded across all samples, resulting in an estimated site population of 2,700 individuals.The data also revealed localized variability in arthropod counts, particularly for Acari, which ranged from 7 to 18 individuals across different samples.

4 | Discussion

Overall, these nine samples provide a comprehensive picture of the diversity of insects across a broad variety of habitats, including forested and lawn plots as well as paved areas with more foot traffic. This data emphasizes the influence of habitat structure, microclimate, local vegetation, and unique environmental differences on the abundance and composition of different insect orders within Duke's campus.

4.1 | *High Acari Density Across Multiple Sites*

Across multiple sites, the Arachnid order Parasitiformes composed of ticks and mites, vastly outnumbered other orders and classes of insects. The Acari order predominated in forested and moist collection sites, such as Site 1 and Site 6 (both in the forested area behind Duke Chapel) as well as landscaped, more urban sites, such as Site 3 (near Campus Pharmacy) and Site 4 (Card Lot). Their abundance ranged from ~53.5% of the total arthropod (insects and other species in the Arthropoda phylum) population for Site 2 to over 80% of the total arthropod population for forested plots such as Site 1.

A testament to the adaptability and resistance of ticks and mites, particularly on Duke's campus, this dominance may be due to a number of factors, each stemming from their environment selection and physiological adaptations to harsher conditions. Species within the Acari order typically live in moist leaf litter and soil with high organic content (Walter & Proctor, 2013), allowing them to occupy a wide range of microhabitats at especially high rates. Furthermore, the relatively short life cycles and high reproductive rates of species in the Acari order allow them to propagate rapidly within the substrate. Additionally, the roles mites and ticks occupy within their ecosystems vary significantly–for example, mites may either function as predators or detritivores, aiding in decomposition–an indication that they harbor efficient nutrient cycling processes and stable, detritus-based food webs [10].

4.2 | *High Collembola Density in Forested, Moist Areas*

Collembola (springtail) population density was particularly high within sites containing large quantities of dense, moist soil–these sites could either be forested or landscaped and semi-urban, where mulch and irrigation processes can simulate typical habitat conditions in natural forests for springtails. Collembola are known soil quality indicators, given their reliance on moist environments and organic debris [11]. The extrapolated population sizes of Collembola in both forested sites, such as Sites 1 and 6 (~98,560 individuals in Site 1 and ~46,932 individuals in Site 6, respectively), and in semi-urban, landscaped sites, such as Site 4 (~381,255 individuals), points to the heterogeneity and high soil quality of habitats across campus. Furthermore, the Collembola population density in areas with lower quality, more compacted soil and less vegetation coverage, such as in Site 3 (~6575 individuals), was much lower, emphasizing their dependence on the nutrient-rich, moist soil found in other areas on Duke's campus.

4.3 | *Site-Specific Variation*

While some insect and arthropod orders, such as Acari and Collembola, were more consistently dense across multiple sites, other orders varied more significantly by site. For example, members of the Hymenoptera order, including bees, ants, and wasps, were moderately abundant in Sites 1 and 8 (~24,303 individuals in Sample 1 and ~10,584 individuals in Sample 8, respectively), but fluctuated seasonally, with samples collected in mid-October bearing higher density measurements. October 2024 was a particularly warm month, ranking as the second-highest October since the National Oceanic and

Atmospheric Administration began weather record-keeping in 1850 [12], which may have contributed to more favorable weather conditions for vegetation such as flowers and other plants. This warm weather and flowering vegetation may have been more suitable for bees and wasps, for example, that rely heavily on flowers and pollination for nutrients. Furthermore, the particularly high numbers of Hymenoptera in Sites 4 and 8 (~104,306 individuals in Site 4, ~10,585 individuals in Site 8) indicate a preference for exposed soil and flowering vegetation.

Other orders also fluctuated by site. For example, species in the Thysanoptera (thrips) order were more abundant in sites with floral surfaces and vegetation, such as Sites 3, 4, and 6 (~21,603 individuals in Site 3, ~100,709 individuals in Site 4, ~20,650 individuals in Site 6). This abundance reflects their pollen-feeding and plant-feeding habits, similar to Hymenoptera above. Furthermore, the thrips population exceeded 100,000 individuals in Site 4, indicating their potential to surge in numbers when environmental conditions allow it [13]. These findings underscore the variety of conditions, microhabitats, and climates of sites on Duke's campus, each able to harbor different species at different abundances.

4.4 | *Rare Orders*

A striking finding was the abundance of rare insect orders such as Diplurans and Proturans in certain sites. Although typically rare and only represented by a few insects per sample, there was a moderately high abundance in forested sites such as Sites 1 and 6 of both Diplura (~1,351 individuals in Site 1, ~939 individuals in Site 6) and Protura (~1,351 individuals in Site 1, ~8,448 individuals in Site 6). These sites, which are less disturbed than other, more urban sites due to less foot traffic, may be more conducive to greater Diplura and Protura propagation and better survival conditions.

4.5 | *Ecological Implications, Limitations, and Future Directions*

Based on our extrapolated population estimates, the amount of insects on Duke's campus is extensive. For example, using the campus area of approximately 3,500,000 m2, we estimate a total population of roughly 2.5 billion Acari across all sampled habitats. Assuming proportional arthropod distribution, a single Duke dorm room, with an average area of approximately 17 m2 [14], could contain over 10,000 Acari!

Such extrapolations provide a perspective on the density and ecological impact of soil-dwelling arthropods. These organisms play critical roles in nutrient cycling, soil aeration, and organic matter decomposition, highlighting their ecological value even in highly urbanized environments like Duke's campus. However, it is important to note the limitations of our study. These population estimates are based on localized sampling and assume uniform distribution across habitats. This approach may not fully account for the considerable ecological diversity present in urban landscapes, such as variations in soil composition, vegetation density, and microclimatic conditions. Additionally, seasonal fluctuations in insect populations, driven by factors like temperature and rainfall, could influence the accuracy and reliability of our findings. These limitations further the need for more comprehensive sampling strategies to better capture the complexity of urban biodiversity.

Future research should expand sampling efforts to include additional habitats, such as aquatic ecosystems and underrepresented urban niches, to provide a more comprehensive picture of campus-wide biodiversity. Investigating the function roles of dominant taxa, such as Acari and Collembola, could also illuminate their contributions to ecosystem processes. Furthermore, studies on the resilience of these populations to urbanization and climate stressors would provide insights into their adaptive mechanisms, such as behavioral and physiological changes, that enable survival in challenging conditions. This information could directly inform conservation strategies aimed at preserving biodiversity by identifying habitat features that support resilient populations. For instance, understanding how soil moisture, organic matter, and temperature variations influence population dynamics can guide urban planning efforts to create more hospitable environments for arthropods. Additionally, these studies could aid in predicting how future environmental changes, such as increased urban sprawl or shifting climate patterns, might impact the diversity and functionality of soil arthropod communities in urban landscapes.

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