Aerial insect populations in the Halifax Backlands and prey availability to the Common Nighthawk (*Chordeiles minor*)

by

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ABSTRACT

Insects are experiencing rapid and dramatic global declines associated with human activities such as agricultural intensification, urbanization and pollution. Drastic loss of insects impairs essential ecosystem functions and services, including food provision for many predators, most notably aerial insectivores, a guild of animals that feed exclusively on insects. Here I focus on the spatiotemporal changes in insect abundance and its possible effects on the Common Nighthawk (*Chordeiles minor*), a migratory, ground-nesting nightjar and Species at Risk in Canada. As an aerial insectivore, insect declines are hypothesized to be one of the leading threats to this species. Observations of the nighthawk in the Halifax Backlands, a suburban wilderness area near Halifax, Nova Scotia, suggest this area hosts important nesting and foraging grounds for this species in Atlantic Canada. Malaise intercept traps and insect light traps were deployed at 21 sites across the Backlands in the summer of 2024 to investigate aerial insect populations in the area. Insect samples were sorted into orders, counted and dried to obtain dry biomass. Insect sample diversity varied between trap types and across sites. Biomass of insect prey > 5 mm did not correlate with nighthawk activity sampled acoustically with autonomous recording units (ARUs). A generalized linear mixed model suggested that insect abundance was greatest in areas with low nighthawk activity, but a generalized linear model indicated nighthawks may travel to sites daily to exploit high insect abundance. Temperature was found to be the best predictor for insect abundance over time, while lunar percentage affected abundance and biomass in light traps samples. No significant difference in insect biomass across sites suggests that nighthawks may opt to forage in areas with lower overall abundance but target larger prey. Important nighthawk foraging areas include north and central regions of the Backlands, but the data did not suggest that nighthawks foraging or breeding habitat choices were driven by insect abundance.

INTRODUCTION

Insects are experiencing rapid and dramatic declines on a global scale, likely as a consequence of anthropogenic activity (Sánchez-Bayo & Wyckhuys 2019; Cardoso et al. 2020). Depletion of insect taxa may reduce the vital ecosystem services they provide, such as pollination, herbivory, detritivory and nutrient cycling (Losey & Vaughan 2006; Goulson 2019). Critically, insects play a central role in most terrestrial ecosystems as an essential food source for a diversity of organisms, including many species of reptiles, amphibians, mammals and birds (Lister & Garcia 2018; Dietzer et al 2024). Severe declines in insect availability may cause bottom-up cascading effects in both terrestrial and freshwater environments that can impact organisms at higher trophic levels. For this reason, insect declines must be considered when evaluating the abundance trends of declining insectivore species, including aerial insectivores, such as the Common Nighthawk (*Chordeiles minor*).

Insect Declines

Despite being the most diverse group of known animal species, insects and their role in natural ecosystems have historically been understudied (Goulson 2019). Of the estimated 5.5 million insect species, approximately 80% remain undescribed (Stork 2018), and there is little long-term data on population abundance and distribution (Dirzo et al. 2014; Goulson 2019). Insect populations are generally much less rigorously documented as compared to many vertebrate groups. Consequently, the global extent of insect biodiversity loss during the Anthropocene remains unclear (Wagner 2020).

Yet, the topic of insect population declines has been highlighted in recent years with the emergence of numerous regional studies on subsets of insect taxa. A large proportion of insect monitoring studies investigate insect abundance and focus on charismatic species, including macro-moths, butterflies, bees and beetles (Habel et al. 2019; Hallman et al. 2020). The focus on these taxa is disproportionately large relative to other groups for their extrinsic value to humans as contributors to ecosystem services required for agriculture, such as pollination and waste decomposition (Losey & Vaughan 2006; Habel et al. 2019). While declines in the abundance of specific taxa have been used to identify trends of a widespread insect decline (Sánchez-Bayo & Wyckhuys 2019), some suggest that insect biomass is a better metric to assess the status of insect populations (Hallmann et al. 2017).

Human activity is identified as the leading force behind documented insect declines. Habitat loss to agriculture and urbanization is hypothesized to be a leading threat to insect biodiversity (Habel et al. 2019; Sánchez-Bayo & Wyckhuys 2019; Cardoso et al. 2020). Habitat fragmentation that arises from these land use changes creates isolated patches with small, disconnected populations, and can be detrimental to highly mobile species that rely on metapopulations for survival (Habel et al. 2019, Cardoso et al. 2020). The degradation of natural and semi-natural areas for human use can lead to the loss of endemic plant communities, indirectly impacting the insect communities that depend on this vegetation (Cardoso et al. 2020). Contamination of terrestrial and aquatic ecosystems with synthetic pesticides used in intensive agriculture directly harm insect populations, while pollution of herbicides, fertilizers and industrial contaminants alter insect habitat and can cause sub-lethal toxicity that bioaccumulates in food webs (Cardoso et al. 2020). The introduction of invasive species leads to local extinctions of insects through excessive predation or increased competition with native species

(Cardoso et al. 2020). Human-driven climate change threatens ecosystems by changing the composition and distribution of species, altering interspecies dynamics among insects and their ecological interactions with other organisms (Lister & Garcia 2018).

Insect population declines can severely impair ecosystem health and function. For example, declines in pollinators diminish pollination services for both wild plant communities and agricultural crops and may lead to the substantial loss of insect-pollinated vegetation and decreased agricultural productivity (Biesmeijer et al. 2006; Potts et al. 2010). Decreases in detritivore insect biodiversity may disrupt nutrient cycling processes and organic waste removal by affecting decomposition rates of carrion (Barton & Evans 2017). Similarly, the decline of herbivorous insects, which enhance litter quality and support plant productivity through limited nutrient cycling, hinders this vital role in maintaining terrestrial ecosystems (Chapman et al. 2003). Reduction of total insect biomass in natural ecosystems lowers the amount of energy that is moved through food webs. For this reason, insect declines often precede extinctions of animals at higher trophic levels (Cardoso et al. 2020).

One group that is almost exclusively dependent on insect prey are aerial insectivores, that is animals that capture insects in flight. These include a diversity of bird and bat species and are directly impacted by declines in insect populations. Many bird species within this guild, including swallows, swifts, flycatchers and nightjars, have shown significant and widespread declines since the 1980s (Nebel et al. 2010). Agricultural intensification, which encompasses land use changes and increased agrochemical use, is hypothesized to affect both aerial and non-aerial insectivorous birds by reducing the availability and quality of insect prey (Spiller & Dettmers 2019). Reduced insect prey due to intensive pesticide use has been linked to lower reproductive success, foraging intensity and chick survival in insectivorous grassland birds

(Poulin et al. 2010) and it is expected that aerial insectivores may be experiencing similar effects (Spiller & Dettmers 2019).

Common Nighthawk (*Chordeiles minor*)

In this thesis, I assess the insect prey of a threatened aerial insectivore, the Common Nighthawk. This long-lived, ground-nesting nightjar listed is as Special Concern under Schedule 1 of the Species at Risk Act (SARA) in Canada (COSEWIC 2018) and as Threatened in Nova Scotia (Nova Scotia Department of Lands and Forestry 2021). This Neotropical-Nearctic migratory bird overwinters in South America and breeds across North America in the summer months (Cockle et al. 2023). Approximately 10% of the population is estimated to breed in Canada (COSEWIC 2018). Common Nighthawks experienced a drastic decline of 68% in southern Canada from 1970 to 2015. The rate of decline in this region slowed to approximately 12% from 2005 to 2015, with the Canadian population believed to have stabilized in western boreal habitats but not in eastern regions (COSEWIC 2018). The leading threats to Common Nighthawks are thought to be the reduced availability of aerial insect prey, increased frequency of severe weather events linked to climate change and the loss, degradation or modification of natural habitat (COSEWIC 2018; Nova Scotia Department of Lands and Forestry 2021).

Diet

Common Nighthawks employ an on-the-wing foraging strategy known as hawking to consume aerial insect prey. This strategy involves diving and swooping of an erratic nature, during which these birds use their gaping mouths to catch insects. Nighthawks forage during crepuscular hours and are visual predators that discriminate between viable prey using sight

(Brigham & Barclay 1995). These birds appear to preferentially target insects > 5 mm in length, which may be due to the better visibility and higher nutrition of large insects over small ones (Todd et al 1998). Nighthawks are believed to selectively forage on *Coleoptera* (beetles) and *Hymenoptera* (flying ants), while consuming *Lepidoptera* (moths) and *Trichoptera* (caddisflies) at levels proportionate to their availability in the environment (Todd et al. 1998; Knight et al. 2018).

Habitat

Common Nighthawk breeding habitat comprises a variety of open and partially open habitats, such as grasslands, forest openings, bogs, rocky outcrops and post-fire landscapes (Brigham et al. 2011; COSEWIC 2018). Disturbed natural areas, such as those affected by wildfire or forest harvest, are used by nighthawks for nesting (Knight et al. 2021). In urban areas, these birds have been known to nest on flat gravel roofs (Brigham et al. 2011). Foraging habitat is not restricted to disturbed areas (Knight et al. 2021), but open areas are still required for hawking during pursuit of aerial insects (Ng 2009). Nighthawks often utilize water bodies, such as rivers and wetlands, for foraging as they provide both sufficient space for diving flight patterns and an abundance of aerial insects (Ng 2009; Brigham 1990). Nighthawks may forage within their breeding territory but are also known to travel up to 12 km from their territory to exploit areas with high aerial insect abundance (Brigham 1990, Brigham & Fenton 1991).

Study Objectives

The objectives of this study were to investigate 1) how aerial insect abundance, diversity and biomass were distributed across a suburban wilderness area, the Halifax Backlands and 2) if abundance, biomass and diversity of insect prey were related to Common Nighthawk presence and activity. I hypothesized that aerial insect diversity would be highest at sites within a 200 m range of wetland or open water, as water is essential for many insects' life cycles, particularly aquatic insects, and serves as a crucial resource for this group of organisms. I predicted a greater abundance of aquatic or semi-aquatic insects at these sites, in addition to aerial insects associated with terrestrial landscapes. I hypothesized that tree canopy would influence insect abundance, in that sites with lower mean canopy height would yield greater insect abundance due to less interference in the flight paths of aerial insects.

Based on previous observations of nighthawk foraging activity where nighthawks were most frequently observed in the northern region of the Backlands, I hypothesized that insect abundance would be highest in samples collected in the north and central regions of the study area. Additionally, I hypothesized that there would be a positive relationship between insect abundance and biomass, with sites supporting more insects also yielding greater overall biomass. I predicted nighthawk detections would be more frequent in areas with greater insect biomass, particularly given their tendency to forage on large insects. To further assess the predator-prey relationship between nighthawks and insects, I investigated the correlation between nighthawk detections and biomass of prey items greater than 5 mm in length, presumed foraging targets for this species. By comparing insect metrics to the quantitative detection of nighthawks, I aimed to improve knowledge on foraging behaviour by Nighthawks in a temperate coastal environment.

METHODS

Study Area

The study area is located within a suburban wilderness area of approximately 1350 ha in Spryfield, a community within the Halifax Regional Municipality (HRM) in Nova Scotia, Canada. This area is composed of park lands, HRM lands, crown lands and private properties which collectively make up a larger wilderness area referred to as the Halifax Backlands (hereafter referred to as the Backlands; Figure 1).

The Backlands feature a diversity of landscapes used by a large variety of wildlife. The central region of the Backlands is a barren landscape with large granite outcrops and low vegetation typical of nutrient-poor temperate coastal regions (Hill & Patriquin 2014). This area, characterized by a long-term fire regime, hosts a Jack Pine (*Pinus banksiana*) and broom crowberry (*Corema conradii*) plant community that is unique to Nova Scotia and Maine and holds significant conservation value (Hill & Patriquin 2014). The study area, which is limited to publicly accessible lands, includes significant portions of William's Lake Watershed and McIntosh Run. These tributaries feed into various wetlands, streams and lakes throughout the Backlands. The south and north regions of the study area host small patches of forest communities that include both coniferous and deciduous species, making it the ideal breeding habitat for a diversity of bird species (Hill & Patriquin 2014).

Community members and local naturalists have reported observations of nighthawks in the Backlands during the summer in recent years. Nighthawks exhibit breeding site fidelity (Ng et al. 2018), making the Backlands a location of importance for this species in Canada.

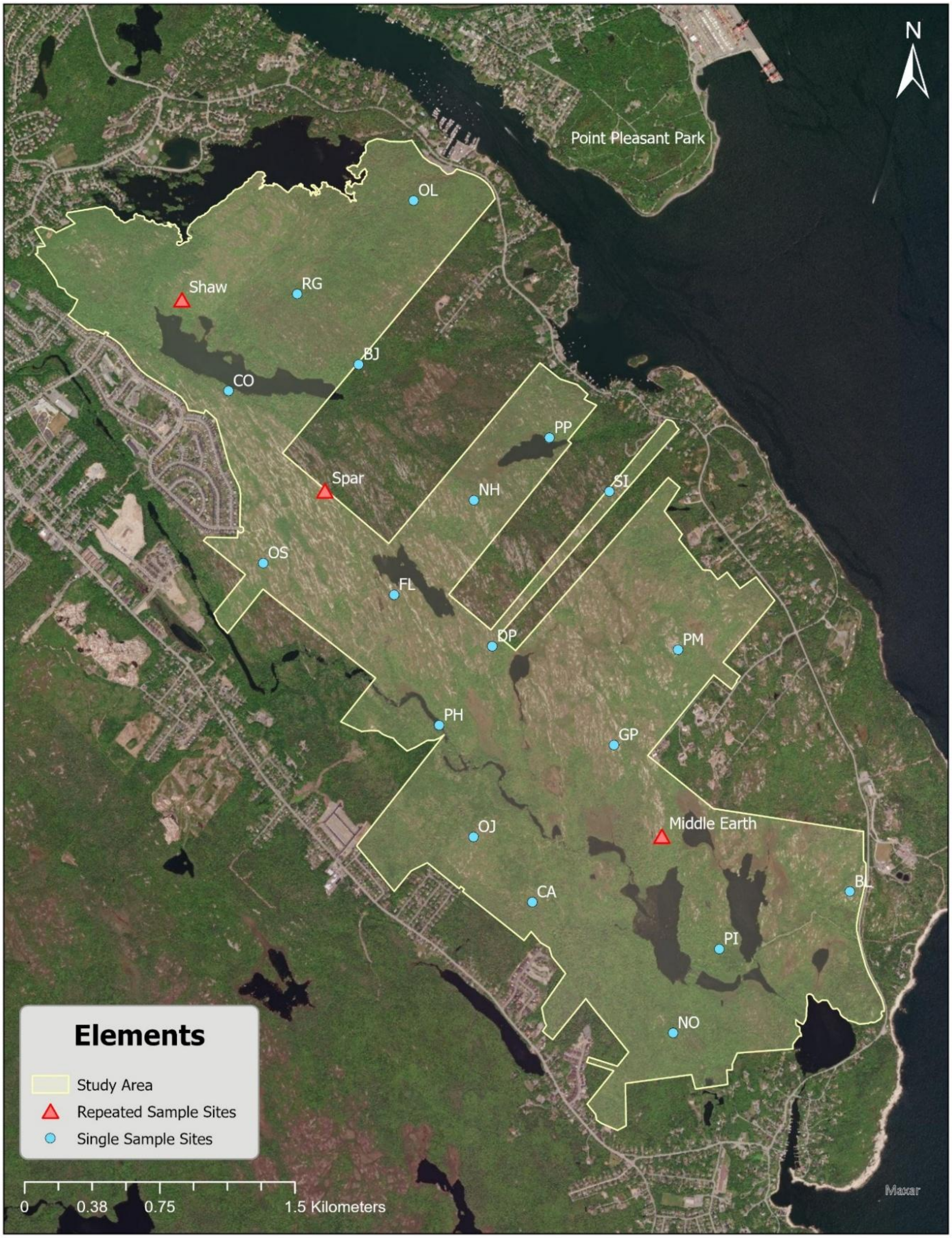

Figure 1. Study area. Shown are repeated, season-long sample sites (triangles) and single-sample sites (circles) in the Halifax Backlands near Halifax, Nova Scotia. Study area shapefile of public lands created by Madeleine Kurtz (2025).

Site Selection

A total of 21 sites were selected for insect sampling. Initially, six sites distributed across the Backlands (*Flat Lake, Middle Earth, Orange Jelly, Piggy Mountain, Shaw, Spar*; Table 1) were selected based on reported sightings of nighthawks by community members. The study area was then divided into three regions of equal size (north, central and south) and the remaining 15 sites were established within 150 m of randomly generated points within these regions (Table 1).

Three of the initial, non-randomly selected sites were sampled over the entire summer from beginning of June to end of August 2024 (*Middle Earth, Shaw, Spar;* Table 1). The remaining sites were sampled only once during a two-week period over this time.

Table 1. Study Sites. Names, abbreviations and coordinates for the 21 study sites in the Halifax Backlands, Nova Scotia, sampled in the summer of 2024. Coordinates are Universal Transverse Mercator (UTM) Zone 20.

Site name	Site abbreviation	UTM Easting	UTM Northing
Blackberry	BL	456093	4936884
Blue Jay	BJ	453369	4939811
Casper	CA	454332	4936826
Colpitt	CO	452647	4939663
Duck Pond	DP	454110	4938246
Flat Lake	FL	453566	4938532
Ghost Pine	GP	454785	4937698
Middle Earth	ME	455050	4937196
New Horizons	NH	454008	4939057
Nora	NO	455112	4936100
Oak Lane	OL	453674	4940721
Orange Jelly	OJ	454005	4937188
Osprey	OS	452840	4938708
Piggy Mountain	PM	455140	4938226
Pine Island	PI	455368	4936565
Pond Hopper	PH	453815	4937808
Purcell's Pond	PP	454427	4939403
Rock Garden	RG	453027	4940202
Shaw	SH	452388	4940174
Sightline	SI	454758	4939105
Spar	SP	453181	4939114

Sampling Equipment

Light Traps

Two pennsylvania-style light traps were used to capture aerial insects. The light traps were constructed around the Entolight, an LED lamp that emits light at 365 nm and 395 nm wavelengths in the ultraviolet spectrum to mimic moonlight. Four vanes constructed from thin plexiglass were arranged around the light (Figure 2A). The light and vane structure were supported by four wooden dowels and sat upon a 25 cm diameter funnel. The funnel was secured to an 8-litre bucket with cotton cord. A Falcon tube with 15 ml of ethyl acetate was placed inside the bucket to kill trapped insects. The light was powered with a 12-volt 28-amp-hour sealed lead acid battery which was placed in a 40 x 20 x 20 cm waterproof bin.

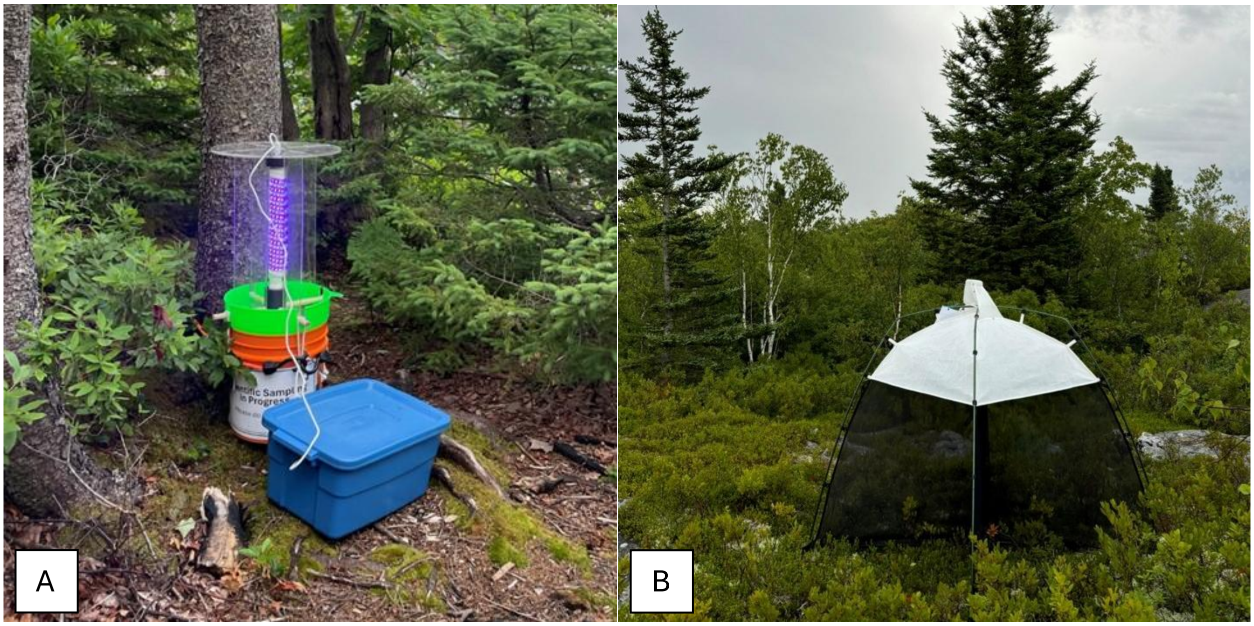

Figure 2. Sampling equipment. Shown are the two trap types used for insect collection. A) Light trap design built around the Entolight, an LED light with UV spectrum emissions produced by *Entoquip*. B) SLAM trap II Malaise intercept trap by *BugDorm*.

Malaise Traps

Six SLAM trap II Malaise intercept traps (Figure 2B) were used to passively capture diurnal and nocturnal aerial insects. These traps capture insects by utilizing their innate instinct to fly upwards when an obstacle has been encountered in their flight path. Insects are directed through a maze of netting to ultimately reach a collecting bottle. The Malaise traps were deployed at ground level to capture targets flying within 1 m of the ground. Small Falcon tubes with 7 ml of ethyl acetate were placed in the collecting bottles of the traps as a killing agent upon trap deployment.

Autonomous Recording Units

A co-located study deployed six AudioMoth Autonomous Recording Units (ARUs) for passive sound monitoring of Common nighthawks in the Backlands (Kurtz 2025). Recordings were processed using BirdNET, a deep neural network designed for bird sound identification (Kahl et al. 2021), to identify nighthawk detections. ARUs were deployed in coniferous trees to reduce noise from wind and rustling leaves and branches. Technical details of nighthawk monitoring can be found in "Spatial ecology of the Common Nighthawk (*Chordeiles minor*) in the Halifax Backlands" (Kurtz 2025).

Field Data Collection

Light traps sampled for 10-hour periods overnight, with deployments between 20:00-20:45 and collection between 6:00-6:45 the following morning. Malaise traps were deployed for 48-hour periods, with deployment and collections conducted during daytime hours. ARUs were programmed to record for 2.5 hours before sunrise and 2 hours after, as well as 2 hours before sunset and 2.5 hours, resulting in a total of 9 hours of recording each day.

Sampling Schedule

Three ARUs were stationed at three repeated-sample sites (Table 2) located in north, central and south regions of the Backlands from late May to early September 2024 (Kurtz 2025). These sites were sampled bi-weekly with light and Malaise traps from June to August 2024, generating seven samples at each site for each trap type. The remaining three ARUs were rotated among the single-sample sites for the same two-week periods that were sampled with both insect trap types (Table 3).

Table 2. Sampling schedule for repeated-sample sites. Three repeated-sample sites in the Halifax Backlands, Nova Scotia, were sampled at regular biweekly intervals with light traps and Malaise traps.

Site name	Dates sampled with light trap	Dates sampled with Malaise trap
Middle Earth	June 6, 20, Jul 7, 19, Aug 1, 16, 29	June 4-6, 19-21, Jul 3-5, 16-18, 30, Aug 1, 14-16, 26-28
Shaw	June 10, 25, Jul 9, 21, Aug 5, 18, 26	June 4-6, 18-20, Jul 2-4, 15-17, 30, Aug 1, 13-15, 26-28
Spar	June 3, 17, Jul 2, 15, 31, Aug 12, 26	June 3-5, 17-19, Jul 2-4, 15-17, 30, Aug 1, 13-15, 26-28

Table 3. Sampling schedule for single-sample sites. Eighteen sites in the Halifax Backlands, Nova Scotia, were sampled once with light traps, once with Malaise traps and with ARUs for a corresponding two-week period in the summer of 2024.

Site name	Light trap	Malaise trap	ARU
Blackberry	Aug 6	Aug 13-15	Aug 9-23
Blue Jay	Jul 21	Jul 15-17	Jul 12-26
Casper	Aug 13	Aug 6-8	Jul 26-Aug 9
Colpitt	August 8	Aug 6-8	Jul 26-Aug 9
Duck Pond	June 17	June 17-19	June 14-28
Flat Lake	June 3	June 3-5	June 5-14
Ghost Pine	July 25	Jul 24-26	July 12-26
New Horizons	July 23	Jul 16-18	Jul 12-26
Nora	June 19	June 17-19	June 14-28
Oak Lane	June 25	June 18-20	June 14-28
Orange Jelly	June 10	June 3-5	June 5-14
Osprey	July 2	Jul 2-4	June 28-Jul 12
Piggy Mountain	June 6	June 4-6	June 4-14
Pine Island	July 7	Jul 3-5	June 28-Jul 12
Pond Hopper	August 7	Aug 6-8	Jul 26-Aug 8
Purcell's Pond	July 10	Jul 3-5	June 28-Jul 12
Rock Garden	August 22	Aug 14-16	Aug 9-Aug 23
Sightline	August 20	Aug 14-16	Aug 8-Aug 23

Sample Processing

Insect Sorting and Drying

Insect catch was sorted into orders and each sample was documented with photographs (Figure 3A). Groups within the sample were then then weighed to the nearest 0.001 g (Figure

3B). Groups were formed based on body length of the insects and were always kept within the same order. Generally, groups were defined within by body length of the following measures: > 20 mm, 15-20 mm, 12-15 mm, 5-10 mm and < 5 mm. There was no limit placed on the number of individuals that could be included in a group.

Grouped insects were placed in small aluminum trays and placed into a drying oven at 60˚C for 24 hours (Figure 3C, Figure 3D). Insects that could not be immediately dried were frozen until drying was possible. After the elapsed period, insects were removed from the oven and weighed again by group. The dry biomass for each group in a sample was summed to give a total dry biomass value for that sampling date.

Figure 3. Sample sorting, weighing and drying methods. Examples of insect sorting (A), weighing (B), and drying (C, D) processes for samples collected from Malaise traps and light traps in the Halifax Backlands, Nova Scotia, in the summer of 2024.

Data Analysis

Diversity Indices

Aerial insect diversity was measured as Shannon-Wiener diversity, richness and evenness for both trap types at each site. Abundances of aerial insect orders were used to calculate order diversity, richness and evenness at single-sample sites. For repeated sample sites (*Middle Earth,* *Shaw, Spar*), aerial insect order abundances were pooled across seven sampling sessions to calculate diversity metrics for the entire sampling season. Diversity indices were calculated for both insect trap types.

Aerial Insect Modelling

A negative-binomial generalized linear model (GLM) was used to determine the influence of habitat, time, environmental variables, lunar cycle and nighthawk activity on the abundance of aerial insects at single-sample sites. Environmental variables were defined as temperature, humidity and windspeed averaged between measurements collected during deployment and collection of traps. To model the effects of the lunar cycle, the lunar percentage was included as a continuous variable, where 100% indicated a full moon and 0% signified a new moon. Habitat characteristics were defined as the percent of wet area and mean tree canopy within a 200 m radius from sampling sites. Mean tree canopy was extracted from a 1m LiDAR canopy height model (Halifax Data, Mapping & Analytics Hub 2018) in ArcGIS Pro. Percentage of wet areas was determined by combining Nova Scotia Wet Areas data (Nova Scotia Department of Natural Resources, 2007) for a depth to water table of ≤ 0.5 m and classifications for inland waters and lake wetlands from Nova Scotia Interpreted Forest Inventory data (Nova Scotia Department of Natural Resources, 2021). Time was defined by the month of the trap deployment date. Nighthawk activity was defined by the number of vocal detections captured by ARUs on both the deployment and collection date during four-hour sunrise and sunset recording periods. A linear model, which applied the same predictor variables as the GLM, was used to model insect biomass at single-sample sites.

A generalized linear mixed model (GLMM) of the Poisson family was used to model the effects of time, nighthawk abundance, lunar cycle and environmental variables on aerial insect abundance at repeated-sample sites. Environmental variables and lunar cycle were the same as with the GLM for single sample sites, and were treated as random predictors of insect abundance. Time was defined as the month of deployment date and was modeled as a fixed factor. Nighthawk abundance was treated as a fixed factor with three levels confounded with site, where Spar was classified as having high abundance, Shaw had intermediate abundance and Middle Earth had low abundance. Assumptions on Nighthawk abundance were formed based on observations of nighthawk activity during the summer of 2023. A linear mixed model (LMM) was created to model aerial insect biomass at repeated-sample sites with the same fixed and random effects as for the GLMM.

Aerial insect modelling was completed using insect data collected with light traps only. Malaise traps were excluded from models with the reasoning that these traps collected insects outside of nighthawk foraging hours, which does not align with my goal to analyze predator-prey relationships.

Nighthawk Activity and Prevalence of Prey

I conducted two Kendall's rank correlation tests to examine the relationship between nighthawk activity and prey availability. I defined prey items as aerial insects > 5 mm in body length belonging to orders *Coleoptera*, *Hymenoptera*, *Lepidoptera* and *Trichoptera*, as these are likely to be targets in nighthawk foraging (Todd et al. 1998, Knight et al. 2018). I chose to compare two levels of nighthawk activity to assess potential correlations with prey availability. Daily nighthawk activity was quantified as the number of BirdNET vocal detections captured by ARUs on the dates of deployment and collection of light traps to capture activity in both four-hour sunrise and sunset time periods. I then calculated the mean number of ARU nighthawk detections for the two-week period that overlapped with insect sampling to obtain a relative measure of nighthawk activity over a two-week timeframe. Prey item biomass was obtained from light trap samples at repeated-sample sites for a complete analysis of trends over the summer. Malaise trap samples were excluded from this analysis, as their 48-hour sampling window allowed for greater error in predicting prey availability during specific nighthawk foraging periods.

RESULTS

Insect abundance, biomass and diversity varied considerably across the season and between sampling sites. Generally, samples taken in the month of July showed the greatest insect abundance and biomass. The most abundant orders in both trap types were *Diptera* and *Lepidoptera*. In light traps samples, biomass was largely attributed to *Lepidoptera*, followed by *Diptera*, *Coleoptera* and *Trichoptera*. In Malaise trap samples, *Lepidoptera* attributed the most biomass, followed by *Coleoptera*. Insect diversity varied between trap types, with light traps collecting a greater range of insect orders than Malaise traps. Malaise trap samples contained next to no insects from secondary aquatic insects, while light trap samples contained higher proportions. Rare orders collected across the Backlands included *Plecoptera* (stoneflies), *Neuroptera* (lacewings) and *Megaloptera* (fishflies), as well as two unique individuals from *Odonata* (dragonflies) and *Orthoptera* (crickets). See Table A1 and A2 in the Appendix for a summary of trap contents.

Analyses of Insect Orders of Interest

I performed detailed analyses of the main order of insects that contribute to nighthawk diet, namely *Hymneoptera*, *Coleoptera*, *Trichoptera* and *Lepidoptera*. All four orders were consistently found in light trap samples, aside from two samples that had no *Coleoptera* (Pond Hopper, Rock Garden) and two that had no aerial *Hymenoptera* (Pond Hopper, Casper). Malaise trap samples had high prevalence of *Coleoptera* and *Lepidoptera* throughout the season but presence of *Trichoptera* and aerial *Hymenoptera* in samples were considerably sparser. Abundance of *Coleoptera* and *Lepidoptera* peaked mid-season in July, while *Trichoptera* displayed an early peak at the end of June with a potential secondary emergence in late July.

Hymenoptera counts suggested an emergence in mid-June, namely of large insects, with a second late peak in August.

Lepidoptera had the greatest abundance of all aerial insect orders collected over the summer and was found in comparable numbers between repeated and single-sample sites given the point of the season when sampling was conducted. *Lepidoptera* individuals made up 17.6% of light trap samples but made up 59.3% of total light trap biomass (Table A1, A2). A similar trend was observed in Malaise samples, where Lepidoptera made up 11.9% of samples and 49.0% of biomass. In both Malaise and light trap samples, *Lepidoptera* counts remained high throughout the summer, but dry biomass declined in August, suggesting that mostly small *Lepidoptera* remained by the end of the season (Figure 3, Figure 4). Malaise traps collected many *Lepidoptera*, but all samples except for two collected in early July at Spar (0.604 g) and Osprey (0.729 g) had biomass less than 0.300 g for this order. While no *Lepidoptera* were collected with Malaise traps at Casper and Orange Jelly, high numbers were collected with light traps.

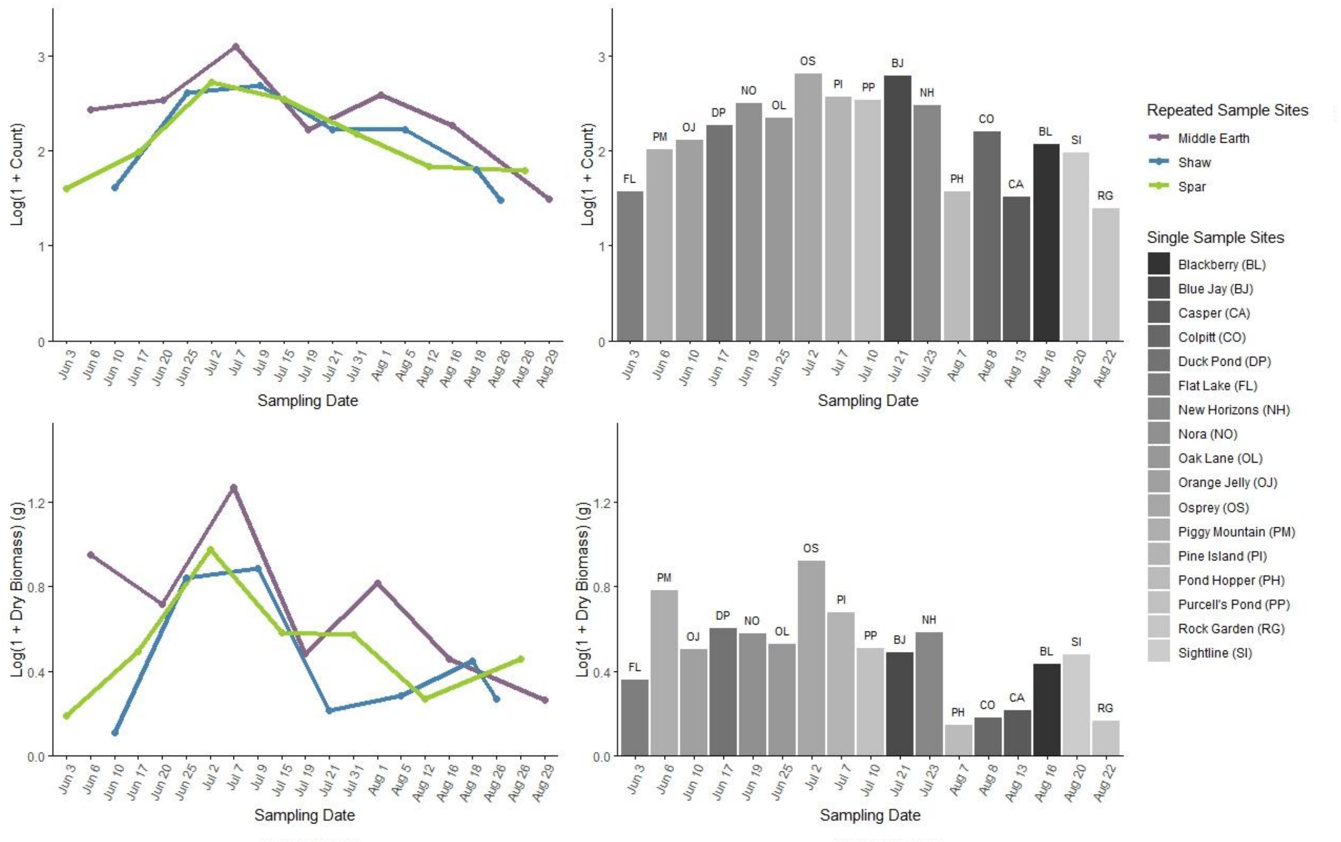

Figure 3. *Lepidoptera* in light trap samples. Log10(1+Count) and log10(1+Dry Biomass) (g) of *Lepidoptera* collected with light traps at repeated and single-sample sites in the Backlands during the summer of 2024.

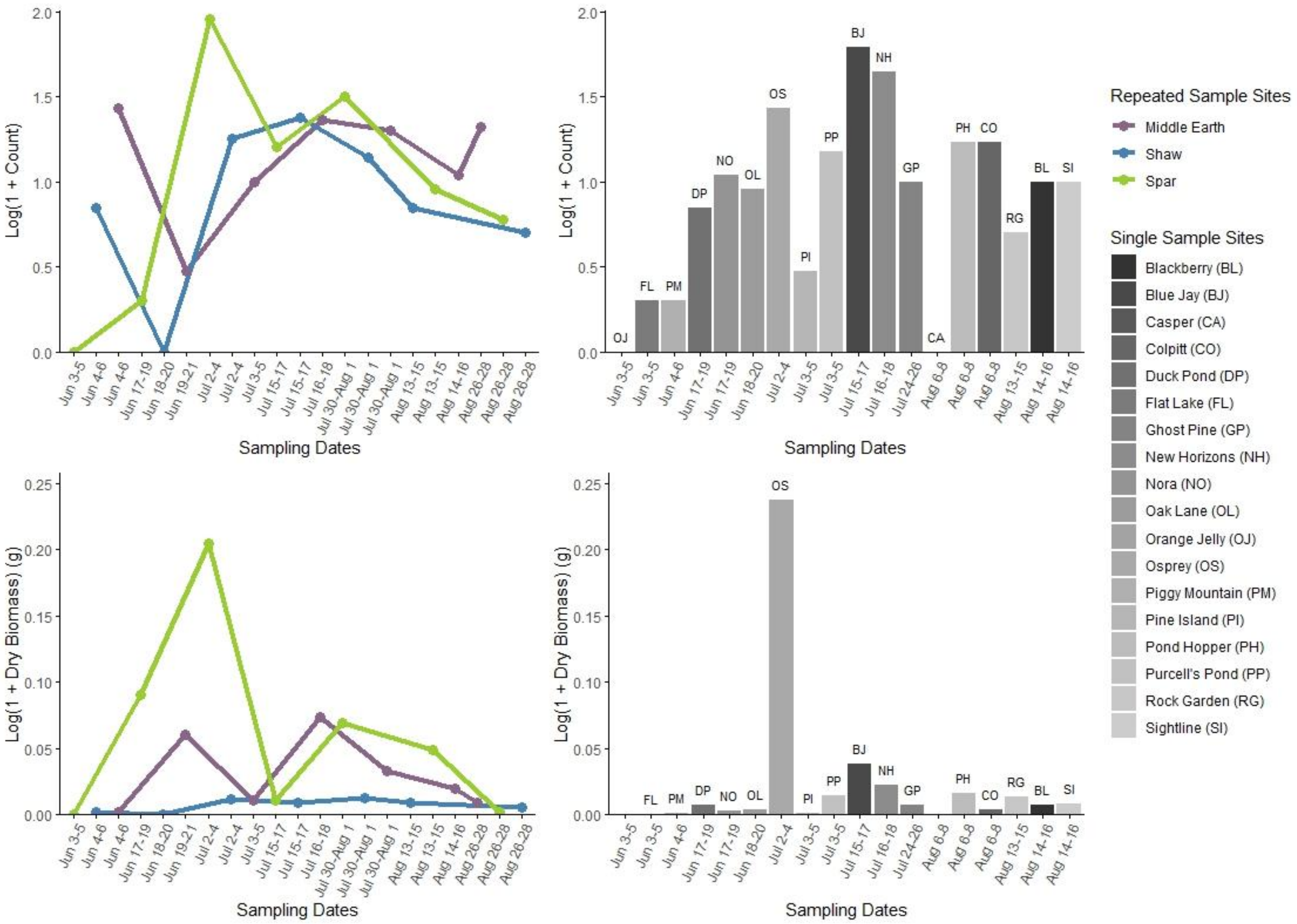

Figure 4. *Lepidoptera* in Malaise trap samples. Log10(1+Count) and log10(1+Dry Biomass) (g) of *Lepidoptera* collected with Malaise traps at repeated and single-sample sites in the Backlands during the summer of 2024.

Coleoptera were not detected with either trap type at Pond Hopper or Rock Garden, open-area sites both sampled in August with less vegetation directly surrounding trap locations. Across repeated-sample sites, trends in this order appeared similar when only light trap samples were considered (Figure 5). *Coleoptera* made up 3.5% of insects in light traps and 13.4% in Malaise traps, but accounted for 13.2% and 26.5% of biomass in each trap type respectively (Table A1, A2). *Coleoptera* in Malaise trap samples varied more considerably throughout the summer but were generally greater in abundance in the month of July (Figure 6).

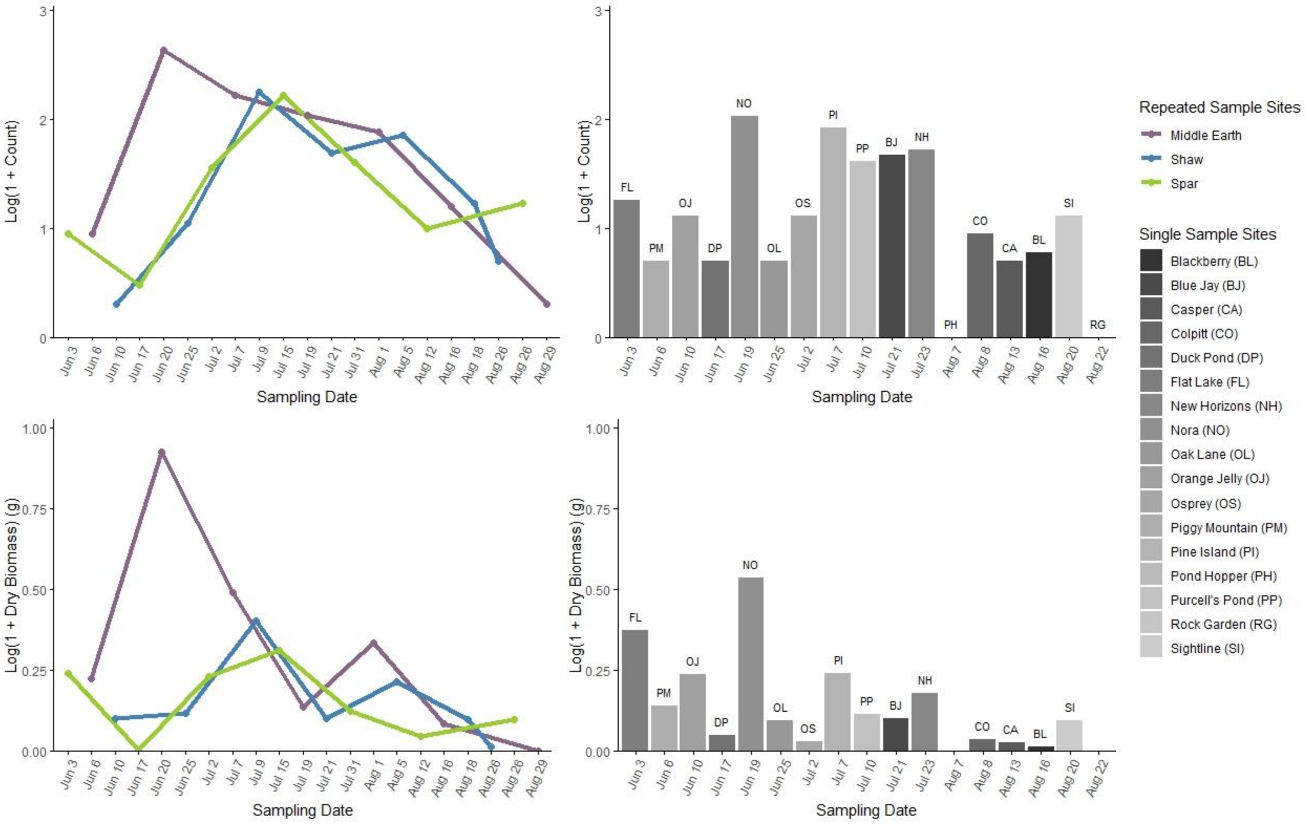

Figure 5. *Coleoptera* in light trap samples. Log10(1+Count) and log10(1+Dry Biomass) (g) of *Coleoptera* collected with light traps at repeated and single-sample sites in the Backlands during the summer of 2024.

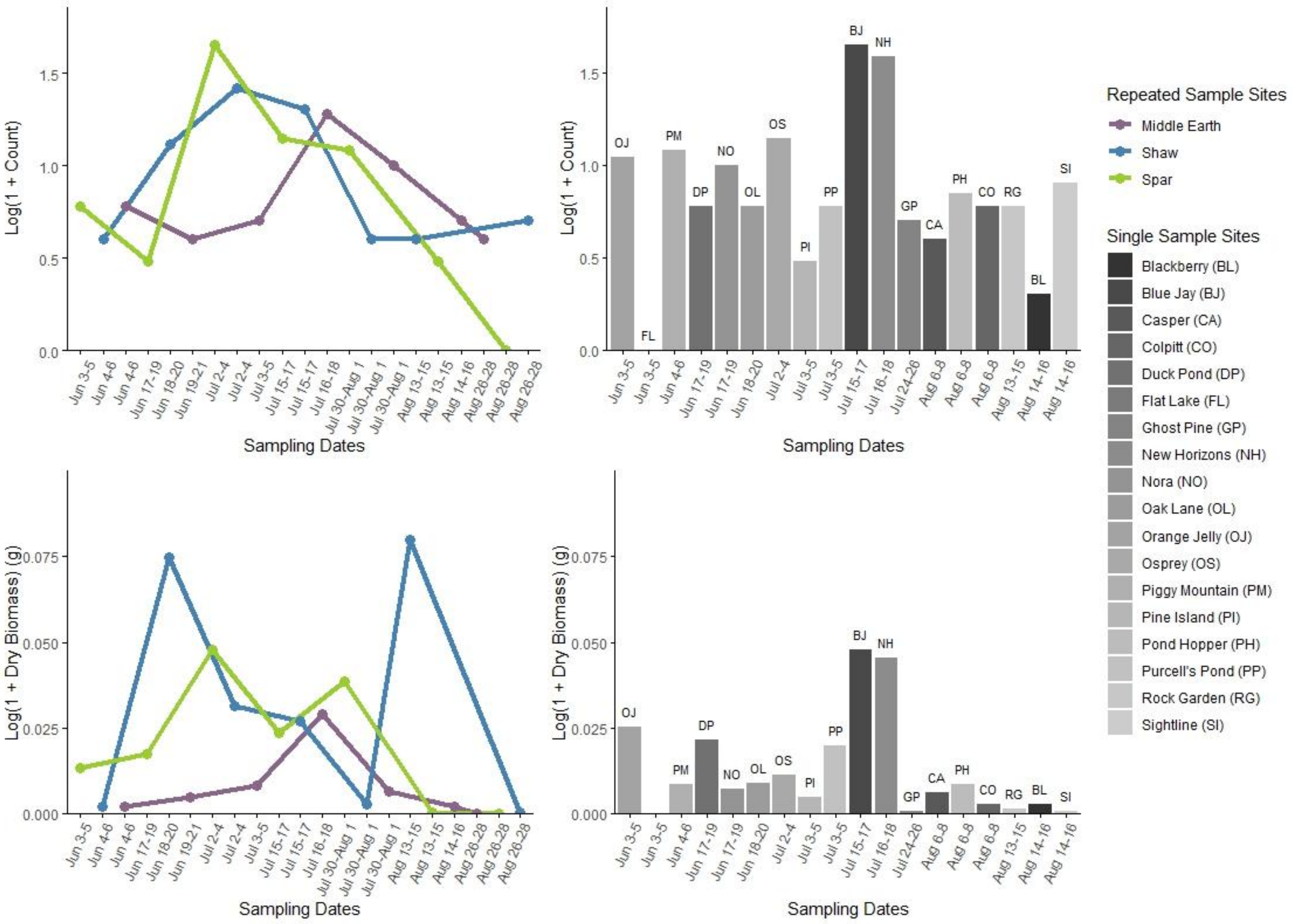

Figure 6. *Coleoptera* in Malaise trap samples. Log10(1+Count) and log10(1+Dry Biomass) (g) of *Coleoptera* collected with Malaise traps at repeated and single-sample sites in the Backlands during the summer of 2024.

Large numbers of *Trichoptera* were consistently captured with light traps at all sites (Figure 7), with an average of 111 individuals per sample. Presence of this order was only captured at six sites total with Malaise traps, with only 32 individuals captured over the whole summer (Figure 8; Table A2). This result suggests that *Trichoptera* may display strong phototactic behaviour, leading to irregular flight patterns that extend beyond the insect's home range. Despite comparable abundances of *Lepidoptera* and *Trichoptera* in light traps, *Trichoptera* had considerably lower dry biomass at 0.528 g per sample than *Lepidoptera*, which had 3.089 g per sample. This implies that while *Trichoptera* are abundant, they do not offer as much sustenance as *Lepidoptera* might.

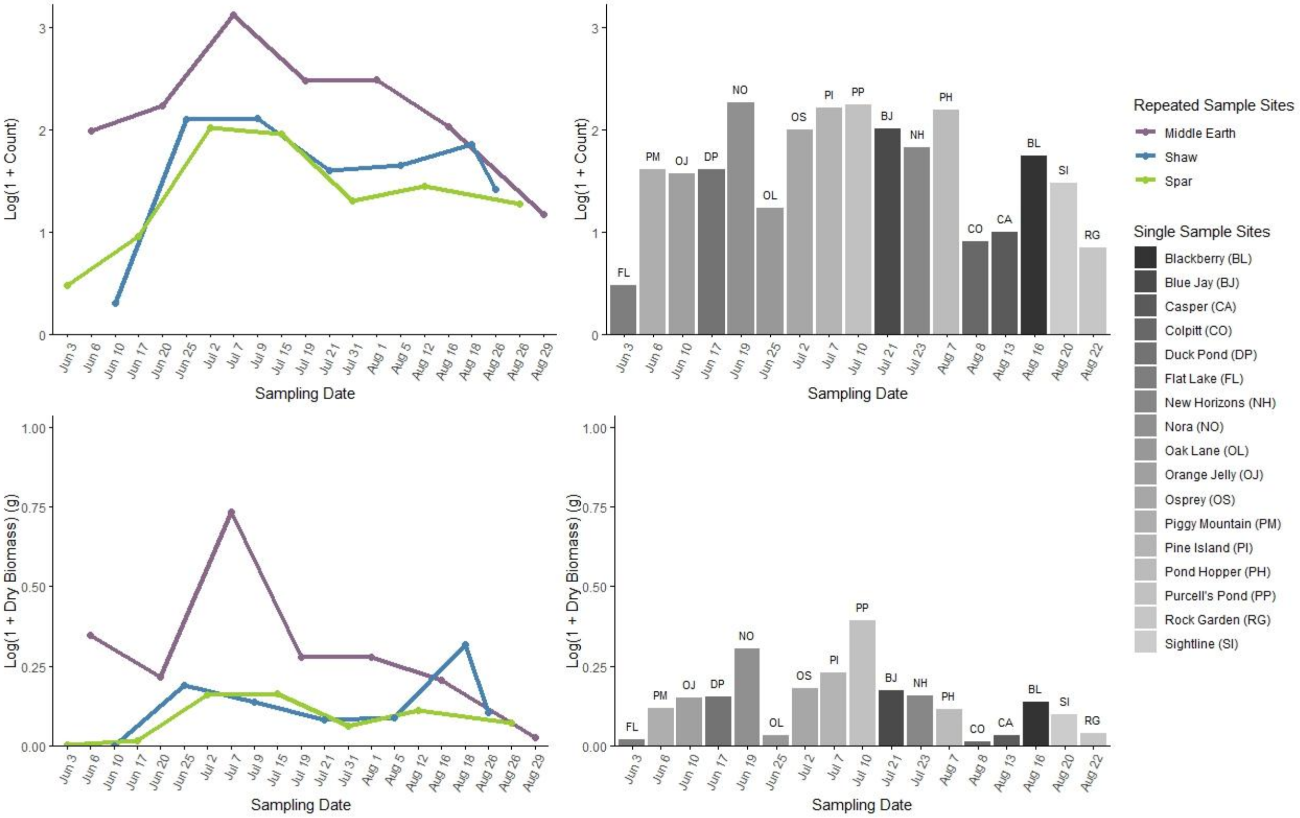

Figure 7. *Trichoptera* in light trap samples. Log10(1+Count) and log10(1+Dry Biomass) (g) of *Trichoptera* collected with light traps at repeated and single-sample sites in the Backlands during the summer of 2024.

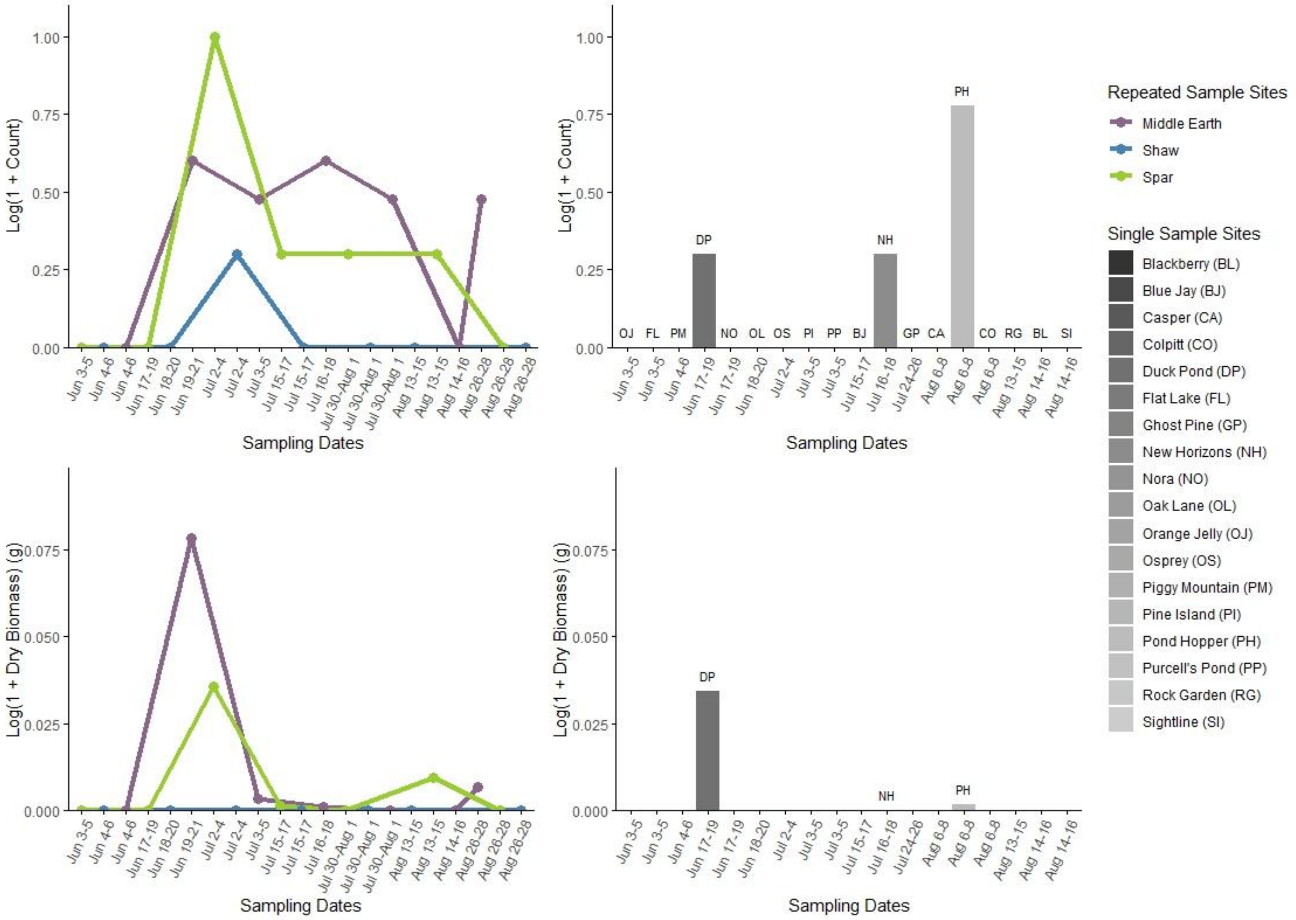

Figure 8. Trichoptera in Malaise trap samples. Log10(1+Count) and log10(1+Dry Biomass) (g) of *Trichoptera* collected with Malaise traps at repeated and single-sample sites in the Backlands during the summer of 2024.

Of the four orders of interest, aerial *Hymenoptera* had the lowest counts and smallest dry biomass in light traps, with an average of eight specimens and 0.065 g dry biomass per sample (Figure 9). Hymenoptera made up greater proportions of Malaise samples (3.18 %) than light trap samples (0.59 %), suggesting that Malaise traps may be more effective at capturing insects from this order. Malaise traps collected small aerial *Hymenoptera* almost exclusively (Figure 10). Small *Hymenoptera* persisted throughout the summer, while peaks in large insects from this order occurred in June and August.

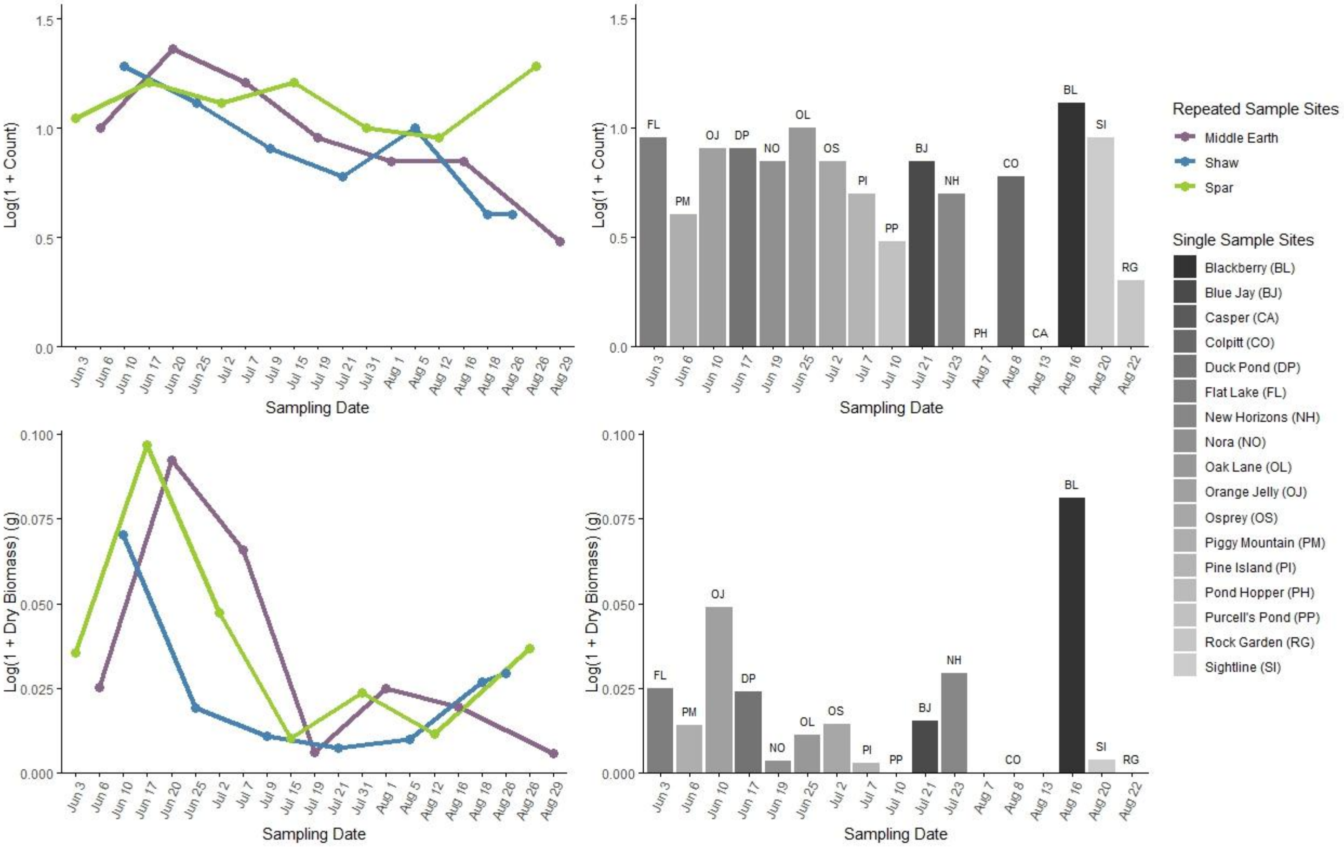

Figure 9. Aerial *Hymenoptera* in light trap samples. Log10(1+Count) and log10(1+Dry Biomass) (g) of aerial *Hymenoptera* collected with light traps at repeated and single-sample sites in the Backlands during the summer of 2024.

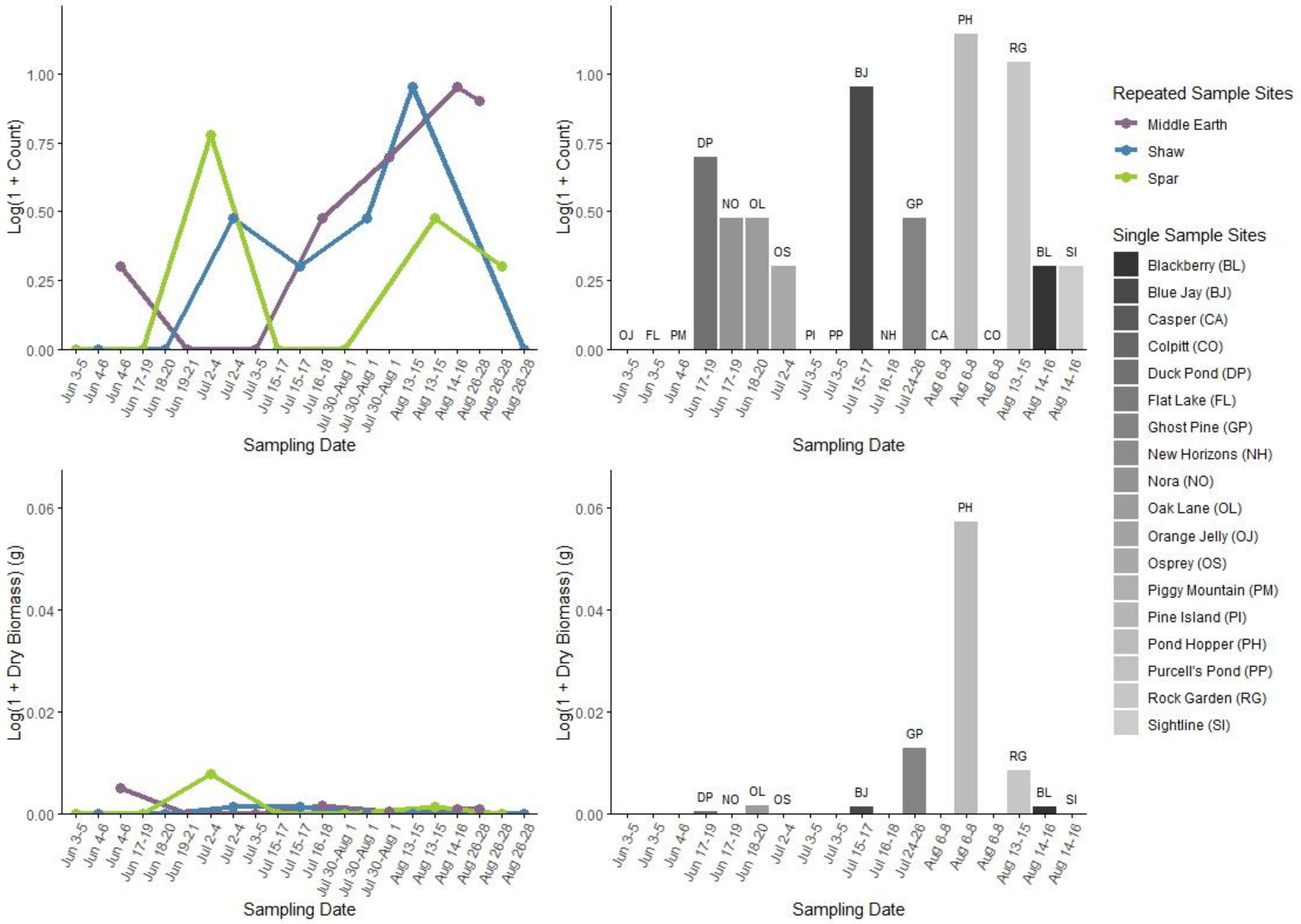

Figure 10. **Aerial *Hymenoptera* in Malaise trap samples.** Log10(1+Count) and log10(1+Dry Biomass) (g) of aerial *Hymenoptera* collected with Malaise traps at repeated and single-sample sites in the Backlands during the summer of 2024.

Shannon-Wiener Diversity Index Calculations

Light Trap Samples

The Halifax Backlands host a broad variety of insect orders at various evenness across the landscape. Light traps collected 13 insect orders across 38 samples, with the largest sample yielding 15,492 insects from Spar on the night of July 3rd, 2024, and the smallest sample yielding 46 insects from Rock Garden on the night of August 23rd, 2024. Counts for terrestrial

Hymenoptera were excluded from Shannon-Wiener Index calculations, as they are not aerial insects and are thus not a component of this study.

Among the single-sample sites, aerial insect order diversity from light traps was greatest at Sightline, where evenness was also highest (H=1.52, J=0.78; Table 4). Blackberry, Nora and Pine Island had similar high diversities of insect orders (H =1.41, 1.40, 1.40), with the Pine Island sample collecting the greatest number of orders across all samples (S=10). Low order diversity was measured at Flat Lake, Oak Lane and Pond Hopper (H=0.94, 0.60, 0.82). Osprey had the lowest diversity across all samples with an extremely low evenness (H=0.26, J=0.13), despite having the largest sample among single-sample sites (n = 13,561). Samples from Casper, Flat Lake and Orange Jelly had the lowest order richness across all samples (S=5).

Table 4. Diversity indices for light trap samples at single-sample sites. Number of individuals (n), Shannon-Wiener index (*H*), richness (*S*) and evenness (*J*) for aerial insect orders collected from light traps deployed at seventeen single-sample sites in the Halifax Backlands, Nova Scotia, in the summer of 2024.

Site name	n	*H*	*S*	*J*
Blackberry	255	1.41	8	0.68
Blue Jay	1,091	1.16	8	0.56
Casper	56	1.18	5	0.73
Colpitt	222	1.02	8	0.49
Duck Pond	419	1.07	6	0.60
Flat Lake	204	0.94	5	0.58
New Horizons	446	1.16	6	0.65
Nora	753	1.40	8	0.67
Oak Lane	257	0.60	6	0.34
Orange Jelly	219	1.18	5	0.73
Osprey	13,561	0.26	7	0.13
Piggy Mountain	221	1.19	6	0.66
Pine Island	779	1.40	10	0.61
Pond Hopper	1,057	0.82	7	0.82
Purcell’s Pond	638	1.23	8	0.59
Rock Garden	46	1.26	6	0.70
Sightline	202	1.52	7	0.78

The Middle Earth and Shaw repeated sampling sites had the same order diversity, richness and evenness when light trap sampling events were pooled together (*H*=1.36, *S*=12, *J*=0.55; Table 5). Spar had a diversity index and evenness that were substantially lower than the other repeated sampling sites (*H*=0.51, *J*=0.21). All three sites detected 11 of the 13 orders of insects collected by light traps in the Backlands in the summer of 2024. In addition to these, one damselfly (Order *Odonata*) was detected at Middle Earth and one cricket (Order *Orthoptera*) was detected at Shaw. Both insects from outstanding orders were collected in late August.

Table 5. Diversity indices for light trap samples at repeated-sample sites. Number of individuals (n), Shannon-Wiener index (*H*), richness (*S*) and evenness (*J*) for aerial insect orders collected from light traps deployed at three repeated sample sites in the Halifax Backlands, Nova Scotia, in the summer of 2024.

Site name	n	*H*	*S*	*J*
Middle Earth	9,474	1.36	12	0.55
Shaw	3,984	1.36	12	0.55
Spar	17,156	0.51	11	0.21

Malaise Trap Samples

Malaise traps collected a narrower diversity of aerial insects across the Backlands than light traps. Only eight orders of aerial insects were collected with Malaise traps, with notably low measures of orders *Plecoptera* (stoneflies, n=3) and *Neuroptera* (lacewings, n=4) over the entire sampling period. Orders not found in Malaise trap catches but found in light trap catches included *Megaloptera* (fishflies), *Ephemeroptera* (mayflies), *Psocoptera* (barklice), *Odonata* (damselflies and dragonflies) and *Orthoptera* (grasshoppers and crickets). Malaise trap samples contained a greater number of spiders and mites (Class *Arachnida*) than light trap samples, with over half of Malaise trap samples containing at least one specimen. Arachnids were excluded from analyses as they are not aerial insects.

Malaise trap catches were substantially smaller in counts and biomass than those of light traps. The largest Malaise trap sample was collected at Middle Earth from July 16th to July 18th, 2024, with 355 aerial insects. This week of sampling had the highest insect counts in Malaise traps for the summer, with an average of 158 aerial insects per sample. The smallest Malaise trap sample was at Spar from 3-5 June 2024, which collected 5 insects total, all beetles (Order *Coleoptera*). Malaise traps collected an average of 70 aerial insects per sample, the majority of which were small midges and mosquitoes (Order *Diptera*).

There were large discrepancies in diversity between Malaise trap and light trap samples at single-sample sites (Table 6). Duck Pond and Pond Hopper had the highest diversity (H =1.63, 1.57) and evenness (J = 0.91, 0.87) among Malaise trap samples. These sites additionally collected the greatest number of orders out of all single-sample sites (S = 6). It is important to note that both Pond Hopper and Duck Pond were sampled with light traps during the period of Malaise trap deployments at these sites, which may have influenced the catch from Malaise traps. Contradictory to light trap results, Blue Jay, Nora and Oak Lane had remarkably similar diversity indices (H = 1.37, 1.35, 1.35), evenness (J = 0.85, 0.84, 0.84) and order richness (S =5). Colpitt, Orange Jelly and Rock Garden had low diversity indices (H = 0.86, 0.60, 0.83). Orange Jelly collected the fewest aerial insect orders (S = 2), but had higher order evenness (J = 0.86) than Colpitt (S = 0.78) or Rock Garden (S = 0.52). Flat Lake was an outlier among single-sample sites, with an exceptionally low diversity index and equally low evenness (H = 0.13, J = 0.10).

Table 6. Diversity indices for Malaise traps at single-sample sites. Abundance (n), Shannon-Wiener index (*H*), richness (*S*) and evenness (*J*) for aerial insect orders collected from Malaise traps at eighteen single-sample sites in the Halifax Backlands, Nova Scotia, in the summer of 2024.

Site name	n	*H*	*S*	*J*
Blackberry	13	1.04	5	0.65
Blue Jay	156	1.37	5	0.85
Casper	8	0.97	3	0.89
Colpitt	24	0.86	3	0.78
Duck Pond	33	1.63	6	0.91
Flat Lake	221	0.13	4	0.10
Ghost Pine	19	1.25	4	0.90
New Horizons	109	1.19	5	0.74
Nora	34	1.35	5	0.84
Oak Lane	27	1.35	5	0.84
Orange Jelly	35	0.60	2	0.86
Osprey	65	1.12	4	0.81
Piggy Mountain	15	0.73	3	0.66
Pine Island	12	1.12	4	0.81
Pond Hopper	58	1.57	6	0.87
Purcell’s Pond	31	1.02	3	0.93
Rock Garden	90	0.83	5	0.52
Sightline	35	1.23	5	0.76

Aerial insect abundance and diversity at Ghost Pine was calculated from a single Malaise trap sample, and had no light trap results for comparison. Ghost Pine exhibited moderate diversity (*H* = 1.25), high evenness (*J* = 0.90) and moderate order richness (*S* = 4) among Malaise trap samples. Ghost Pine collected 19 aerial insects in total, making it the fifth smallest Malaise sample of the single-sample sites in for the season. Smaller samples included Casper (n=8), Pine Island (n=12), Blackberry (n=13) and Piggy Mountain (n= 15). Only New Horizons (H_{light} = 1.16, $H_{malaise}$ = 1.19) and Nora (H_{light} = 1.40, $H_{malaise}$ = 1.35) had similar diversity indices between Malaise and light trap samples.

Malaise trap samples reflected a greater range of aerial insect diversities at the repeated sample sites than did light traps (Table 7). Unlike its light trap results, Middle Earth exhibited the lowest Shannon-Wiener diversity and lowest evenness of the three sites (H = 0.79, J=0.40) while Spar had the highest (H=1.31, J=0.73). Shaw had similar evenness for Malaise trap samples and light trap samples, but a lower diversity in Malaise trap samples (J = 0.54, H = 1.05). Like light trap samples, Middle Earth and Shaw had higher species richness than Spar (S=7). Both Middle Earth and Shaw had samples containing lacewings (Order *Neuroptera*), insects not detected with Malaise traps at Spar.

Table 7. Diversity indices for Malaise trap samples at repeated-sample sites. Number of individuals (n), Shannon-Wiener index (*H*), richness (*S*) and evenness (*J*) for aerial insect orders collected from Malaise traps deployed at three repeated sample sites in the Halifax Backlands, Nova Scotia, in the summer of 2024.

Site name	n	*H*	*S*	*J*
Middle Earth	939	0.79	7	0.40
Shaw	458	1.05	7	0.54
Spar	352	1.31	6	0.73

Prey Item and Nighthawk Detection Correlations

Insects likely to be nighthawk prey were defined as *Coleoptera*, *Hymenoptera*, *Lepidoptera* and *Trichoptera* with body lengths > 5 mm collected using light traps. Of the three repeated sampled sites, Middle Earth had the largest average prey item biomass over the summer ($\bar{x}$ = 8.528 g; Figure 11). However, this site also had the greatest variation in prey biomass of the three sites (*SD* = 7.683), suggesting nighthawk prey was not consistently available in high quantity at Middle Earth. Shaw and Spar had similar availability of prey ($\bar{x}$ = 3.331 g, $\bar{x}$ = 3.490 g), with less than half the average biomass at Middle Earth. Spar had the lowest variation of prey item biomass for the summer (*SD*=2.917), suggesting this site had the most consistent levels of suitable prey for the Common Nighthawk.

ARUs were deployed at Spar, Shaw and Middle Earth from mid-May until early September. For this analysis, nighthawk activity from 22 May – 3 Sept 2024 was used to capture seven two-week periods that corresponded with insect sampling periods. Among the three sites, the ARU at Spar detected the most nighthawk activity with a total of 54,945 detections for the summer. Spar had approximately 321 times more detections than Middle Earth, where the ARU recorded only 171 detections for the duration of the season. Of the 105 days where recordings were considered, 87 (82.9%) days did not have any detections at Middle Earth. Shaw had a total of 9,142 detections for the summer. The number of detections at Shaw dropped substantially in late August, whereas detections at Spar remained high for approximately two weeks later (Figure 3). Kendall’s rank correlation tests found that there were no significant correlations of prey biomass with nightly nighthawk detections (p = 0.69, *tau* = - 0.06) nor with average nighthawk detections over corresponding two-week periods (p = 0.323, *tau* = - 0.16).

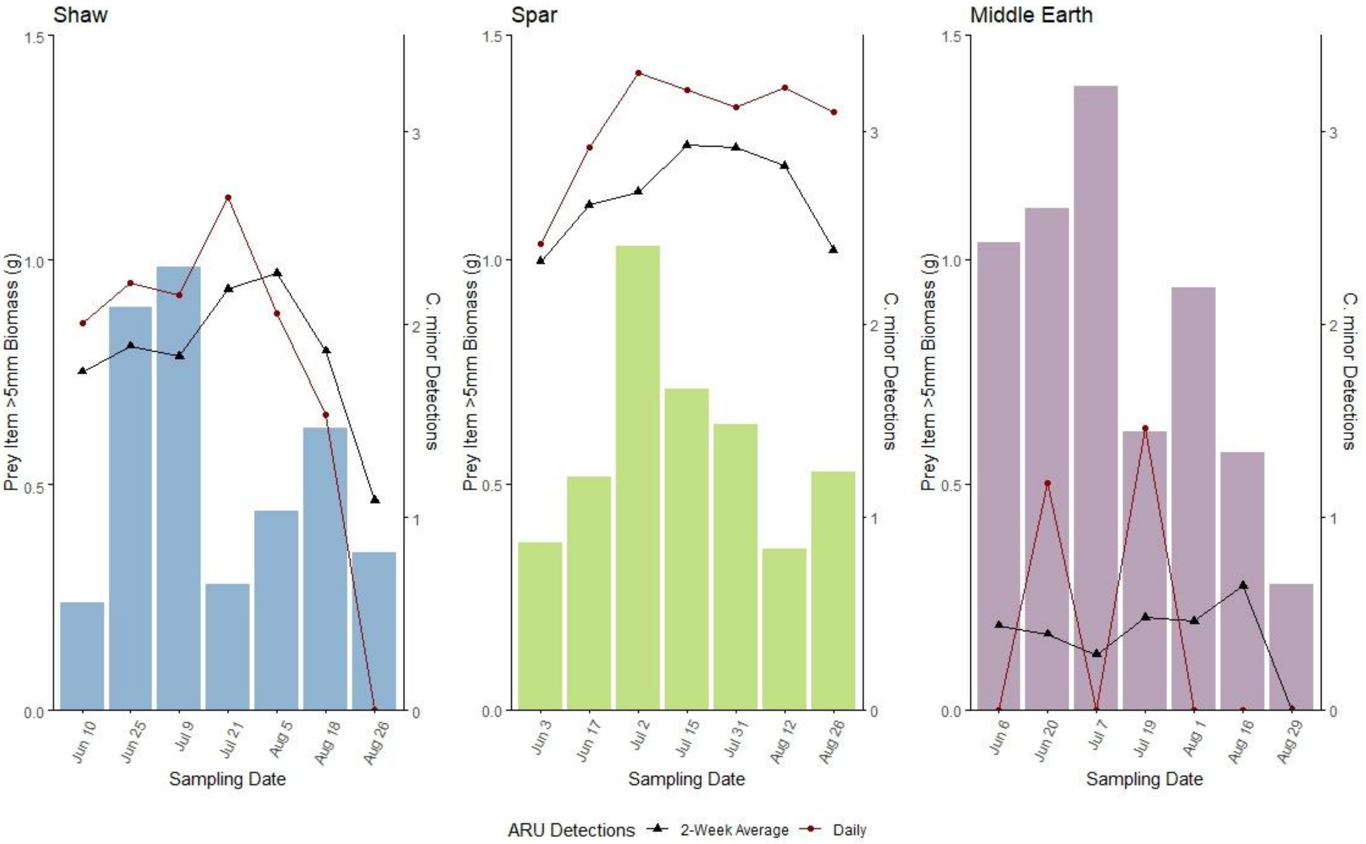

Figure 11. Comparison of insect biomass and nighthawk activity. Dry biomass of prey items (Aerial *Hymenoptera*, *Coleoptera*, *Lepidoptera* and *Trichoptera*) > 5 mm body length captured in light traps alongside daily and 2-week average auditory *Chordeiles minor* ARU detections for repeated sample sites Shaw, Spar and Middle Earth sampled throughout the summer of 2024. All variables were log10+1 transformed. ARU detections were processed by Madeleine Kurtz for a co-located study (Kurtz 2025).

Modelling Abundance at Repeated-Sample Sites

Light Trap Samples

Multiple GLMMs with different combinations of random effect variables were created to model aerial insect abundance at Middle Earth, Shaw and Spar (Table 8). Across all GLMMs, the month of July had a significant positive effect on aerial insect counts. The effects of nighthawk detections and site varied across models. Average windspeed, temperature and humidity were highly correlated and could not be successfully incorporated into the same model. However, each could be incorporated with lunar percentage to create models with reasonably good fit.

Model selection completed using Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC) indicated that a model with average temperature as the sole random effect was the most parsimonious model for predicting aerial insect abundance at the repeated sample sites (AIC = 327.5, BIC = 333.7; Table 8). This best-fitting model also revealed a significant effect of site on aerial insect abundance, showing that insect counts were highest at Middle Earth, where nighthawk detections were lowest ($\beta = 1.10$, $p = 0.016$). Shaw had intermediate nighthawk abundance and also showed a significant increase in insect abundance ($\beta = 0.25$, $p = < 0.001$) relative to Spar, which had high nighthawk detections. Deployment month had a highly significant effect on aerial insect abundance, with higher counts in the month of July ($\beta = 1.76$, $p = < 0.001$) than in June and August, which had similar insect abundance. Average temperature contributed some variability to insect abundance (*variance* = 0.95, *SD* = 0.98), but likely was not the primary driver of changes in aerial insect abundance across sites.

Aside from this best-fit model, there were three alternative models with reasonable performance that had similar AIC and BIC criterion (Models LT 2, LT 3, LT 4; Table 8). These models incorporated lunar percent as a random effect in tandem with average windspeed, humidity and temperature respectively. Across all three, lunar percent contributed to more variability in the model than the other random effects, suggesting it may be a good secondary predictor for aerial insect count in light traps.

Table 8. GLMM comparison for light trap samples. Generalized linear mixed models (GLMMs) for light trap samples collected at repeated sampling sites in the summer of 2024. Fixed factors present in all models were deployment month and *Chordeiles minor* activity (Middle Earth = low, Shaw = medium, Spar = high).

Model	Random effects	AIC	BIC	logLik	Deviance	df
LT 1	Temperature	327.5	333.7	-157.7	315.5	15
LT 2	Windspeed, Lunar Percent	333.7	341.0	-159.8	319.7	14
LT 3	Humidity, Lunar Percent	334.8	342.1	-160.4	320.8	14
LT 4	Temperature, Lunar Percent	334.9	342.2	-160.4	320.9	14
LT 5	Lunar Percent	349.5	355.8	-168.8	337.5	15
LT 6	Humidity	361.7	368.0	-174.8	349.7	15
LT 7	Windspeed	1914.3	1920.6	-951.1	1902.3	15

Modelling Abundance at Single-Sample Sites

Light Trap

A negative binomial GLM was used to model aerial insect abundance at single-sample sites. Predictor variables included average overnight temperature, average windspeed, average humidity, auditory nighthawk detections, lunar percent, and deployment month. Mean canopy height and percent of wet area within a 200 m radius from the site were also included. The dispersion parameter ($\theta = 6.27$) confirmed that a negative binomial model is appropriate for these data.

Multiple predictors were found to have highly significant effects on aerial insect abundance. Unlike the findings from my three repeated-sample sites, windspeed and humidity were found to have strong significant effects on the abundance of aerial insects in light traps at single-sample sites. Windspeed had a strong positive effect on insect abundance ($p = < 0.001$, β

=0.49), indicating that insect abundance was greater at sites with higher average windspeed. Humidity had a strong negative effect (p = < 0.001, β = -0.12), indicating insects were not in high abundance at sites where high humidity was measured.

Characteristics of habitat within a 200 m radius of sampling sites contributed to aerial insect abundance. Mean canopy height was highly significant (p = < 0.001, β =0.66), suggesting that light traps collected more insects at single-sample sites with higher tree canopy. Percentage of wet areas was borderline insignificant, and may have a very weak positive effect on aerial insect abundance (p = 0.052, β = 0.025).

Deployment month had significant effects on aerial insect abundance at single-sample sites. Unlike what was observed at repeated sample sites, June had significantly higher insect counts than August (p = 0.02, β = 0.88). Sites sampled in July also had greater aerial insect abundance than those sampled in August, but not by a significant amount (p = 0.095, β = 0.68).

Lunar percentage had a strong negative effect on insect counts (p = < 0.001, β = - 0.028), meaning fewer insects were collected in light traps on nights with a full or near-full moon. Auditory nighthawk detections were found to have a strong significantly positive relation with aerial insect count from light traps (p = < 0.001, β = 0.0014), suggesting there may have been greater insect abundance at sites where nighthawks were most active. This contradicts what was found in the GLMM for repeated-sample sites, where nighthawk activity was highest at the sites with lower insect abundance.

Temperature was the only predictor variable to have no significant effect on aerial insect count from light traps at single-sample sites (p = 0.14, β = 0.11). This contrasts with the analysis of repeated sample sites, which found that temperature was among the best predictors for aerial insect abundance in light trap samples. A GLM without temperature as a predictor had a very similar fit (AIC = 230.83) to the GLM that included temperature as a predictor (AIC = 230.55). This suggests that temperature could be removed from the GLM for insect abundance to reduce complexity without heavily impacting model fit.

Modelling Biomass at Repeated-Sample Sites

A LMM was created to model the effects of season, site and environmental variables on total aerial insect biomass at repeated sample sites, including both presumed prey and non-prey items for Common Nighthawks. The model with the most parsimonious fit had lunar percent as the only random effect and was fitted using restricted maximum likelihood (*REML* = 15.8).

Like the insect abundance models, aerial insect biomass was higher in July than in August, though this effect was weaker and only marginally significant ($\beta = 0.66$, $p = 0.06$). Insect biomass was also greater in June than August, but this effect was not statistically significant ($\beta = 0.21$, $p = 0.29$). Site had no significant effect on insect biomass ($p = > 0.05$), indicating that variation in nighthawk activity across sites was not due to differences in available insect biomass. Lunar percentage accounted for moderate variation in biomass across sites (*variance* = 0.099, *SD* = 0.32), while a small amount remained unexplained (*residual* = 0.012, *SD* = 0.10).

Modelling Biomass at Single-Sample Sites

A linear model was used to model the effects of habitat, season, nighthawk activity and environmental conditions on aerial insect biomass at single-sample sites. Nighthawk activity was the transformed (log10+1) number of ARU detections on the dates of deployment and collection for light traps. Backwards stepwise model selection removed average humidity and nighthawk activity from the model as they appeared to contribute no variation to insect biomass at single-sample sites.

As observed for the other models, samples collected in the month of July had significantly greater biomass than those collected in August ($\beta = 0.48$, $p < 0.001$). Samples in June also collected significantly greater biomass than samples in August ($\beta = 0.43$, $p = 0.003$). Lunar percentage appeared to contribute to insect biomass, where samples collected near the full moon weighed less than samples collected near new moons, but this effect was not statistically significant ($\beta = - 0.002$, $p = 0.09$). Temperature may be a good predictor for insect biomass, with higher temperatures contributing to significantly greater insect biomass in light traps at single-sample sites ($\beta = 0.05$, $p = 0.02$). The percentage of wet area near sites and average windspeed had marginally significant effects on insect biomass, where increased windspeeds ($\beta = 0.05$, $p = 0.06$) and a slightly smaller percentage of wet areas ($\beta = - 0.007$, $p = 0.05$) suggest greater insect biomass. Mean canopy height had no significant effect on insect biomass ($p = 0.206$).

DISCUSSION

My results for insect diversity, abundance and biomass varied between the two trap types and between repeated and single-sample sites. Measures of diversity, richness and evenness differed between Malaise trap samples and light trap samples from the same site, suggesting each trap type collected different subsets of insect taxa. Notably, Malaise traps collected very few insects with aquatic life histories, as no *Megaloptera* or *Ephemeroptera* and very few *Plecoptera* and *Trichoptera* were found in samples. Malaise traps collected relatively few insects overall when compared to light trap samples. This was to be expected, as Malaise traps collect insects passively, while light traps feature an attractant that ultimately increases the likelihood of insect capture.

Models generally found that insect samples collected in July had greater abundance and biomass than those collected in June or August. Insect models for repeated-sample sites found that abundance was highest at Middle Earth, followed by Shaw then Spar. These results represent an inverse trend between nighthawks and insects, where nighthawks frequented areas with low insect abundance more often than those with high abundance. I found that temperature and lunar phase contributed to some variation in insect abundance but were very likely not the only important factors. Variation from other, undocumented variables were likely influencing insect numbers. Unlike abundance, biomass did not vary significantly between repeated-sample sites, suggesting that while Spar and Shaw had lower insect abundance than Middle Earth, these sites had larger insects that made up the difference in biomass.

Model results for single-sample sites did not coincide with findings for repeated-sample sites. Models for single-sample sites incorporated mean canopy height and percent of surrounding wet areas to delineate different sites rather than use categorical variables for nighthawk abundance as was done for repeated-sample sites. Nighthawk detections from ARUs recording at these sites during light trap deployment were used as a separate predictor. Multiple factors were found to contribute to differences in insect abundance across single-sample sites. High average tree canopy and higher percentage of wet areas were found to positively affect insect abundance, while high humidity lowered insect counts. Temperature did not significantly affect insect abundance but was found to have a significant positive effect on biomass, suggesting that warmer temperatures could be correlated with larger insects. Windy sites had high abundance and biomass, while lunar phases around the full moon led to smaller samples with lower biomass. In contrast to what was found at repeated-sample sites, nighthawk detections correlated with high insect abundance and had no effect on biomass at single-sample sites. Nighthawks appeared to spend most of their time near Shaw and Spar, but may have traveled to different sites to exploit high abundance of insects where available.

Direct examination of the correlation between nighthawk detections and prey item biomass found that neither daily nor biweekly predator activity correlated with high prey availability. This analysis does not account for other factors that may be at play and is limited in scope. However, these results suggest that nighthawks could be foraging on insects outside of the predicted targets, including insects from other orders not previously considered nighthawk prey. Combined, the results of my study suggest that nighthawks breeding in the Backlands are not food limited and may be provided with enough insect resources in northern regions of the study area to limit travel to dispersed foraging sites in central and southern regions.

Sample Discrepancies Between Trap Types

Aerial insect diversity varied by trap types. Of the 21 sites, only New Horizons and Nora had order diversities that were comparable between Malaise and light traps. Discrepancies in aerial insect diversity between trap types are most clearly observed when examining indices from samples at repeated-sample sites. Middle Earth had the greatest light trap diversity, but the lowest Malaise trap diversity. Spar showed the inverse, with high diversity in Malaise trap samples and low diversity in light trap samples

Differences in diversity indices between trap types likely stem from each trap being optimized for capturing different insect orders. Williams (1939) found that *Diptera* constituted 86.7% of light trap samples serviced over four years, with the next largest proportion being *Lepidoptera* at 10.3% and all other orders making up only 3% of catch. An experiment conducted by Marchioro et al. (2020) suggested that light traps are very effective for trapping released *Diptera* and *Lepidoptera* but were less effective at trapping *Coleoptera* for their superior ability to escape traps. Meanwhile, Kalile et al. (2022) found that *Hemiptera* were drawn to UV light and could be successfully captured with light traps. Karlsson et al. (2020) identified Malaise traps as best suited for collecting *Hymenoptera* and *Diptera* but least effective at trapping large, active flying insects including *Lepidoptera* or *Odonata*. Further, Karlsson et al. (2020) found that over a three-year period, *Coleoptera* and *Homoptera*, a suborder of *Hemiptera,* made up less than 3% and 2% of Malaise catch, suggesting Malaise traps do not collect high proportions of these orders.

Proportions of orders in light trap samples in this study are consistent with previous findings. *Diptera* made up 65.7% of aerial insects, while *Lepidoptera* constituted roughly 17.6%. Approximately 3.5% were Coleoptera, while only 0.68% were *Hemiptera*. Malaise samples collected a substantially smaller proportion of *Lepidoptera* (20.5%) but collected *Diptera* at a similar percentage (59.8%). *Hymenoptera* were collected at a higher proportion in Malaise traps (3.18%) than in light traps (0.59%) but did not make up nearly the same fraction of samples as observed in Karlsson et al.'s (2020) study. *Hemiptera* were collected in both trap types used in my study, with Malaise traps collecting a slightly greater proportion (1.72%) than light traps (0.68 %). *Coleoptera* made up 13.4% of my Malaise trap samples, a higher proportion than what was found by Karlsson et al. (2020).

Trichoptera (caddisflies) and *Plecoptera* (stoneflies) were rare in Malaise trap samples, while *Megaloptera* (fishflies) and *Ephemeroptera* (mayflies) were absent. These orders are secondary aquatic insects, meaning they have aquatic larvae but undergo complete or incomplete metamorphosis to become terrestrial adults (Boda et al. 2014). Adults are generally weak fliers and typically do not disperse far from water they emerged from. Boda et al. (2014) demonstrated that insects from these orders rely on phototaxis, the attraction to light, and polarotaxis, the orientation with a plane of light, to detect the water on which their life strategy depends. This innate behaviour is likely what drove greater abundance of aquatic insects in light traps than in Malaise traps in the current study. Low dispersal from water bodies further explains why individuals from these orders were only collected at select sites, such as Middle Earth, Pine Island, Pond Hopper and Purcell's Pond, that had high percentages of surrounding wet area (Table A3).

In addition to secondary aquatic insects, Malaise traps collected lower numbers of *Neuroptera* (lacewings) and *Psocoptera* (barklice) than light traps. Both orders have adult forms that are poor fliers, exhibiting short bursts of flight rather than extended periods of air travel. This makes insects from these orders unlikely nighthawk prey. Park et al. (2023) found that

Neuroptera were attracted to LED light between 385 and 450 nm, while Diaz-Montano et al. (2016) found that wingless *Psocoptera* showed attraction to LED light at 351 nm, both of which fell within the UV LED spectrum of light traps used in my study. Reduced mobility and attraction to light may explain why these orders were collected predominantly in light traps.

Sample proportions of *Hemiptera* and *Hymenoptera* suggest that best estimates of abundance for these orders may be obtained using Malaise traps as opposed to light traps. Longer sampling windows of a week or more, as done in Karlsson et al.'s (2020) study, may achieve more accurate abundance estimates for these orders. *Diptera* are very abundant in the Backlands and can be detected with either light or malaise traps. Aquatic or semi-aquatic insects are best detected with light traps. My findings suggest that *Coleoptera* and *Lepidoptera* can be detected with either Malaise or light traps. While this may be true, it is possible that overlapping sampling windows between Malaise and light traps at the same site affected Malaise trap samples by capturing phototactic insects attracted by light traps. It is therefore possible that Malaise traps collected at sites where light traps were deployed during the same period collected samples misrepresentative of the immediate local insect populations.

Lunar Effects on Light Trap Samples

Lunar phase was found to affect aerial insect abundance across light traps samples. At both site types, high lunar percentages associated with full or near-full moons significantly decreased the number of aerial insects collected with light traps. This trend is likely a consequence of phototactic behaviour in conjunction with the use of moonlight for flight orientation in nocturnal insects. Similar effects of lunar phase on aerial insect light trap catch have been observed in many previous studies. Williams (1936) found that three times the amount of noctuid moths were caught during a new moon compared to a full moon. Later, investigations conducted over a four-year period by Willaims (1939, 1940) found that total insect catch reached a minimum during the full moon, at which time samples were approximately 34% smaller than normal. The same study found that samples were largest a few days after the new moon, at 66% greater than the normal sample size.

The results obtained in my study echo those found by Williams (1939, 1940), with the largest samples generally collected during the week of the new moon. This was particularly pertinent to single-sample sites, where Osprey collected the largest sample (13,561) three nights before the new moon on July 3rd, 2024. Other single-samples sites that were sampled during weeks of the new moon included Pine Island (779), Pond Hopper (1, 057) and Colpitt (222). Similar to findings by Williams (1939, 1940), lunar effects did not have as consistent an effect on single-sample site samples collected on or around the full moon. Blue Jay collected 1, 091 aerial insects on the night of the full moon at the end of July, while Nora collected 753 when the moon was roughly 93.5% full in late June. These sites had some of the highest mean canopy height (Nora: 5.22 m, Blue Jay: 4.59 m; Table A3) , which may have contributed to a reduced effect of the moon, as the immediate habitat is naturally sheltered by the trees from the effects of moonlight in general.

The reduced effects of the lunar cycle on light traps at repeated-sample sites may be in part due to the high abundance of aerial insects at Middle Earth. Ligh trap sampling events at Middle Earth only fell during the weeks of the new and full moons. Despite this, aerial insect abundance at Middle Earth was consistently high, with little difference in sample size observed between lunar phases or percentages. It is possible that nights sampled on the full moon at Middle Earth were cloudy, reducing the effect of moonlight on insect interaction with light traps.

However, it seems unlikely that the three nights sampled during the week of the full moon at this site in June, July and August would have had all had sufficient cloud cover throughout the night to impact sample size. My results suggest that Middle Earth may contain some of the highest-quality insect habitat in the Backlands. The area surrounding the light trap sampling site could represent pristine insect habitat, potentially leading to consistently high insect captures due to the trap's proximity to ideal conditions, regardless of the lunar phase or available moonlight.

Nighthawk Foraging Activity

It is possible that nighthawks in the Backlands elect to forage opportunistically in areas near their nesting sites as opposed to areas farther away. Kurtz (2025) observed male nighthawk territorial wing-boom displays at high density in the central and north regions of the Backlands in the summer of 2024. Knight et al. (2021) determined wing-booms are associated with nest location, which suggests nighthawks may have been nesting in the north and central regions near sites Shaw and Spar. Intermediate and high nighthawk detections at Shaw and Spar respectively further demonstrate that nighthawks frequented these areas more heavily than Middle Earth. Brigham (1990) observed that nighthawks travelled up to 12 km to reach optimal foraging sites from roosting areas, suggesting nighthawks will travel far distances to exploit high congregations of prey. However, Brigham (1990) did not explicitly investigate distance travelled to foraging sites from nesting grounds. Armstrong (1965) found that breeding nighthawk home range was approximately 10.4 ha in an urban area, which suggests foraging activity occurs close to nests. Nighthawks breeding in the Backlands may exhibit similar behaviour, where foraging activity occurs close to nesting sites, despite greater abundance of insects elsewhere.

Nighthawks are limited in their foraging abilities in that they exploit a small window of time to collect large prey numbers or biomass. This species must therefore maximize the use of their energy during foraging events to collect prey efficiently and meet energetic requirements. Travelling farther distances from nesting grounds to forage may be a wasteful use of energy during periods of high energetic requirement, such as egg incubation and chick rearing during the breeding season. It is reasonable to assume that, despite being lower than what is observed at Middle Earth, insect abundance at Shaw and Spar are sufficient to support breeding nighthawks in the Backlands.

Of the repeated-sample sites, aerial insect abundance was modelled to be lowest at Spar while insect biomass was not significantly different between sites. This suggests that while the number of insects were lower at Spar, it likely had a high frequency of large insects. Brigham and Fenton (1991) found that nighthawk diet consisted of individuals no smaller than 5 mm in body length, hypothesizing that both attack rate and visual constraints could contribute to this result. The same study found that nighthawks consumed *Coleoptera*, *Diptera* and *Trichoptera* individuals that were significantly larger in size than the average available for that order, suggesting nighthawks target larger insects. Spar may support insect populations with an optimal balance of abundance, size and biomass, making it one of the best foraging sites for nighthawks in the Backlands.

Limitations

Nighthawk Detections

Nighthawk activity was quantified in this study by the number of auditory detections recorded in daily four-hour periods synchronized with dawn and dusk. In this context, auditory detections encompassed mid-frequency vocal calls (3-5 kHz) known as ‘peents’, which are used by nighthawks across their home range (Brigham et al. 2011). Peents are commonly associated with foraging but may also occur during air travel or during courtship displays (Hannah et al. 2022). Previous studies suggest peents are usually produced alongside mechanical wing-booms during territorial displays, with at least one peent accompanying wing-booming behaviour (Knight et al. 2021). Wing booms are much less common, however. Despite the detection of peents being a good method for determining foraging behaviour of nighthawks, peents alone may be imprecise and may contribute to an inaccurate interpretation of a predator-prey relationship in this study. A more accurate assessment of foraging requires visual surveys, where observations of hawking and swooping flight patterns can be used to confirm foraging activity.

Environmental Variables and Habitat

Measurements for temperature, humidity and windspeed for overnight periods during light trap sampling were recorded at time of deployment and collection using hand-held instruments. Evening and morning measurements were averaged to serve as a representative measure of each variable for the entire night. While this method allowed for actual data collection at the specific sites, it generalizes environmental conditions. Averaging humidity, temperature and windspeed across a ten-hour period ignores the variability of these factors within the timeframe. Events such as sudden temperature drops, humidity spikes or wind gusts are not represented accurately in the data, potentially limiting the strength of conclusions on correlation between environmental variables and aerial insect metrics.

Habitat characteristics for study sites in the Backlands were extracted from three public databases using ArcGISPro. Aside from limited qualitative observations in field notes, habitat characteristics were not formally assessed in field at the time of study. While the effort was made to ensure databases were recent and relatively accurate, the data from these are not an exact representation of field conditions. Potential discrepancies between these data and field conditions may contribute to some inaccuracies in conclusions made about insect distribution findings.

Study Design

To capture insect distribution and nighthawk activity in the Backlands, we randomly selected twenty-one sites across various regions of the study area. We elected to repeatedly sample only three of these sites, located in three different regions of the study area, to examine nighthawk activity and aerial insect trends throughout the summer season. The remaining sites were sampled to understand the broader use of the study area by both insects and nighthawks. Due to a small number of insect traps and ARUs, alongside the infeasibility of visiting all sites in the given time frame, these sites were sampled only once. While single samples may provide some insight into insects inhabiting the surrounding area, it is impossible to know if the observed abundance and biomass are reflective of that site throughout the summer. Consequently, results obtained from single-sample sites are not as reliable and are statistically weaker than those achieved at repeated-sample sites.

Recommendations for Future Sampling

Suggestions for future insect sampling in the Backlands will depend on specific research goals. To further understand overall aerial insect population composition in this suburban wilderness area, I suggest that Malaise traps be used for sampling. While in this study Malaise traps did not collect nearly the same abundance of insects as light traps, they may collect samples that are more representative of the entire insect population. The passive nature of Malaise traps ensures there are no strong biases towards specific insect groups. Light traps do not provide this quality and target a limited range of insects that constitutes nocturnal, positively phototrophic aerial insects. Results from light traps likely do not capture the complete diversity of insects in the Backlands. I recommend that, should Malaise traps be used, they be placed at selected sites for the duration of the summer and serviced weekly. Longer sampling windows may allow for larger samples to accumulate, while weekly servicing can allow for trends in emergence or changes in diversity to be observed continuously throughout the summer.

Light traps are suitable for assessing insect groups targeted in this study. Particularly, light traps should be used to quantify *Lepidoptera*, *Trichoptera* or other secondary aquatic insects in this study area. My results suggest that the use of light traps may also be a good means for collecting large numbers of *Coleoptera*, but these organisms can be detected in Malaise traps as well. Future studies investigating large nocturnal insects should use light traps instead of Malaise traps, as my results suggest they are more effective at trapping large flying insects. Light traps may also be used to assess nocturnal insect biomass, a realm of study emerging in nocturnal pollinator and insectivore conservation. Should light traps be used, I recommend the sampling window used in this study, a 10 h overnight period. I recommend that sites be re-visited weekly, or biweekly, if feasible with battery charging times.

To better understand interactions between nighthawk and their prey in the Backlands, I suggest an alternative method for insect sampling. Light traps should be deployed for specific windows that overlap with a predicted period of nighthawk activity at dawn or dusk. Deployments should last for roughly two hours, during which time a researcher can record visual observations of nighthawk activity at the same site. At the end of the sampling window, the researcher can return from the site with the light trap and its insect catch. This study design may warrant extended periods in the field but reduces the number of trips taken to and from the site, which are time intensive in themselves. This design also allows for visual nighthawk observations that were unavailable for my study alone and improves accuracy of available prey items by narrowing the timeframe to specific periods of presumed nighthawk activity.

CONCLUSIONS

My study investigated the diversity, abundance and biomass of aerial insects in the Halifax Backlands. Light traps were more effective than Malaise traps at collecting abundant insect samples and collected greater order diversity by capturing insects with aquatic life histories. Insect abundance and biomass peaked in July, with potential site-specific differences influenced by tree canopy, wetland proximity, temperature, humidity and windspeed. Light trap samples collected during the week of the full moon had lower abundance and smaller biomass, identifying lunar percentage as an important factor in scheduling nocturnal insect trapping efforts. Repeated-sample sites showed that insect abundance did not always align with insect biomass, suggesting differences in average insect size across sites. Common Nighthawk activity at repeated-sample sites suggests that these birds frequented areas with low insect abundance but consistent biomass most often, while findings at single-sample sites show that nighthawks may adjust their foraging strategies based on spatial and temporal insect availability. My findings suggest that nighthawks breeding in the Backlands have access to sufficient insect prey across the landscape, and that prey availability likely is not the main factor contributing to specific breeding site selection.

REFERENCES

Armstrong JT. 1965. Breeding home range in the nighthawk and other birds: Its evolutionary and ecological significance. Ecology. 46(5):619-629. https://doi.org/10.2307/1935001

Barton PS, Evans MJ. 2017. Insect biodiversity meets ecosystem function: differential effects of habitat and insects on carrion decomposition. Ecol. Entomol. 42(3):364-374. https://doi org.ezproxy.library.dal.ca/10.1111/een.12395

Biesmeijer JC, Roberts SPM, Reemer M, Ohlemüller R, Edwards M, Peeters T, Schaffers AP, Potts SG, Kleukers R, Thomas CD, Settele J, Kunin WE. 2006. Parallel declines in pollinators and insect-pollinated plants in Britain and the Netherlands. Science. 313(5745):351-354. https://www.jstor.org/stable/3846650

Boda P, Horváth G, Kriska G, Blahó M, Csabai Z. 2014. Phototaxis and polarotaxis hand in hand: night dispersal flight of aquatic insects distracted synergistically by light intensity and reflection polarization. *Naturwissenschaften.* 101:385-395. https://doi.org/10.1007/s00114-014-1166-2

Brigham RM. 1990. Prey selection by big brown bats (*Eptesicus fuscus*) and Common Nighthawks (*Chordeiles minor*). Am. Midl. Nat. 124:73-80. https://doi.org/10.2307/2426080

Brigham RM, Barclay RMR. 1995. Prey detection by common nighthawks: does vision impose a constraint? Écoscience. 2(3):276-279. https://doi org.ezproxy.library.dal.ca/10.1080/11956860.1995.11682294c

Brigham RM, Fenton MB. 1991. Convergence in foraging strategies by two morphologically and phylogenetically distinct nocturnal aerial insectivores. J. Zool. 223(3):475-489. https://doi.org/10.1111/j.1469-7998.1991.tb04778.x

Brigham RM, Ng J, Poulin RG, Grindal SD. 2011. Common Nighthawk (*Chordeiles minor*), version 2.0. In The Birds of North America Online (A. F. Poole, Editor). Cornell Lab of Ornithology, Ithaca, NY, USA. https://doi.org/10.2173/bna.213

Cardoso P, Barton PS, Birkhofer K, Chichorro F, Deacon C, Fartmann T, Fukushima CS, Gaigher R, Habel JC, Hallmann CA, Hill MJ, Hochkirch A, Kwak ML, Mammola S, Noriega JA, Orfinger AB, Pedraza F, Pryke JS, Roque FO, Settele J, Simaika JP, Stork NE, Suhling F, Vorster C, Samways MJ. 2020. Scientists' warning to humanity on insect extinctions. Biol. Conserv. 242:108426. https://doi.org/10.1016/j.biocon.2020.108426

Chapman SK, Hart SC, Cobb NS, Whitham TG, Koch GW. 2003. Insect herbivory increases litter quality and decomposition: an extension of the acceleration hypothesis. Ecology. 84(11):2867-2876. https://doi.org/10.1890/02-0046

Cockle KL, Villalba O, Fariña N, Bodrati A, Pagano LG, Stein ED, Norris AR. 2023. Nonbreeding ecology of a Neotropical-Nearctic migrant, the Common Nighthawk (*Chordeiles minor*): habitat, activity patterns, molt, and migration. J. Field. Ornithol. 94(3):8. https://doi.org/10.5751/JFO-00293-940308

COSEWIC. 2018. COSEWIC assessment and status report on the Common Nighthawk (*Chordeiles minor*) in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa; Canada (Species at Risk Public Registry).

Diaz-Montano J, Campbell JF, Phillips TW, Cohnstaedt LW, Throne JE. 2016. Evaluation of light attraction for the stored-product psocid, *Liposcelis bostrychophila*. J. Pest Sci. 89:923-930. https://doi.org/10.1007/s10340-015-0724-5

Dietzer MT, Keicher L, Kohles JE, Hurme ER, Ruczyński I, Borowik T, Zegarek M, Choiński M, Dechmann DKN. 2024. High temporal resolution data reveal low bat and insect activity over managed meadows in central Europe. Sci Rep. 14(1):7498. https://doi.org/10.1038/s41598-024-57915-0

Dirzo R, Young HS, Galetti M, Ceballos G, Isaac NJB, Collen B. 2014. Defaunation in the Anthropocene. Science. 345(6195):401-406. https://www.jstor.org/stable/24745121

Goulson D. 2019. The insect apocalypse, and why it matters. Curr. Biol. 29(19). https://doi.org/10.1016/j.cub.2019.06.069

Habel JC, Samways MJ, Schmitt T. 2019. Mitigating the precipitous decline of terrestrial European insects: Requirements for a new strategy. Biodivers. Conserv. 28(6):1343-1360. https://doi.org/10.1007/s10531-019-01741-8

Halifax Data, Mapping & Analytics Hub. 2018. LiDAR 2018. https://data-hrm.hub.arcgis.com/documents/tree-canopy/explore

Hallmann CA, Sorg M, Jongejans E, Siepel H, Hofland N, Schwan H, Stenmans W, Müller A, Sumser H, Hörren T, Goulson D, de Kroon H. 2017. More than 75 percent decline over 27 years in total flying insect biomass in protected areas. PLOS ONE. 12(10): e0185809. https://doi.org/10.1371/journal.pone.0185809

Hallman CA, Zeegers T, Van Klink R, Vermeulen R, Van Wielink P, Spijkers H, Van Deijk J, Van Steenis W, Jongejans E. 2020. Declining abundance of beetles, moths and caddisflies in the Netherlands. Insect Conserv. Divers. 13(2):127-139. https://doiorg.ezproxy.library.dal.ca/10.1111/icad.12377

Hannah KC, Leston LFV, Knight EC, Weeber R. 2022. In the twilight zone: patterns in Common Nighthawk (*Chordeiles minor*) acoustic signals during the breeding season and recommendations for surveys. Avian Conserv. Ecol. 17(2): 18. https://doi.org/10.5751/ACE-02241-170218

Hill N, Patriquin D. 2014. Ecological assessment of the plant community of the Williams Lake Backlands. Report. Halifax (NS):The William's Lake Conservation Company. 108 p.

Kahl S, Wood CM, Eibl M, Klinck H. 2021. BirdNET: A deep learning solution for avian diversity monitoring. Ecol. Inform. 61:101236. https://doi.org/10.1016/j.ecoinf.2021.101236

Kalile MO, Janssen A, Fancelli M, Magalhães DG, Cardoso AC, Rosa MS, Ledo CAS, Ragni M. 2022. UV light attracts *Diaphorina citri* and its parasitoid. Biol. Control. 170:104928. https://doi.org/10.1016/j.biocontrol.2022.104928

Karlsson D, Hartop E, Forshage M, Jaschhof M, Ronquist F. 2020. The Swedish Malaise trap project: a 15 year retrospective on a countrywide insect inventory. Biodivers. Data J. 8:e47255. https://doi.org/10.3897/BDJ.8.e47255

Kim KN, Huang QY, Lei CL. 2019. Advances in insect phototaxis and application to pest management: a review. Pest Manage. Sci. 75(2):3135-3143. https://doi.org/10.1002/ps.5536

Knight EC, Brigham RM, Bayne EM. 2021. Specialist or generalist? It depends. Context dependent habitat relationships provide insight into forest disturbance effects for a boreal bird species. For. Ecol. Manag. 503:119720. https://doi.org/10.1016/j.foreco.2021.119720

Knight EC, Brigham RM, Bayne EM. 2022. The Big Boom Theory: The Common Nighthawk wing-boom display delineates exclusive nesting territories. Ornithology. 139(1):1-10. https://doi.org/10.1093/ornithology/ukab066

Knight EC, Ng JW, Mader CE, Brigham RM, Bayne EM. 2018. "An inordinate fondness for beetles": first description of Common Nighthawk (*Chordeiles minor*) diet in the boreal biome. Wilson J. Ornithol. 130(2):525-531. https://doi.org/10.1676/16-219.1

Kurtz, M. 2025. Spatial ecology of the Common Nighthawk (*Chordeiles minor*) in the Halifax Backlands. Honours thesis. Dalhousie University, Halifax NS.

Lister BC, Garcia A. 2018. Climate-driven declines in arthropod abundance restructure a rainforest food web. PNAS. 115(44):e10397-e10406. https://doi.org/10.1073/pnas.172247711

Losey JE, Vaughan M. 2006. The economic value of ecological services provided by insects. Bio. Sci. 56(4):311323. https://doi.org/10.1641/00063568(2006)56[311:TEVOES]2.0.CO;2

Marchioro M, Battisti A, Faccoli M. 2020. Light traps in shipping containers: A new tool for the early detection of insect alien species. J. Econ. Entomol. 113(4):1718-1724. https://doi.org/10.1093/jee/toaa098

Nebel S, Mills A, McCracken JD, Taylor PD. 2010. Declines of aerial insectivores in North America follow a geographic gradient. Avian Conserv. Ecol. 5(2):1. http://dx.doi.org/10.5751/ACE-00391-050201

Ng JW. 2009. Habitat used and home range characteristics of Common Nighthawks (*Chordeiles minor*) in mixed-grass prairie. Master's thesis. University of Regina.

Ng JW, Knight EC, Scarpignato AL, Harrison AL, Bayne EM, Marra PP. 2018. First full annual cycle tracking of a declining aerial insectivorous bird, the Common Nighthawk (*Chordeiles minor*), identifies migration routes, nonbreeding habitat and breeding site fidelity. Can. J. Zool. 96:869-875. https://doi.org/10.1139/cjz-2017-0098

Nova Scotia Department of Lands and Forestry. 2021. Recovery plan for the Common Nighthawk (*Chordeiles minor*) in Nova Scotia [Final]. Nova Scotia Endangered Species Act Recovery Plan Series.

Nova Scotia Department of Natural Resources. 2007. Nova Scotia Wet Areas. http://www.novascotia.ca/natr/forestry/gis/wamdownload.asp

Nova Scotia Department of Natural Resources. 2021. Nova Scotia Interpreted Forest Inventory – Current Forest Data. https://novascotia.ca/natr/forestry/gis/forest-inventory.asp

Park YG, Lee YS, Sarker S, Ham EH, Lim UT. 2023. Attractiveness of four wavelengths of LED light: UV (385 nm), violet (405 nm), blue (450 nm), and red (660 nm) for seven species of natural enemies. Biol. Control. 179:105166. https://doi.org/10.1016/j.biocontrol.2023.105166

Potts SG, Biesmeijer JC, Kremen C, Neumann P, Schweiger O, Kunin WE. 2010. Global pollinator declines: trends, impacts and drivers. Trends Ecol. Evol. 25(6):345-353. https://doi.org/10.1016/j.tree.2010.01.007

Poulin B, Lefebvre G, Paz L. 2010. Red flag for green spray: adverse trophic effects of Bti on breeding birds. J. Appl. Ecol. 47(4):884-889. https://doi org.ezproxy.library.dal.ca/10.1111/j.1365-2664.2010.01821.x

Sánchez-Bayo F, Wyckhuys KAG. 2019. Worldwide decline of the entomofauna: a review of its drivers. Biol. Conserv. 232:8-27. https://doi.org/10.1016/j.biocon.2019.01.020

Spiller KJ, Dettmers R. 2019. Evidence for multiple drivers of aerial insectivore declines in North America. Condor. 121(2): duz010. https://doi.org/10.1093/condor/duz010

Stork NE. 2018. How many species of insects and other terrestrial arthropods are on Earth? Annu. Rev. Entomol. 63(1):31-45. https://doi.org/10.1146/annurev-ento-020117-043348

Todd LD, Poulin RG, Brigham RM. 1998. Diet of Common Nighthawks (*Chordeiles minor*: *Caprimulgidae*) relative to prey abundance. Am. Midl. Nat.139(1):20-28. https://doi.org/10.1674/0003-0031(1998)139[0020:DOCNCM]2.0.CO;2

Wagner DL. 2020. Insect declines in the Anthropocene. Annu. Rev. Entomol. 65:457-480. https://doi.org/10.1146/annurev-ento-011019-025151

Williams CB. 1936. The influence of moonlight on activity of certain nocturnal insects, particularly of the family *Noctuidae*, as indicated by a light trap. Philos. Trans. R. Soc. Lond., Biol. Sci. 226(537):357-389. http://www.jstor.org/stable/92272

Williams CB. 1939. An analysis of four years captures of insects in a light trap. Part I. General survey; sex proportion; phenology; and time of flight. Trans. R. Entomol. Soc. Lond. 89(6):79-131. https://doi.org/10.1111/j.1365-2311.1939.tb00738.x

Williams CB. 1940. An analysis of four years captures of insects in a light trap. Part II. The effect of weather conditions on insect activity; and the estimation and forecast of changes in the insect population. Trans. R. Entomol. Soc. Lond. 90(8):227-306. https://doi.org/10.1111/j.1365-2311.1940.tb03000.x

APPENDIX

Table A1. Total contents for light traps samples. Total count, proportion of total abundance (%), dry biomass (g) and proportion of total biomass (%) for all orders collected with light traps in the Halifax Backlands, Nova Scotia, in the summer of 2024.

Order	Count	Proportion of total abundance (%)	Dry biomass (g)	Proportion of total biomass (%)
Coleoptera	1,804	3.52	26.031	13.2
Diptera	34,626	67.5	28.181	14.3
Ephemeroptera	862	1.68	0.460	0.23
Hemiptera	351	0.68	2.197	1.11
Hymenoptera	300	0.59	2.322	1.17
Lepidoptera	9,003	17.6	117.369	59.3
Megaloptera	20	0.04	0.996	0.50
Neuroptera	27	0.05	0.032	0.02
Odanata	1	< 0.01	0.006	<0.01
Orthoptera	1	< 0.01	0.030	<0.01
Plecoptera	14	0.03	0.023	0.01
Psocoptera	59	0.12	0.044	0.02
Trichoptera	4,211	8.21	20.068	10.1

Table A2. Total contents for Malaise trap samples. Total count, proportion of total abundance (%), dry biomass (g) and proportion of total biomass (%) for all orders collected with Malaise traps in the Halifax Backlands, Nova Scotia, in the summer of 2024.

Order	Count	Proportion of total abundance (%)	Dry biomass (g)	Proportion of total biomass (%)
Coleoptera	365	13.4	1.535	26.5
Diptera	1,635	59.8	0.651	11.3
Hemiptera	47	1.72	0.070	1.21
Hymenoptera	87	3.18	0.250	4.32
Lepidoptera	561	20.5	2.853	49.3
Neuroptera	4	0.15	0.001	0.02
Plecoptera	3	0.11	0.005	0.09
Trichoptera	32	1.17	0.421	7.28

Table A3. Habitat characteristics for study sites in the Backlands. Mean tree canopy (m) derived from 1 m LiDAR Halifax Open Data, Mapping & Analytics Hub (2018) and percent wet area (%) derived from Nova Scotia Department of Natural Resources wet areas mapping (2007) and forestry data (2021) within a 200 m radius of sampling sites in the Halifax Backlands.

Site name	Mean tree canopy height (m)	Percent wet area (%)
Blackberry	2.20	5.93
Blue Jay	4.59	22.9
Casper	4.55	5.98
Colpitt	3.48	39.3
Duck Pond	1.27	9.68
Flat Lake	0.66	45.0
Ghost Pine	1.03	8.54
Middle Earth	2.30	18.3
New Horizons	1.94	18.0
Nora	5.22	0.00
Oak Lane	7.54	0.38
Orange Jelly	2.86	0.98
Osprey	0.88	17.1
Piggy Mountain	1.57	13.1
Pine Island	2.62	43.2
Pond Hopper	2.50	25.2
Purcell’s Pond	3.83	37.5
Rock Garden	4.09	21.8
Shaw	3.03	22.4
Sightline	3.56	1.71
Spar	1.02	1.47