INFLUENCE OF HABITAT AND BAT ACTIVITY ON MOTH COMMUNITY COMPOSITION AND SEASONAL PHENOLOGY ACROSS HABITAT TYPES

BY

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THESIS

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ABSTRACT

Understanding the factors that influence moth diversity and abundance is important for monitoring moth biodiversity and developing conservation strategies. Studies of moth habitat use have primarily focused on access to host plants used by specific moth species. How vegetation structure influences moth communities within and between habitats and mediates the activity of insectivorous bats is understudied. Previous research into the impact of bat activity on moths has primarily focused on interactions in a single habitat type or a single moth species of interest, leaving a large knowledge gap on how habitat structure and bat activity influence the composition of moth communities across habitat types.

I conducted monthly surveys at sites in two habitat types, restoration prairie and forest. Moths were collected using black light bucket traps and identified to species. Bat echolocation calls were recorded using ultrasonic detectors and classified into phonic groups to understand how moth community responds to the presence of these predators. Plant diversity and habitat structure variables, including tree diameter at breast height, ground cover, and vegetation height were measured during summer surveys to document how differences in habitat structure between and within habitats influences moth diversity.

I found that moth communities vary significantly between habitat types. I identified 6023 moths from 252 species in twelve families. We found significant differences in moth community between the two habitat types, with greater diversity and 75% of total specimens collected in forest. Forest sites averaged 568 specimens and 97 species collected over the course of the project, while prairie sites averaged 185 specimens and 48.9 species. I identified 2019 bat call passes, with the majority in prairie habitat. In prairie habitat, increased bat activity is correlated with decreased moth diversity and abundance. There was no relationship between bat activity

and moth diversity in forest habitat, and the habitat as a whole appears to be a refugia from bat predation. Moth diversity was negatively related to increasing tree diameter, suggesting that more dense forests may support a greater number of species. While overall structural complexity is decreased in prairie habitat, heterogeneity in ground vegetation may mediate interactions between moths and their bat predators. Many moth species were found in both habitat types, suggesting high dispersal out of the more specious and abundant forest habitat.

Sampling occurred over most of a year, and we documented trends in moth phenology between the two habitat types. Moth communities were strongly correlated with temperature, and diversity and abundance were highest during the summer, though there were two peaks in species richness over the summer, independent of temperature. Several species, specifically *Paleacrita vernata, Sericaglaea signata,* and *Epiglaea decliva*, are present predominately during winter months and subsequent research should focus on this understudied activity period. Six species from three families are potential new state records for Illinois. The species list created by this project can be used as a baseline for future research and monitoring in southern Illinois, and this methodology can be used as a standard protocol for subsequent studies of moth communities.

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CHAPTER 1

Impact of Habitat Structure and Bat Activity on Moth Diversity and Abundance across Habitat Types

INTRODUCTION

Understanding the habitat factors that shape insect diversity and abundance is central to developing conservation strategies. Many insect groups are highly speciose, with a large number of species responding to habitat variables in similar ways. Determining which habitat factors most affect large species groups can inform conservation strategies to simultaneously benefit dozens or hundreds of species within a small geographic area. The order Lepidoptera (Butterflies, Moths, and Skippers) is one such highly-diverse group: as of 2016, 11,930 moth species were recognized in North America (Pohl, Patterson, and Pelham 2016). This large and diverse group is in ecological flux- population declines due to climate change and human development have been recorded in large numbers of moth species (Fox 2013; Lintott et al. 2014). Moths have numerous interactions with other taxa, functioning as herbivores, pollinators, and prey, and informed conservation strategies that protect and restore moth diversity will also benefit communities of plants, vertebrates, and other insects.

Access to host plants is an important determinant of moth diversity and abundance in larval and adult life stages, especially among specialists and oligophagous species (Camargo 2016). Many host plant species support a disproportionately high number of moth species, and the abundance of these commonly shared host species can be more important than overall plant richness in shaping moth communities (Highland, Miller, and Jones 2013). In the gypsy moth *Lymantria dispar* (Lepidoptera: Erebidae) the best predictor of abundance is the percentage of oaks, the preferred host species, present in the landscape (Gray et al. 2008). This reliance on specific host plants makes moth communities vulnerable to changes in, or simplification of,

vegetative community (Ober and Hayes 2010), and restoration efforts that restore native vegetation communities increase Lepidoptera diversity (Korpela et al. 2013).

Along with host plant availability, habitat structure is another aspect of vegetation that has a major, if understudied, impact on moth communities by increasing overall habitat and reducing exposure to predators (Summerville, Steichen, and Lewis 2005). Habitat structure is most commonly described as "the composition and arrangement of physical matter at a location… [and] is the physical template underlying ecological patterns and processes" (Byrne 2007). Increased habitat complexity creates more ecological niches that support a greater diversity of moth species. Additionally, measurements of structure can provide insights into harder to measure habitat variables. For example, tree basal area can be used as a surrogate for time since disturbance (Summerville et al. 2005). Habitat structure can also mediate the impact of abiotic conditions- increased structural complexity may shelter moths from wind, allowing for increased flight activity even during periods of high wind speed (Pollard et al. 1993, Ober and Hayes 2010). Finally increased structural complexity reduces movement in bats and other vertebrate predators of moths, creating refugia were moths experience reduced predation pressure (Adams 2012).

One of the most important and influential predators of moths are insectivorous bats (Class Mammalia, Order Chiroptera; Feldhamer et al. 2015, Dodd et al. 2012; Denzinger and Schnitzler 2013; Hofstede and Ratcliffe 2016). Moths are an important component of the diet of Midwestern bats (Whitaker 2004; Feldhamer et al. 1995), and these two groups have a co-evolutionary history spanning an estimated 65 million years (Connor and Corcoran 2012). In response to bat predation moths have evolved a suite of behavioral, chemical, and acoustic defenses, including ears that are sensitive to the ultrasonic echolocation calls used by foraging

bats (Hofstede and Ratcliffe 2016). This co-evolutionary arms race has resulted in the auditory thresholds of moth ears being well attuned to the echolocation call frequency ranges used by sympatric bat species, and many eared moths only detect and respond to echolocation calls in the frequency range used by sympatric bat species (Hofstede et al. 2013; Feldhamer 2015).

While the morphological and behavioral mechanisms moths use to avoid bat predation are well studied, the importance of habitat in sheltering moths from bat predation remains understudied (Adams 2012; Rainho et al. 2010). In heavily vegetated landscapes, moth prey can be unavailable to foraging bats because structural complexity constrains bat flight (Threlfall et al. 2012). Moth abundance is lower in disturbed, more open habitat where moths are more exposed to bat predation, and moth abundance increases with vegetation density (Rainho et al.2010; Dodd et al. 2014). For example, earless ghost swifts, *Helialus humuli* (Lepidoptera: Hepialidae), fly close to vegetation in hayfields to escape bat predation, with the majority of predation caused mortality in this species occurring when the moths leave this vegetated zone (Rydell 1998). Along a height gradient in forest vegetation layers, moths are more abundant in the structurally complex understory and canopy, while abundance is lower in the more open subcanopy layer (Adams 2012).

Despite research into the importance of habitat structure and other variables, significant knowledge gaps exist in the understanding of the factors that drive moth diversity and abundance. One limitation is that previous studies have primarily focused on moth-bat-habitat interactions within a single habitat type. Moths are highly mobile and can be collected long distances from their preferred habitat type, or may utilized resources in multiple habitats (Ricketts 2001). Additionally, studies into moth-bat interactions have primarily focused on bat foraging strategies and treat moth populations as an available resource, rather than the focus of

the study (Rainho et al. 2010; Johnson and Lacki 2013). Of the studies focused on moth habitat use in these habitat-mediated moth-bat interactions, many have focused on a single species (Rydell 1998), leaving a significant knowledge gap in how moth diversity and abundance across a community is influenced by these interactions.

I examined the impact of habitat structure and bat activity on moth community composition between two habitat types, restoration prairie and forest, at Paul Wightman Subterranean Nature Preserve (PWSNP). The main goals of this study were to better understand differences in moth diversity and abundance between habitat types, how habitat structure influences moth communities within habitat, and how bat activity is mediated by habitat structure. I hypothesized that 1) Moth diversity and abundance would be higher in forest habitat. 2) Within each habitat, moth diversity will be greater in areas with greater vegetation structural complexity, where there is greater protection from bat predation and increased available niches and overall habitat. 3) In both habitat types moth diversity and abundance will decrease as bat activity increases, with this decrease being more apparent in prairie habitat.

A better understanding of how habitat structure and bat activity influence moth community composition across habitat types will enable us to create conservation and restoration plans that prioritize the habitat characteristics that are most important to supporting diverse moth communities. Previous research and conservation efforts have focused primarily on the availability of host plants. However, a lack of appropriate habitat structure to protect moths from predation and unfavorable abiotic conditions may limit the ability of moths to utilize host resources. Additionally, knowledge of moth habitat associations is crucial to using this group as indicators of habitat quality and harder to measure biological features, especially in restoration efforts (Kitching et al. 2000; Lomov 2006). This research will contribute to conservation and

management actions aimed at protecting the diversity and abundance of moths and the plant, insect, and vertebrate species they interact with.

METHODS

Study Site

Paul Wightman Subterranean Nature Preserve (PWSNP) is a 535 acre land preserve located in Monroe County, Illinois (-90.135912, 38.200792) south of the town of Waterloo. In 2013 Clifftop NFP purchased this property and began restoration efforts to protect the watershed of Fogelpole Cave, the longest cave in Illinois. Current land cover at the property includes 134.6 acres of forest, 264.8 acres of restoration prairie, 4.1 acres of permanent sinkhole ponds, 3.6 acres of ephemeral sinkhole ponds, and 115.4 acres of agricultural fields. At PWSNP, Clifftop NFP has used herbicide treatments, plantings, mowing, and controlled burns to control invasive plant species, reintroduce a native prairie community, and enhance forest plant community. As part of Clifftop NFP's mission, multiple previous and ongoing research projects at this site have contributed to developing lists of vertebrates, invertebrates, and plants, highlighting the unique biodiversity of this site.

Two hundred potential sample sites within PWSNP were randomly generated with ArcMap 10 (Environmental Systems Research Institute, Inc., California). A 25 m buffer was established around each site, based on the maximum attractive distance of black light bucket traps to moths (Merck and Slade 2014). Potential sites from the list were selected if the 25 m buffer excluded other selected sites, habitat edge, and permanent water features. Visibility from property edge was considered during site selection to minimize the risk of disturbance or vandalization to field equipment. Sixteen sample sites were selected, with eight in forest and

eight in restoration prairie (Figure 1.1). Ground 6merican of sites verified the accuracy of habitat features analyzed in ArcMap and the suitability of each selected site.

Data collection occurred in monthly site visits when night time low temperatures were above 0°C, a temperature that corresponds with increased winter moth activity levels (Donnell and Groden 2017). Site visits occurred from September through November 2016, and February through August 2017. Each monthly site visit occurred over two nights and each site was sampled using two methods: bat acoustic detectors and black-light bucket traps for moth collection (details below; Desbrow 2013). On each night of surveying, eight bucket traps and eight acoustic detectors were deployed. On the first night of each survey, half of the sites (four forest sites, four prairie sites) were sampled using bucket traps and half (four forest sites, four prairie sites) were sampled using acoustic detectors. On the second night, each site was sampled using the alternate method. Sites were not sampled using both methods simultaneously to avoid recording bats attracted to moth congregations at black light bucket traps. The order of site deployments within each visit was randomly determined. Vegetation surveys were conducted from June through September, 2017.

Moth Collection

Moths were collected using 12W black light bucket traps (BioQuip, Rancho Domingo, California #2851U), with one trap placed at ground level at the center of each site (Harrison 2011). Each trap consists of a 12W DC black light powered by a 12V ACS battery, with the light mounted above a funnel leading into a plastic 5-gallon bucket. A photoelectric switch connecting the battery to the trap activated the black light between sunset and sunrise. Approximately 1 hour before sunset a glass jar filled with approximately 200 ml of 99.9% ethyl acetate ACS reagent

was placed inside the bucket as the killing agent. Bucket traps were closed and specimens recovered from the traps beginning approximately 1.5 hours after sunrise. All insect specimens were collected and frozen to facilitate identification (Summerville et al. 2006). Before redeployment for the second night of sampling, ethyl acetate jars were refilled to compensate for evaporation and batteries were recharged. These traps have a maximum attraction distance of 25 m, so I can be confident that moths collected were already present at each site, and were not attracted from outside the site or habitat type (Merck and Slade 2014).

Macro-moths were removed from the diverse insects in the samples and identified. This subgroup of nocturnal Lepidoptera was selected for its relative ease of sampling and identification, the large body of knowledge on macro-moth host plant preferences and ecological importance, and their close co-evolutionary relationship with bat predators (Hofstede & Ratcliffe 2016; Merckx & Slade 2014). While macro-moth species are generally larger, the terms macro-moth and micro-moth primarily refer to evolutionary age, with macrolepidoptera including the younger moth families, which are more recently diverged (Beadle & Leckie 2012). Macro-moths include the superfamilies Drepanoidea, Geometroidea, Mimallonoidea, Bombycoidae, Sphingoidae, and Noctuoidae (Moth Photographers Group).

Macro-moths were identified to species (or morphospecies) based on external morphology and color patterns of wings, antennae, and bodies using Beadle & Leckie (2012), Triplehorn & Johnson (2004), the MothPhotographersGroup.com plate series curated by the Mississippi Entomological Museum, Bugguide.com, consultation with regional moth experts, and the Illinois Natural History Survey (INHS) Insect Collection. Morphospecies are defined as groups of specimens that were distinct from other species, but could not be identified as a single identified species. The morphospecies identified in this project were primarily those where two

species that are externally identical co-occur within the study area and cannot be distinguished without dissection. Specimens that were too damaged to be identified to a species (or morphospecies) level were excluded from diversity analysis, and were only included in abundance analysis. Voucher specimens were pinned and spread for all species collected and will be deposited in the INHS Insect Collection.

Bat Acoustic Data Collection

Bat echolocation call passes were collected using Anabat Express Bat Detectors (Titley Scientific, Columbia, Missouri, #AAAB001). One detector was placed 1.3 m above the ground at the center of each site. Detectors were mounted on steel t-posts (prairie sites) or on trees within 1 m of the center of each site (forest sites) with the microphone perpendicular to the ground. While these detectors use omnidirectional microphones, sensitivity is slightly reduced in the area directly behind the detector (Anabat Express User Manual, V. 1.4). To account for this, the orientation of each detector was randomly selected during each deployment. Sensitivity and data division ratio were set to 8, the recommended setting for use across habitat types (Anabat Express User Manual, V. 1.4). Detectors were programmed to activate 30 minutes before sunset and deactivate 30 minutes after sunrise. Sunset and sunrise times were automatically set based on geographic location as determined by the detector's internal GPS.

Bat call passes were manually vetted using the program AnalookW V. 4.2. (Titley Scientific, Columbia, Missouri). A bat call pass signifies a series of individual echolocation calls recorded as a bat flies past a bat detector. Each call pass ended when the bat left the detection range of the detector, or when the 15 second file size was exceeded and a new file recording began. Due to limitations of the quality of zero-cross data generated by the Anabat Express Bat

Detectors, similarity between bat species calls, and high call variation within bat species, bat calls were not identified to a species level, except in a small subset of data used to identify species present at PWSNP. Because many moths only detect and respond to bat calls of a certain frequency range, bat calls were categorized into two phonic groups so I could determine if moths in each habitat are more responsive to a certain group of bat call frequencies (Feldhamer 2015). Based on the general divisions of bat echolocation call frequencies and differences in moth ear tuning, bat call passes were categorized as high frequency (if the minimum frequency was ≥ 30kHz) or low frequency (if the F_{min} was < 30 kHz; Loeb 2014). Audio files were identified as bat calls or noise, and bat calls were classified into phonic group. Acoustic data were examined a second time to confirm the identifications made.

Vegetation Surveys

Ground cover vegetation variables, including ground cover species composition, percent ground cover, floral resources, and vegetation height structure, were sampled in late-June 2017. Forest tree variables, including tree diversity and density, understory species diversity and density, and canopy cover, were sampled in early September 2017. While sampled after moth sampling finished, these tree and understory variables are not expected to change significantly from month to month. When measuring diameter at breast height, breast height was standardized as 1.3 m (Mitchell 2010).

Vegetation height structure may create more niches and exclude bats as vegetation height and density increases. Vegetation height structure was measured at 16 points at each site, with points spread every 5 m in all four cardinal directions from the center of the site. Vegetation height was assessed using a 3 m long rod (2.54 cm diameter PVC) divided into 20 cm intervals,

with a total of 15 intervals (Yanahan and Taylor 2014). The number of points of contact in each interval was recorded for both live and dead vegetation in the categories grass, herbaceous plants, and woody plants. From these data, a height index was computed for each vegetation type at each sample site:

$$Height\ Index = \sum_{i=1}^{N} h_i n_i / \sum_{i=1}^{N} ni$$

where N is the number of height classes (15), h_i is the midpoint of each height class, and n_i is the number of vegetation contacts in the *i*th height class (Gibson et al. 1987; Yanahan and Taylor 2014).

Ground cover composition is important for understanding the availability of host plants and how vegetation heterogeneity can create spaces that shelter low flying moths, especially in prairie habitat (Beck 2002). Ground cover species composition and percent ground cover were assessed in eight 1 m^2 quadrats at each site, spaced at 5 m and 15 m from the center of each site in all cardinal directions. At each 1 m^2 quadrat, all plant species (excluding woody plants greater than 1.3 m tall) were identified to species level (Beck et al. 2002; Valtonen 2006). Plants that could not be identified in the field were photographed and samples were collected using a plant press for future identification in consultation with botanists at the Illinois Natural History Survey and Clifftop NFP. Percent ground cover was based on digital images, with the photograph taken from directly overhead so that the 1 m^2 quadrat filled the majority of the image. A 10 x 10 grid of points was overlaid on the photograph, and the grid of points was adjusted so that it fit the 1 m^2 quadrat (Yanahan and Taylor 2014). Percent ground cover was defined as the number of the 100 points falling on each category: grasses, herbaceous plants, woody plants, bare ground, dead wood, and leaf litter. An average percent ground cover for these categories was calculated for each site. Percent ground vegetation describes the average percent of each vegetation quadrat for

each site covered by vegetation (live or dead), excluding bare soil and leaf litter. Floral resources represent an important nutritional resource for many adult moths, and high flower concentrations may increase site-specific moth activity, especially among specialists (Slade et al. 2013). Floral resource availability was assessed using percent flower coverage at each site using digital images, using the same methodology as percent ground cover (Korpela et al. 2013). Photographs of flower cover were taken in late afternoon and early evening, to focus on flowers available to the nocturnal moths studied in this project.

Understory plants, including shrubs and young trees, are important as host plants and moth diversity is increased in the understory compared to other forest levels, in part because a dense understory may exclude foraging bats (Beck 2002; Adams 2012). Understory plants were recorded at eight survey circles within each site, which each had a radius of 2.5 m and were spaced 5 m and 15 m from the center of the site in each cardinal direction. Within each survey circle, every woody plant greater than 1.3 m tall and less than 5 cm diameter at breast height (DBH) originating within the circle was identified, and DBH was recorded as a measure of understory plant size (Beck et al. 2002). Plants were classified as woody shrub (multiple stems arising from the same base or less than 2 cm DBH) or understory tree (single stem arising from the same base and 2-5 cm DBH (Ober and Hayes 2010). For plants with multiple stems, the DBH for each separate stem was measured, and these values were summed to calculate basal area (Mitchell 2010)

Trees play an important role in shaping forest habitat structure and are a primary host species for may forest specialist moths (Summerville 2005; Gray 2008). Tree diversity and diameter were assessed using the point centered quarter method (PCQM). Trees were identified as woody plants with DBH 5 cm or greater (Ober and Hayes 2010). PCQM survey points were

established at the center of the site, and at 10 m and 20 m from the center of the site in all cardinal directions. The area surrounding each PCQM survey point was divided into four quadrants (NE, SE, SW, NW). The tree closest to the survey point in each quadrant was located, and its species, DBH, and distance from the survey point was recorded (Mitchell 2010). Because tree basal area can be used as a surrogate for habitat disturbance and woodland age, mean tree basal area was calculated for each site (Summerville et al. 2005). Tree density was calculated as the average number of trees per square meter at each of the eight forest sites. Percent canopy cover can have an influence on moth diversity, and this variable is often excluded from studies of moth communities (Ober & Hayes 2010). Canopy cover was assessed using digital images, which were taken with the camera pointed vertically and held at approximately 2 m from the ground with the lens set to a 1 x 1 frame size. Five images were taken at each site- at the center of the site, and 10 m from the center in each cardinal direction. Canopy cover was scored using the same method as percent ground cover, with 10 x 10 grid of points adjusted to fit the 1 x 1 size of the each photo (Yanahan and Taylor 2014).

Abiotic Factors

Abiotic factors were included in analyses to better understand the total sum of factors that influence moth diversity and abundance, and so that the impact of habitat variables and bat activity on moth communities could be distinguished from the impact these abiotic factors. Abiotic data was collected remotely, using the site Weather Underground (https://www.wunderground.com/), and by accessing data collected at the East St Louis weather station. Because of the high seasonality in moth communities, high and low night temperature were included in analysis (Threlfall et al. 2012). To study if moth seasonality is related to time of

year instead of temperature, Julian date was also included. Increasing wind speed decreases moth and bat flight ability, and may alter moth habitat use (Fukui et al. 2006, Pollock 1993). Additionally, percent moon visible was included because moon fullness can alter moth activity, decrease capture rates of black light bucket traps, and increase visibility of moths to bat predators (Kitching et al. 2000; Highland et al. 2013; Yela 1997).

Statistical Analysis

Analysis was conducted in the program R Version 3.2.4 (R Core Team 2016). Moth diversity was calculated using the Shannon Index (H'). Based on the use of the Shannon index in similar studies (Ober 2010, Adams 2012, Harrison 2011) and the large number of rare species collected, the Shannon index was chosen over the other common diversity index, the Simpson Index, which is weighted towards common species and gives less weight to rare species. Diversity was calculated for site totals and each site-night, and for plant diversity at ground cover, understory, and tree levels using the R package *vegan* (Oksanen 2016). To account for large numbers of zeros in the data, months of data were excluded if five or more sites failed to collect moths. The four months with the lowest counts of diversity and abundance, November 2016 and February, March, and April 2017 were excluded.

Forest and prairie data were analyzed separately. Data were analyzed at two time periods: across all months (September-October 2016, May-August 2017) and July. Analysis across all months included the abiotic factors, which can drive trends in moth diversity and abundance independent of habitat characteristics. Because of the significance of seasonality to trends in moth diversity and abundance, I analyzed the July data independently to remove the impact of seasonal variables such as temperature and focus analysis on habitat variables and bat activity

(Brehm and Axmacher 2006). July was selected for this single month analysis because most vegetation surveys were conducted during that month and midsummer is the peak of moth activity. Many vegetation variables, such as floral resources and ground plant composition, can change significantly from month to month. Because moth data was sampled monthly but vegetation variables were sampled only once, vegetation variables that change rapidly with time should only be compared to the moth data collected at the same time. Because tree and woody understory vegetation is not expected to change from month to month, these variables were included in forest analysis across all time periods.

Across all months data were analyzed with mixed-effects models (MEM), which are also called multilevel models, hierarchical linear models, or nested data models (Winter 2013). Mixed-effects models were used to account for the multiple sampling events that occurred at each site. For the July data, the single sampling period removed the need for nested data, and analysis was conducted using ordinary least squares regression (OLS). Log transformations were used to account for non-normal distributions in some of the variables. Mixed-effects models were created using the R package *lmerTest* (Kuznetsova et al. 2017). Models were created to compare all variables and were ranked using Akaike's information criterion (AIC) using the package *MuMIn* (Barton 2018; Beck et al. 2002). Models for the linear regression analysis of the July data were created with different combinations of all variables and compared until the best fit model was identified using AIC. Once a best-fit model was selected using AIC, it was examined to confirm that at least one independent variable was significant at $p < 0.1$, 0.05, or 0.01.

To confirm that differences in moth richness between habitat types were representative of actual differences between habitat, rather than a result of the different number of specimens

collected in the two habitats, data was rarefied using the package *vegan* and rarefied species richness was compared between sites (Oksanen 2016). Based on similarities between rarefied and raw data, raw data was used in final analysis.

RESULTS

Moth Data

A total of 6,023 macro-moth specimens belonging to 252 species or morphospecies from twelve families were collected during monthly sampling occurring from September- through November 2016, and February- through August 2017. The majority of species (62.4%) were represented by fewer than ten specimens, and 38 species (15% of total species) were singletons, meaning only one individual of that species was captured over the course of the project. Only nine species (3.6%) had greater than 100 specimens, and the most numerous species, *Anavitrinella pampinaria* (the common gray: Geometridae), was represented by 239 specimens. The most abundant family was Erebidae, with 2050 specimens, while the most diverse family was Noctuidae, with 103 species. Five families were represented by only one species (Figure 1.2). 98.9% of specimens collected were from families that are known to have ears capable of hearing bat echolocation calls, justifying the focus on macro-moths and the inclusion of bat activity as a variable (Hofstede & Ratcliffe 2016).

Greater moth abundance, richness, and diversity were found in forest habitat than in prairie. 4545 specimens were collected at forest sites while 1478 were collected from prairie sites (Figure 1.3), despite similar sampling effort between these two habitat types. Individual capture rates ranged from 97 to 760 specimens per site over the course of the study, with an average of

568.23 specimens (+/- 156.03) collected per forest site and an average of 184.75 (+/-70.11) specimens collected per prairie site.

Richness was also greater in forest sites, with an average richness of 97.25 (+/- 13.47) species per forest site and 48.88 (+/- 8.95) species per prairie site. An examination of rarefied data confirmed that greater richness in forest habitat was representative of actual trends in moth diversity, and was not a result of greater numbers of moths collected in forest than prairie. Because these findings from rarefied data supported the actual data, actual data was used in analysis. Average diversity (H') at forest sites was 3.99 (+/-0.11), and was 3.38 (+/-0.23) at prairie sites. Of the 252 species identified, 115 species (46%) were found only in forest habitat and only 31 species (12%) were found only in prairie habitat. The remaining 106 species (42%) were found in both habitat types.

Bat Data

Bat detectors captured 33609 sound files that were processed and identified to 2019 bat call passes, with 825 call passes in forest habitat and 1194 in prairie habitat. Calls in the high frequency phonic group (minimum frequency $\geq$ 30kHz) and low frequency phonic group (minimum frequency < 30kHz) were recorded in both habitat types, with high frequency calls making up 97.8% of forest calls and 70.1% of prairie calls (Figure 1.4). Low frequency calls were excluded from forest analysis because of the small number of calls identified (n=18). The number of bat calls varied across time, ranging from nine identified calls in February, 2017, to 672 total identified calls in July, 2017.

Deployment Failures

On several nights equipment did not function properly and failed collect moths and record bat acoustic data. One prairie site, P92, was established after the September 2016 month site visit and no moth or bat data exists for this site for September 2016. Bat detectors failed to activate and bat call passes were not recorded at forest site F154 on September 11, 2016, forest site F165 on September 11, 2016, and forest site F182 on March 31, 2017. Additionally, the black light bucket trap was not opened at forest site F102 on September 10, 2016 and did not collect moths.

Vegetation

One hundred and forty eight plant species were identified, with 80 species present in forest habitat and 67 species present in prairie habitat. Only one species, *Ulmus 17mericana*, was present in both habitat types. (Table 1.1, 1.2).

Abiotic Factors

Night length, measured as the time between sunset and sunrise, ranged from 13 hours and 36 minutes in November to 9 hours and 11 minutes in June. Percent moon phase ranged from 36% to 100% full. Nightly high temperature ranged from 29.4 C in June to 8.9 C in March. Night low temperature ranged from 22.8 C in June to 3.3 C in November. Only one night, February 11th had precipitation, but this was one of the nights excluded from final analysis. Increasing moon fullness was correlated with greater abundance ($p < 2.21e-06$). Diversity was higher in June and August than in July, three time periods where moon phase average was 67%, 97.5%, and 32%, respectively (Table 1.3).

Predictors of Diversity and Abundance

Temperature was the best predictor of moth community across both habitat types, and moth diversity and abundance were positively correlated with temperature across all months. In prairie habitat, moth diversity and abundance decreased in response to increasing bat activity. Because few variables besides temperature and bat activity (in prairie habitat) were significantly related to moth diversity and abundance, I focused on the best fit model for each time period, even if it included non-significant variables. The best fit models for each time period and habitat type are described below:

Prairie Moth Diversity

Across all months, moth diversity in prairie habitat was positively correlated with temperature ($p < 4.1e-08$) and negatively correlated with the number of low frequency bat call passes ($p < 0.0289$). In July, moth diversity was negatively correlated with the number of low frequency bat call passes ($p < 0.0022$) and percent ground vegetation ($p < 0.031$). The July model also included a negative relationship with increased topographic variation ($p < 0.188$), but this variable was not significant (Table 1.4).

Forest Moth Diversity

Across all months, forest moth diversity was positively correlated with two significant variables: high night temperature ($p < 2.22e-16$) and percent moon visible ($p < 2.21e-06$). This model also included tree diversity, though this variable was not significant ($p < 0.1958$). In July, moth diversity was negatively related to total tree basal area ($p<0.0374$). The July model also included negative relationships with average understory plant diameter at breast height ($p <$

0.0932) and the total number of bat call passes ($p < 0.1172$), but these variables were not significant (Table 1.5).

Prairie Moth Abundance

Across all months, moth abundance was positively correlated with average high night temperature ($p < 3.01e-11$). In the July only data prairie moth abundance was not significantly correlated with any variable (Table 1.6).

Forest Moth Abundance

Across all months, forest moth abundance was best explained by a positive relationship with average high night temperature ($p < 2e-16$). This model also showed that moth abundance was negatively correlated with tree diversity, though this variable was not significant ($p < 0.378$). No variable significantly explained moth abundance in July (Table 1.7).

DISCUSSION

Differences in moth community between habitat types

As predicted, moth communities varied significantly between habitat types, showing that multiple factors influence moth diversity and abundance at a habitat-wide scale. One factor is habitat age, which can affect overall abundance and community composition (Ruiz-Carbayo 2017). Forest fragments at PWSNP are older than the prairie habitat, and the young age of this restoration prairie may help explain its lower moth diversity and abundance. Prior to restoration the non-forest areas of PWSNP were primarily soybean and corn agricultural fields, and most native plants species in this restoration prairie were planted in May 2015, with a few additional

species hand planted in 2016. Prairies accumulate insect species as they age, and it is unlikely that this newly available habitat has been discovered by all potential prairie moth species (Summerville et al. Fox 2007; Alison et al. 2016). Prairie moth community at PWSNP will continue to develop at this site, justifying ongoing moth sampling to study trends in moth richness and species accumulation as the prairie habitat matures. This study establishes a methodology for future moth surveys and can be used as baseline data.

In addition to age, habitat connectivity influences trends in moth diversity and abundance between habitat types. The majority of moth activity at PWSNP occurred in the fragments of forest habitat, with only a few species were found exclusively in prairie. While some species have broad habitat requirements and can use resources in both habitat types, the small number of prairie-only species suggests that many of the species collected from both habitat types are forest specialists moving between patches of suitable habitat. This is further supported by relative abundance of species shared between habitats- for the most abundant species found in both habitat types, the majority of specimens were collected in forest habitat. As highly mobile insects that are not constrained by fixed nests or colonies, adult moths are to disperse long distances. Increased habitat specificity in moths can be correlated with increased dispersal ability, allowing specialist species to travel the greater distances required to move between areas of preferred habitat (Slade & Merckx 2016). Many moth species can be found in "halos" around their preferred habitat, and in a forest-agriculture system, forest specialists can be collected in agricultural fields up to 1.4 km away from forest edge (Ricketts et al. 2001). All of the forest fragments used in this study were well within this range and there is likely high dispersal between habitat patches. This dispersal is just one of the ways moth communities are influenced by biotic and abiotic factors at each site.

Impact of abiotic factors

In both habitats temperature is consistently the most important determinant of moth diversity and abundance. Increasing temperature decreases larval development time and increases adult activity, leading to greater diversity and abundance during the summer across temperate habitats (Highland et al. 2013; Boyles and Storm 2007; Jonason et al. 2011; Boersma 2017). The concentration of moth activity during the summer in this study justifies the exclusion of winter and early spring specimens from final analysis (Slade & Merckx 2016). In this study system, moth diversity was more strongly correlated with temperature than other measures of seasonality, such as Julian date or night length. This suggests that warming temperatures as a result of climate change may cause moth populations to emerge earlier in the year (van Dyck 2014).

An unexpected finding was the significant positive relationship between forest moth diversity and increasing moon fullness in forest habitat. Because black light bucket traps use light to attract moths, the attractiveness of these traps can be reduced during the full moon. (Kitching et al. 2000). However, increasing moon fullness also alters insect activity (Yela 1997). For example, emergence of adult *Helicoverpa zea* (the corn earworm: Noctuidae), one of the species captured in this project, is synchronized with moon phase (Nemfc 1971). Because many moths have short lifespans as adults, synchronizing adult emergence based on periods of high moonlight may be an adaptation that ensures adults will find each other for mating (Nowinszky et al. 2010). These trends in moon-based moth emergence have been confirmed through the use of bait traps, which do not use light to attract moths so their attractiveness does not vary based on moon phase (Yela 1997). Given the importance of moon phase to both moth activity and trap attractiveness, future studies of moth diversity should avoid sampling on nights with high

ambient moonlight, excluding a period of at least four nights before and after the full moon (Brehm and Axmacher 2006; Summerville et al. 2005). Moth diversity was only correlated with moon fullness in the forest, suggesting that habitat type or vegetation characteristics may play some role in mediate the impact of this and other abiotic factors on moth communities.

Impact of vegetation

Within each habitat type, vegetation factors contribute to moth diversity and abundance. Total basal area was the only significant predictor of moth diversity in the July model. Because a standardized number of trees were surveyed for each forest site, total basal area is a measure of average tree basal area. The negative relationship between moth diversity and tree basal area shows that moth diversity decreases as tree size increases, suggesting that forests dominated by larger trees may support fewer moth species. While this research does not support some findings that moth diversity is positively correlated with tree basal area (Lintott et al. 2014), it does support studies showing that overall forest structure can contribute to shaping moth diversity. Smaller trees may create gaps that support an increased understory plant community leading to more dense vegetation that increases the overall amount of habitat, with more leaves and flowers to support larger populations of foraging larval and adult moths (Summerville et al. 2005). Additionally, younger trees may represent a more preferred food source for many herbivorous insects, and this higher quality resource may influence moth diversity, abundance, and habitat use (Ernst 1989; Lemoine et al. 2017).

Tree diversity did not have a statistically significant relationship with moth community composition, but this variable's presence in the best fit models for both forest moth diversity and abundance indicates that tree diversity may interact with other variables to shape forest moth

communities. Many tree species are used as hosts by multiple moth species. The short life spans and different emergence periods of many moth species enables related moth species to subdivide resources temporally, allowing a single host plant to support multiple species across time with minimal competition (de Camargo et al. 2016; Curtis et al. 2015). An estimated fifty four percent of Lepidoptera species use their larval host plant as an adult food source, further emphasizing the importance of certain plant species within a habitat (Altermatt and Pearse 2011). The negative relationship between forest moth diversity and tree diversity suggest that the proportion of commonly shared tree species may be more important than overall tree diversity (Summerville and Crist 2004; Highland et al. 2013). Further research at PWSNP should identify which tree species are most commonly shared and are most important to forest moth communities so these tree species can be prioritized in future restoration efforts.

Bat Activity between Habitats

Bat activity and its impact on moth communities in forest and prairie habitat matched our hypothesis. The number of both high and low frequency bat calls was greater in prairie habitat, suggesting that total habitat complexity in forests suppresses bat activity, while the more open prairie habitat allows for greater bat activity. This supports findings that habitat type plays a dominate role in determining bat forage site selection (Dodd et al. 2012; Rydell et al.1996). The large number of high frequency call passes ($F_{min} \geq 30$kHz) in both habitat types suggests that the use of high frequency calls is a generalist strategy that is useful for foraging across habitat types and levels of clutter. Because low frequency calls ($F_{min} < 30$kHz) travel longer distances and were more common in prairie habitat, this call type is better suited for foraging in open areas, and its use is limited by clutter (Feldhammer 2015).

Moth and bat interactions

Bat activity impacts moth diversity and abundance differently in these two habitat types. The forest fragments at PWSNP appear to be relatively uniform in their suppression of bat activity. Indeed, the greatest amount of forest bat activity occurred at a site bisected by a walking trail, which bats may use as a flight corridor (Figure 1.4; Hohoff 2016). This indicates that without modifications that reduce vegetation clutter, forests at PWSNP are relatively inaccessible to bats, making the entire habitat type a refuge from bat predation.

In prairie habitat, moth diversity and abundance were influenced by bat activity. While low frequency calls represented less than a third of prairie bat calls, prairie moth diversity was more negatively correlated with low frequency bat calls than high frequency calls. This relationship between prairie moth diversity and low frequency bat calls is likely related to the sympatric evolutionary relationship between prairie moth species and the low frequency echolocation calls that are preferentially used in prairie habitat. This finding suggests that many of the moths captured in prairie habitat do not primarily use this habitat type, and were captured while flying between different patches of forest habitat, as found in previous studies (Ricketts et al. 2001). Because these non-prairie moths are not sympatric with low frequency calling bats, these moths may be less able to detect and evade bats using low frequency calls. In contrast, prairie specialist moth species that are sympatric to these low frequency calling bat species are better able to detect and avoid bat predation through behavioral, chemical, and acoustic defenses (Conner and Corcoran 2012). Increased low frequency bat activity may select against non-sympatric moth species or moths whose ears are tuned to high frequency bat calls.

Habitat structure as a mediator

Many variables, including predation risk, cause moth communities to vary significantly based on habitat type, even within a small geographic area (Beck et al. 2002). Within habitat types, habitat structure may play a role in moderating the interaction between bats and moths. In prairie habitat, where bat activity has a significant impact on moth community composition, habitat structure can mediate the interactions between moths and bats. Decreasing percent ground vegetation, the measure of the amount of ground within each site covered by vegetation, may be important to moth diversity by increasing habitat heterogeneity on a microhabitat scale in prairie habitat (Harrison and Berenbaum 2013). Less complete ground cover creates spaces between plants, and may facilitate movement of moths so that they fly within the vegetation layer instead of above it, where they are more vulnerable to foraging bats. This shelters moths from bat activity and may mitigate the impact of bat predation on moth diversity and abundance (Rydell 1998; Pollock 1993). Finally, many prairie plant species form dense tussocks of vegetation separated from other plants by a buffer of bare ground. These dense growing species may be important host plants that provide primary feeding or oviposition habitat for prairie moth species, while simultaneously excluding bats (Littlewood et al. 2012).

In forest habitat, the size of understory woody vegetation, primarily tree saplings, may play a minor role in moderating interactions between moths and foraging bats. As DBH increases, understory plants become more tree-like, reducing the concentration of habitat near ground level. These larger, more tree-like understory plants may also develop more defined canopies, creating a more open subcanopy with spaces that bats can navigate through and forage in (Adams 2012).

Multiple studies have investigated the interaction between bat foraging behavior and insect availability, and some have suggested that studies of bat foraging behavior can be used to make inferences about moth community composition (Rainho et al. 2010; Johnson and Lacki 2013). Given how differently habitat structure influences these two groups and the negative relationship between bat activity and moth diversity and abundance, it appears that these studies of bat foraging activity will not be useful for understanding trends in moth community composition. These findings further highlight the need for ongoing research focused on the factors driving moth diversity and abundance both between and within habitat types.

CONCLUSION

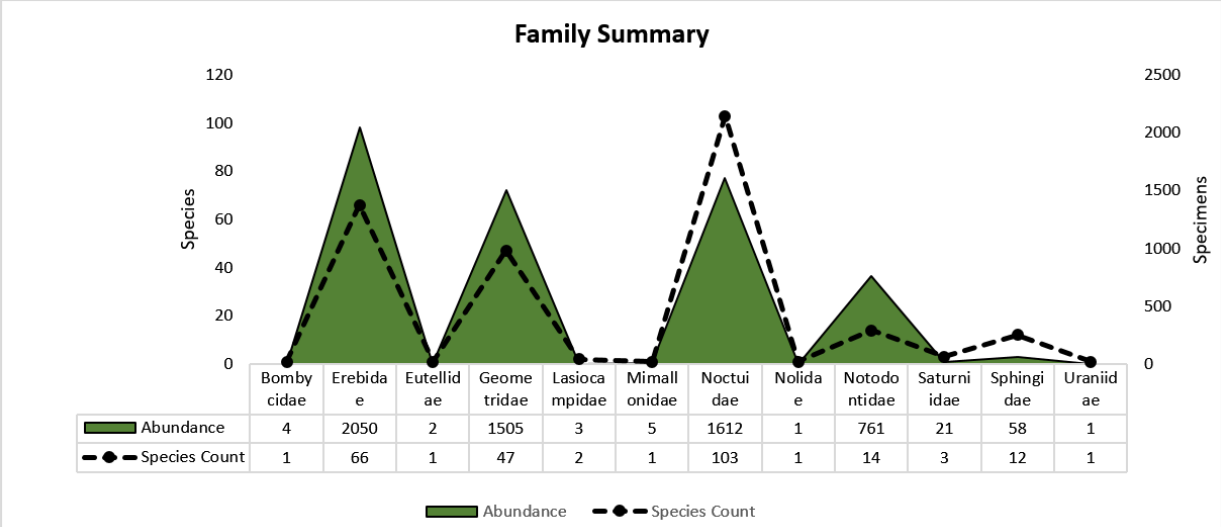
Moth diversity and abundance differ significantly between habitat types, with habitat structure and bat activity having distinctly different impacts on moth communities depending on habitat. Forest habitat has higher overall structural complexity and lower bat activity and supports greater moth diversity and abundance. In prairie habitat moth diversity and abundance are decreased. Prairie has higher levels of bat activity, and variation in ground vegetation may increase moth movement and mediate the impact of bat activity. Overall, there appears to be dispersal out of the more abundant and speciose forest habitat. Effective conservation efforts require an understanding of existing biodiversity and community structure, and comprehensive baseline studies with a consistent and replicable methodology are often lacking in entomology. This project's species list can be used as a baseline for research and monitoring of moths in southern Illinois, and for recognizing future changes in range and biodiversity. This methodology can be used to create standardized sampling effort in future research, allowing for more direct comparisons of results across time and study areas. Moths are a complex, mobile, and fairly

easily identifiable group. With a more complete understanding of moth ecology, biodiversity, and habitat use, moths can be used as bioindicators, study species for tracking changes in species range, and ambassadors for entomological outreach.

TABLES AND FIGURES



Figure 1.1. Location of sixteen sample sites which were divided equally between prairie and forest habitat. Locations were selected randomly to ensure sites were spread across the property. Paul Wightman Subterranean Nature Preserve is marked with a black border.



	Bombycidae	Erebidae	Eutelliidae	Geometridae	Lasiocampidae	Mimallonidae	Noctuidae	Nolidae	Notodontidae	Saturniidae	Sphingidae	Uraniidae
Abundance	4	2050	2	1505	3	5	1612	1	761	21	58	1
Species Count	1	66	1	47	2	1	103	1	14	3	12	1

Figure 1.2. Moth diversity and abundance within the twelve families identified. The four most abundant families represent 91% of species and 98.4% of moths collected.

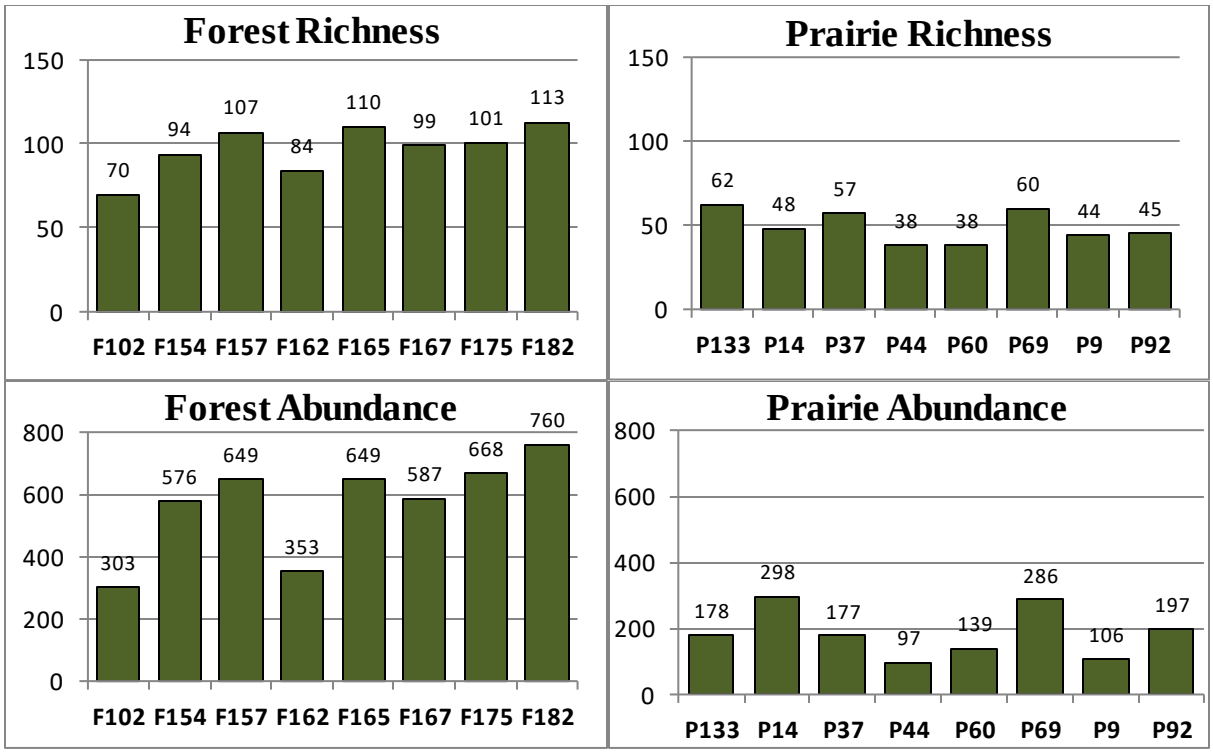


Figure 1.3. Counts of moth diversity and abundance at each site, showing cumulative results from across time periods. The y-axis for was kept constant each metric of moth community between both habitat types to better illustrate differences in moth community between forest and prairie.

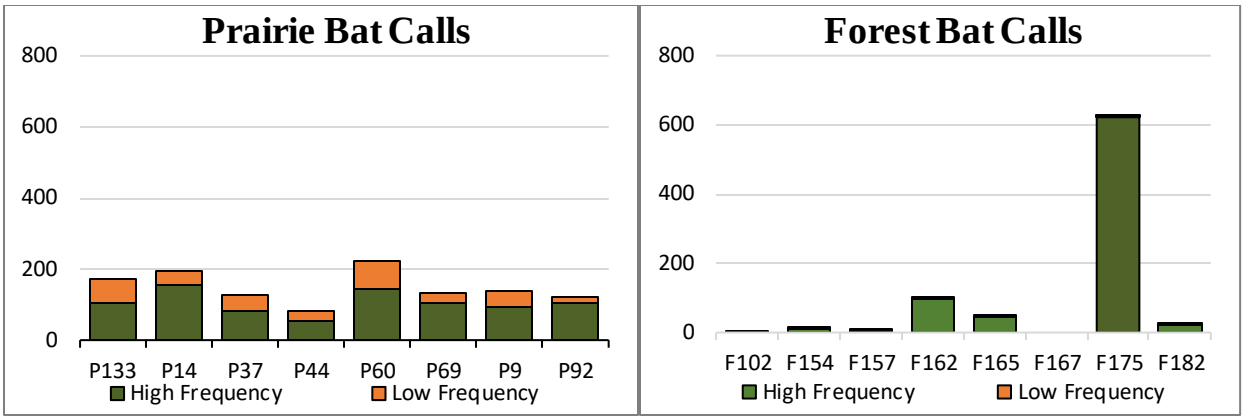


Figure 1.4. Bat call totals from all field sites across time. Prairie sites (left) had larger amounts of both high and low frequency bat call passes than forest sites (right). The greatest number of call passes were recorded at a forest site bisected by a trail, indicating that in forest habitat bat activity is restricted to specific flight corridors.

Table 1.1. Forest habitat structure variables. Percent ground vegetation is a measure of the percentage of each site covered by upright vegetation, either alive or dead.

Site	Percent Ground Vegetation	Number Understory Trunks	Average Understory DBH	Vegetation Height Index	Total Tree Basal Area (cm^2)	Percent Canopy Cover	Distance to Habitat Edge (m)
F102	41.63	65	1.57	103.521	580.4	88	32.5
F154	44.25	16	2.4	31.1475	595.2	95.2	35
F157	21.01	57	1.73	112.727	590.1	88.4	28
F162	24.63	78	1.83	146.792	550.2	92.25	52
F165	26.88	46	1.89	129.333	681.7	92.8	35.2
F167	33.38	82	1.93	155.833	534.3	91.8	34.9
F175	42.63	61	1.49	130	565	86.2	32.4
F182	48.26	72	1.88	138.866	670.6	94.8	34

Table 1.2. Prairie habitat variables. Some habitat variables were studied in both habitat types, but overall the more simple vegetation structure in prairie led to fewer vegetation variables being analyzed in this habitat type.

Site	Percent Ground Vegetation	Vegetation Height Index	Total Available Floral Resources	Distance to Habitat Edge (m)	Total Elevation Change (m)
P133	76.88	29.87	30	31.5	27.3
P14	82.38	21.54	12	107.6	17.3
P37	81.39	32.77	44	33.9	13.6
P44	96.15	31.24	32	41	40.1
P60	89.01	30.28	34	29.5	23.2
P69	92.38	32.06	61	44.7	28.4
P9	95	31.06	12	34.9	41.3
P92	87.39	28.11	18	44.1	37.6

Table 1.3 Weather data collected for each night of surveying. Shaded rows indicate months excluded from final analysis.

Night	Survey Month	Night Length	Percent Moon Visible	High Night Temperature	Low Night Temperature	High Wind Speed	Low Wind Speed
Sept/10/2016	September	11:23	71	22.8	12.2	12.7	0
Sept/11/2016	September	11:25	80	22.8	12.2	5.8	0
Oct/07/2016	October	12:29	36	15.0	6.7	10.4	0
Oct/08/2016	October	12:31	45	16.1	6.0	0	0
Nov/04/2016	November	13:33	21	15.6	5.0	3.5	0
Nov/05/2016	November	13:36	29	15.0	3.3	3.5	0
Feb/10/2017	February	13:23	100	13.9	8.3	6.9	4.6
Feb/11/2017	February	13:21	99	18.3	3.9	21.9	0
Mar/04/2017	March	12:31	42	17.8	9.4	11.5	0
Mar/05/2017	March	12:28	53	12.8	10.0	18.4	6.9
Mar/31/2017	April	11:24	17	8.9	4.4	12.7	3.5
Apr/01/2017	April	11:21	27	11.1	7.2	8.1	3.6
May/06/2017	May	10:01	84	16.7	6.1	5.8	0
May/07/2017	May	9:59	91	19.4	10.6	3.5	0
June/02/2017	June	9:19	62	29.4	18.3	3.5	0
June/03/2017	June	9:18	72	28.9	20.6	6.9	0
Jun/28/2017	July	9:11	27	27.8	22.8	9.2	3.5
June/29/2017	July	9:12	37	28.3	22.8	5.8	0
Aug/08/2017	August	10:07	99	23.9	12.2	5.8	0
Aug/09/2017	August	10:09	96	25.6	18.9	6.9	0

Table 1.4. Best fit models of moth diversity in prairie habitat for two time periods: across all months and July. The number of low frequency call passes was more important than high frequency call passes or total bat activity. Model type is listed as mixed effects model (MEM) or ordinary least squares regression (OLS).

Best Prairie Model Across All Months (MEM)					
log(High Night Temperature) + log(Low Frequency Bat Calls)					
	Variable	**Estimate**	**T-value**	**R_2**	**P**
	log(High Night Temperature)	2.8467	6.799	0.665	4.1e-08
	log(Low Frequency Bat Calls)	-0.5120	-2.265	0.182	0.0289
Best Prairie Model for July (OLS)					
log(Low Frequency Bat Calls) + log(Topographic Variation) + log(Percent Ground Vegetation)					
	log(Low Frequency Bat Calls)	-1.961	-7.025	0.925	0.0022
	log(Topographic Variation)	-0.444	-1.587	0.386	0.1877
	log(Percent Ground Vegetation)	-4.619	-3.262	0.727	0.031

Table 1.5. Best fit models of moth diversity in forest habitat, in two time periods: across all months and July. Despite the importance of moon phase to overall forest moth diversity, this model was not improved by including cloud cover, and cloud cover was not a significant explanatory variable. Model type is listed as mixed effects model (MEM) or ordinary least squares regression (OLS).

Best Forest Model Across All Months (MEM)					
log(High Night Temperature) + log(Tree Diversity) +log(Percent Moon Visible)					
	Variable	**Estimate**	**T-value**	**R^2**	**P**
	log(High Night Temperature)	2.5155	12.971	0.885	2.22e-16
	log(Percent Moon Visible)	0.5882	5.462	0.576	2.21e-06
	log(Tree Diversity)	-1.5172	-1.314	0.073	0.1958
Best Forest Model for July (OLS)					
log(Total Tree Basal Area) + log(Average Understory Plant DBH) * log(Total Bat Calls)					
	log(Total Tree Basal Area)	-2.9704	-3.574	0.810	0.0374
	log(Average Understory Plant DBH)	-2.2494	-2.432	0.663	0.0932
	log(Total Bat Calls)	-1.0346	-2.181	0.613	0.1172
	log(Average Understory Plant DBH) * log(Total Bat Calls)	2.1883	2.225	0.623	0.1125

Table 1.6. In prairie habitat, moth abundance was only correlated with temperature across all months. No variables significantly explained moth abundance for the July data.

Best Prairie Model Across All Months (MEM)					
log(Average High Night Temperature)					
	Variable	**Estimate**	**T-value**	**R^2**	**P**
	log(Average High Night Temperature)	1.5664	9.220	0.777	3.01e-11
Best Prairie Model for July (OLS)					
No model with statistical significance at p> 0.1, 0.05, or 0.1					

Table 1.7. In forest habitat, bat activity was not significant in explaining moth abundance. Because woody understory variables are expected to remain relatively constant from month to month, vegetation variables were included in the analysis of data across all months. No variables significantly explained moth abundance for the July data.

Best Forest Model Across All Months (MEM)					
log(High Nightly Temperature) + log(Tree Diversity)					
	Variable	**Estimate**	**T-value**	**R^2**	**P**
	log(Average High Night Temperature)	1.95	17.415	0.912	2e-16
	log(Tree Diversity)	-3.02	-0.953	0.144	0.378
Best Forest Model for July (OLS)					
No model with statistical significance at p> 0.1, 0.05, or 0.001					

CHAPTER 2

Species Presence and Observations of Seasonal Moth Phenology in a Preservation Habitat in Illinois

INTRODUCTION

Human activity threatens insect biodiversity globally, and insect population declines are often inadequately documented and their causes are often poorly understood (Fox 2013). Climate change and destruction of natural habitats represent two of the most significant threats to insect diversity (Lintott et al. 2014; Fox et al. 2014). Habitat requirements of rare species are often poorly known, decreasing the effectiveness of conservation efforts. The high diversity and global distribution of the Order Lepidotera (Butterflies, Moths, and Skippers) makes this order a prime candidate for use as indicators of habitat quality or as surrogates for taxa or ecological conditions which are more difficult to study (Kitching et al. 2000; Summerville and Crist 2003). However, these indicators rely on well-documented trends in moth populations across time and habitat, and insufficient biological records limit the ability of conservation plans to effectively protect biodiversity (Guralnick et al. 2015). Conservation efforts aimed at protecting these insects and their trophic interactions with plants and predators should be informed by trends in moth ecology and distribution.

Conservation efforts require long-term monitoring, repeated surveying, and comparisons to baseline data (Baker et al. 2016). Documenting species distribution in space and time is necessary for monitoring biological changes and informs conservation planning and management (Porfirio et al. 2014). This project collected moths from sixteen sites in two habitat types over ten months (September-November 2016, February-August 2017) and provides a nearly year-long record of species presence and distribution at Paul Wightman Subterranean Nature Preserve (PWSNP) in Monroe County, Illinois. These records establish a basis for future moth research

and monitoring, allowing future study of changes in moth distribution at this site. There are two objectives to this study: 1) create a checklist of macro-moth species present at PWSNP, and 2) document ecologically important trends in moth populations, including winter behavior, seasonality, and potential new state records.

METHODS

This study took place at Paul Wightman Subterranean Nature Preserve (PWSNP), a 535 acre land preserve located in Monroe County, Illinois (-90.135912, 38.200792). Current land cover at the property includes 134.6 acres of forest, 264.8 acres of restoration prairie, 4.1 acres of permanent sinkhole ponds, 3.6 acres of ephemeral sinkhole ponds, and 115.4 acres of agricultural field.

Two hundred potential sample sites within PWSNP were randomly generated with ArcMap 10 (Environmental Systems Research Institute, Inc., California). Shapefiles delineating land class boundaries served as a framework for the selection of sample sites. A 25 m buffer was established around each potential site based on the maximum attractive distance of black light bucket traps to moths (Merck and Slade 2014). To ensure site independence, a potential sample site was selected if the 25 m buffer around each site excluded other potential sample sites, forest-prairie habitat edges, and permanent water features. Sites were randomly selected from this list and analyzed to ensure they fit the above criteria until there were sixteen sample sites, with eight in forest and eight in restoration prairie.

Moth specimen collection occurred in monthly site visits when night time lows were above 0°C, a temperature that correspond with increased winter moth activity levels (Donnell and Groden 2017). Site visits occurred from September through November 2016, and February

through August 2017. Moths were collected using 12W black light bucket traps (BioQuip, Rancho Domingo, California), with one trap placed at ground level at the center of each site (Harrison 2011). Each trap consists of a 12W DC black light powered by a 12V ACS battery, with the light mounted above a funnel leading into a plastic 5-gallon bucket. A photoelectric switch connecting the battery to the trap activated the black light between sunset and sunrise. Approximately 1 hour before sunset a glass jar filled with approximately 200 ml of 99.9% ethyl acetate ACS reagent was placed inside the bucket as the killing agent. Bucket traps were closed and specimens collected beginning approximately 1.5 hours after sunrise. All insect specimens were collected and frozen to facilitate identification (Summerville et al. 2006).

Macro-moths were identified to species based on external morphology and color patterns of wings, antennae, and bodies using Beadle & Leckie (2012), Triplehorn & Johnson (2004), the MothPhotographersGroup.com plate series curated by the Mississippi Entomological Museum, Bugguide.com, the Illinois Natural History Survey (INHS) Insect Collection, and consultation with regional moth experts. When specimens were determined to be unique, but could not confidently be identified to a known species, they were assigned a unique morphospecies identifier. Specimens that were too damaged to be confidently identified to family level were excluded from analysis. Voucher specimens were pinned and spread for all species collected and will be deposited at the Illinois Natural History Survey Insect Collection.

RESULTS AND DISCUSSION

Moth Species

4599 moth specimens were identified to 214 species and 37 morphospecies. This analysis focuses on the 214 species identified (Table 2.1). These 214 species represented eleven of the

twelve families of Lepidoptera captured as part of this project. The twelfth family, Nolidae, was represented by a specimen that was too badly damaged to confidently identify to species level and is not included in this analysis. Four of these families were represented by only one species, and one family, Lasiocampidae, was represented by two species. The most diverse family was Noctuidae, whose members are commonly called owelets, cutworms, and armyworms, which contained 87 species. Of the 214 species identified, 38 were singletons, meaning that only one individual of that species was collected over the course of the project. Two of these singleton species, *Paectes oculatrix* and *Callizzia amorata,* were the only representatives of their families, Euteliidae and Uraniidae, respectively. The most abundant species was *Anavitrinella pampinaria* (Family Geometridae), with 239 individuals collected.

Species Distribution across Habitat and Time

Forest had greater species richness than restoration prairie. 98 species (45.8%) were captured only in forest habitat, 23 species (10.7%) were found only in prairie habitat, and 93 species (43.5%) were found in both habitat types. The restoration prairie was planted in 2015 on land that was previously used for corn and soy agriculture. Although restoration planting has concluded, the young age of this habitat could be a contributing factor to its lower species richness as it continues to accumulate moth species as species discover this newly available habitat (Summerville et al. 2007; Alison et al. 2016; Ruiz-Carbayo 2017). These trends suggest that moth richness will continue to increase as the restoration prairie ages, and the overall moth richness at PWSNP will increase. Future species monitoring should study changes in moth community in this maturing habitat.

In both habitat types, moth richness was greater in the summer (Table 2.2). There were two peaks in summer richness, which were present in both habitat types and which potentially represent the emergence of multiple broods (Figure 2.1). These peaks are offset between the two habitats, with richness peaking a month earlier in the forest. *Anavitrinella pampinaria* (Guenée 1858, family Geometridae) was the most abundant species overall, with 239 individuals captured in both habitat types (Figure 2.2). While this species was found in both habitats, it was primarily present in prairie habitat. *A. pampinaria* larvae feed on a variety of tree species and given the relatively short distances between forest fragments at PWSNP, it is likely that *A. pampinaria* specimens from prairie sites were captured as they moved between forest fragments. This likely occurred with many of the species captured in both habitat types. *Nadata gibbosa* (Smith 1797, family Notodontidae) was the second most abundant species, with 231 individuals collected in both habitat types (Figure 2.2). This species had two prominent peaks in population, in July and August, which supports documentation of two to three broods per summer, especially in the southern portion of its range (Wagner 2005). The presence of a third brood in the future could indicate a northern range shift due to climate change. *Idia rotundalis* (Walker 1866, family Erebidae) was the most abundant species found only in forest habitat, with 40 individuals collected (Figure 2.2). This species deviates from the trend higher summer abundance and appears to be a fall and winter specialist that was only collected in February, September, and October. It is likely that *I. rotundalis* was also present in November but was not collected. *Agnorisma bollii* (Grote 1881, family Noctuidae) was the most abundant species found only in prairie habitat, and was only collected in October 2016.

Winter Activity

Moth richness declined rapidly in the fall and was slow to increase in the spring, with few species active in the winter months of surveying (November 2016 and February 2017). Because of sub-freezing nightly temperatures, no field work was conducted in December 2016 or January 2017. In November 2016, only seven individuals from four species were captured- one Erebid (*Anticarsia gemmitalis*) and three Noctuids (*Epiglaea decliva, Sunira bicolorago,* and *Mythimna unipuncta*). All four species have documented winter activity. Two (*E. decliva, S. bicolorago*) are primarily active as adults in the winter and two have year-round adult activity (*A. gemmitalis, M. unipuncta*). In February 2017, five species were captured- two Erebids (*Hypena scabra, Idia rotundalis*), two Geometers (*Paleacrita vernata, Iridopsis defectaria*), and one Noctuid (*Sericaglaea signata*). The four November species and five February species were distinct and had no overlap in species presence between these two months. Three of these nine species are winter specialists: *P. vernata, S. signata,* and *E. decliva* were found only in the winter months (Figure 2.3). The remaining six species have distribution outside of the winter months, indicating that they have year-round distribution and November and February were on the ends of their season, rather than being their primary season of adult activity.

Documentation of winter moth activity is important for understanding interactions between moths and their bat predators. While bats are less active in the winter, hibernation in bats is often interrupted by brief periods of activity to hydrate, forage, and groom. With few exceptions (Frick et al. 2014), insectivorous bats, including all thirteen bat species in Illinois, are obligate carnivores that rely on insect prey for survival, and the presence of adult moths over the winter provides an important food source for these bats. Winter foraging can be energetically profitable for bats on warm nights when insects are active, and even northern bat population

continue to forage periodically throughout the winter to supplement fat stores built up during the fall (McGuire 2016). While low critical temperatures may allow certain moth species to remain active throughout much of the winter when bat activity is reduced, bat predation remains a threat on warm nights when it is energetically profitable for these bats to forage. A large portion of bat winter diet consists of Lepidoptera, indicating that this order continues to remain an important dietary component for overwintering bats (Hope et al. 2014). Due to the low number of specimens captured for each species (ranging from one to 33 individuals in November and February), increased sample sizes are necessary for future research into winter moth activity. Most moth research occurs during summer seasons when temperatures are above a certain threshold, usually 10°C, and thus there is limited knowledge of moth diversity and abundance in cooler seasons. This further justifies future research and sampling to better understand and document winter moth activity (Slade & Merckx 2016).

New State Records

Six species from three families (Erebidae, Geometridae, and Noctuidae) were examined as potential new state records. These species were not present in Illinois in species distribution maps used by the North American Moth Photographers Group, which is curated by the Mississippi Entomological Museum (http://mothphotographersgroup.msstate.edu/). These species were compared to the Illinois Natural History Survey (INHS) Insect Collection. This collection comprises over seven million specimens, and is the primary repository for insect specimens in Illinois (http://wwx.inhs.illinois.edu/collections/insect). In this collection there were no representatives from these six species that were collected in Illinois, further indicating that they are new state records for Illinois (Table 2.3). A complete literature review was

conducted for *Agnorisma bollii* (Lepidoptera: Noctuidae). While this species has been documented in nearby states to the east and west, including Kansas, Arkansas, and Ohio, its lack of documentation in Illinois records confirms that it is a new species (Snyder 2015). Literature reviews are underway for the remaining five species, *Speranza brunneata, Dasychira vagans, Besma endropiaria, Anicla forbesi,* and *Metaxaglaea semitaria,* to confirm their status as new state records for Illinois. These specimens will be donated to the INHS Insect Collection for identification confirmation and for preservation and use in future research.

CONCLUSIONS

Baseline species records followed by repeated future sampling are crucial for detecting species loss, gain, and range shifts, and are an essential asset to conservation efforts. This project established a checklist of macro-moth species present at PWSNP over ten months of sampling. A record of moth species present in 2016 through 2017 will provide a baseline for future monitoring that can assess species recruitment as a result of conservation efforts at this site. For example, further research can show the changes in moth diversity as prairie matures and other conservation efforts, such as the removal of the invasive bush honeysuckle, *Lonicera maackii,* continue at PWSNP. This research also established a methodology for future documentation of moths at PWSNP and increases available location data in Illinois for the species identified. Additionally, further research should study the importance of winter moth activity as an evolutionary strategy in moths, and its role as a food source for hibernating bats. Winter moth activity could be significant to the survival of overwintering bats, and conservation of winter-specialist moth species may be important to sustaining local bat populations. Future research

should adapt this methodology to create long term monitoring projects that document changes in moth biodiversity and range to inform conservation and management actions.

TABLES AND FIGURES

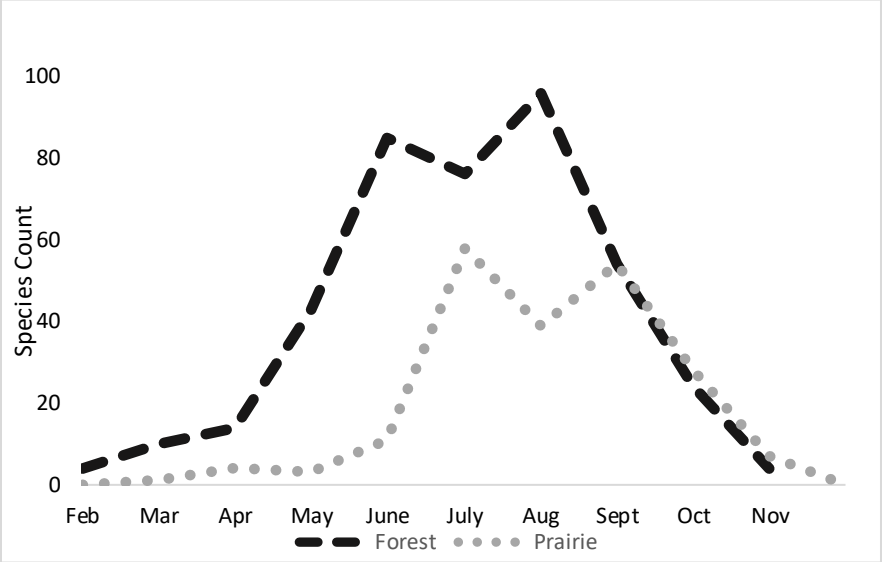


Figure 2.1. The number of moth species captured in both habitat types was lower in spring and fall, and peaked during the summer. Moth populations in both habitats showed a similar trend of two separate peaks in species richness during the summer, thought the in forest moth richness occurred a month earlier.

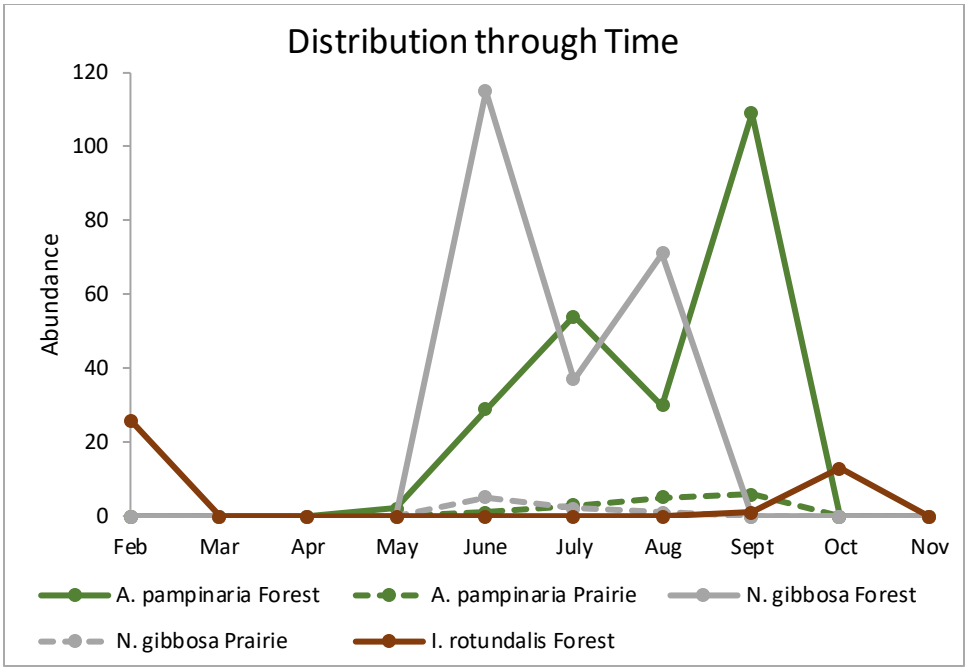


Figure 2.2. Distributions through time for three example species. The two most abundant species throughout the project, *A. pampinaria* and *N. gibbosa*, were present in both habitats, but were most abundant in forest. Both of these species had two peaks in abundance, potentially representing multiple broods across the summer. *I. rotundalis*, the most abundant species found only in forest habitat, was only present in fall and winter.



Figure 2.3. Seasonal activity of the nine moth species collected in the winter survey months (November, February). The left column is the four moth species collected in November, and the right column is the moths collected in February. Several species, including *E. decliva*, *P. vernata*, and *S. signata*, were only collected during winter months.

Table 2.1. Complete species list for the specimens confidently identified to species. Macro-moths were identified from 11 families, though the majority of species belonged to 5 families: Erebidae, Geometridae, Noctuidae, Notodontidae, and Sphingidae. Hodges number, also known as the MONA (Moths of America North of Mexico) number, is an numbering system developed by Ronald W. Hodges that assigns each moth species a number that is used as a distinct identifier that is independent of higher level taxonomic changers (Hodges 1983).

Family	***Species***	**Common Name**	**Hodges**
Bombycidae	*Apatelodes torrefacta*	Spotted Apatelodes	7663
Erebidae	*Anticarsia gemmatalis*	Velvetbean Caterpillar Moth	8574
	Arugisa lutea	Common Arugisa	8509
	Caenurgina chloropha	Vetch Looper	8733
	Caenurgina crassiuscula	Clover Looper	8738
	Caenurgina erechtea	Forage Looper	8739
	Catocala judith	Judith's Underwing	8781
	Catocala maestosa	Sad Underwing	8793
	Catocala retecta	Yellow-gray Underwing	8788
	Catocala vidua	Widow Underwing	8792
	Catocola piatrix	Penitent Underwing	8771
	Celiptera frustulum	Black Bit Moth	8747
	Cisseps fulvicollis	Yellow-Collared Scape Moth	8267
	Clemensia albata	Little White Lichen Moth	8098
	Cycnia tenera	Delicate Cycnia	8230
	Dasychira tephra	Tephra Tussock Moth	8292
	Dasychira vagans	Variable Tussock Moth	8294
	Estigmene acrea	Salt Marsh Moth	8131
	Euchaetes egle	Milkweed Tussock Moth	8238
	Haploa clymene	Clymene Moth	8107
	Haploa lecontei	Leconte's Haploa	8111
	Haploa reversa	Reversed Haploa	8109
	Hypena abalienalis	White-Lined Hypena	8445
	Hypena scabra	Green Cloverworm Moth	8465
	Hypena sordidula	Sordid Snout	8448
	Hypoprepia fucosa	Painted Lichen Moth	8090
	Hypsoropha hormos	Small Necklace Moth	8528
	Idia americalis	American Idia Moth	8322
	Idia rotundalis	Rotund Idia Moth	8326
	Isogona tenuis	Thin-Lined Owlet	8493
	Lascoria ambigualis	Ambiguous Moth	8393
	Ledaea perditalis	Lost Owlet	8491
	Lesmone detrahens	Detracted Owlet	8651
	Mocis texana	Texas Mocis	8745

(Table 2.1 cont.)

	Orgyia leucostigma	White-Marked Tussock Moth	8316
	Palthis angulalis	Dark-Spotted Palthis	8397
	Palthis asopialis	Faint-Spotted Palthis	8398
	Panopoda carneicosta	Brown-Lined Panopoda	8588
	Panopoda rufimargo	Red-Lined Panopoda	8587
	Parallelia bistriaris	Maple Looper	8727
	Phalaenophana pyramusalis	Dark-Banded Owlet	8338
	Phalaenostola larentioides	Black-Banded Owlet	8364
	Phoberia atomaris	Common Oak Moth	8591
	Phyprosopus callitrichoides	Curve-Lined Owlet	8525
	Plusiodonta compressipalpis	Moonseed Moth	8534
	Pyrrharctia isabella	Isabella Tiger Moth	8129
	Renia adspergillus	Speckled Renia	8386
	Renia discoloralis	Discolored Renia Moth	8381
	Scolecocampa liburna	Dead-Wood Borer Moth	8514
	Spilosoma congrua	Agreeable Tiger Moth	8134
	Spilosoma virginica	Virginia Tiger Moth	8137
	Tetanolita mynesalis	Smoky Tetanolita Moth	8366
	Virbia aurantiaca	Orange Virbia	8121
	Zale horrida	Horrid Zale	8717
	Zale lunata	Lunate Zale Moth	8689
	Zanclognatha obscuripennis	Dark Zanclognatha Moth	8347
	Zanclognatha protumnusalis		8349
Euteliidae	*Paectes oculatrix*	Eyed Paectes	8957
Geometridae	*Anavitrinella pampinaria*	Common Gray	6590
	Besma endropiaria	Straw Besma	6884
	Besma quercivoraria	Oak Besma	6885
	Costaconvexa centrostrigaria	Bent-Line Carpet	7416
	Ectropis crepuscularia	Small Engrailed	6597
	Ennomos magnaria	Maple Spanworm	6797
	Epimecis hortaria	Tulip-Tree Beauty	6599
	Euchlaena irraria	Least-Marked Euchlaena	6739
	Eupithecia miserulata	Common Pug	7474
	Eusarca confusaria	Confused Eusarca	6941
	Eutrapela clemataria	Curve-Toothed Geometer	6966
	Glena cribrataria	Dotted Gray	6449
	Haematopis grataria	Chickweed Geometer Moth	7146

(Table 2.1 cont.)

	Heterophleps triguttaria	Three-Spotted Fillip	7647
	Ilexia intractata	Black-Dotted Ruddy Moth	6711
	Iridopsis defectaria	Brown-Shaded Gray Moth	6586
	Iridopsis larvaria	Bent-Lined Gray	6588
	Iridopsis vellivolata	Large Purple Gray Moth	6582
	Lomographa glomeraria	Gray Spring Moth	6668
	Lytrosis unitaria	Common Lytrosis	6720
	Macaria multilineata	Many-Lined Angle Moth	6353
	Melanolophia canadaria	Melanolophia canadaria	6620
	Metarranthis homuraria	Purplish Metarranthis Moth	6828
	Nematocampa resistaria	Horned Spanworm	7010
	Nemoria bistriaria	Red-Fringed Emerald Moth	7046
	Paleacrita vernata	Spring Cankerworm Moth	6662
	Patalene olyzonaria	Juniper-Twig Geometer	6974
	Pero honestaria	Honest Pero	6753
	Phigalia strigataria	Small Phigalia Moth	6660
	Plagodis alcoolaria	Hollow-Spotted Plagodis	6844
	Probole amicaria	Friendly Probole Moth	6838
	Prochoerodes lineola	Large Maple Spanworm	6982
	Scopula limboundata	Large Lace-Border	7159
	Selenia kentaria	Kent's geometer	6818
	Speranza brunneata		6286
	Synchlora aerata	Wavy-Lined Emerald	7058
	Tetracis crocallata	Yellow Slant-Line	6963
	Timandra amaturaria	Cross-Lined Wave	7147
Lasiocampidae	*Artace cribrarius*	Dot-Lined White	7683
	Tolype velleda	Large Tolype	7670
Mimallonidae	*Lacosoma chiridota*	Scalloped Sack-Bearer	7659
Noctuidae	*Abagrotis alternata*	Greater Red Dart	11029
	Acronicta funeralis	Funerary Dagger	9221
	Acronicta hasta	Speared Dagger Moth	9229
	Acronicta increta	Raspberry Bud Dagger Moth	9249
	Acronicta laetifica	Pleasant Dagger Moth	9227
	Acronicta morula	Ochre Dagger Moth	9236
	Acronicta retardata	Retarded Dagger Moth	9251
	Acronicta rubricoma	Ruddy Dagger Moth	9199
	Acronicta tristis		9247
	Acronicta vinnula	Delightful Dagger	9225
	Agnorisma badinodis	Pale-Banded Dart	10955
	Agnorisma bollii		10956
	Agrotis gladiaria	Swordsman Dart	10648
	Agrotis ipsilon	Ipsilon dart	10663

(Table 2.1 cont.)

Amyna bullula	Hook-tipped Amyna Moth	9069
Anagrapha falcifera	Celery Looper	8924
Anicla forbesi	Forbes's Dart	10902
Apamea helva		9373
Apamea devastator	Glassy Cutworm Moth	9382
Athetis tarda	The Slowpoke	9650
Azenia obtusa	Obtuse Yellow Moth	9725
Balsa labecula	White-Blotched Balsa	9664
Bellura densa	Pickerelweed Borer	9526
Callopistria mollissima	Pink-Shaded Fern Moth	9631
Cerma cerintha	Tufted Bird Dropping Moth	9062
Charadra deridens	Laugher Moth	9189
Choephora fungorum	Bent-Line Dart	10998
Chrysodeixes includens	Soybean Looper	8890
Condica sutor	The Cobbler	9699
Condica vecors	Dusky Groundling Moth	9696
Condica videns	White-Dotted Groundling	9690
Copivaleria grotei	Grote's Sallow	10021
Crambodes talidiformis	Verbena Moth	9661
Cucullia asteroides	Goldenrod Hooded Owlet	10200
Dargida rubripennis	The Pink-Streak	10434
Elaphria grata	Grateful Midget Moth	9684
Epiglaea decliva	Sloping Sallow	9946
Eudryas grata	Beautiful Wood-Nymph	9301
Eudryas unio	Pearly Wood-Nymph	9299
Feltia gladiaria		10648
Feltia jaculifera	Dingy Cutworm	10670
Feltia subgothica	Subgothic Dart	10674
Galgula partita	The Wedgeling	9688
Helicoverpa zea	Corn Earworm	11068
Himella fidelis	Intractable Quaker	10502
Homophoberia apicosa	Black Wedge-Spot	9057
Lacinipolia meditata	Thinker Moth	10368
Lacinipolia renigera	Bristly Cutworm	10397
Leucania linita	Linen Wainscot	10440
Leuconycta diphteroides	Green Leuconycta	9065
Marimatha nigrofimbria	Black-Bordered Lemon Moth	9044
Megalographa biloba	Bilobed Looper	8907
Meropleon ambifusca	Newman's Brocade	9428
Metaxaglaea semitaria	Footpath Sallow Moth	9945
Mythimna unipuncta	The White-Speck	10438
Nephelodes minians	Bronzed Cutworm	10524

(Table 2.1 cont.)

	Ogdoconta cinereola	Common Pinkband	9720
	Orthodes majuscula	Rustic Quaker Moth	10585
	Orthosia garmani	Garman's Quaker	10488
	Orthosia rubescens	Ruby Quaker	10487
	Papaipema baptisiae	Indigo Stem Borer	9485
	Papaipema limpida	Vernonia Borer	9507
	Papaipema maritima	Maritime Sunflower Borer	9500
	Papaipema nebris	Stalk Borer	9496
	Peridroma saucia	Variegated Cutworm	10915
	Perigea xanthioides	Red Groundling Moth	9689
	Ponometia candefacta	Olive-Shaded Bird-Dropping Moth	9090
	Protodeltote muscosula	Large Mossy Lithocaodia	9047
	Protolampra brunneicollis	Brown-Collared Dart	11006
	Proxenus miranda	Miranda Moth	9647
	Psaphida electilis	Chosen Sallow	10012
	Psaphida grandis	Gray Sallow	10013
	Psaphida resumens	Figure-Eight Sallow	10019
	Pseudeustrotia carneola	Pink-Barred Pseudeustrotia	9053
	Raphia frater	The Brother	9193
	Resapamea passer	Dock Rustic	9391
	Schinia arcigera	Arcigera Flower Moth	11128
	Schinia lynx	Lynx Flower Moth	11117
	Schinia rivulosa	Ragweed Flower Moth	11135
	Sericaglaea signata	Variable Sallow	9941
	Spodoptera dolichos	Sweetpotato Armyworm Moth	9671
	Spodoptera frugiperda	Fall Armyworm	9666
	Spodoptera ornithogalli	Yellow-Striped Armyworm Moth	9669
	Spragueia leo	Common Spragueia	9127
	Sunira bicolorago	Bicolored Sallow	9957
	Sympistis dinalda		10066.1
	Tarache aprica	Exposed Bird Dropping Moth	9136
Notodontidae	*Clostera albosigma*	Sigmoid Prominent	7895
	Datana angusii	Datana angusii	7903
	Datana contracta	Contracted Datana	7906
	Datana perspicua	Spotted Datana Moth	7908
	Furcula occidentalis	Western Furcula	7939
	Heterocampa guttivitta	Saddled Prominent	7994
	Heterocampa varia	Sandplain Heterocampa	7982
	Hyperaeschra georgica	Georgian Prominent	7917
	Lochmaeus bilineata	Double-Lined Prominent	7999

(Table 2.1 cont.)

	Nadata gibbosa	White-Dotted Prominent	7915
	Nerice bidentata	Double-Toothed Prominent Moth	7929
	Schizura ipomoeae	Morning-Glory Prominent	8005
Saturniidae	*Actias luna*	Luna Moth	7758
	Antheraea polyphemus	Polyphemous Moth	7757
	Automeris io	Io Moth	7746
Sphingidae	*Amorpha juglandis*	Walnut Sphinx	7827
	Darapsa myron	Virginia Creeper Sphinx	7885
	Deidamia inscriptum	Lettered Sphinx	7871
	Deidamia myron		7885
	Dolba hyloeus	Pawpaw Sphinx	7784
	Hyles lineata	White-Lined Sphinx Moth	7894
	Paonias excaecata		7824
	Paonias myops	Small-Eyed Sphinx	7825
	Paratrea plebeja	Plebeian Sphinx	7793
	Smerinthus jamaicensis	Twin-Spotted Sphinx	7821
	Sphinx kalmiae	Laurel Sphinx	7809
	Xylophanes tersa	Tersa Sphinx	7890
Uraniidae	*Callizzia amorata*	Gray Scoopwing	7650

Table 2.2. The number of species collected in both habitat types was highest in the summer months, which are highlighted. Species richness was greater in forest habitat in all months.

Month	Season	Forest Richness	Prairie Richness
Feb	Winter	4	1
Mar	Spring	10	4
Apr	Spring	14	3
May	Spring	43	11
June	Summer	85	58
July	Summer	76	39
Aug	Summer	96	54
Sept	Fall	54	28
Oct	Fall	24	7
Nov	Winter	4	0

Table 2.3. The six potential new state records for Illinois. Representatives of these species collected in Illinois are absent from the Illinois Natural History Survey Insect Collection. *A. bollii* has be identified as a new state record, and literature reviews of the remaining five species are ongoing.

Family	Subfamily	Tribe	Species	Common Name
Erebidae	Lymantriinae	Orgyiini	*Dasychira vagans*	Variable Tussock Moth
Geometridae	Ennominae	Ourapterygini	*Besma endropiaria*	Straw Besma
Geometridae	Ennominae	Macariini	*Speranza brunneata*	
Noctuidae	Noctuinae	Noctuini	*Agnorisma bollii*	
Noctuidae	Noctuinae	Noctuini	*Anicla forbesi*	Forbes's Dart
Noctuidae	Noctuinae	Xylenini	*Metaxaglaea semitaria*	Footpath Sallow Moth

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APPENDIX A: SPECIES CAPTURE RECORDS

The supplementary file Appendix A: Species Capture Records.xlsx includes a log of the sites and nights where each of the 252 species identified by this project were collected. The column "Date" refers to the night that each specimen was collected, as described by the date the black light bucket trap was deployed. The sixteen sample sites are listed in the column "Site." "Habitat" further clarifies which of the two habitat types, forest and prairie, each site was placed in. For each species listed, each cell describes the number of specimens of that species collected on a given site, on a given night. Morphospecies are named using the convention "m_Identifier Number_Family," for example: "m_0002_Geometridae."