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EDITOR'S NOTE

The goal of this special section of the Journal is to bring much needed attention to the efforts of individuals that show promise for future inquiry involving butterflies and moths. Each paper in this section contains the results of experiments that were designed, implemented, and evaluated by undergraduate and graduate students (with their advisors, of course). The impetus for this special section of the Journal was Tewksbury et al.'s recent paper (2014, *BioScience*) that called our collective attention to what has become a significant decline in the study of natural history. The papers collected for this special section suggest that the decline in natural history can be offset by a concerted effort to encourage the next generation of lepidopterists. Beyond what is published here, countless other developing lepidopterists are producing quality research that is not featured in this section. Thus, in my view, it seems that the future of research involving Lepidoptera appears quite bright.

Keith S. Summerville, Editor
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COMMUNITY PATTERNS IN URBAN MOTH ASSEMBLAGES

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ABSTRACT. In order to gain a better understanding of the effects of urbanization on insect biodiversity we compared moth assemblages between residential yards and urban woodlots in East Lansing, Michigan. We surveyed 36 sites over six trapping nights, for a total of 24 hours of nighttime light-trapping at each site. We captured over 2700 macromoth individuals and over 4000 micro-moth individuals; more than 97% of macromoth individuals were identified to species. We analyzed differences in life history traits such as body size and feeding guild between residential moths and urban woodlot moths. Urban woodlots had a higher overall abundance of moths and higher species richness than residential yards. Residential yards were found to have a high proportion of “tourist species.” Urban woodlot moth species were significantly larger than residential moth species, leading us to hypothesize that larger moths may be more prone to predation in open habitats. The woodlot moth assemblage was also characterized by a higher percentage of tree generalist species; the residential moth assemblage had a higher percentage of grass/herb generalist species.

Additional key words: Urban biodiversity, phenotype, woodlot, residential

The urbanization of natural and semi-natural landscapes is often associated with biodiversity loss (McKinney 2002, 2008; Turner et al. 2004). Biodiverse cities are important because of high intrinsic value to natural flora and fauna; they provide ecosystem services (Bolund & Hunhammar 1999) and increase awareness about habitat conservation (Miller & Hobbs 2002; Turner et al. 2004). While often viewed as household pests, different guilds of urban arthropods can serve as primary consumers, secondary consumers and

decomposers in every type of urban micro-habitat, ranging from backyards to parks to urban woodlots. Moths, for example, serve as primary consumers during their larval stage and convert vegetative matter into biomass that is then consumed by birds, small mammals, amphibians, and reptiles. While public consciousness oftentimes focuses on visible and colorful species as targets of biodiversity conservation (e.g., birds or butterflies), cryptic species like moths are also of critical importance since they play a key role in

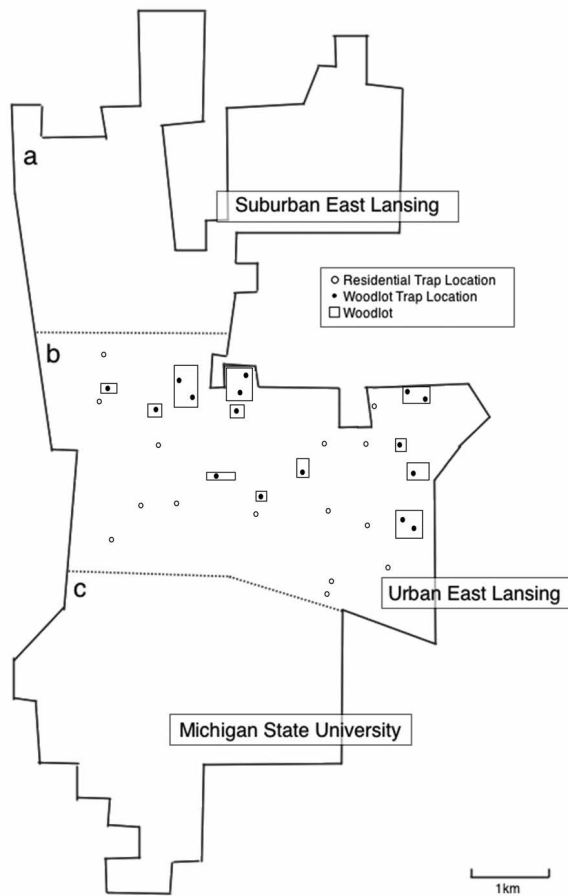


FIG. 1. East Lansing, Michigan. Moth trapping was conducted at 16 woodlot locations and 16 residential locations in Urban East Lansing (area b above).

ecological communities (Summerville & Crist 2003).

Recent estimates indicate that urbanization is on the rise; more humans are living in cities than they did in past decades (McKinney 2002). The potential dramatic growth in urban centers suggests a need to more thoroughly quantify how urbanization impacts biodiversity. Over 70% of studies reviewed by McKinney (2008) show a peak of invertebrate species richness at low intensities of urbanization. Urbanization has the potential to not only affect moths in habitats that are converted for residential purposes, it can influence the biodiversity of moths in adjacent woodlots that are less disturbed (Summerville 2013). Urban woodlots have the potential to augment urban biodiversity; however, little research has been done to characterize their ecological value (McIntyre 2000).

Moth assemblage dynamics and moth assemblage phenotypes are often affected by habitat disturbance. In a review, McIntyre (2000) identified two common outcomes of habitat disturbance. The first outcome is when green areas, such as woodlots, promote species

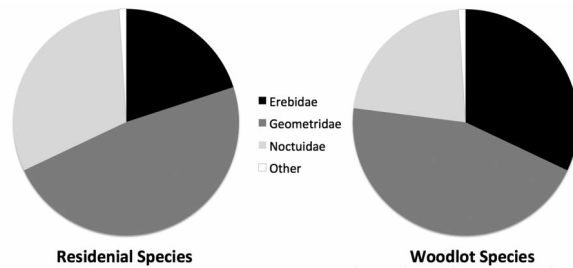


FIGURE 2 A comparison of families of macromoth individuals captured in residential sites and in woodlot sites. There were a total of 98 residential species, composed of 570 individual moths. There were a total of 173 woodlot species, composed of 2146 individuals.

richness because they are undisturbed (e.g., Okuma & Kitazawa 1982; McGeoch & Chown 1997). The second outcome is when intermediate levels of disturbance increases diversity, likely due to the increased number of habitat niches facilitated by low-grade fragmentation and habitat change (e.g., Blair & Launer 1997; McKinney 2008). This second finding would generally support the intermediate disturbance hypothesis (Connell 1978). Since moths are dependent on the presence of suitable host- and food-plants, the increase in plant diversity associated with urbanization (for example, habitat disturbance and the introduction of exotic flora) may result in more moth species; including non-native species (Sattler et al. 2010; McKinney 2008; Shuey et al. 2012).

Availability of host plants is not the only factor to consider when it comes to the impact of disturbance on moth assemblages; life history traits such as feeding preferences and body size can also play an important role in determining which species persist in a disturbed landscape. For example, although disturbances may increase overall hostplant diversity, moths that specialize on one or two hosts may be negatively impacted should those hosts be eliminated from the hostplant pool (Shuey et al. 2012; Öckinger et al. 2010). Feeding behavior has also been related to wingspan and body size, where specialists tend to be smaller in size and generalists tend to be larger (Neiminen 1996; Neiminen et al. 1999). Hambäck et al. (2007) found a significant interaction between body size and feeding guild, suggesting that these two traits should be analyzed together to investigate their potential impact on moth assemblage dynamics in disturbed landscapes.

Here we investigate the differences in moth assemblage characteristics between urban woodlot sites and adjacent urban residential sites in East Lansing, Michigan, USA. The two types of habitat represent different levels of disturbance, where urban residential sites have high levels of habitat disturbance and urban

woodlot sites have comparatively low levels of direct disturbance. We surveyed moth populations in the summer of 2014 and measured the assemblage richness, abundance, and life history traits of the moths in the two habitat types.

METHODS AND MATERIALS

Location

Moth assemblages were studied across the urban cityscape of East Lansing, Michigan (Figure 1; Appendix 1). East Lansing covers ~36km² and has a population of nearly 50,000 people. The average annual temperature is 8.2 °C, ranging from an average of -4.5°C in winter months to an average of 20.3°C in summer months. The average annual rainfall is 785mm. It has been named one of nearly 3400 “Tree Cities” across the USA by the Arbor Day Foundation, recognizing its commitment to urban tree propagation and management.

Moth Surveys

Moth surveys were conducted using light traps over the course of twelve nights in the summer of 2014 between mid-June and the end of July. Trapping was

done in two types of locations: residential yards and urban woodlots. Residential trap sites (n = 16) were in backyards or front yards of city residents who volunteered to be a part of this study. The potential pool of volunteers was first drawn from social media contacts and later augmented by door-to-door solicitation in areas of the city that appeared to be under sampled. Urban woodlot sites (n = 16) were located in wooded areas, both designated parks and undeveloped woodlots, within the city. The number of woodlot sites was limited by the number of viable woodlots within the cityscape. The residential and woodlot sites were surrounded by urban neighborhoods and were never directly neighboring each other (Figure 1). The mean nearest neighbor distance between sites was 358 m, ranging between 142 m and 609 m (Appendix 1).

Trapping was conducted on nights with clear or partly cloudy conditions with wind speeds no greater than 5 km/hr. The light traps used in this study were the BioQuip Universal Black Light Trap model 2851 with a 12-watt black light bulb. These traps were powered by 12V 15mAH batteries, and fitted with 12V Digital LCD programmable timers.

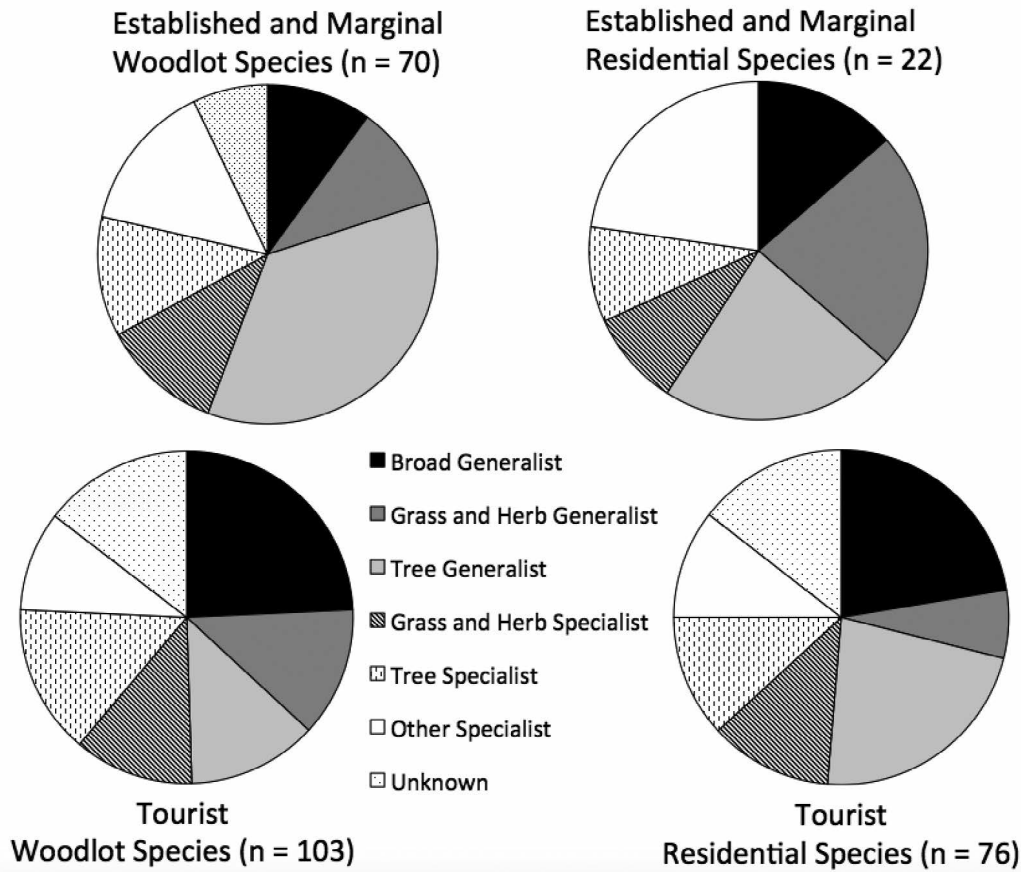


FIG. 3. A comparison of feeding preferences among woodlot and residential moth assemblages.

On each viable night, a random subset of between 14 and 18 sites was surveyed (half of the traps set in each habitat type for a given night). Light traps were set by timer to operate between 11:30pm and 3:30am. This ensured that each trap operated with the same amount of survey effort, and reduced the visibility of traps (and thus the possibility of vandalism) during the evening and early morning hours of the day. At the end of the survey period, the 32 sites were surveyed for 24 nighttime hours (6 nights \times 4 hours per night). Pesticide strips containing 18.6% dichlorvos (2,2-dichlorovinyl dimethyl phosphate) were used in the light trap buckets to kill the moths so the moths could be identified.

Moth Identification

Moths were separated from all other insects and any non-Lepidopteran by-catch was discarded. Macromoths were identified using available field guides and by comparing samples to the Lepidoptera collection available at the A.J. Cook Research Collection at Michigan State University (MSUC). Two guides for eastern North American moths were used: *Field Guide to Moths of North Eastern North America* (Beadle and Leckie, 2012), and *Les Papillons du Quebec* (Handfield, 2011). The latter guide was particularly useful as it provided full color plates of more than 1500 Lepidoptera species. In instances where moth individuals could not

be positively identified to a particular species, they were compared to moth specimens housed in the MSUC, which contains over 163,000 specimens, many of which were obtained in the Great Lakes Region. Micromoth species were identified when possible, but this was not often the case for want of a comprehensive identification guide. Even so, all micromoths were counted at each survey location and added to the total moth abundance measure. Moths identified to be in the superfamilies Gelechioidea, Pterophoroidea, Pyraloidea, Tortricoidea, and Yponomeutoidea were considered "micromoths."

Moths that were unidentifiable due to scale damage were recorded as "unknown." These moths were not included in species richness counts, but were included in species abundance counts at each location. Moths that were unidentifiable, but were in good condition, were given an alpha-numeric species identifier (i.e., a pseudo-species name), and all subsequent moths that matched the voucher specimen were given the same alpha-numeric species identifier. This second group of unidentifiable moths was included in species richness and total abundance counts at each location. Voucher specimens were kept of each moth species along with a digital photo taken with a Canon EOS Rebel T3i camera fitted with a macro-lens. Digital photos were stored on our lab computers.

TABLE 1 (a) The five most common macromoth species at urban residential and urban woodlot sites and (b) the five most common (identifiable) micromoth species at urban residential and urban woodlot sites. Family names are given in parentheses.

		Woodlot		Residential	
a)					
Rank	Macromoth Species	# of Individuals (% of Individuals)	Macromoth Species	# of Individuals (% of Individuals)	
1	<i>Speranza pustularia</i> (Geometridae)	476 (22.2%)	<i>Speranza pustularia</i> (Geometridae)	169 (29.6%)	
2	<i>Haploa lecontei</i> (Erebidae)	251 (11.8%)	<i>Orthodes cynica</i> (Noctuidae)	34 (6.0%)	
3	<i>Bleptina caradrinalis</i> (Erebidae)	100 (4.7%)	<i>Idia americanis</i> (Erebidae)	32 (5.6%)	
4	<i>Eusarca confusaria</i> (Geometridae)	73 (3.4%)	<i>Bleptina caradrinalis</i> (Erebidae)	31 (5.4%)	
5	<i>Halysidota tessellaris</i> (Erebidae)	69 (3.2%)	<i>Noctua pronuba</i> (Noctuidae)	28 (4.9%)	
b)					
Rank	Micromoth Species	# of Individuals (% of Individuals)	Micromoth Species	# of Individuals (% of Individuals)	
1	<i>Chrysoteuchia topiarius</i> (Crambidae)	272 (9.7%)	<i>Microcrambus elegans</i> (Crambidae)	180 (13.8%)	
2	<i>Crambus agitatellus</i> (Crambidae)	267 (9.6%)	<i>Chrysoteuchia topiarius</i> (Crambidae)	120 (9.2%)	
3	<i>Choristoneura rosaceana</i> (Tortricidae)	198 (7.1%)	<i>Crambus agitatellus</i> (Crambidae)	120 (9.2%)	
4	<i>Olethreutes caldanum</i> (Tortricidae)	95 (3.4%)	<i>Choristoneura rosaceana</i> (Tortricidae)	89 (6.8%)	
5	<i>Microcrambus elegans</i> (Crambidae)	48 (1.7%)	<i>Acleris forsskalleana</i> (Tortricidae)	34 (2.6%)	

Richness, Assemblage, and Abundance Characterization

Macromoth richness, macromoth abundance, and micromoth abundance were calculated for each site across the study period. As some micromoths were not identified to species, a computation of average micromoth richness was not possible. Macromoths species where 10 or more individuals were captured across a habitat type were categorized as “Established Species” in that habitat type (i.e., across residential sites, or across woodlot sites). Macromoths species where between 5 and 9 individuals were captured (inclusive) were categorized as “Marginal Species”; species where fewer than 5 individuals were captured were categorized as “Tourist Species.”

Body Size

Body size was measured for each species that was captured throughout the study period by measuring the forewing length for up to 10 individuals. The forewing length of 10 individuals in a given species was assigned as the mean forewing length for that species. In instances where fewer than 10 individuals of a given species were captured in our study region, voucher specimens from the MSUC were measured.

Feeding Guild

Feeding guilds were assigned based on hostplant associations recorded in the *Field Guide to Moths of North Eastern North America* (Beadle and Leckie, 2012), and *Les Papillons du Quebec* (Handfield, 2011). Six broad guilds were identified: (1) Tree Specialists, (2) Tree Generalists, (3) Grass and Herb Specialist, (4) Grass and Herb Generalist, (5) Broad Generalist, and (6) Other Specialist. Tree specialists were species that were documented to use three or fewer hostplant tree species, or one genus of hostplant tree; tree generalists used more than three hostplant tree species, or more than one genus of hostplant tree. Grass and herb specialists were species that were documented to use three or fewer hostplant grass and/or herb species, or one genus of hostplant grass and/or herb; grass and herb generalists used more than three hostplant grass and/or herb species, or more than one genus of hostplant grass and/or herb. Broad generalists were species that were documented to use a wide array of tree and grass and/or herb hostplants. Other specialists used a wide array of

hostplant material including dead leaves, lichen, mosses and aquatic plants.

RESULTS

General

Each moth trap was deployed for 24 hours of nighttime moth collection. The traps were thus deployed for a cumulative total of 768 hours (24 hours per site × 32 sites) over the course of 12 survey nights: June 13, 14, 20; July 7, 10, 11, 15, 16, 22, 23, 29, 30. No trap was ever surveyed for two successive nights and a minimum 4-day gap was used between survey dates to minimize any effect of repeated sampling.

A total of 570 macromoths and 1309 micromoths were collected from residential sites. The residential macromoth assemblage was composed of 98 different species. A total of 2146 macromoths and 2794 micromoths were collected from woodlot sites. The woodlot macromoth assemblage was composed of 173 species. Across all sites, 53 individual moths could not be identified (i.e., “Unknown” due to scale damage). Both the residential and urban assemblages had a large proportion of Geometrid individuals, representing between 40 and 45% of each group (Figure 2). At the residential sites, 21% of individuals were Erebid moths and 30% were Noctuid moths. The opposite was observed at the woodlot sites; 21% of individuals were Noctuid moths and 34% of individuals were Erebid moths.

The most common macromoth at both types of habitat was the Lesser Maple Spanworm (*Speranza pustularia*, (Guenée, 1858); Table 1a). The most common identifiable micromoth at residential sites was the Elegant Grass-Veneer (*Microcrambus elegans*, (Clemens, 1860); Table 1b); the most common identifiable micromoth at woodlot sites was the Topiary Grass-Veneer (*Chrysoteuchia topiarius* (Zeller, 1866); Table 1b).

Among macromoths, residential sites had a higher proportion of tourist species compared to woodlots; woodlots tended to have more substantial numbers of established and marginal species (Table 2) ($\chi^2 = 9.05$, $p = 0.011$). This corresponded to a higher percentage of tourist species individuals (i.e., abundance) at residential sites compared to woodlot sites (Table 2) ($\chi^2 = 65.6$, $p < 0.001$).

TABLE 2. The number of species and individuals surveyed in residential sites and woodlot sites.

	Established Species (total individuals)	Marginal Species (total individuals)	Tourist Species (total individuals)
Residential sites	10 (384)	12 (69)	76 (117)
Woodlot Sites	32 (1699)	38 (262)	103 (185)

Feeding Guilds

The established and marginal species in the woodlot macromoth assemblage were dominated by generalist feeders, particularly tree generalists (Figure 3). At residential sites, there was more parity between generalist and specialist feeders in the macromoth assemblage, though tree generalists were substantially scarcer in the residential assemblage compared to the woodlot assemblage. Tourist species in both assemblages were characterized by a high proportion of broad generalists and (in residential areas) tree generalists (Figure 3).

Body Size

Established moth species in woodlots had larger wing sizes, on average, than established moth species in residential sites (t-test, $p < 0.0001$, Figure 4). Among marginal species, woodlot moths had marginally significantly larger wing sizes (t-test, $p = 0.088$). There was no significant difference in wing size among woodlot and residential tourist species (t-test, $p = 0.92$).

DISCUSSION

Differences in Species Richness and Abundance

In this study a total of 1879 moths were collected from residential sites and the assemblage of macromoths was composed of 98 different species, compared to 4940 total moths and 154 different macromoth species collected from woodlot sites. We were able to identify more than 97% of the macromoths caught in our study, giving us confidence that our data is a reasonable representation of the moth assemblages in the two habitats. Our data show that urban woodlots contain more macromoth species and a higher overall moth abundance than do residential sites. This supports the finding that highly disturbed habitats often have less species richness and contain a different assemblage of species than habitats that are not as highly disturbed (Öckinger et al. 2010). There was a substantial amount of overlap in species assemblage between residential and woodlot sites even though the most common species in the two habitats differed (Table 1). Even with this overlap, the representation of macromoth families differs between the sites. A higher percent of Erebidae species came to the light traps in woodlot sites than residential sites, while a higher percent of Noctuidae species came to the light traps in residential sites than in woodlots. The percent of Geometridae species was not substantially different between sites (Figure 2). The geospatial layout of our residential sites and woodlot sites seems to support the suggestion that we were in fact surveying two different assemblages. Generally, a black light moth trap is effective at attracting moths up to a

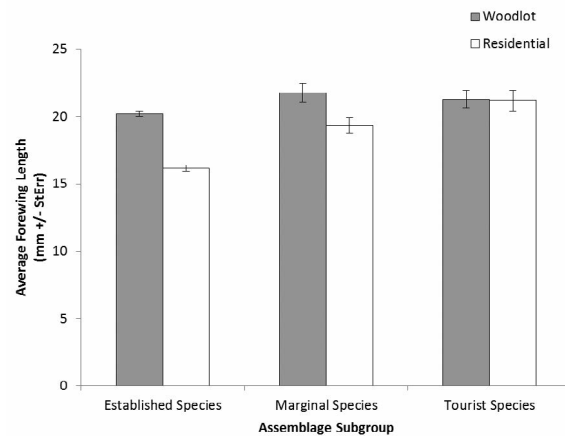


FIG. 4. Comparison of average forewing length among individuals in Established Species, Marginal Species, and Tourist Species groups. The average individual wing size of Established woodlot species was larger than the average individual wing size of Established residential species ($t = -9.38$, $p < 0.0001$). The differences in wing size within the other two groups were not significant.

distance of about 10 meters, after which its effectiveness declines significantly (Plaut 1971; Truxa & Fielder 2012). The shortest distance between any two traps in our study was 142 m, and light from one trap location was never visible at an adjacent trap location due to surrounding trees and houses.

Forewing Size

Moth body size may confer an important advantage to moths in disturbed landscapes; large-winged moths sometimes exhibit better dispersal capacities, though they may experience higher predation rates. In a study of moth migration between islands, Nieminen (1996) found that migration rates dropped by about 10% from moths with wingspans of greater than 40 mm to moths with wingspans of less than 30 mm. Among the life history traits examined by Sekar (2012), wingspan is considered to be the most important in predicting dispersal of butterflies. The analysis of four datasets in this particular study showed positive relationships between wingspan and both mobility index and mean dispersal distance. This supports the idea that larger bodied moths with larger wingspans have the potential to be stronger fliers and more capable of long-distance colonization over hostile habitat when compared to their shorter-winged counterparts.

If large wingspans can be used as a proxy for dispersal ability (Öckinger et al. 2010), we might expect to see larger moths in residential areas due to their ability to disperse long distances and fly through open areas. Conversely, we found that average forewing sizes of macromoths were larger in woodlots than in residential sites. Established macromoth species had larger

forewing lengths in woodlots than in residential sites ($p < 0.0001$), but tourist species had the same average forewing length in residential and woodlot sites (Figure 4). This supported the alternate hypothesis that larger moths may be easier targets for predation of birds, bats and other predators in urban habitats. This pattern did not extend to tourist species compared across habitats. Tourists likely spend less time in open habitat, compared to established populations, and thus may not be under the same constant predation pressure as the more established species.

There is evidence that predators, such as bats, may prefer larger prey (Pavey & Burwell 1998). In one study on moth predation, a gut analysis showed that bats preferred feeding on moths with forewing sizes greater than 10mm (Pavey & Burwell 1998). Small moths are not only less noticeable in open spaces but may also be able to take advantage of the smaller scale of resources sometimes found in residential areas (McIntyre 2000). Bat foraging activity in urban areas often peaks at the edges of forest stands (Avila-Flores & Fenton 2005), and in urban habitats, bat foraging has been recorded at high levels around lights (Furlonger et al. 1987). Urban development can also provide roosting sites, preferred by some bat species (Duchamp et al. 2004).

Feeding Guild

Generalists were widespread across residential and woodlot habitats, however the abundance of tree generalist and grass/herb generalists differed from residential sites to woodlots. This was not entirely unexpected; there are more trees in woodlots and residential areas have a greater density of grasses and low plants (i.e., rather than trees). Some moth species prefer the early successional stages (McIntyre 2000) that may be more prevalent in unkempt backyards. These species would generally inhabit disturbed habitats until larger shrubs and trees begin to become abundant. In urban areas, however, where some habitat is continually disturbed, these species may thrive for an extended period of time. Some species may be able to feed on introduced plants that are sometimes avoided by other herbivores (Nuckols & Connor 1995).

In conclusion, a higher overall moth abundance was found in urban woodlots when compared to urban residential areas. The assemblage of species also differed among these two habitats and patterns were observed by a combination of natural history traits; moth size and feeding guild. We found woodlots to be composed of a higher abundance of tree generalists and macromoths with larger wings, while residential sites were found to have a higher abundance of grass/herb generalists and macromoths with smaller wings. We hypothesize that this may be due to higher levels of predation in

residential habitat around the edges of woodlots. While large moths have higher dispersal ability, they may also be easier targets for predation. This would explain the higher abundance of small specialists in residential areas. Future studies could be performed to determine the effects of predation on moth assemblage and if predation is impacted by urbanization.

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APPENDIX 1. The latitude, longitude and nearest neighbor distance for each of the 32 sites in our study.

Site	Latitude	Longitude	Distance to Nearest Neighbor (m)
Residential 1	42°43'53	84°27'53	142
Residential 2	42°43'57	84°27'52	142
Residential 3	42°44'01	84°27'21	609
Residential 4	42°44'12	84°28'17	488
Residential 5	42°44'15	84°29'50	521
Residential 6	42°44'18	84°27'31	468
Residential 7	42°44'25	84°27'52	506
Residential 8	42°44'28	84°29'34	435
Residential 9	42°44'29	84°29'15	435
Residential 10	42°44'53	84°27'53	495
Residential 11	42°44'53	84°27'31	459
Residential 12	42°44'54	84°29'28	503
Residential 13	42°45'09	84°27'24	478
Residential 14	42°45'13	84°30'03	191
Residential 15	42°45'34	84°30'03	510
Residential 16	45°44'24	84°28'31	234
Woodlot 1	42°44'17	84°27'04	185
Woodlot 2	42°44'21	84°27'10	185
Woodlot 3	42°44'31	84°28'29	234
Woodlot 4	42°44'39	84°27'03	437
Woodlot 5	42°44'39	84°28'53	566
Woodlot 6	42°44'41	84°28'06	494
Woodlot 7	42°44'52	84°27'10	459
Woodlot 8	42°45'07	84°28'45	331
Woodlot 9	42°45'10	84°29'29	422
Woodlot 10	42°45'13	84°26'53	258
Woodlot 11	42°45'14	84°27'04	258
Woodlot 12	42°45'14	84°29'12	232
Woodlot 13	42°45'17	84°28'41	171
Woodlot 14	42°45'18	84°29'58	191
Woodlot 15	42°45'20	84°29'17	232
Woodlot 16	42°45'23	84°28'39	171