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## Heterospecific Hymenoptera Found Inside the Nests of *Bombus impatiens* (Hymenoptera: Apidae).

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### Abstract

The nests of social Hymenoptera are particularly attractive to species engaging in resource robbing due to their concentration of resources. Here, the identity of heterospecific intruders in *Bombus impatiens* Cresson (Hymenoptera: Apidae) nests are described, with a particular focus on intrusion by invasive species – *Vespula germanica* (Fab.) (Hymenoptera: Vespidae) and *Anthidium oblongatum* (Illiger) (Hymenoptera: Megachilidae). While *V. germanica* is well known as a resource robber, this is the first time *Anthidium* spp. have been documented entering the nest of a social heterospecific. Of 16 *B. impatiens* colonies placed in a field in Lansing, MI, eight had heterospecific intruders, including *Apis mellifera* L. (Hymenoptera: Apidae), *A. oblongatum*, and *V. germanica*. Motivations behind entering a foreign nest are discussed.

**Keywords:** *Anthidium*, *Vespula*, *Apis mellifera*, resource robbing

The nests of social Hymenoptera contain highly rewarding resources, such as stored nectar and pollen, making them particularly appealing targets for resource robbers. Thieves can range from conspecifics to vertebrate intruders (e.g. bears, honey badgers, humans) (Schneider and Blyther 1988, Gulati and Kaushik 2004). Localized brood also make colonies an appealing protein source for carnivorous species (e.g. the aphytrophagous lycaenid caterpillar, *Cigaritis acamas* Klug (Sanetra and Fiedler 1995)). It is therefore not surprising that social Hymenoptera have evolved effective ways to defend against nest intruders, with coordinated defensive mechanisms (Evans and Schmidt 1990). Yet still, foreign interlopers find their way inside social Hymenopteran nests. Here, I focus on heterospecific Hymenopteran intrusion into the colonies of *Bombus impatiens* Cresson, the common eastern bumble bee.

Both foreign conspecifics and heterospecific Hymenoptera have been documented entering the nests of social bees. Worker drift between conspecific colonies has been well documented in social species such as *Bombus* and *Apis*. “Drifting” can be a reproductive strategy, where workers will enter a foreign conspecific nest to lay male offspring, but may also occur due to orientation error, particularly when nests are in close proximity (Smith and Loope 2016). Workers entering a foreign nest can also be done with the goal of resource robbing (stealing stored nectar and pollen). Conspecific resource robbing behav-

ior is common in *Apis mellifera* L., particularly when resources are scarce (Free 1977). It is also suspected that *A. mellifera* will rob *Bombus* spp. when in close proximity, and it is recommended that managed bumble bee colonies be placed away from honey bee colonies for this reason (pers. comm. Koppert Biologicals).

Nest intrusion is also a strategy used by obligate or facultative nest parasites. Nest parasitism occurs in order to co-opt conspecifics or heterospecifics for rearing of young. Obligate parasites, such as the cuckoo bumble bees (*Bombus*, formally *Psithyrus*), are unable to provision their own nests, and must kill or suppress a host queen to reproduce (Fisher 1988). Facultative parasitism among conspecifics has been documented in bumble bees as well. Here, a conspecific, non-founding queen will enter a foreign nest and usurp the founding queen, using the host workers to raise her offspring (Sakagami 1976). (See Weislo 1987 for a full list of known Hymenopteran nest parasites).

Outside of Anthophila, Vespids have been documented entering *Apis* spp. colonies and can cause significant damage (Edwards 1980, Clapperton et al. 1989, Akre and Mayer 1994, Ono et al. 1995). Many Vespids will prey on adult *Apis*, though they usually target individuals outside the hive. However, *Vespa mandarinia japonica* Radoszkowski (Hymenoptera: Vespidae) attack the colony itself with large scale coordinated attacks between nestmates. These attacks can



Table 1. Heterospecifics found in *Bombus impatiens* colonies, in East Lansing, MI, USA.

Hive number	Date first discovered	Species
1	5 Sept 2017	1 male <i>Athidium oblongatum</i>
5	29 Aug 2017	1 <i>Anthidium</i> sp. (not recovered during dissection)
9	5 Sept 2017	1 female <i>A. oblongatum</i> , 2 male <i>A. oblongatum</i> , 4 female <i>Apis mellifera</i>
10	12 Sept 2017	3 female <i>A. mellifera</i>
11	5 Sept 2017	1 female <i>Vespula germanica</i>
12	(During dissection)	1 female <i>A. mellifera</i>
13	29 Aug 2017	3 female <i>A. mellifera</i>
15	5 Sept 2017	1 male <i>A. oblongatum</i> , 2 female <i>A. mellifera</i>

decimate a colony, as each wasp is able to kill up to 40 *A. mellifera* per minute (Ono et al. 1995). *Vespula germanica* (Fab.) and *vulgaris* (L.) have also been documented causing significant damage to honey bees, as they will both rob honey stores and kill adult *A. mellifera* (Clapperton et al. 1989). Much less is known about Vespids targeting *Bombus*, though they have been documented showing aggressive behavior towards *Bombus* when competing at the same floral resources (Thomson 1989). In this study, heterospecific Hymenoptera found inside the nests of commercially reared *B. impatiens* colonies are identified.

Materials and Methods

On 15 August 2017, 16 commercial *Bombus impatiens* colonies (Biobest U.S.A. Inc., Leamington, Ontario) were placed in an open field in Lansing, MI (Location: 42.691383 N, -84.496945 W). For another study, these colonies were being monitored for growth over a six-week period. Growth was determined through weekly, nighttime weighing. During weighing, colonies were visually checked to note any dead individuals, or emergence of reproductives. At this time, presence of heterospecifics inside the nests were also recorded. All *B. impatiens* colonies were frozen after six weeks (27 September 2017), and later dissected. During dissections, any heterospecifics found in the nests were collected and identified.

Results

In the third week of *B. impatiens* colony placement (29 Aug 2017), a dead *Anthidium* was found inside one of the *B. impatiens* colonies (Table 1). In another colony, three *A. mellifera* workers were also found. In the following weeks, additional dead *Anthidium* and *A. mellifera* were found, as well as a Vespid wasp. Heterospecifics inside the colonies were always located along the outer edges of the hive box (plastic box located inside card-

board housing) away from comb and brood. In the fourth week, an *Anthidium* was also found outside the plastic hive box, between the hive box and the sugar water reservoir located below. Heterospecific specimens were not collected until colony dissections, so as to minimize disruption of the *B. impatiens* colonies (as colonies were being used for another study).

Five *Anthidium* spp. were recovered from the *B. impatiens* colonies during dissections. All five *Anthidium* were *A. oblongatum* (Illiger) (Hoebeke and Wheeler Jr. 1999, Miller et al. 2002, Romankova 2003, Gonzalez and Griswold 2013). Four males, and one female (Table 1). One *Anthidium* was not recovered. The one wasp was identified as *V. germanica* (Buck 2008).

Discussion

Two Old World species of *Anthidium* have been introduced to the eastern United States. *Anthidium manicatum* L. was first discovered in upstate New York in the early 1960s (Severinghaus et al. 1981), but has since rapidly expanded its range across the continent (Miller et al. 2002, Gibbs and Sheffield 2009, Maier 2009, Strange et al. 2011, Graham and MacLean 2018). *A. oblongatum* was first discovered in eastern Pennsylvania in 1995, but is now found throughout the Northeast, and northern Midwest states (Hoebeke and Wheeler Jr. 1999, Miller et al. 2002, Maier 2009, O'Brien et al. 2012). The introduction of *A. manicatum* has been particularly noteworthy due to its aggressive behavior towards native bees while defending floral resources (Severinghaus et al. 1981, Starks and Reeve 1999). Within a defended floral territory, male *A. manicatum* discourage foraging by heterospecific pollinators through direct attacks that often result in severe injury or death to the encroaching pollinator (Wirtz et al. 1988). Comparatively, we know significantly less about *A. oblongatum*'s interactions with heterospecifics. This study finds a unique behavior for *A. oblonga-*

*tum*, heterospecific nest intrusion that has not been recorded in any other congeners.

For *Anthidium*, no instances of resource robbing have ever been recorded (to the best of my knowledge). Therefore, it is more likely that *A. oblongatum* are entering *B. impatiens* hives for alternative reasons. *A. oblongatum* is known to fly into August/September (Hoebeke and Wheeler Jr. 1999, Maier 2009), with this experiment marking the end of *A. oblongatum*'s activity. The nights around the first incidence of *A. oblongatum* discovery marked several unseasonably cold nights, where temperatures dropped below 4°C (measured by temperature probes inside the *B. impatiens* nests). These conditions continued into the following week prior to the other *A. oblongatum* discoveries. Therefore, it is possible that *A. oblongatum* were searching for a warm place to spend the night. They were then either killed by *B. impatiens* workers defending the nest, or died from natural causes.

However, resource robbing as an alternative explanation cannot be discarded. Floral resources were particularly scarce in the landscape during that time, with very few late summer flowering species found in close proximity. For *A. mellifera* and *V. germanica*, resource robbing is a more likely explanation for nest intrusion, as both of these species have previously shown robbing behavior (Free 1977, Edwards 1980). However, additional work would need to be done to confirm this.

While the underlying motivations behind entering a heterospecifics nest are still highly speculative, they are certainly interesting in light of the invasive status of *A. oblongatum* and *V. germanica*. If they are indeed resource robbing, it would indicate an additional negative impact on native bees. There is still a lot left unknown about heterospecific nest intrusion in managed *Bombus* colonies.

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## Intercepted Silvanidae (Insecta: Coleoptera) from the International Falls, MN (U.S.A.) Port of Entry

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### Abstract

Silvanidae species recorded in association with imported commodities, at United States ports-of-entry, have not been comprehensively studied. The present study examines the species of beetles of the family Silvanidae intercepted during agricultural quarantine inspections at the International Falls, MN port-of-entry. A total of 244 beetles representing two subfamilies, three genera, and four species of Silvanidae were collected between June 2016 and June 2017. Taxa were associated with 13 imported commodities and recorded from seven countries of origin. A substantial proportion (97.4%) of the records included *Silvanus lewisi* Reitter and *Ahasverus advena* (Waltl), two cosmopolitan species associated with dried stored products and various imported commodities. Both *Psammoecus simonis* Grouvelle and an undetermined species of the genus *Psammoecus* (sp. 01) were intercepted on a single occasion.

The introduction of non-native species as contaminants of global trade can dramatically alter ecosystems (Wittenberg and Cock 2001), reduce biological diversity (Kenis et al. 2007), and impose economic costs on forestry, agriculture and human health (Pimentel et al. 2002). Identifying non-indigenous species and creating species inventories have proven to be important, for such data contribute to the development of risk assessment methods for alien species and introduction pathways which provide the basis for prevention of biological invasions (Kenis et al. 2007). The family Silvanidae Kirby, 1837 (Coleoptera: Cucujoidea) includes approximately 500 described species divided between two subfamilies and about 58 genera (Thomas and Leschen 2010). Although the biology of most species is unknown, the family is generally considered to be fungivorous with a few known predatory species (Thomas and Leschen 2010). Silvanidae is cosmopolitan with the highest diversity in the tropics (Friedman 2015, Thomas 2002). At present, there are 32 species recognized in the United States, with at least 14 of those classified as exotic (Thomas and Yamamoto 2007), including several, widely distributed, common stored product pests (Thomas 2002). The United States Department of Agriculture (USDA) currently categorizes the Silvanidae as non-quarantine significant, however, there exists a paucity of data on the Silvanidae species recorded in association with imported commodities, at United States ports-of-entry. Herein, I report the Silvanidae taxa intercepted at the International

Falls, MN [USA] port-of-entry. This study represents an initial review and characterization of the Silvanidae species collected in association with imported cargo along the northern border of the United States.

The intercepted Silvanidae were a result of agricultural quarantine inspections conducted by Department of Homeland Security, United States Customs and Border Protection (CBP) personnel between the dates of 10 June 2016 and 30 June 2017. Beetles were pinned and identified to species using Halstead (1973, 1993), Pal (1985), and Yoshida and Hirowatari (2014), and other reference material. Voucher specimens were deposited at the Smithsonian Institution National Museum of Natural History (Washington, D.C., USA) under the voucher numbers IFALLS0001 – IFALLS0025.

A total of 244 beetles, representing two subfamilies, three genera, and four species of Silvanidae were recorded from the International Falls, MN port-of-entry (Table 1). The dataset consisted of 75 individual interception events with an average of 3.17 (SE  $\pm$  0.46) beetles collected per interception. Species were recorded associated with 13 imported commodities (Table 2) and from seven countries of origin (Table 1). Overall, more than 74% (n = 57) of the interceptions were with three commodity types (Table 2). A total of 45.5% (n = 35) were associated with automobile parts, 16.9% (n = 13) with metal products, and 11.7% (n = 9) with tiles. The commodities that transit through the port-of-entry are represented by these products and not necessarily a reflection of beetle pref-

Table 1. Species and Origin of Intercepted Silvanidae [Insecta: Coleoptera] from the International Falls, MN USA Port-of-Entry

Subfamily	Species	China	Hong Kong	Malaysia	Philippines	South Korea	Taiwan	Vietnam	Total Number <sup>1</sup>
Brontinae									
	<i>Psammoeecus simonis</i> Grouvelle		1 (1)				1 (1)		1 (1)
	<i>Psammoeecus</i> sp. 01								1 (1)
Silvaninae									
	<i>Ahasverus advena</i> (Waltl)	24 (52)		1 (1)	2 (2)	2 (3)	1 (1)	2 (2)	32 (61)
	<i>Silvanus lewisi</i> Reitter	35 (171)	2 (3)				3 (3)	3 (4)	43 (181)
Total Number <sup>1</sup> :		59 (223)	3 (4)	1 (1)	2 (2)	2 (3)	5 (5)	5 (6)	77 (244)

<sup>1</sup>Number of Silvanidae interception events with the total number of collected beetles in parentheses.



**Table 2. Commodities Associated with Silvanidae Interceptions from the International Falls, MN USA Port-of-Entry**

Commodity	Interception Events (No. Beetles) <sup>1</sup>
Automobile parts	35 (155)
Conveyance (miscellaneous)	4 (5)
Electrical parts	1 (1)
Granite	2 (6)
Hardware	4 (9)
Laminate flooring	2 (2)
Limestone	3 (8)
Machine parts	1 (2)
Machinery	1 (2)
Marble tiles	1 (1)
Metal Products	13 (21)
Porcelainware	1 (6)
Tiles	9 (26)
Total Number:	77 (244)

<sup>1</sup>Number of Silvanidae interception events with the total number of collected beetles in parentheses.

erences for those goods. Collection remarks provided by CBP noted silvanid beetles were intercepted crawling on pallets and shipping container floors. Taking into account that shipping containers are exchanged on a continual basis, some intercepted taxa may be a result of contamination of the container and not necessarily from the stated commodity or origin.

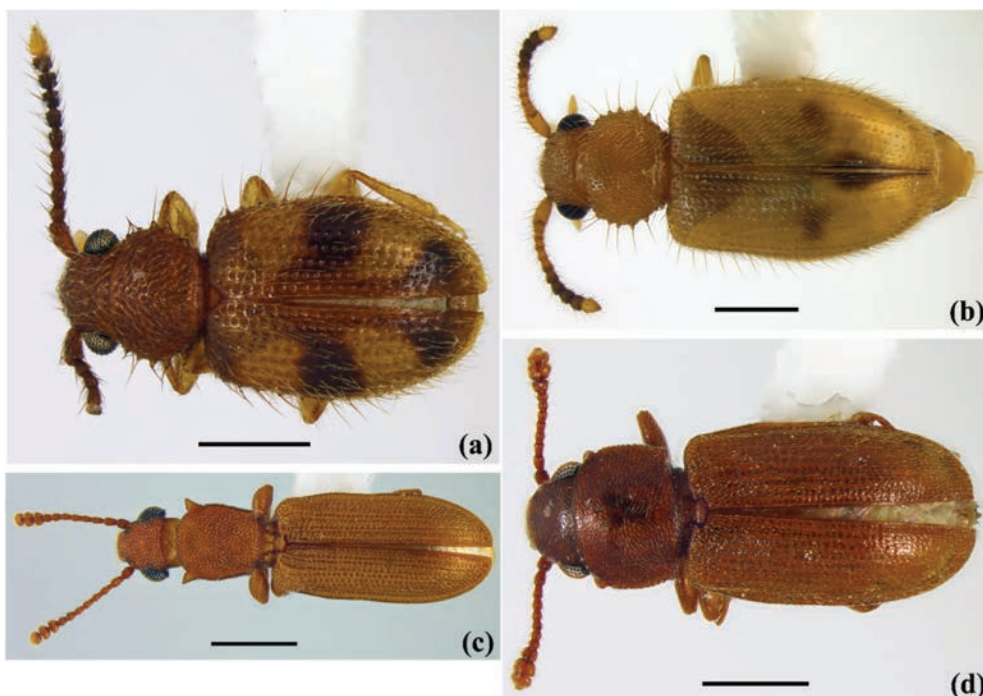
Nearly all interceptions (97.4%, n = 75) consisted of two common synanthropic taxa, *Silvanus lewisi* Reitter and *Ahasverus advena* (Waltl) (Fig. 1), which are often imported on stored grains, dried products, and various commodities in transit (Halstead 1973, Yoshida and Hirowatari 2014). *Silvanus lewisi* was the most commonly intercepted species, accounting for 55.8% of all records (n = 43). This species, whose known distribution includes the Indomalayan region and China, is often transferred and distributed worldwide on wood packing, dunnage, and stored products (Halstead 1973, Halstead and Mifsud 2003). *Silvanus lewisi* has also been introduced and is now established in Florida since at least 1998 (Peck and Thomas 1998). The second most common species, *A. advena*, comprised 41.6% (n = 32) of the interception records. This cosmopolitan taxon, native to the Neotropics, is distributed in most warm temperate and tropical regions and feeds on surface molds of stored food and dried food products (Friedman 2015). Though this species is abundantly transported to various countries with dried stores (Halstead 1993), it has been imported on commodities such as wood and dry plant products (Friedman 2015). Although, not directly tested here, a correlation may exist between the number of interceptions and establishment in the wild.

The two most commonly intercepted silvanid beetles, both exotic taxa, are now established in the United States.

Noteworthy was the genus *Psammoe-cus* which was collected on two occasions. *Psammoe-cus simonis* Grouvelle (Fig. 1) was intercepted with metal products from Taiwan and is a species widely distributed in the Indomalayan region with records known from India, Indonesia, Japan, Madagascar, Malaysia, Philippines, and Sri Lanka (Yoshida and Hirowatari 2014) as well as from Taiwan (Yoshida, pers. comm.). An unidentified species of the same genus (here as *Psammoe-cus* sp. 01) (Fig. 1) consisted of a female similar to the Asian species *P. trimaculatus* Motschulsky, *P. triguttatus* Reitter and *P. labyrinthicus* Yoshida & Hirowatari in addition to the African species *P. personatus* Grouvelle (Yoshida, pers. comm.). These taxa are often confused and difficult to separate morphologically and their identification requires comparison of dissected male genital parameres (Yoshida and Hirowatari 2014). However, the species *P. trimaculatus* has been introduced in both Brazil (Thomas and Yamamoto 2007) and Florida (Thomas 2015) where it is now considered widely established.

Developing non-indigenous species inventories provides data and the underlying support for the creation of risk assessment methods for both alien species and invasion pathways (Kenis et al. 2007). The present study is a preliminary evaluation of the Silvanidae species recorded in association with imported cargo from the International Falls, MN port-of-entry. Although it is possible that further inspections, over an extended time period, may yield additional taxa, this





**Figure 1.** Silvanidae species intercepted from the International Falls, MN port-of-entry. *Psammoecus simonis* Grouvelle (a); *Psammoecus* sp. 01 (b); *Silvanus lewisi* Reitter (c); and, *Ahasverus advena* (Waltl) (d). Scale bars: 0.5 mm per unit. Photos courtesy of G. D. Ouellette, U.S. Department of Agriculture.

work serves as an initial base to support future studies on Silvanidae of quarantine importance.

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## Pentatomidae (Hemiptera: Heteroptera: Pentatomidae) Captured on Purple Prism Traps Deployed for Detection of Emerald Ash Borer (*Agrilus planipennis*) (Coleoptera: Buprestidae) in Minnesota

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### Abstract

The observation of bycatch from insect trapping programs, though often considered bothersome, may hold value for ecological and taxonomic studies. In Minnesota, a large trapping survey consisting of pheromone-baited purple prism traps, has been conducted for early detection of *Agrilus planipennis* Fairmaire, the emerald ash borer (Coleoptera: Buprestidae). Stink bugs (Heteroptera: Pentatomidae), which are pests of increasing importance in the North Central U.S., were observed to be captured by these traps. The objective of this study was to use trap bycatch from the *A. planipennis* traps for further documentation of the abundance and diversity of Pentatomidae in Minnesota. In 2011 and 2012, 4,401 and 5,651 purple prism traps, respectively, were deployed and checked in Minnesota. Across both years, a total of 17 species of Pentatomidae were identified from 2 subfamilies, Asopinae and Pentatominae. The most abundant and prevalent species collected were *Banasa calva* (Say), *B. dimidiata* (Say), *Chinavia hilaris* (Say), *Euschistus tristigmus luridus* Dallas, *Menecles insertus* (Say), and *Podisus maculiventris* (Say). The pentatomid community observed on purple prism traps deployed in arboreal habitats differed from pentatomid communities reported in Minnesota crops (i.e., soybean, wheat and corn). Results of this study show that many pentatomid species are captured on purple prism traps and therefore bycatch of these traps could provide valuable information on the pentatomid community. However, purple prism traps should be used in addition to traditional surveillance or scouting methods for pentatomids.

**Keywords:** *Agrilus planipennis*, bycatch, invasive species, purple prism traps, stink bugs

An important component of integrated pest management of invasive species is early detection (Venette and Koch 2009). The goal of early detection programs is to detect invading populations early in the invasion process to increase the likelihood of successful eradication or containment of these incipient infestations (Venette and Koch 2009). Early detection surveys are often conducted on state, regional or national scales, and may employ the use of baited traps. The bycatch of such trapping programs, though often considered bothersome, may hold value for ecological and taxonomic studies (Buchholz et al. 2011, Spears and Ramirez 2015). For example, Coyle et al. (2012) recently documented the composition and phenology of native Siricidae of Minnesota based on the bycatch of an early detection trapping program targeting a new invader of North

America, *Sirex noctilio* Fabricius (Hymenoptera: Siricidae), the sirex woodwasp.

A large, trapping-based early detection program was conducted for *Agrilus planipennis* Fairmaire (Coleoptera: Buprestidae), the emerald ash borer, in Minnesota (United States Department of Agriculture 2012). Skvarla and Holland (2011) documented that a diversity of insect families are captured by the traps deployed for *A. planipennis* and suggest that examination of the trap bycatch could yield a wealth of information on the distribution and density of non-target species. The list of non-target taxa captured by *A. planipennis* traps includes several hemipteran families, but does not include Pentatomidae (Skvarla and Holland 2011). However, various native Pentatomidae were observed on purple prism traps deployed for *A. planipennis* in Minnesota in 2010 (R.L.K. personal observation), which suggested the potential utility of these traps for documentation of the pentatomid fauna.

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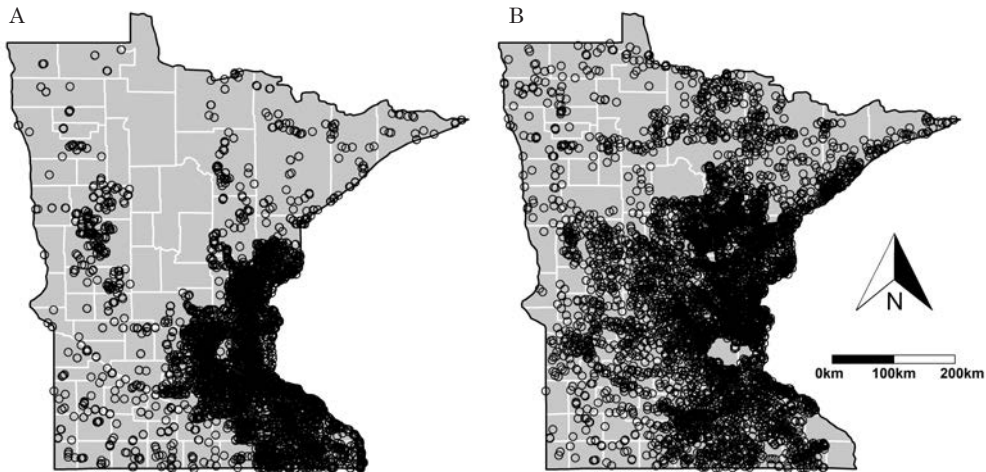


Figure 1: Locations of 4,401 and 5,651 purple prism traps in Minnesota that were checked for Pentatomidae in 2011 (A) and 2012 (B), respectively.

The family Pentatomidae is the fourth largest family within the order Hemiptera and contains around 4,700 species worldwide (McPherson and McPherson 2000). Fifty-two pentatomid species (49 native and 3 exotic) have been recorded in Minnesota, spanning the subfamilies Asopinae, Pentatominae and Podopinae (Koch et al. 2014, Koch et al. 2018) and accounting for approximately 23% of the 222 species known to occur in North America (Froeschner 1988, McPherson and McPherson 2000). Pentatomids are increasing in pest importance in the North Central U.S., because of the apparent increasing abundance of native species (Hunt et al. 2011, 2014; Michel et al. 2013) and introduction of exotic species (Swanson and Keller 2013, Koch 2014, Koch et al. 2018). However, due to their historical lack of economic importance in the region, stink bugs are relatively poorly documented in Minnesota. *Halyomorpha halys* (Stål), the brown marmorated stink bug, was first detected in North America in Pennsylvania in 1996 (Hoebeke and Carter 2003). This pest has since spread throughout much of the United States (Leskey et al. 2012) and was first detected in Minnesota in 2010 (Koch 2014). *Halyomorpha halys* has potential to cause significant adverse impacts as a pest of a diversity of crops and as a nuisance household invader (Hoebeke and Carter 2003, Leskey et al. 2012, Bergmann et al. 2016, Koch et al. 2017). *Fraxinus americana* L., white ash, is a host for *H. halys*, especially from early July to mid-October (Nielsen and Hamilton 2009) and is one of the *Fraxinus* species in which *A. planipennis* traps are deployed. Other North

American Pentatomidae documented in association with *Fraxinus* species include *Banasa rolstoni* Thomas & Yonke, *B. subcarnea* Van Duzee, *Brochymena quadripustulata* (Fabricius) and *Euschistus tristigmus* (Say) (Sites et al. 2012). In this paper we explore the use of *A. planipennis* traps as an additional tool for documentation of the abundance and diversity of Pentatomidae in Minnesota.

### Materials and Methods

In 2011 and 2012, Pentatomidae were collected from traps deployed in a statewide survey for *A. planipennis*. Trapping was conducted using purple prism traps (35.5 × 60.9 cm on each rectangular face) as described by Francese et al. (2008), which were deployed, maintained, and checked according to the national protocol (United States Department of Agriculture 2012). Traps were supplied by the USDA, Animal and Plant Health Inspection Service, Plant Protection and Quarantine for the purpose of emerald ash borer survey. Each trap was baited with a Z-3-Hexen-1-ol lure and a manuka oil lure (Crook et al. 2008) (Synergy Semiochemicals Corp., Burnaby, Canada). Traps were hung in the lower canopy of ash (*Fraxinus* spp.) trees, throughout the state of Minnesota (Fig. 1). Allocation of traps was based on national priorities for detection and delimitation of *A. planipennis* infestations (United States Department of Agriculture 2012). In 2011, 4,401 traps were placed in the field beginning 11 April. After approximately 60 days the traps were checked and the lures were replaced. Traps were checked again



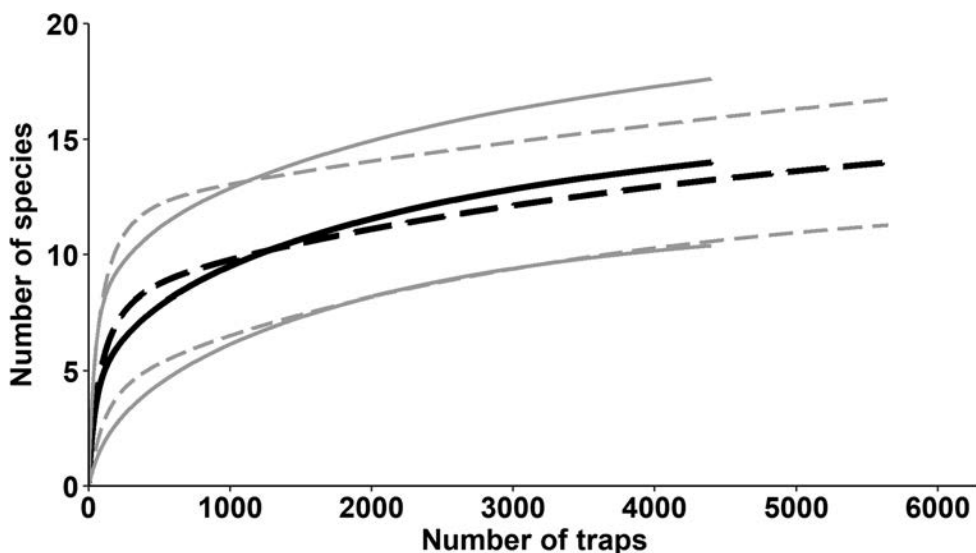


Figure 2: Sample-based rarefaction curves (black lines) and 95% confidence intervals (gray lines) indicating the number of pentatomid species collected on purple prism traps over the trapping season in 2011 (solid lines) and 2012 (dashed lines).

and removed from the field by 24 October. In 2012, 5,651 traps were placed in the field beginning 2 April. As in 2011, the traps were checked and the lures were replaced after approximately 60 days, and the traps were checked again and removed from the field by 8 September. On each date that a trap was checked, Pentatomidae observed on the traps were carefully removed with a forceps, placed in small plastic zipper-locking bags (4 × 5 cm) and were transferred within 24 hours to a freezer for storage until later identification in the laboratory. Pentatomidae were identified using McPherson and McPherson (2000), Rider (2012) and Paiero et al. (2013).

For each year, species abundance was summarized on a per-trap basis over the two collection dates. From this, the relative abundance of each species was calculated as a percentage of the total individuals collected, and prevalence (i.e., frequency of detection) was calculated as the percentage of traps from which each species was collected. Nonparametric Friedman's Test and *post hoc* multiple comparisons were used to compare relative abundance among species within each year (Hothorn et al. 2006, 2008) and logistic regression with Tukey-Kramer-adjusted pairwise comparisons of least square means were used to compare prevalence among species within each year (Hothorn et al. 2008, Lenth 2016). The aforementioned analyses were performed with R version 3.4.4 (R Core Team 2018) and RStudio Desk-

top version 1.1.383 (RStudio Team 2016). In addition, sample-based rarefaction curves with 95% confidence intervals were computed for each year with EstimateS using the Colwell method (Colwell et al. 2012).

### Results and Discussion

Observation of bycatch from traps, although uncommon, can provide valuable information (e.g., relative abundance and diversity) on non-target insects (Buchholz et al. 2011, Spears and Ramirez 2015). Captures from invasive species surveys, such as the national *A. planipennis* survey with purple prism traps, are of particular value because these efforts are deployed across large geographic areas with standardized protocols and can provide a wealth of data on non-target organisms (Spears and Ramirez 2015). A previous study of non-target insect families collected on purple prism traps identified 25 families from 5 insect orders; however, no pentatomid species were reported (Skvarla and Holland 2011).

In contrast, the present study showed that pentatomid species can be captured on purple prism traps and therefore bycatch from these traps could provide valuable information on the pentatomid fauna. The greater sampling intensity in the present study compared to Skvarla and Holland (2011) may have contributed to differences in pentatomid capture. From the purple prism

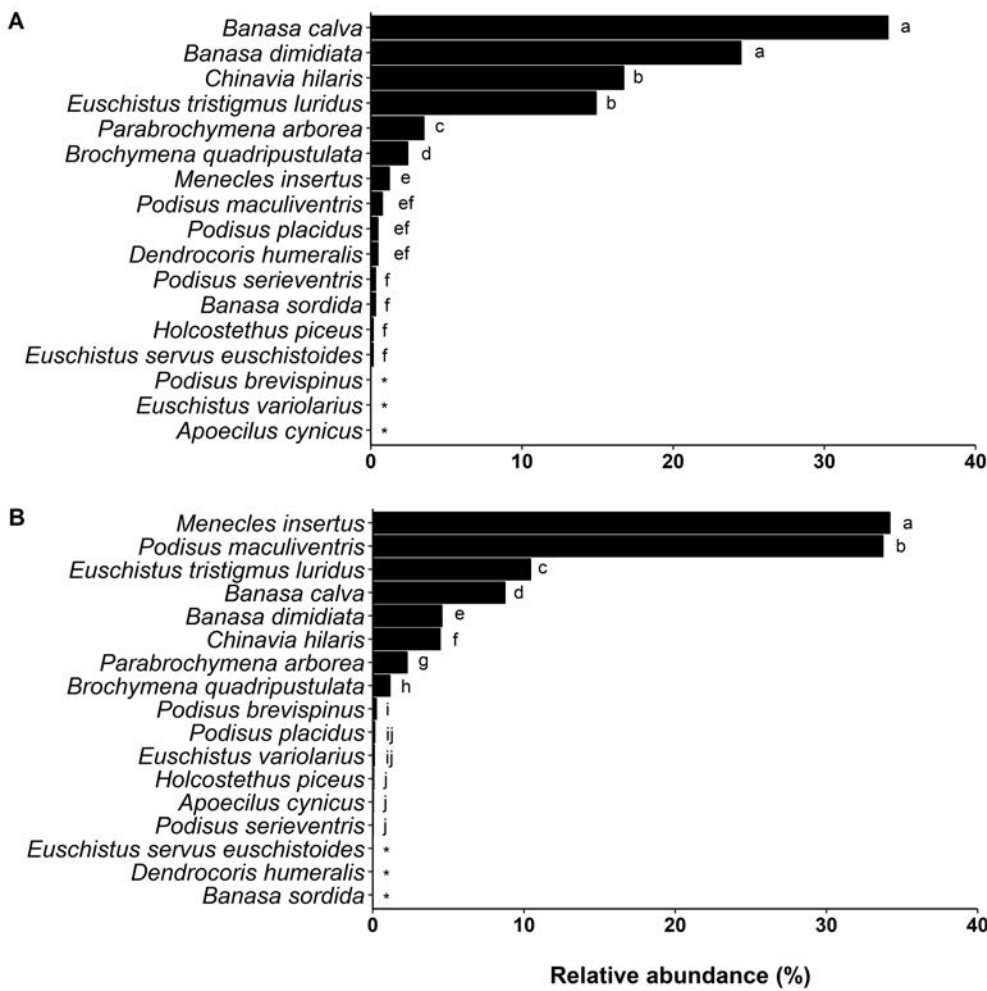


Figure 3: Relative abundance of adult Pentatomidae collected on purple prism traps in 2011 (A) and 2012 (B) in Minnesota. In 2011 and 2012, 658 individuals were collected from 4,401 traps and 5,714 individuals were collected from 5,651 traps, respectively. Species followed by the same letter do not differ ( $\alpha < 0.05$ ), *post hoc* analysis on Friedman's test. Asterisks (\*) indicate that a species was not detected.

traps deployed over the duration of the two year study, a total of 6,377 adult pentatomid specimens were collected, comprising 17 species from 2 subfamilies. The subfamily Asopinae, which contains predatory species, was represented by a total of 5 species from two genera: *Apoecilus cynicus* (Say), *Podisus brevispinus* Phillips, *P. maculiventris* (Say), *P. placidus* Uhler, and *P. serieiventris* Uhler. The subfamily Pentatominae, which contains herbivorous species, was represented by a total of 12 species from 8 genera: *B. calva* (Say), *B. dimidiata* (Say), *B. sordida* (Uhler), *B. quadripustulata*, *Chinavia hilaris* (Say), *Dendrocoris humeralis* (Uhler), *Euschistus*

*servus euschistoides* (Vollenhoven), *E. tristigmus luridus* Dallas, *E. variolarius* (Palisot de Beauvois), *Holcostethus piceus* (Dallas), *Menecles insertus* (Say), and *Parabrochymena arborea* (Say). The species of Pentatomidae collected in this study have all previously been reported to occur in Minnesota (Koch et al. 2014). The invasive *H. halys* was not detected in either year, despite purple prism traps being deployed in southeastern Minnesota, where low-level populations of *H. halys* were known to occur (Koch 2014, Koch et al. 2014). Sample-based rarefaction curves approached asymptotes for both years, which indicates that a sufficient number of



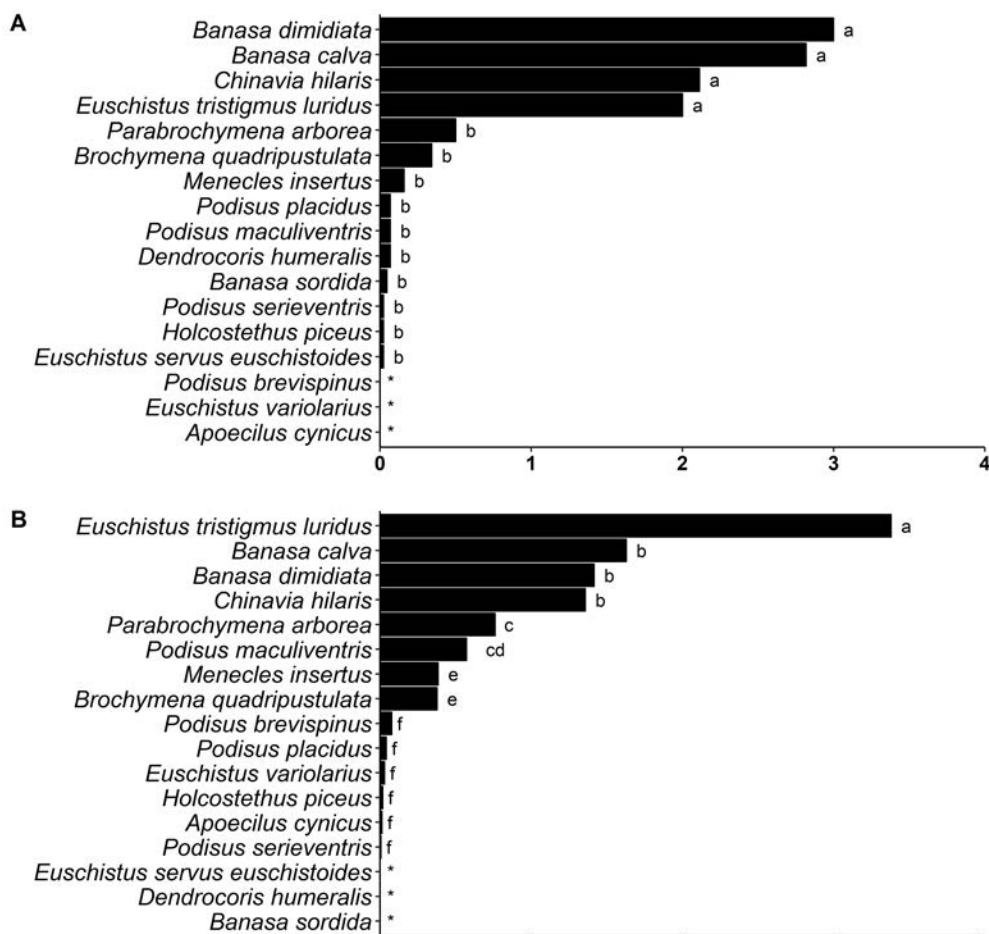


Figure 4. Prevalence (i.e., frequency of detection) of adult Pentatomidae collected on purple prism traps in 2011 (A) and 2012 (B) in Minnesota. Species followed with the same letter do not differ ( $\alpha = 0.05$ ) based on logistic regression with Tukey-Kramer-adjusted pairwise comparisons. Asterisks (\*) indicate that a species was not detected. X-axes of graphs A and B are on different scales.

purple prism traps were checked to obtain a reasonable estimate of species richness (Fig. 2). Furthermore, the overlapping 95% confidence intervals of the rarefaction curves indicate that a similar number of species was collected between years (Fig. 2).

In 2011, 658 specimens comprising 14 species across 9 genera were collected from purple prism traps (0.15 specimens per trap/year). The relative abundance differed significantly among species ( $\chi^2 = 1324.2$ ,  $df = 16$ ,  $P < 0.001$ ) with *B. calva* (34.19%) and *B. dimidiata* (24.47%) having the highest relative abundance, followed by *C. hilaris* (16.72%), and *E. tristigmus luridus* (14.89%) (Fig. 3A). Prevalence (i.e., frequency of detection) also differed significantly among species in 2011 ( $\chi^2 = 1053.2$ ,  $df = 16$ ,  $P <$

0.001). *Banasa dimidiata*, *B. calva*, *C. hilaris* and *E. tristigmus luridus* were the most prevalent species, found in 2.90, 2.80, 2.10 and 1.90% of the traps, respectively (Fig. 4A). In 2012, 5,719 specimens comprising 14 species across 8 genera were collected from purple prism traps (1.01 specimens per trap/year). The relative abundance differed significantly among species ( $\chi^2 = 4014.0$ ,  $df = 16$ ,  $P < 0.001$ ) with *M. insertus* (34.20%) having the highest relative abundance, followed by *P. maculiventris* (33.73%), *E. tristigmus luridus* (10.42%), *B. calva* (8.73%), and *B. dimidiata* (4.56%) (Fig. 3B). Prevalence (i.e., frequency of detection) also differed significantly among species in 2012 ( $\chi^2 = 3204.3$ ,  $df = 16$ ,  $P < 0.001$ ). *Euschistus tristigmus luridus* was the most prevalent species,

found in 10.10% of the traps (Fig. 4B). Due to differences in trap allocation throughout the state (Fig. 1), comparison of abundance, relative abundance and prevalence between years was not performed.

The most commonly collected species mentioned above have biologies associated with the types of deciduous habitats in which the purple traps were deployed. *Banasa calva* is commonly found on herbaceous plants and deciduous trees and *B. dimidiata* on ornamental plants and small fruits (McPherson 1982). *Menecles insertus* is an arboreal species that feeds on a wide variety of deciduous trees, such as hickory, beech, hackberry and maple (McPherson 1982). Because of its apparent lack of economic importance, little is known about *M. insertus* biology and behavior. *Chinavia hilaris* can be found on a wide variety of wild hosts and cultivated plants including fruits, vegetables and grain crops. However, it has preference for feeding on woody plants (McPherson 1982, Kamminga et al. 2012). *Euschistus tristigmus luridus* feeds on a variety of deciduous trees and herbaceous and cultivated plants (McPherson 1982). *Podisus maculiventris* is the most common predatory stink bug in the U.S. (De Clercq 2000). These predators have a broad host range, reportedly attacking ninety insect species from over eight orders, including several economically important pests (De Clercq 2000).

The community of Pentatomidae observed on purple prism traps deployed in arboreal habitats in this study differed considerably from pentatomid communities reported in Minnesota crops, such as soybean (Koch et al. 2014, Koch and Pahs 2014), wheat (Koch et al. 2016) and corn (Koch and Pahs 2015). For example, the one-spotted stink bug, *E. variolarius*, and the brown stink bug, *E. servus euschistoides*, are the most abundant phytophagous pentatomid species reported in crops in Minnesota, with relative abundances of approximately 60% and 20%, respectively (Koch et al. 2014; Koch and Pahs 2014, 2015; Koch et al. 2016). However, *E. variolarius* and *E. servus euschistoides* relative abundances were only 0.08% and 0.02% on purple prism traps deployed in Minnesota (Fig. 3). The most abundant species of herbivorous pentatomidae (i.e., *B. calva* and *M. insertus*) captured on purple prism traps in arboreal habitats were uncommonly encountered in Minnesota crops (Koch and Pahs 2014, 2015; Koch et al. 2016; Koch et al. 2017). These differences in the pentatomid communities documented for the arboreal and crop habitats are likely driven by species-specific host preferences and behaviors that may influence likelihood of detection via the different survey methods.

Results presented in this study show that observation of bycatch from purple prism traps deployed for detection of *A. planipennis* can provide additional information about the community of Pentatomidae in arboreal habitats. However, it remains unknown whether any of these pentatomids were attracted to the traps, or if their capture was result of random interception with the traps. Therefore, traditional surveillance or scouting for pentatomids of interest should continue to be implemented. The results presented here provide further evidence that bycatch from large coordinated pest surveys is an available and useful resource for entomologists.

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## An Inventory of Cicadellidae, Aphrophoridae, and Delphacidae (Hemiptera) in the Alvar Grasslands of the Maxton Plains, Michigan

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### Abstract

Alvars are rare grassland communities found in the North American Great Lakes Region consisting of thin mineral soil over limestone bedrock and act as refugia for many unique and threatened endemic species. Few studies have catalogued Hemiptera species present in the alvars of the Maxton Plains on Drummond Island, MI. We aimed to add to these species lists, compare species diversity between alvar sites with varying levels of exposed bedrock, and test if an unpaved limestone road running through our sample sites influenced Hemipteran populations. We collected several prairie endemic species of Cicadellidae (Hemiptera), including a new record for the island, *Laevicephalus unicoloratus* (Gillette and Baker). We found that pavement alvars, those with large portions of exposed bedrock, had higher species diversity on both of our collection dates despite having less overall vegetation when compared to grassland alvars with continuous soil coverage ( $H' - \text{Date 1: pavement} = 0.649$ , grassland = 0.471;  $H' - \text{Date 2: pavement} = 0.982$ , grassland = 0.855). We observed that distance relative to the unpaved limestone road affected the population densities of our target Hemiptera groups (Cicadellidae, Aphrophoridae, and Delphacidae), likely due to dust arising from dry conditions and road use. Our results, and the results of others, indicate the biological uniqueness of the alvars. Alvars face threats from off-road vehicle use, individual disregard for their conservation, and a changing climate. The continued monitoring, maintenance and protection of remaining alvars is imperative if their existence is to be continued beyond our lifetime.

**Keywords:** Alvar, Hemiptera, Maxton Plains, Drummond Island, prairie, grassland, pavement, Cicadellidae, Aphrophoridae

Alvars are rare grassland communities that consist of thin mineral soil over limestone bedrock with areas of exposed bedrock called “pavement” occurring only in the Great Lakes Region of North America, northwest Ireland, and the Baltic Region of Northern Europe (Catling and Brownell 1995, Albert 2006). Grasses, sedges and shrubs dominate these unique northern grasslands and the Michigan Natural Features Inventory (MNFI) classifies alvars as threatened in the state of Michigan (Albert 2006, Kost et al. 2007). The Maxton Plains Natural Area on Drummond Island, Michigan is one of the largest remaining high quality alvar sites in North America. Alvars are composed of an unusual mix of arctic and prairie plant species including several threatened and/or special concerned plants native to Michigan including *Geum triflorum* Pursh, *Sporobolus heterolepis* (A. Gray) A. Gray, *Cirsium hillii* (Canby) Fernald and *Carex richardsonii* R. Br. Rare insects including several Cicadellidae and Aphrophoridae (previously Cercop-

idae) species occur in these grasslands, but few surveys have been completed (Tilman and Downing 1994; Hamilton 1995, 2005).

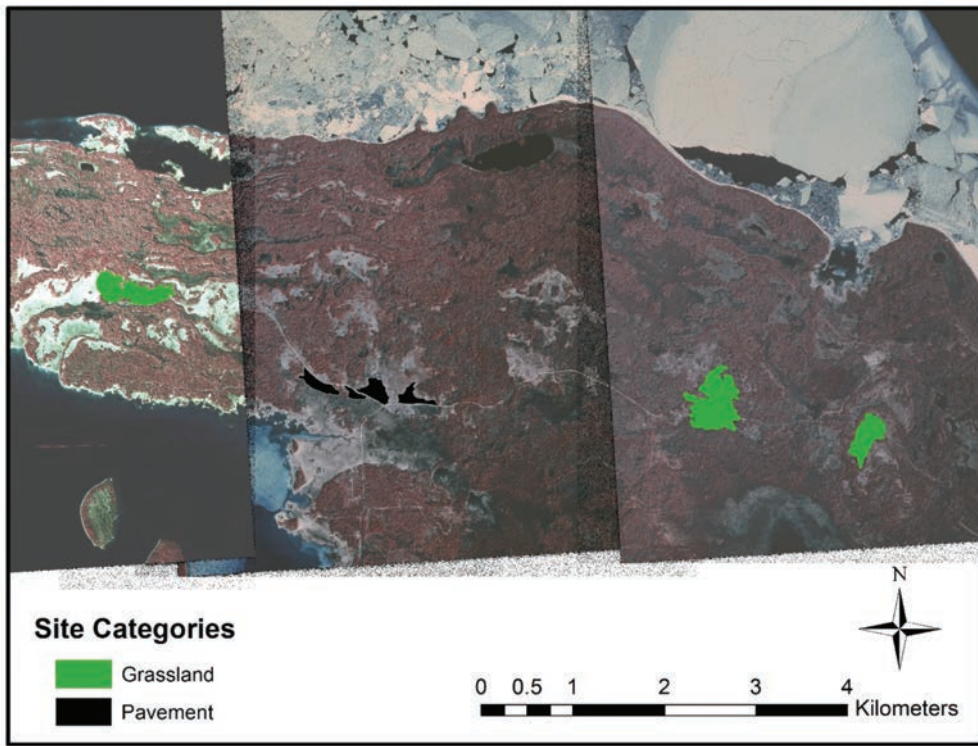
Cicadellidae, Aphrophoridae and Delphacidae (Hemiptera) are diverse taxa and nymphs and adults of these insects are herbivorous with close evolutionary associations with host plants (Hamilton 2005) making them ideal inventory species for estimating “quality” of ecosystem integrity (Hamilton 1995, 2005; Dunn et al. 2007). In addition, they make ideal organisms to monitor changes in environmental factors over time due to stressors such as anthropogenic climate change. Knowledge of insect species that inhabit rare ecosystems is important in conservation management, as several important ecological processes including stability and productivity relate to species richness (Kim 1993, Tilman and Downing 1994, Duffy 2009).

The Nature Conservancy (TNC) has identified critical research needs for Great Lakes alvar including species inventories of insects, as they play an important role in the ecological function of grasslands (Hamilton 1995, Reschke et al. 1999). While an inventory of the vascular plants has been completed

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**Figure 1.** A site map of pavement and grassland alvars of Maxton Plains on Drummond Island, MI.

in the area (Stephenson 1983), there is a paucity of information on the insect species that occur in the area (Hamilton 2005). Our study objective was to carry out a species inventory of leafhoppers (Cicadellidae), spittlebugs (Aphrophoridae) and planthoppers (Delphacidae) of the Maxton Plains alvars and to investigate the effect of a non-improved road that bisects a majority of the preserve on species richness and abundance.

### Materials and Methods

Drummond Island, Chippewa Co., MI is an irregularly shaped island with an approximate size of 310 km<sup>2</sup> located near the eastern edge of Michigan's Upper Peninsula at the point where the St. Mary River system and Lake Huron converge. The island lies atop a bedrock of Silurian age dolomitic limestone, which is exposed at many sites due to extensive glacial tilling. The Maxton plains, a series of alvars surrounded by dense forest, are located near the northern edge of the island on a strip that extends 5.5 km from the western shore to the eastern shore.

We surveyed two main categories of alvar found at the Maxton Plains: grassland

alvar and pavement alvar (Fig. 1). We classified pavement alvar sites as alvars that contained large portions of exposed bedrock, while we defined grassland alvar sites as alvars primarily covered in vegetation with a thin layer of topsoil. Our sites were flanked by wetlands to the south and upland forests to the north. Our most western grassland alvar site is owned by TNC while the rest of our two grassland and four pavement alvar sites were overseen by the Michigan Department of Natural Resources (DNR).

We conducted two sweep surveys for Cicadellidae, Aphrophoridae, and Delphacidae on four pavement alvar and three grassland alvar sites in the Maxton Plains (46°04'42.88"N, 83°41'07.90"W). Sampling occurred on 29 June and 20 July, 2013. We performed the collections between 1000–1500 hours. The taxa are the most diverse in July, when both early and late season species are present (Hanna 1970, Hamilton 1995, Dunn et al. 2007). Most species are adults by mid-July, which facilitates their determination. Insects were collected by sweeping (38 cm diam. net) through the plant canopy on 100m transects that were set parallel to the road at increasing distances (5m, 25m, 45m).



Aphrophoridae were determined to species using the keys of Hamilton (1975, 1982) and Hanna and Moore (1966). Cicadellidae and Delphacidae were identified first to genera by the regional key of Hamilton (unpublished), then to species using the keys of Beirne (1956), Ross and Hamilton (1972), Oman (1985), Whitcomb and Hicks (1988), Hamilton (1994, 1995, 1998, 1999) and Sinada and Blocker (1994) using genital dissection. Specimens were confirmed by Dr. Christopher Dietrich, Curator of Insects for the Illinois Natural History Survey, and compared to voucher specimens contained at Grand Valley State University from previous studies (Dunn et al. 2007).

We used ecological diversity indices as described in Magurran (1988) and Krebs (1989) that best fit our data including the Simpson's Dominance Index (I) and the Brillouin Diversity Index (HB) and compared results amongst treatments. Simpson's Dominance Index is effectively used to identify the ecological importance of common species, which occur in a community that has many rare species (Magurran 1988, Krebs 1989), with higher values indicating single species dominance. The Brillouin Diversity Index is best used when samples are drawn from a community in which few species are known (Pielou 1966), and higher values are associated with higher species diversity.

Since plants influence insect diversity and abundance, and our two categories of alvar contained very different plant community compositions, we performed an assessment of plant cover of the principal plant guilds in our sites to supplement the insect data (Kindscher and Wells 1995). We set up three stratified 60m transects which began at the road and extended into our sites. We stratified transects into three sections: 0–20m, 20–40m and 40–60m. Within each stratification we randomly established five 1m<sup>2</sup> plots and within each we estimated the cover of grasses, sedges, forbs, woody plants, invasive plants and barren substrate to seven cover classes of 0%, 1–5.5%, 6–12%, 13–25%, 26–50%, 51–75% and 76–100% with a graduated plant frame. We determined differences in cover classes of each plant guild between grassland alvar and pavement alvar by Mann-Whitney U-Tests.

## Results and Discussion

We collected sixteen species of Cicadellidae (Table 2) with the dominant species being *Diplocolenus evansi* (Ashmead), an extremely common species in northern localities of North America. It was present in five of our seven sites. We found several prairie specialists as designated by Hamilton (1995) and Panzer et al. (1995) in our sites. The

most common among these was *Mocuellus americanus* Emeljanov, which was present in six of our seven sites. Others included *Laevicephalus unicoloratus* (Gillette and Baker) a new record for Drummond Island, *Flexamia delongi* Ross and Cooley, and *Limotettix urnura* Hamilton all of which were found almost exclusively on pavement sites. We found the invasive species *Doratura stylata* (Boheman) in low numbers at two grassland sites.

Three species of Aphrophoridae were collected (Table 2). The meadow spittlebug, *Philaenus spumarius* (Linnaeus), and boreal spittlebug, *Aphrophora gelida* (Walker), are both highly polyphagous species, feeding upon many plant species found in prairies and several species of woody plants; therefore, they are not prairie obligates (Hanna and Moore 1966; Hamilton 1982, 1995). The invasive European species, the lined spittlebug, *Neophilaenus lineatus* (Linnaeus), was present at one site.

We determined the differences in plant composition between our grassland and pavement alvar sites by collecting plant cover-class data (Table 1). Grasses and forbs dominated our grassland alvar sites (medians of 26–50% and 20–38%, respectively) while pavements sites contained far more substrate (a median of 6–12% with a Q3 of 26–50%) and woody plants such as *Juniperus* spp. (a median of 6–12%). We also found that grassland alvar sites contained a greater cover of invasive plant species when compared to pavement alvar sites (median of 6–12% with a Q3 of 13–25% for grassland sites compared to a median of 0% with a Q3 of 1–5.5% for pavement sites). The most common invasive species we encountered were *Leucanthemum vulgare* Lam., *Centaurea maculosa* Lam., *Hypericum perforatum* L., *Hieracium caespitosum* Dumort and *Pilosella aurantiaca* (L.) Schultz and Schultz-Bipontinus. Comparing our results with a previous plant cover survey reveals that invasive species are becoming more prevalent within alvar sites over time (Stephenson 1983). According to the previous survey, non-native species—including *P. aurantiaca* and *H. perforatum*—were only abundant near the roadside and in areas of disturbance within his study sites, and that both *C. maculosa* and *L. vulgare* were not present in his study sites other than near roadsides (Stephenson 1983). We found that these species were abundant throughout the entirety of our two eastern grassland alvar sites and portions of our western (TNC) grassland alvar site. Yet, we found an almost complete absence of non-native plant species in our pavement alvar sites, which may be due to the extreme flooding, drought and lack of mineral soil found in those sites

**Table 1.** Comparison of cover-class ranks<sup>†</sup> of plant guilds among pavement and grassland alvar communities in the Maxton Plains on Drummond Island, MI, by Mann-Whitney U-Test. n=64 per treatment per guild.

Guild	Pavement		Grassland		P
	Median Rank (25,75 percents)	U State	Median Rank (25,75 Percents)	U State	
Grass	4 (3,4)	915.5	5 (4,6)	1998.5	<0.01
Sedge	2 (1,4)	1712.5	1 (1,3)	1203.5	ns
Forbs	2 (2,3)	40.0	4.5 (4,5)	2714.0	<0.01
Woody Plants	3 (2,4)	2540.0	1 (1,1)	376.0	<0.01
Invasives	1 (1,2)	348.0	3 (2,4)	2571.0	<0.01
Bare Substrate	3 (2,5)	2630.0	1 (1,2)	286.0	<0.01

<sup>†</sup> Cover classes: 1=0%, 2=1-5.5%, 3=6-12%, 4=13-25%, 5=26-50%, 6=51-75%, and 7=76-100% cover.

**Table 2.** Number of each Auchenorrhyncha taxa as collected by sweep sampling from 4 pavement alvar sites (2400m) and 3 grassland alvar sites (1800m) on Drummond Island in Chippewa Co., Michigan from June 2013 and July 2013.

Species	Pavement	Grassland	Totals
<b>a. Cicadellidae</b>			
<i>Aceratagallia sanguinolenta</i> (Provancher)	0	3	3
<i>Aphrodes bicincta</i> (Schränk)	0	7	7
<i>Athysanella acuticauda</i> Baker	1	1	2
<i>Balclutha neglecta</i> <sup>†</sup> (Delong and Davidson)	1	4	5
<i>Chlorotettix unicolor</i> <sup>†</sup> (Fitch)	2	3	5
<i>Diplocolenus evansi</i> (Ashmead)	4	150	154
<i>Diplocolenus configuratus</i> (Uhler)	10	0	10
<i>Doratura stylata</i> <sup>*</sup> (Boheman)	0	3	3
<i>Flexamia delongi</i> <sup>†</sup> Ross and Cooley	3	0	3
<i>Idiodonus kennecotti</i> (Uhler)	3	0	3
<i>Laevicephalus unicoloratus</i> <sup>†</sup> (Gilette and Baker)	3	0	3
<i>Latalus personatus</i> Beirne	2	10	12
<i>Limotettix urnura</i> <sup>†</sup> Hamilton	5	0	5
<i>Macrosteles quadrilineatus</i> (Stål)	27	7	34
<i>Mocuellus americanus</i> <sup>†</sup> Emeljanov	7	21	28
<i>Psammotettix</i> spp.	5	0	5
<i>Scaphytopius acutus</i> (Say)	2	1	3
<b>b. Aphrophoridae</b>			
<i>Aphrophora gelida</i> (Walker)	1	0	1
<i>Philaenus spumaris</i> (Linnaeus)	0	13	13
<i>Neophilaenus lineatus</i> (Linnaeus)	1	0	1
<b>c. Delphacidae</b>			
<i>Laccocera vittipennis</i> Van Duzee	34	126	160
Species Richness	16	12	21

<sup>†</sup>: Prairie obligate species

<sup>\*</sup>: Invasive species

**Table 3.** Diversity indices used to analyze the communities of Auchenorrhyncha in grassland and pavement alvars of the Maxton Plains on Drummond Island, MI compared between June (Date 1) and July (Date 2) 2013 collection dates. \*

	Pavement		Grassland	
	Date 1	Date 2	Date 1	Date 2
Simpson's Dominance (I)	0.338	0.149	0.416	0.188
Brillouin Diversity (HB)	0.547	0.867	0.444	0.802
Shannon Diversity (H')	0.649	0.982	0.471	0.855

\* Higher values of Simpson's (I) indicate higher levels of single species dominance. Higher values of Shannon's (H') and Brillouin's (HB) indicate higher species diversity.

**Table 4.** Diversity indices used to analyze the communities of Auchenorrhyncha in grassland and pavement alvars of the Maxton Plains on Drummond Island, MI in June 2013 (Date 1) and July 2013 (Date 2) compared between transects progressively further from a limestone road. \*

	Date 1					
	5m		25m		45m	
	Pavement	Grassland	Pavement	Grassland	Pavement	Grassland
Simpson's Dominance (I)	0.289	0.517	0.359	0.372	0.407	0.440
Brillouin Diversity (HB)	0.370	0.286	0.399	0.479	0.419	0.385
Shannon Diversity (H')	0.507	0.322	0.558	0.531	0.531	0.417

	Date 1					
	5m		25m		45m	
	Pavement	Grassland	Pavement	Grassland	Pavement	Grassland
Simpson's Dominance (I)	0.095	0.258	0.198	0.165	0.159	0.208
Brillouin Diversity (HB)	0.720	0.583	0.678	0.732	0.688	0.721
Shannon Diversity (H')	0.922	0.684	0.846	0.842	0.854	0.794

\* Higher values of Simpson's (I) indicate higher levels of single species dominance. Higher values of Shannon's (H') and Brillouin's (HB) indicate higher species diversity.

**Table 5.** ANOVA of Auchenorrhyncha densities as influenced by sources of variation on grassland alvar communities, Maxton Plains, Drummond Island, MI.

Variation	PF	MS	F	P
Alvar Type <sup>1</sup>	1	2209.00	23.53	<0.01
Site Replication	3	177.43	1.89	0.15
Date <sup>2</sup>	1	4.02	0.04	0.84
Distance from Road	2	413.65	4.41	0.02
Alvar Type x Distance	2	269.79	2.87	0.07
Residual Error	32	93.9		
Total	41			

1 Pavement alvar and grassland alvar.

2 June and July sampling.

3 5m, 25m and 45m from road

(Stephenson and Herendeen 1986, Rosen 1995, Jones and Reschke 2005).

Dates played a significant role in diversity and dominance (Table 4). Simpson's Dominance index (I) indicates less single species dominance in both the grassland

and pavement treatments on the July collection date (0.188 and 0.149, respectively) compared to the June collection date (0.416 and 0.338, respectively). The same can be said for diversity, as both Brillouin Diversity (Table 4; HB) and Shannon Diversity (Table 4; H') indices values are higher in July for

**Table 6.** Mean ( $\pm$  s.e.) and confidence intervals (C.I.) of *Auchenorrhyncha* among alvar habitat type and distance of capture from an unimproved limestone road, Maxton Plains, Drummond Island, MI.

Variable	N	$\bar{x} \pm \text{s.e.}$	Lower 95% C.I.	Upper 95% C.I.
Pavement Alvar	24	5.4 $\pm$ 1.95	3.68	7.1
Grassland Alvar	18	21.0 $\pm$ 2.52	14.02	30.0
5m from Edge of Road <sup>1</sup>	14	7.71 $\pm$ 1.78 <sup>a</sup>	3.86	11.57
25m from Edge of Road	14	12.36 $\pm$ 3.87 <sup>ab</sup>	4.00	20.72
45m from Edge of Road	14	17.43 $\pm$ 4.46 <sup>b</sup>	7.81	27.1

1 Means followed by a different letter are significantly different at the  $P < 0.05$  level (Tukey HSD), see Table 5. for significant ANOVA results.

both grassland and pavement alvars. Regardless of date pavement alvars displayed lower single species dominance and higher species diversity in contrast with grassland alvars (Table 3 and 4). This indicates higher diversity in pavement alvars, despite lower population densities and lower vegetative cover. Our diversity results reflect those found in other studies and can help inform conservation policy when deciding which alvars are made a priority, as pavement alvar sites likely contain a greater diversity of species—especially prairie obligates—in other locations as well.

There is an unpaved limestone road that bisects or borders every one of our sites that generated significant dust during dry periods. We wanted to test for any effect that the road might have on the combined population densities of Cicadellidae, Aphrophoridae, and Delphacidae. We found that as the distance from the road increased, so did population densities. Our ANOVA results show that there is a clear effect on population densities regarding distance from the road ( $F = 4.41$ ;  $df = 2, 41$ ;  $P = 0.02$ ; Table 5). A Tukey HSD test further supported this find, showing a significant difference between our 45m and 5m transects while both overlapped with our 25m transects (Table 6; Tukey 1949). Roads exert drastic effects on both vegetative and insect communities. Dust from unpaved roads reduces primary productivity by coating vegetation which blocks sunlight from reaching chlorophyll containing cells, prevents transpiration by blocking stomata, and opens plants for invasion by pathogens and other pollutants through mechanical damage (Farmer 1993, Vardaka et al. 1995), thereby reducing the nutritional quality of vegetation. Additionally, dust causes direct mechanical harm to insects through desiccation, impeding movement of limbs and mandibles, and obstructing guts (Flanders 1941, Alstad and Edmunds Jr. 1982).

These results, along with other recent studies on Great Lakes alvars, indicate the biological uniqueness of the alvars. Not only

are they unique, they are endangered and arguable the rarest ecosystem in the Great Lakes region (Stephenson 1983, Catling and Brownell 1995, Bouchard 1997, Reschke et al. 1999, Bouchard et al. 2001). Five prairie endemic species of Cicadellidae and Aphrophoridae were found in our study, one of which is new to the Maxton Plains and can be added to a growing list of those already discovered (Reschke et al. 1999, Bouchard et al. 2001) and many more could be present.

An immediate concern for the long-term ecological quality of alvars at the Maxton Plains is due to excessive off-road vehicle (ORV) damage that is evident at all sites, both along the unimproved road and within the sites. ORV damage alters the hydrology of the sites and causes damage to both vegetation and soil. We found that the unpaved road bisecting the sites has a measurable effect upon populations of *Auchenorrhyncha*: Cicadellidae, Aphrophoridae and Delphacidae. Great Lakes alvars are a refuge for many rare species in Michigan and may become extirpated within our lifetime—the importance of monitoring and protecting remaining alvars cannot be understated.

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## Dragonfly (Odonata: Corduliidae, Macromiidae, Gomphidae, Aeshnidae) and Damselfly (Odonata: Calopterygidae) Exuviae Observed at Record Heights in *Pinus strobus* and *Picea abies* Canopies

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### Abstract

Most odonate species do not typically climb higher than 50 cm when choosing an emergence support. We observed multiple species of odonate nymphs using trees as emergence supports at heights greater than 50 cm and up to 4, 6.9, and 14.6 m for *Calopteryx maculata* (de Beauvois) (Ebony Jewelwing, Odonata: Calopterygidae), *Somatochlora minor* (Calvert) (Ocellated Emerald, Odonata: Corduliidae), and *Didymops transversa* (Say) (Stream Cruiser, Odonata: Corduliidae), respectively. These heights represent the greatest heights ever documented for odonate nymph emergence supports. Our research suggests that some species (*S. minor*; *D. transversa*) appear to have a greater affinity for climbing to great heights during emergence than others (*Dromogomphus spinosus* Selys (Black-Shouldered Spinyleg, Odonata: Gomphidae); *Basiaeschna janata* (Say) (Springtime Darner, Odonata: Aeshnidae); *Macromia illinoensis* Walsh (Swift River Cruiser, Odonata: Corduliidae)). Odonate nymphs appeared to have a strong preference for emergence sites at the underside or base of branches. Researchers have hypothesized that competition for emergence sites drives climbing to such great heights. We propose three alternative hypotheses that could potentially explain these unique behaviors.

**Keywords:** Emergence, support structures, larvae, nymph, climbing behavior, Wisconsin

In 2014, we began exploring the habitat potential of *Pinus strobus* L. (White Pine) canopies in northern Wisconsin (Laughlin et al. 2017). While climbing a large and old (>70 cm diameter at breast height, >100 years) *P. strobus* research tree on 6 June 2017 we observed *Didymops transversa* (Say) (Stream Cruiser) exuviae and a few emerging adults at various heights in the canopy (Fig. 1; Table 1; N46.20231, W-91.11506). Exuviae were found at 14.6, 11.1, 9, 8.7, 7.4, 6.8, and 1.3 m; adult dragonflies were found at both 11.1 m and 1.3 m. In total, 8 exuviae and 2 adults were observed. Most exuviae were located on the trunk of the tree underneath and at the base of lateral branches (Fig. 1). All exuviae and adults were observed on the north side of the tree, which faced the nearby lakeshore. The lakeshore of Lake Namekagon, Wisconsin, a warm-water eutrophic lake, was approximately 15 m from the base of the tree (Table 1). The shoreline near this tree is forested with a number of old

growth and second growth trees that have been unmanaged since region wide harvests from 1890-1900, and is adjacent to Fairyland State Natural Area near Cable, Wisconsin.

Additional observations of odonate nymphs using trees as emergence structures were noted throughout the summer. On 10 July 2017, *Somatochlora minor* (Calvert) (Ocellated Emerald) exuviae were found on a *Picea abies* (L.) Karst. (Norway Spruce) less than 1 m from Bay City Creek (N46.580401, W-90.876279), a semi-urban creek that flows through Ashland, Wisconsin (Table 1). Exuviae were found at 6.9, 6.4, 6.3, 5.6, 4.7, 3.8, 3.2, and 2 m, and also situated underneath the base of branches. The tree could not be accessed safely beyond 8 m, so any exuviae present beyond that height could not be observed. On 11 July 2017, a *Calopteryx maculata* (de Beauvois) (Ebony Jewelwing) exuvia was observed at 4 m on the stem of a *P. strobus* research tree (N46.494608, W-90.930152) located 1 m from the shore of the White River, a sandy-bottomed stream located six miles south of Ashland, Wisconsin (Table 1). Lastly, on 17 July 2017, exuviae of *Dromogomphus spinosus* Selys (Black-Shoul-

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**Table 1.** Observations of odonate species using trees as emergence supports.

Location	Species	Height range observed	Distance from water source	Tree species
Lake Namekagon	<i>Epitheca principis</i>	1 m – 8 m?*	15 m	<i>Pinus strobus</i>
Lake Namekagon	<i>Didymops transversa</i>	1 m – 14.6 m	15 m	<i>Pinus strobus</i>
Lake Namekagon	<i>Macromia illinoiensis</i>	1 m – 1.5 m	15 m	<i>Pinus strobus</i>
Lake Namekagon	<i>Dromogomphus spinosus</i>	1 m – 1.5 m	10 m	<i>Tsuga canadensis</i>
Lake Namekagon	<i>Basiaeschna janata</i>	1 m – 1.5 m	10 m	<i>Tsuga canadensis</i>
White River	<i>Calopteryx maculata</i>	4 m	1 m	<i>Pinus strobus</i>
Bay City Creek	<i>Somatochlora minor</i>	2 m – 6.9 m	<1 m	<i>Picea abies</i>

\*An exuvia of *Epitheca principis* was found in a *Didymops transversa* sample bag collected between 1 m and 8 m on a research tree. We cannot be certain of the height the *E. principis* exuvia was collected.

dered Spinyleg), *Basiaeschna janata* (Say) (Springtime Darner), and *Macromia illinoiensis* Walsh (Swift River Cruiser) were observed between 1 m and 1.5 m on the stem of *Tsuga canadensis* (L.) Carrière (Western Hemlock) and *P. strobus* trees near one of our research trees on Lake Namekagon (N46.20231, W-91.11506) (Table 1).

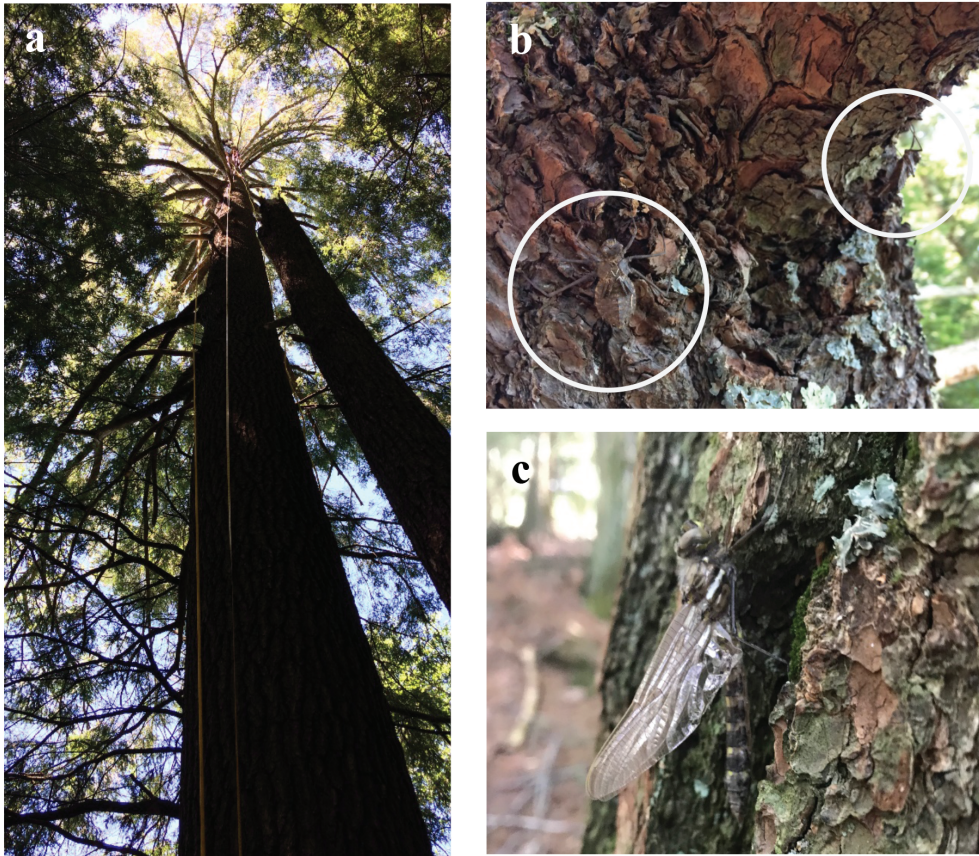
To support our observations, exuviae were collected and identified using the keys in Needham et al. (2000) and Westfall and May (2006). Specimens from the Hilsenhoff Aquatic Insect Collection at the Wisconsin Insect Research Collection (Madison, WI) were also examined for comparison.

The regular nature of our observations (multiple observations at multiple heights) on an individual tree for *D. transversa* and *S. minor* suggest that these species may regularly climb to great heights in adjacent forest canopies during emergence. In fact, Hill and Hill (2008) documented *D. transversa* nymphs migrating long distances (as far as 50.3 m) and climbing structures to heights up to 5 m during emergence in the upper peninsula of Michigan. At our Lake Namekagon study site it is notable that *D. transversa*, *D. spinosus*, *B. janata*, and *M. illinoiensis* were all present, yet only *D. transversa* was observed above 1.5 m; further indicating that certain species are more likely to climb to greater heights during emergence than others.

Climbing to such great heights is a seemingly atypical behavior, as most odonate species do not typically climb higher than 50 cm when choosing an emergence support (Corbet 2004). Corbet documents the greatest distances traveled and heights climbed by odonate nymphs during emergence—of 20 species listed, only two have been documented to climb above 5 m. These two

species—*Brachythemis contaminata* (Fabricius) (Ditch Jewel, Odonata: Libellulidae) and *Pantala flavescens* (Fabricius) (Globe Skimmer, Odonata: Libellulidae)—were documented at 12.5 m in India (Mathavan and Pandian 1977). To our knowledge, our observation of *D. transversa* at 14.6 meters is the highest documented climb of any odonate nymphs.

Intense competition for emergence structures may drive such atypical climbing behaviors (Mathavan and Pandian 1977, Corbet 2004). However, our observations of *D. transversa* and *S. minor* do not appear to support the intraspecific competition hypothesis, in part, because of the high availability of vertical structures nearby at all of our study sites. Corbet (2004) hypothesizes that predator avoidance could also explain odonate climbing behavior during emergence. Failure to molt, failure to expand and harden wings (sclerotization), and predation are the top three causes of mortality for odonate nymphs during emergence (Corbet 2004). Most of the exuviae we observed for both *D. transversa* and *S. minor* were at the base and undersides of branches (though not all). We speculate that odonate nymphs may select such habitats for emergence a) to avoid possible detection and predation from birds (i.e., protection provided by branch), b) to exploit gravitational forces which may play an important role in allowing for uniform wing expansion (Andrew and Patankar 2010), or alternatively, c) odonate nymphs likely have a fixed energy supply that restricts the maximum distance traveled for terrestrial movements during the first stage of emergence, and that they may stop once they encounter one of the first obstacles. In the case of the research tree surveyed near Lake Namekagon, there were scattered, small, senesced branches (branch diameter less than 10 cm,



**Figure 1.** (a) Author MML ascending a *Pinus strobus* research tree; (b) *Didymops transversa* exuviae underneath the branch of a *P. strobus* research tree and (c) adult *D. transversa* observed in a *P. strobus* research tree.

with a trunk diameter of 60 cm) beginning at 8 m above ground, while live branches with larger diameters began at approximately 13 m above ground. Therefore, in this situation, the potential habitat (large branches) begins a considerable distance above ground and coincides with observations of exuviae. While our data does not allow us to fully test these hypotheses, we suggest that preferential selection for slightly overhanging emergence sites and the relative availability of branches at various heights above ground could explain the emergence heights we observed for *D. transversa* and *S. minor*. We recommend further research on this topic to better understand the factors influencing the selection of emergence structures in climbing odonate species.

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## Novel Prey Record for *Scymnus caudalis* LeConte and First Records of Four Other Species of Coccinellidae (Coleoptera) in Wisconsin, U. S. A

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### Abstract

New prey and distribution records are presented for five species of lady beetles (Coleoptera: Coccinellidae). *Scymnus (Pullus) caudalis* LeConte is recorded for the first time preying on *Aphis asclepiadis* Fitch (Hemiptera: Aphididae). Four other lady beetle species are newly recorded in the state of Wisconsin, U.S.A: *Diomus amabilis* (LeConte), *Diomus terminatus* (Say), *Scymnus (Pullus) unicus* Wingo, and *Hyperaspidius wolcottii* (Nunenmacher). The new state records represent minor to moderate extensions of previously known geographic distributions for these species. In addition, the records emphasize the importance of processing uncured entomological specimens to provide information about the prey of particular species and to enhance knowledge about a region's biodiversity. Furthermore, some specimens with the new state records were obtained as trap bycatch and thereby demonstrate the importance of processing nontarget species to increase knowledge of regional biodiversity.

**Keywords:** *Diomus*, *Hyperaspidius wolcottii*, *Scymnus*

Frequent collecting and the subsequent processing of entomological specimens is necessary to maintain current faunal lists for various taxa, to accurately estimate regional biodiversity, and to understand interactions among species (Brodman et al. 2002, McCorquodale and Bondrup-Nielsen 2004, Marché 2017). Faunal lists for an area change due to geographic range expansion of native and introduced species and the discovery of new species within an area (Brodman et al. 2002, Fauske et al. 2003, McCorquodale and Bondrup-Nielsen 2004, Diepenbrock et al. 2016). Sometimes, specimen data may be used to establish new host plant or prey associations when that information is included as part of the collection label or otherwise documented (Wheeler 2003, Hesler and Kieckhefer 2008a).

Gordon (1985) provided a comprehensive overview of the lady beetle (Coleoptera: Coccinellidae) fauna of North America north of Mexico. Several additional species have been discovered for this region (e.g., Gordon and Vandenberg 1991, Gordon 1993, Pollock and Michels 2003), and Hesler and Kieckhefer (2008b) suggested that continued

examination of undetermined material in beetle collections may yield further species records of coccinellids. In this paper, we present a prey record for one lady beetle and new state records for four other species of lady beetles in Wisconsin, U.S.A.

### Material Examined

Uncured specimens from the Wisconsin Insect Research Collection (WIRC), University of Wisconsin, Madison, WI, were examined and species determined using keys in Gordon (1976) and Gordon (1985). A revised classification of the Coccinellidae (Seago et al. 2011) was used for nomenclatural purposes. Pinned specimens of beetles that represent the primary state records in this paper were deposited as voucher specimens in the WIRC.

### Results

**New prey record.** *Scymnus (Pullus) caudalis* LeConte is newly recorded preying on *Aphis asclepiadis* Fitch (Hemiptera: Aphididae) from two locations in Wisconsin. The lady beetles were found as larvae among the aphids on *Asclepias syriaca* L. (common milkweed), collected with the aphids, and reared indoors to adults. The first record comprises

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7 *S. caudalis* from Muscoda RR Prairie (T8N R1W Section 10), Grant County, on 17 June 1999; and the second record consists of 10 *S. caudalis* from Kessler RR Prairie (T2N R11E Sections 13 and 24), Rock County, on 18 June 1999.

**New geographic distribution records.** Four lady beetle species were recorded for the first time from Wisconsin, as follows.

***Diomus amabilis* (LeConte, 1852)  
(Coccinellinae: Diomini)**

**WISCONSIN:** Dane Co., Lake Waubesa, 14-IX-1985, P. Dolan, 2 males, 6 females. Dane Co., Lake Waubesa, 14-IX-1985, P. Dolan, 2 females. Door County, degraded alvar, T28N/R25E/SC27NE, 10-VI-1999, K Kirk ED Maurer, 1 female. **New state records.** The Wisconsin records establish an intermediate geographic distribution of *D. amabilis* between its known distribution in the central U.S.A. from Louisiana northward to Minnesota and that along the northern Atlantic coast (Gordon 1976).

***Diomus terminatus* (Say, 1835)  
(Coccinellinae: Diomini)**

**WISCONSIN:** Dane County, Prairie du Sac, 27-IX-1983, N. Randin, 1 female. Dane Co., Lake Waubesa, 14-IX-1985 coll. P. Dolan, 1 male. Dane Co., Madison, U.W. Arboretum, 18-IX-1985, P. Dolan, 1 male. Sauk County, Leopold Reserve, 23-VIII -7-IX-1988, Malaise trap, 1 male. Dane County, Madison, U.W. Campus Muir Woods, 30-IX-1991, Peter R. Edelman, 1 female. La Crosse County, La Crosse R. Tr. Pr., 24-VIII-1995, 1 male. Monroe County, Ft. McCoy 1.5 mi. E, 17 to 22-VII-1997, Judith A. Maxwell, 1 female. Green County, T3N R8E, section 10, roadside of Hwy EE, 27-VIII -1999, on leaf of *A. syriaca* among aphids, *Aphis nerii* Boyer de Fonscolombe (Hemiptera: Aphididae) and reared from a pupa; Andrew H. Williams, 1 female. Dane County, Madison, 1-IX-1999, A. Mengistu, 1 male. Columbia Co., T19N, R10E, S33, 7-IX-1999, A. Mengistu, 1 male. **New state records.** These records extend the known geographic distribution of *D. terminatus* a few hundred miles north of its previously known most proximate range in northern Illinois (Gordon 1976).

***Scymnus (Pullus) uncus* Wingo, 1952  
(Coccinellinae: Coccidulini)**

**WISCONSIN:** Grant County, T6N R6W, S17, 29-V-3-VI-1975, Gypsy Moth M.T., 2 males; Grant County, T6N, R6W, S17, 7-14-VI-1976, Gypsy Moth M.T., 1 male; Grant County, T6N R6W, S17, 28-V-7-

VI-1976, Gypsy Moth M.T., 1 male; Grant County, T6N, R6W, S17, 7-14-VI-1976, Gypsy Moth M.T., 1 female; Jackson County, T21N, R4W, S33, 3-7-VI-1976, Gypsy Moth M.T., 1 female; Grant County, T6N, R6W, S17, 8-15-VII-1975, Gypsy Moth M.T., 1 female; Grant County, T6N, R6W, S17, 29-V-3-VI-1975, Gypsy Moth M.T., 1 female; Wood County, Babcock, 20 May 1989, J. E. Fetter, 1 female; Iowa County, T6N R5W, S1, 1-7-VI-1976, Gypsy Moth M.T., 1 female. **New state records.** Gordon (1976) describes *S. uncus* as widely distributed, but rarely collected. However, in an annotated list of coccinellids from states in the upper Mississippi River basin, including Wisconsin, Wingo (1952) noted *S. uncus* only from Iowa. The records herein establish Wisconsin as an additional state within the geographic distribution of *S. uncus* in the upper Mississippi River basin.

***Hyperaspidius wolcottii*  
(Nunenmacher, 1911)  
(Coccinellinae: Hyperaspidini)**

**WISCONSIN:** Shawano Co., Navarino Wildlife Area, 44° 39' 11' N, 88° 34' 49' W; 6-18-VI-2002, Jeffrey P. Gruber, 1 male. **New state record.** This specimen extends the known geographic distribution of *H. wolcottii* northward from previous records in northwest Indiana and northern Iowa (Gordon 1985).

## Discussion

Members of the genus *Scymnus* prey on various Hemiptera, including aphids, Adelgidae, and Pseudococcidae (Gordon 1976, Lyon and Montgomery 1995). However, the prey of many species in this genus is unknown, and we did not find published prey records for *S. caudalis*. Thus, its predation on *A. asclepiadis* is apparently novel information. *Aphis asclepiadis* was considered a specialist on *Asclepias* (milkweed plants), but recent analysis determined it to be a senior synonym for the polyphagous aphid previously known as *Aphis carduella* Walsh (Lagos-Kutz et al. 2016). Future surveys are needed to determine whether *S. caudalis* preys on *A. asclepiadis* on other host plants. Moreover, additional surveys are needed to determine prey for several other *Scymnus* species.

New state records of the other four coccinellid species presented here are minor to moderate extensions of their previously known geographic distributions, and increase knowledge of Wisconsin's insect biodiversity. The records demonstrate the importance of continual processing of uncurated entomological material (Fauske et al. 2003, Hesler and Kieckhefer 2008b).

The specimens were collected by various methods, but some of *Scymnus uncus* were obtained from gypsy moth (*Lymantria dispar* [L.], Lepidoptera: Erebidiae) trapping, and thus they provide another example of the value in processing bycatch to increase knowledge of species inventories and to accurately depict broad-scale distribution ranges (Buchholz et al. 2011, Kelly et al. 2013, Spears and Ramirez 2015).

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## INSTRUCTIONS FOR AUTHORS

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Manuscripts must be typed in English with line numbers, double-spaced, with 1" margins and uploaded. Please use italics rather than underline. Use subheadings sparingly and set them into paragraphs in boldface.

Footnotes (except for authors' addresses, which must be on the title page, and treated as a footnote), legends, and captions of illustrations should be on separate pages.

Titles should be concise, identifying the order and family discussed. The author of insect species must be given fully at least once in the abstract and text, but not in the title. If a common name is used for a species or group, it should be in accordance with the common names published by the Entomological Society of America, or the Entomology Society of Canada.

The format for references must follow that described in the style guidelines used by the Entomological Society of America, except that journal titles are not abbreviated.

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