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Cover Page Footnote

1 1 Campus Drive, Biology Department, Grand Valley State University, Allendale, MI 49401 * corresponding author (email: mws@uoregon.edu) ** corresponding author (email: dunnj@gvsu.edu) Acknowledgements: We thank both The Nature Conservancy and the Michigan Department of Natural Resources for allowing us access to their preserves. We thank Dr. Andrew Hamilton of Agriculture & Agri-Food Canada for directing us to Dr. Chris Dietrich, Curator of Insects for the Illinois Natural History Survey, who assisted in identification, and Mike Calkins for help with fieldwork. We also thank the Office of Undergraduate Research and Scholarships at Grand Valley State University for funding our study through the Student Summer Scholars program. We also gratefully acknowledge the time and suggestions of the reviewers.

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' – Date 1: pavement = 0.649, grassland = 0.471; H' – 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

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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 Cercopidae) 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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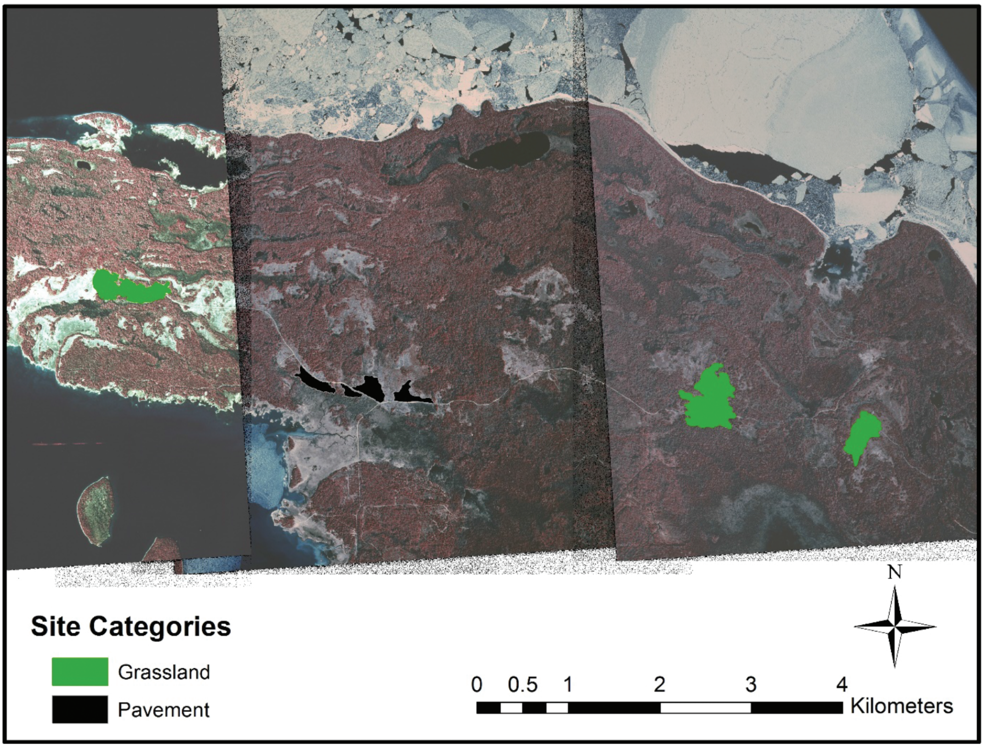

Figure 1. A site map of pavement and grassland alvars of Maxton Plains on Drummond Island, MI.

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^2 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^2 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 spumaris* (Linnaeus), and boreal spittlebug, *Aphrophora gelida* (Walker), are both highly polyphagus 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%, respectfully) 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† 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.

	Pavement		Grassland		
Guild	Median Rank (25,75 percents)	U State	Median Rank (25,75 Percents)	U State	P
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

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

†: Prairie obligate species
*: 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 2					
	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 Auchenorryncha densities as influenced by sources of variation on grassland alvar communities, Maxton Plains, Drummond Island, MI.

Variation	**PF**	**MS**	**F**	**P**
Alvar Type[1]	1	2209.00	23.53	<0.01
Site Replication	3	177.43	1.89	0.15
Date[2]	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 (± s.e.) and confidence intervals (C.I.) of Auchenorryncha among alvar habitat type and distance of capture from an unimproved limestone road, Maxton Plains, Drummond Island, MI.

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

Acknowledgments

We thank both The Nature Conservancy and the Michigan Department of Natural Resources for allowing us access to their preserves. We thank Dr. Andrew Hamilton of Agriculture & Agri-Food Canada for directing us to Dr. Chris Dietrich, Curator of Insects for the Illinois Natural History Survey, who assisted in identification, and Mike Calkins for help with fieldwork. We also thank the Office of Undergraduate Research and Scholarships at Grand Valley State University for funding our study through the Student Summer Scholars program. We also gratefully acknowledge the time and suggestions of the reviewers.

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