Community Composition and Phenology of Native Siricidae (Hymenoptera) Attracted to Semiochemicals in Minnesota

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ABSTRACT As a result of the introduction of *Sirex noctilio* F. into North America, there has been increased interest in the poorly-described native Siricidae communities. To date, few studies have surveyed specifically for Siricidae, and many reports of native siricid populations are byproducts of sampling efforts targeting Coleoptera. We report results from a survey targeted specifically at native and exotic Siricidae in Minnesota. We used Lindgren funnel traps from 2006 to 2008 baited with α/β-pinene (*Sirex* lure), ethanol (EtOH), EtOH + α-pinene, or *Ips* 3-part lures. We captured 704 native Siricidae comprising seven species, of which none were exotic. To our knowledge, this is one of the largest field collections of Siricidae from a single discrete set of localities in existence. Adult Siricidae began flying in June and continued into October each year. The α/β-pinene lure was most effective, but the EtOH + α-pinene lure was also moderately effective. We compare our data with those from several states and provinces in the Great Lakes Region of North America. Our data provide insight into the community composition of native Siricidae in Minnesota, while concurrently providing evidence that *S. noctilio* populations have not yet reached this far into the continental United States.

KEY WORDS funnel traps, *Pinus*, *Sirex*, *Tremex*, *Urocerus*

The family Siricidae is comprised of 23 relatively uncommon woodwasp species in North America (Morgan 1968, Schiff et al. 2006). After adults emerge from June to October, females mate and insert their eggs into weakened or stressed trees. Larvae can take up to 3 yr to develop (Schiff et al. 2006). Species in the subfamily Siricinae attack gymnosperms, whereas species in the subfamily Tremicinae attack deciduous trees. Symbiotic associations between woodwasps and *Amylostereum* spp. fungi (Stillwell 1966, Slippers et al. 2003) and bacteria (Adams et al. 2011) are well documented, although not all species of Siricidae have microorganismal symbionts (Fukuda and Hijii 1997). *Amylostereum* fungi provide food for the larvae in the subfamily Siricinae, and along with *Streptomyces* spp. and γ-Proteobacteria assist in breaking down cellulose (Talbot 1977, Adams et al. 2011). Species in the subfamily Tremicinae harbor *Cerrena* spp. fungi (Stillwell 1964, Tabata and Abe 1995), but these associations are not as well-characterized as those with the Siricinae. Siricidae in the genus *Xeris* do not have symbiotic fungi and tend to oviposit in areas that were inoculated previously with a wood decay fungus by another siricid (Fukuda and Hijii 1997). Hymenopteran parasitoids (Smith and Schiff 2002, Long et al. 2009) and host resistance (Morgan 1968) are agents that contribute to natural population control of native Siricidae in North America.

Native Siricidae are generally economically inconsequential pests, although *Urocerus* spp. have shown the potential to cause economic damage (Wilson 1962). Conversely, some exotic Siricidae can cause extensive damage (Haugen 1990). The European woodwasp, *Sirex noctilio* F., is the most notorious exotic woodwasp in North America. Native to Eurasia and northern Africa, *S. noctilio* has been introduced to Australia, South Africa, and South America (Ciesla 2003). *Sirex noctilio* was first discovered in North America in 2004 in New York (Hoebeke et al. 2005), and has the potential to cause extensive damage and mortality to *Pinus* species across the continent (Carnegie et al. 2006, Dodds et al. 2007, Dodds et al. 2010). Within 20 yr, annual losses could exceed $254 million in Canada alone (Yemshanov et al. 2009), and Rabaglia and Lewis (2006) predict annual losses over a 55-yr period in the United States in excess of $2.8 billion.

A proactive approach, including effective monitoring programs and open communication among scientists and managers, is regarded universally as the most valuable tool in invasive species management (Lovett et al. 2006, Yemshanov et al. 2010). Early detection of exotic wood boring pests is essential for timely reac-

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Table 1. Trapping effort for Siricidae in Minnesota from 2006 to 2008

Region	County	Number of Sites			Number of Traps		
		2006	2007	2008	2006	2007	2008
Northeast	Carlton	4	3	5	20	15	15
Northeast	Itasca	0	0	2	0	0	2
Northeast	St. Louis	11	9	12	50	45	34
East Central	Anoka	3	2	7	15	10	20
East Central	Chisago	0	1	2	0	3	5
East Central	Hennepin	10	7	14	50	35	36
East Central	Sherburne	4	2	4	20	10	10
East Central	Stearns	0	2	6	0	10	15
East Central	Wright	0	1	4	0	5	10
	TOTAL	32	27	55	155	133	147

tion to their introduction, and provides both economic and environmental benefits (Rabaglia et al. 2008, Moser et al. 2010). Early detection is also an essential component for the construction of accurate pest risk maps (Venette et al. 2010). Early detection strategies (e.g., assessment and monitoring of identifiable, high-risk introduction pathways) coupled with rapid response efforts (eradication or quarantine) are less costly to implement than management should an exotic species become established, and increase the likelihood of local eradication (Keefer et al. 2010). Prompt response is critical, because established exotic species are difficult, if not impossible, to eradicate. Little published information exists regarding native Siricidae in North America, especially in the states and provinces surrounding the Great Lakes. Our objective was to document the Siricidae community in high risk areas of Minnesota, with a specific emphasis on surveying for invasive species. We extensively surveyed the Siricidae in northeastern and east-central Minnesota during the summers of 2006–2008. The abundance of potential woodwasp introduction sites in these regions puts them at elevated risk for the introduction of *S. noctilio* (Koch et al. 2011). In addition to providing data on the presence or absence of exotic Siricidae, this survey documented, in part, the composition of the poorly characterized native Siricidae fauna of Minnesota. Studies like these, although rare, provide baseline ecological data that will underlie future assessments of the direct and indirect impacts of *S. noctilio* and the biological control tactics used to mitigate them.

Materials and Methods

Study Locations. All trapping was conducted in northeastern and east-central Minnesota. During our study months (April through October), average monthly maximum temperature was 22.1°C, average minimum temperature was 10.7°C, and average precipitation was 8.9 cm in the east-central region compared with 18.4°C, 7.6°C, and 8.2 cm, respectively, in the northeastern region of Minnesota. A detection network consisting of semiochemical-baited Lindgren funnel traps (Lindgren 1983) placed in stands dominated by red pine (*Pinus resinosa* Aiton), Eastern white pine (*Pinus strobus* L.), jack pine (*Pinus banksiana* Lamb.), and Scots pine (*Pinus sylvestris* L.) was established for detection of exotic Siricidae (Table 1). Trapping focused primarily on over-stocked stands in natural areas or parklands near high-risk introduction sites, such as port areas, green waste areas, major importers (e.g., stone, tile, etc.), and forest industries.

Trapping Methodology. Trapping methodology was based on United States Department of Agriculture survey guidelines (PPQ/EDP/EP Staff 2006). Lindgren funnel traps were hung from host trees in partial shade, at least 30 cm above the ground, and with at least 25 m between traps at each site. In 2006 and 2007, three traps at each site were baited with α/β-pinene (the standard *Sirex* lure, consisting of 170 g of 70:30 blend S(-) α/β-pinene at ≈50% enantiomeric excess) and the collection cups contained propylene glycol (RV Plus Antifreeze, Zecol Products Co., Medina, MN). Two additional traps at each site were baited with an *Ips* 3-part lure (3.5 g of 2,3,2-methylbutenol, 40 mg of racemic ipsdienol, and 150 mg of S(-) *cis*-verbenol) or an ultra high release ethanol (EtOH) lure (100 ml of 95% EtOH) with dry collection cups. Therefore, in 2006 and 2007, there were five traps at each site: three *Sirex* lures, one *Ips* 3-part lure, and one EtOH lure. In 2008, the EtOH lure was replaced with an EtOH + α-pinene lure (85 g of R(+) α-pinene with an enantiomeric excess of 50%) and the collection cups for all traps contained propylene glycol. Therefore, each site also had five traps in 2008: three *Sirex* lures, one *Ips* 3-part lure, and one EtOH + α-pinene lure. The initial batch of lures used in 2006 was obtained from Advanced Pheromone Technologies (Portland, OR). All subsequent lures used in 2006, and all lures used in 2007 and 2008, were obtained from Synergy Semiochemical Corp. (Burnaby, BC, Canada). Traps were checked approximately every 2 wk. Lures were changed on the following frequency: once every 2 mo for the α/β-pinene, *Ips*, and EtOH + α-pinene lures, and once every 3 mo for the EtOH lure. Traps in east-central Minnesota were monitored from 14 June to 26 October 2006 (134 d), 16 April to 18 October 2007 (185 d), and 7 April to 27 October 2008 (203 d). Traps in northeastern Minnesota were monitored from 24 May to 11 October 2006 (140 d), 16 April to 18 October 2007 (185 d), and 9 April to 23 October 2008 (197 d). Samples were stored in a freezer until processing. All Siricidae were identified to species by using Schiff et al. (2006), and reference

Table 2. Total Siricidae captured in Minnesota from 2006 to 2008 in Lindgren funnel traps baited with α/β-pinene (*Sirex*), EtOH, EtOH + α-pinene, and *Ips* 3-part exotic bark beetle lures

Species	Year			Lure				Total	% of Total
	2006	2007	2008	α/β-pinene	EtOH	EtOH + α-pinene	*Ips*		
Sirex edwardsii	171	27	70	253	0	10	5	268	38.1
Sirex juvencus	4	1	10	9	0	5	1	15	2.1
Sirex nigricornis	145	34	84	231	4	19	9	263	37.4
Tremex columba	21	8	21	39	1	4	6	50	7.1
Urocerus albicornis	11	1	16	18	0	8	2	28	4.0
Urocerus cressoni	19	14	37	53	0	17	0	70	9.9
Xeris spectrum	0	4	6	6	0	4	0	10	1.4
Total Siricidae	371	89	244	609	5	67	23	704	100.0

The EtOH lure was used in 2006 and 2007, and the EtOH + α-pinene lure was used in 2008. All species are native to North America. Within a species, the Total column represents both the sum of the sampled years and the sum of the four lures used.

samples were deposited in the University of Minnesota insect collection.

Statistical Analyses. Phenology curves for all species of Siricidae captured were made using the α/β-pinene lure baited trap catch data summed across all traps and standardized by total trap-days. A high proportion of traps captured zero Siricidae; hence, data were nonnormally distributed and thus failed to meet the requirement for analysis of variance (ANOVA). Transformations were unsuccessful in achieving normality. Therefore, we used nonparametric analytic techniques. Kruskal–Wallis tests were run using R statistical software (version 2.8–1 for Mac OS X) on total Siricidae captures for year (overall), region (northeastern and east-central), lure within year (2006–2008) and year within lure (α/β-pinene, *Ips*, and EtOH). Tests were run on 2571 observations that were summed within unique combinations of constraints (function: aggregate; constraints: lure type, region, year, and location) and standardized by total trap days per observation. All reported *P* values were Bonferroni corrected by a factor of eight. The adjusted *P* value that would result in a rejected null hypothesis would be $0.05/8 = 0.00625$.

Results

Species Composition. We captured 704 individuals representing seven native species of Siricidae (Table 2). Exotic Siricidae, including *S. noctilio,* were not detected in Minnesota. Traps were numerically dominated by *Sirex edwardsii* Brullé and *Sirex nigricornis* F. (Table 2). With the exception of *Xeris spectrum* L., at least one specimen of each species was caught in each year.

Flight Activity. Overall, Siricidae flight activity lasted from early to mid-June until late-October. Peak Siricidae flight occurred in early September in 2006 and 2007, and in early October in 2008 (Fig. 1). *Xeris spectrum* flight activity occurred earlier than all other Siricidae in the 2 yr it was captured (Fig. 1).

Geographical, Temporal, and Lure Variation in Siricidae Captures. Siricidae captured in all years combined did not differ significantly between northeastern and east-central Minnesota (Table 3). Siricidae were captured most often in 2006, followed by 2008 and 2007 (Tables 2 and 3). The α/β-pinene lure captured the most Siricidae in each year, but in 2008 the EtOH + α-pinene lure captured over half as many Siricidae as did α/β-pinene (Fig. 2). Siricidae captures by the the α/β-pinene lure were greatest in 2006, followed by 2008, but captures by the the *Ips* or EtOH lure did not differ among years (Table 3).

Discussion

The Siricidae community in Minnesota was dominated by two species in our study, *S. edwardsii* and *S. nigricornis.* All other species were rarely captured. *Sirex edwardsii, Tremex columba* L., and *Urocerus albicornis* F. have been reported previously in Minnesota (Washburn 1918), as have *Urocerus cressoni* Norton and *X. spectrum* (Gandhi et al. 2009). Numerically, our results differed greatly from those of Gandhi et al. (2009), who captured five species in extreme northeastern Minnesota, the majority of which were *U. cressoni* and *X. spectrum* (Table 4). This contrast is quite interesting because each study sampled for multiple years by using multiple baits. However, Gandhi et al. (2009) did not use the α/β-pinene lure, which may have contributed to their low captures of Siricidae.

Native Siricidae populations in the Great Lakes Region of North America are spatially variable, even within a state (Tables 4 and 5). To our knowledge, this is the first peer-reviewed study to explicitly target Siricidae using semiochemical lures. Although several reports stipulate this goal (Table 4), these data have rarely been published, making reconstruction of the native Siricidae community difficult. We contacted insect research collection and museum curators throughout the Great Lakes Region to compile a preliminary list of native Siricidae (Table 5). Certain patterns are evident; for instance, *Sirex juvencus* L., *S. edwardsii, U. cressoni,* and *T. columba* are widely distributed. However, some species, including *Sirex varipes* Walker and *S. areolatus* (Cresson) are quite rare, and these specimens most likely represent adults emerged from lumber originating in the western United States (D. Smith, personal communication. With the limited data available, it is difficult to determine the prevalence of some species.

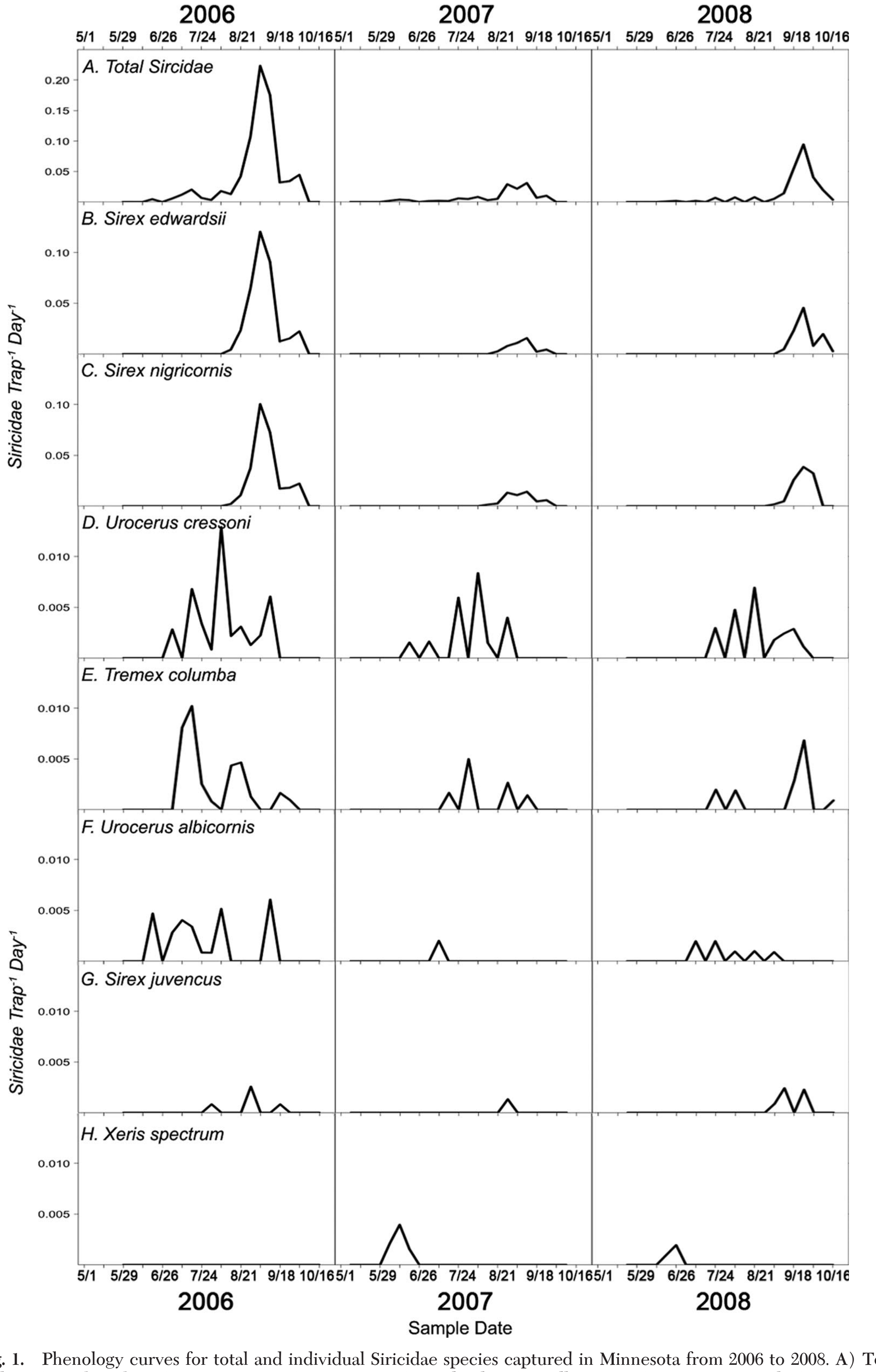

Fig. 1. Phenology curves for total and individual Siricidae species captured in Minnesota from 2006 to 2008. A) Total Siricidae, B) *S. edwardsii*, C) *S. nigricornis*, D) *U. cressoni*, E) *T. columba*, F) *U. albicornis*, G) *S. junvencus*, and H) *X. spectrum*.

Table 3. Kruskal-Wallis statistical values for region, year, lure within year, and year within lure statistical analyses

	Test	H	df	P	Bonferroni corrected P
	Region (northeast - east central)	0.98	1	0.323	1.000
	Year (2006–2008)	29.09	2	<0.001	<0.001
Lure within Year	2006 (α/β−pinene, *Ips*, and EtOH)	154.63	2	<0.001	<0.001
	2007 (α/β−pinene, *Ips*, and EtOH)	119.78	2	<0.001	<0.001
	2008 (α/β−pinene, *Ips*, and EtOH + α-pinene)	61.82	2	<0.001	<0.001
Year within Lure	α/β−pinene (2006–2008)	35.84	2	<0.001	<0.001
	EtOH (2006–2007)	4.13	1	0.344	1.000
	Ips (2006–2008)	0.89	2	0.127	1.000

Bonferroni corrected P values >1 were rounded down to 1.000.

Native Siricidae populations also exhibit considerable annual variation. Total Siricidae captures in South Dakota were more than twice as high in 2004 as in 2003 (Costello et al. 2008). Likewise, in our study, total captures in 2006 were more than twice as high as 2008 levels (Fig. 1). Individual species abundance also varies greatly. In our study, *S. nigricornis* showed a 10-fold variation in abundance between 2006 and 2007, and *X. spectrum* was not even captured in 2006 (Fig. 1). Annual variation such as this is not undocumented; in Japan, *X. spectrum* emergence varied nine-fold between study years and *U. japonicus* (F. Smith) was only captured in one of 2 yr (Fukuda and Hijii 1997). Conversely, populations of *S. juvencus, U. cressoni,* and *U. albicornis* were relatively consistent from 2006 to 2008 in our study (Fig. 1). Within the year, a late summer peak in Siricidae abundance is common (Fukuda and Hijii 1997, McIntosh et al. 2001, Smith and Schiff 2002, Costello et al. 2008) with *X. spectrum* being the only exception. This species, which does not carry symbiotic fungi, emerges earlier than most other siricids (Fukuda and Hijii 1997, Fig. 1).

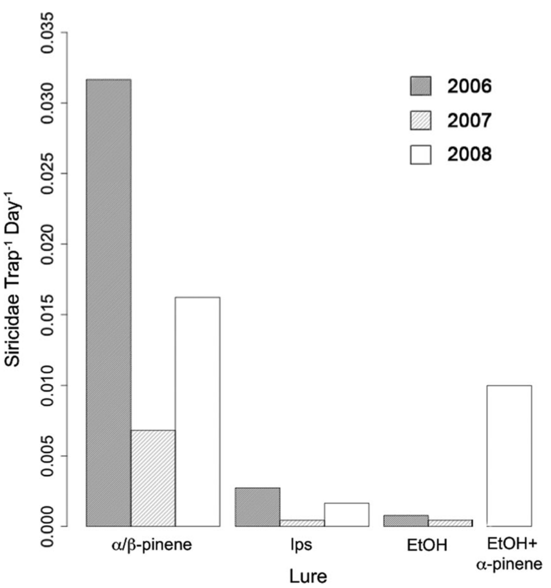

Fig. 2. Total Siricidae captured by year (2006–2008) and lure type (α/β pinene, EtOH, EtOH + α-pinene and *Ips* 3-part) standardized by trapping effort (per total trapping days).

The attractiveness of α/β-pinene to siricids has been known for several decades (Simpson and McQuilkin 1976). This lure was the most efficacious in our study, and the presence of α-pinene seemed to increase captures on EtOH. α-pinene and β-pinene have been used successfully to capture Siricidae in South Dakota (Costello et al. 2008) and Minnesota (Gandhi et al. 2009), although their efficacy does not appear to be equal to that of α/β-pinene. However, comparisons

Table 4. Siricidae captured in Minnesota compared with other published reports in the Great Lakes Region of North America

Species	MN[a]	MN[b]	IN[c]	ONT[d]	SD[e]	WI[f]
Sirex behrensii (Cresson)		6				
Sirex cyaneus Fabricius		6			86	
Sirex edwardsii Brullé	268		75	73		18
Sirex juvencus (Linnaeus)	15			82	192	
Sirex nigricornis Fabricius	263		125	432		19
Sirex noctilio Fabricius				5		
Sirex spp.						3
Tremex columba (Linnaeus)	50		17	6		
Urocerus albicornis (Fabricius)	28			116		5
Urocerus cressoni Norton	70	170	11	267	2	36
Urocerus gigas flavicornis (Fabricius)		3		2	36	
Xeris morrisoni (Cresson)					11	
Xeris spectrum (Linnaeus)	10	81		2		
Total Siricidae	704	266	228	985	327	81

[a] This study, captured in Lindgren funnel traps baited with ethanol, *Ips* 3-part exotic bark beetle, α/β-pinene, and ethanol + α-pinene lures from 2006 to 2008.

[b] Gandhi et al. (2009), captured in Lindgren funnel traps baited with ipsenol, α-pinene, ipsdienol, *cis*-verbenol, lanierone, frontalin, 1-methyl-2-cyclohexenol, scudenol, β–pinine, 3-carene, and *exo*-brevocomin from 2000 to 2003.

[c] Indiana Forest Health Highlights (2008), captured in Lindgren funnel traps baited with α/β-pinene from 2006 to 2008.

[d] Hodge et al. (2007), captured in panel and funnel traps baited with α/β-pinene in 2007.

[e] Costello et al. (2008), captured in modified panel and funnel traps baited with ethanol, α-pinene, ipsenol, ipsdienol, and 3-carene from 2003 to 2004.

[f] Wisconsin DATCP Report (2008), captured in Lindgren funnel traps baited with α/β-pinene in 2007.

Table 5. Siricidae present in University and Government insect collections in the Great Lakes Region of North America

Species	IA	IL	MAN	MI	MN	ND	ONT	WI
Sirex areolatus (Cresson)		x		x				
Sirex behrensii (Cresson)					x			
Sirex cyaneus Fabricius		x		x	x	x	x	
Sirex edwardsii Brullé[b]		x		x	x			x
Sirex juvencus (Linnaeus)		x	x	x	x		x	
Sirex nigricornis Fabricius			x	x	x		x	x
Sirex noctilio Fabricius				x			x	
Sirex varipes Walker	x[b]							
Tremex columba (Linnaeus)	x	x	x	x	x	x	x	x
Urocerus albicornis (Fabricius)		x	x	x	x	x	x	x
Urocerus californicus Norton		x		x				x
Urocerus cressoni Norton	x	x	x	x	x	x	x	x
Urocerus sah (Mocsáry)							x	
Urocerus gigas flavicornis (Fabricius)		x	x	x	x	x	x	
Urocerus taxodii (Ashmead)							x	
Xeris morrisoni (Cresson)[a]				x				
Xeris spectrum (Linnaeus)				x	x	x	x	

Specimens reported were collected from the state or province of reference, not just present in the collection.
[a] Likely arrived via lumber, as this species is known to occur only in the southwestern US (D. Smith, pers. comm.)
[b] Specimen emerged in Iowa from wood collected in Wisconsin.

among the three lures were not explicitly tested. Several states and provinces also use α/β-pinene as their primary lure for trapping Siricidae (Table 4). Our study supports the use of α/β-pinene, and indicates that EtOH alone and the *Ips* 3-part lure are ineffective.

Many studies of the biodiversity of a region are initiated in search of invasive species (e.g., *S. noctilio*). In fact, most published studies concerning Siricidae focus on *S. noctilio,* because of its potential and realized economic losses (Ciesla 2003, Dodds et al. 2010). Most states and provinces have implemented survey protocols either to track the distribution of or monitor forests for *S. noctilio.* Though these surveys are physically and logistically demanding, the information generated from them is invaluable. At this time, there is little record of the native Siricidae community in the north-central portion of North America. For example, specimens captured by Gandhi et al. (2009) included three new Minnesota state records. To our knowledge, our data represent the most extensive survey of Siricidae in the upper Midwest of the United States, and comprise one of the largest surveys in North America. Combined with data from Gandhi et al. (2009), we can begin to construct a preliminary picture of the Siricidae community in the Great Lakes Region.

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