

## Bark Beetle (Coleoptera: Curculionidae: Scolytinae) Community Structure in Northeastern and Central Minnesota

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### Abstract

Large-scale surveys of forest insects provide two distinct benefits: the detection of invasive and exotic species that cause millions of dollars of damage annually to forest and ornamental industries, and the addition of a wealth of species distribution and diversity information to the scientific community. We intensively surveyed the Northeast and East-central regions of Minnesota from 2006-2008 for invasive/exotic and native Scolytinae using Lindgren funnel traps baited with one of four lures ( $\alpha/\beta$ -pinene, ultra-high-release ethanol [EtOH], EtOH+ $\alpha$ -pinene, and *Ips* 3-part). We captured 16,841 scolytines (representing 25 genera) of which over 40% were *Ips pini* (Say) and *Ips grandicollis* (Eichhoff). We found two exotic Scolytinae, *Scolytus multistriatus* (Marsham) and *Scolytus schevyrewi* Semenov, both of which had previously been recorded in Minnesota. Two native species, *Conophthorus coniperda* (Schwarz) and *Crypturgus pusillus* (Gyllenhal), were reported for the first time in Minnesota. Non-metric multi-dimensional scaling and analysis of similarities indicate that lure types capture different Scolytinae communities, while year, weather pattern and region factors were not significant. We also report the seasonal phenology of the seven most abundantly captured species; *Dendroctonus valens* LeConte, *Hylastes porculus* Erichson, *Hylurgops rugipennis pinifex* (Fitch), *I. grandicollis*, *I. pini*, *Orthotomicus caelatus* (Eichhoff) and *Pityophthorus* spp. Eichhoff.

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Bark and ambrosia beetles (Coleoptera: Curculionidae: Scolytinae) are phloeophagous, xylophagous and xylomycetophagous insects, with over 475 species in North America (Wood 1982). Most species oviposit in weakened and dying host trees where larvae feed/develop, contributing greatly to primary decomposition in forests (Wood 1982). Scolytines are primarily attracted to host trees via volatile oleoresins, terpene hydrocarbons, alcohols, or other substances emitted by injured or dying host tissue (Rudinsky 1966), and often secondarily attracted by the release of beetle-produced sex pheromones (Wood 1970). At high populations, several species within the Scolytinae (e.g., *Dendroctonus* spp.) are capable of mass attacking and killing well-defended host trees, causing significant disturbances within healthy forest stands (Raffa et al. 1993). Anderson (1961) estimated that more than 60% of all insect-related tree mortality is caused

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by bark and ambrosia beetles, making the scolytines one of the most important groups of insect pests impacting North American forests (Rabaglia et al. 2006).

Scolytinae introductions represent a growing threat to native forests. Due to their vast range and diverse environment, forests are particularly susceptible to damage by exotic insect species (Liebhold et al. 1995). Exotic insects can alter biogeochemical processes (Peltzer et al. 2010), threaten rare native species (Wagner and Van Driesche 2010), and contribute to range alteration of native species, especially when the effects of future climate change are considered (Walther et al. 2009). An increasing number of exotic species make their way into North America each year, costing the U.S. economy an estimated \$137 billion annually (Pimentel et al. 2000). The \$8.6 billion forest products industry in Minnesota (<http://www.minnesotaforests.com/resources/pdfs/economy.pdf>), combined with the high potential for Curculionidae invasion near U.S. ports-of-entry (Liebhold et al. 1995), make insect community surveys and management studies a priority in this region. Invasive species are generally managed via chemical, biological, or silvicultural methods, yet success of these methods varies (Gandhi and Herms 2010).

A proactive approach, including effective monitoring programs (i.e., early detection) and open communication among scientists and managers, is universally regarded as the most valuable tool in invasive species management (Lovett et al. 2006). Rapid response efforts such as eradication and/or quarantine efforts are often more effective when coupled with early detection strategies. Continued monitoring programs, such as CAPS (Cooperative Agricultural Pest Survey) and USFS (US Forest Service) programs, help assist in the early detection of invasive/exotic species, allowing more appropriate/cost effective management or eradication techniques to be implemented (Haack 2006), as well as provide a framework for a survey and description of known and native species communities (Gandhi et al. 2010).

In addition to information gathered on the presence or absence of invasive species, surveys of insect communities provide an invaluable wealth of ecological information. Survey data can be used to study the effects of climate change (Hillstrom and Lindroth 2008) and land management strategies (Wilby et al. 2006), as well as provide an abundance of information on interspecific interactions. Broad surveys aid in the understanding of complex ecological interactions by providing data on primary and secondary species within a community, the latter of which can be very important to and are often missing from studies on primary species interactions (Abbot et al. 2009). Elucidating interspecies relationships with the aid of survey data may provide insight into the population ecology of individual keystone species (Elton and Miller 1954).

Using four different lures over a three-year period, we intensively sampled regions of Minnesota that are at high-risk for exotic bark and ambrosia beetle introductions. Overstocked pine stands near high-risk introduction sites such as port areas, green waste areas, and major stone and tile importers, were targeted as trapping locations. Trapping focused primarily on stands of host trees or parklands close to potential introduction sites in or near metropolitan areas. The objectives of this study were to detect any new, exotic Scolytinae infestations, describe the known Scolytinae community in terms of spatial and temporal variation, and evaluate the trapping efficacy of the attractant lures used in the survey.

## Methods and Materials

**Study locations.** All sampling occurred in Northeast and East-central Minnesota (Table 1). Average temperatures and rainfall were slightly higher in the East-central than the Northeast region (Table 2). Overall, the counties surveyed had nearly 101,000 ha of pine and mixed hardwoods. All study sites were at least 0.02 ha in size and contained plantings at least three trees wide.

Table 1. County level allocation of sampling effort from 2006 to 2008 in seven counties in Minnesota. Total number of traps deployed includes all lure types ( $\alpha/\beta$ -pinene (NA 2006), EtOH+ $\alpha$ -pinene (NA 2006 and 2007), EtOH (NA 2008), and *Ips* 3-part).

Region	County	Sites monitored			Traps deployed		
		2006	2007	2008	2006	2007	2008
East-central	Anoka	3	2	7	15	10	20
Northeast	Carlton	4	3	5	20	15	15
East-central	Chisago	0	1	2	0	3	5
East-central	Hennepin	10	7	12	50	35	36
East-central	Sherburne	4	2	4	20	10	10
Northeast	St. Louis	11	9	12	50	45	34
East-central	Stearns	0	2	6	0	10	15
East-central	Wright	0	1	4	0	5	10
<b>Total</b>		<b>28</b>	<b>27</b>	<b>54</b>	<b>135</b>	<b>133</b>	<b>147</b>

**Trapping methodology.** Trapping was based on United States Department of Agriculture Animal and Plant Health Inspection Service (USDA APHIS) guidelines (PPQ/EDP/EP 2006). A detection network consisting of semiochemical-baited Lindgren funnel traps (Lindgren 1983) was established and maintained in stands of host trees (*Pinus resinosa* Ait, *Pinus strobus* L., *Pinus banksiana* Lamb, and *Pinus sylvestris* L.). Traps were hung at least 25 m apart, in partial shade, and at least 30 cm above the ground. Funnel traps were hung with dry collection cups (containing Vapona) in 2006–2007 and wet collection cups (containing propylene glycol) in 2008. Traps were baited with one of four lure types; 1) *Sirex* lure with  $\alpha/\beta$ -pinene (170 g of 70:30 blend S(-)  $\alpha/\beta$ -pinene at ~50% enantiomeric excess) in 2007–2008, 2) ultra high-release ethanol (EtOH) (100 ml of 95% EtOH) in 2006–2007, 3) EtOH+ $\alpha$ -pinene (100 ml of 95% EtOH and 85 g of R(-)  $\alpha$ -pinene at ~50% enantiomeric excess) in 2008, and 4) *Ips* 3-part exotic bark beetle lure (3.5 g of 2,3,2-methylbutenol, 40 mg of racemic ipsdienol, and 150 mg of S(-) cis-verbenol; 2006–2008). Given all lures were not used in each year, 'NA' is used to indicate non-sampled years. Traps were checked approximately every two weeks, and lures were changed every four to six weeks per manufacturer directions. Lures were obtained from Phero Tech, Inc. (now Contech Enterprises, Delta, BC, Canada) for the initial batch in 2006, and Synergy Semiochemical Corp. (Burnaby, BC, Canada) for the remainder of 2006 as well as 2007–2008. Traps in the East-central region were monitored from 14 June to 26 October 2006, 16 April to 18 October 2007, and 7 April to 27 October 2008. Traps in northeastern Minnesota were monitored from 24 May to 11 October 2006, 16 April to 18 October 2007, and 9 April to 23 October 2008. Samples collected from traps were delivered to the St. Paul office of the Minnesota Department of Agriculture and stored in a freezer for processing. All bark beetles were sorted to species by the lead trapper (AMJ in 2006, TLP in 2007 and 2008) and verified by Dr. John Luhman (Minnesota Department of Agriculture). Voucher specimens are housed in the University of Minnesota Insect Museum, St. Paul, Minnesota.

**Statistical analyses.** The original purpose of this study was to identify new exotic Scolytinae, and we accept that our sample design lacks symmetry in terms of trapping lures and effort (Table 1). This uneven sample design provided significant challenges regarding data analyses, and therefore we have taken a conservative and exploratory approach. All data were analyzed using R statistical software version 2.14.0 for Mac OS X (R Development Core Team 2011), and all analyses were performed (except rarefaction curves) on species community data standardized by trap days.

Table 2. Average temperature during the study period (April-October, 2006-2008) and total precipitation and snowfall (year round, 2006-2008) in Duluth, MN (212248 Duluth WSO AP) and New Hope, MN (215838 NEW HOPE), Duluth and New Hope are chosen to be representative of Northeast and East-central Minnesota. Temperature, precipitation and snowfall were recorded by the National Weather Service and obtained from the University of Minnesota climate center (<http://climate.umn.edu/hidradius/radius.asp>).

Year	Duluth				New Hope			
	Ave. Max. Temp. (°C)	Ave. Min. Temp. (°C)	Total Precip. (cm)	Total Snowfall (cm)	Ave. Max. Temp. (°C)	Ave. Min. Temp. (°C)	Total Precip. (cm)	Total Snowfall (cm)
2006	18.9	8.0	62.4	156.0	22.0	10.9	85.9	90.9
2007	19.1	7.8	76.3	263.9	22.9	11.4	83.9	157.7
2008	17.3	6.8	78.7	200.9	21.3	9.9	68.8	139.7

Rarefaction curves were used to determine if sampling intensity was adequate to capture the majority of bark beetle diversity in our study areas, defined as the bark beetle community attracted to at least one of the trap lures;  $\alpha/\beta$ -pinene, EtOH, EtOH+ $\alpha$ -pinene and *Ips* 3-part (Heck et al. 1975). Rarefaction curves were calculated using study site as the unit of replication for each year independently and collectively (function: specaccum, package: vegan, method: rarefaction, permutations = 100). Trap catch data were aggregated additively (function: aggregate, constraints: trap year and trap site).

Due to the high number of traps with zero captures, data for individual species and total Scolytinae captures failed to meet the normality requirement for analysis of variance. All transformation attempts were unsuccessful at achieving normality; therefore, combined with the community-based nature of our data we used ordinal analytical methods (Kruskal 1964, Minchin 1987). Community-level trends were visualized using non-linear multi-dimensional scaling (NMS) (function: nmds, package: ecodist, 300 runs, random start configuration). Statistical trends in community assemblage data were calculated by analysis of similarities (ANOSIM) (function: anosim, package: vegan) (Clark 1993). Ordination and ANOSIM analyses were performed on community data resembled to a Bray-Curtis distance matrix data (function: distance, package: ecodist). Data used to create the distance matrix was standardized by total trap days and aggregated additively (function: aggregate, constraints: region, trap type, week and year). Aggregated samples with fewer than five total species captured were removed from the data matrix for NMS analyses. Likewise, individual species appearing in less than five samples were removed from NMS analysis. Species correlations vectors (Jongman et al. 1995) (function: vf, package: ecodist) for the seven most abundant beetle species were fit on the NMS ordinations. Significant species correlations ( $P < 0.05$ ) are denoted with an asterisk (fig. 2).

Phenology curves (function: xyplot, package: lattice) created for the seven most abundant scolytine species were compiled from additively aggregated (function: aggregate, constraints: trap date and type) data.

## Results

We captured 16,841 Scolytinae, representing 13 tribes, 25 genera, and 52 species, of which more than 40% were *Ips grandicollis* (Eichhoff) and *Ips pini* (Say) (Table 3). Native species captures of *Conophthorus coniperda* (Schwarz) and *Crypturgus pusillus* (Gyllenhal) are new Minnesota state records. The only exotic Scolytinae captured were *Scolytus multistriatus* (Marsham) and *Scolytus chevrewi* Semenov, neither of which were new to Minnesota. Exotic species accounted for only 0.16% of total Scolytinae captured in our study.

Rarefaction analyses indicated that we surveyed a majority of the Scolytinae diversity in Minnesota (as possibly sampled by our 4 lure types) over the entire study period, but not within an individual year; due in large part to the variations in lure composition and deployment between years (Fig. 1).

The Scolytinae community in the East-central region did not differ in species composition from that of the Northeast region (ANOSIM  $R = 0.075$ ,  $P = 0.191$ ). Species community composition did not differ based on average yearly temperature (Table 2) (ANOSIM  $R = -0.013$ ,  $P = 0.510$ ) or total yearly precipitation/snowfall (Table 2) (ANOSIM  $R = -0.013$ ,  $P = 0.500$ ). The community did not significantly vary among years (ANOSIM  $R = 0.065$ ,  $P = 0.200$ ) (Fig. 1), although large swings in individual species abundances were observed from the unstandardized data (e.g., *Hylurgops rugipennis pinifex* 1(Fitch)).

Lure types caught different communities of Scolytinae (ANOSIM  $R = 0.802$ ,  $P < 0.001$ ) (Fig. 2).  $\alpha/\beta$ -Pinene was the most effective lure for catching a broad range of abundant Scolytinae (Table 3, Fig. 2), although *I. pini* and *Lymantor decipiens*

Table 3. Total bark and ambrosia beetles (Coleoptera: Curculionidae: Scolytinae) captured in East-central and Northeast Minnesota from 2006-2008 using four lure types ( $\alpha/\beta$ -pinene (NA 2006), EtOH+ $\alpha$ -pinene (NA 2006 and 2007), EtOH (NA 2008), and *Ips* 3-part). Total beetle captures have been broken down by year, lure type and study region.

Tribe	Species	Year				Lure				Region			% of Total
		2006	2007	2008	$\alpha/\beta$ -pinene	EtOH+	EtOH	<i>Ips</i> 3-part	North-east	East-central	Total		
Xyleborini	<i>Anisandrus obesus</i> (LeConte)	42	1	358	12	208	43	138	183	218	401	2.4	
Corthylini	<i>Conophthorus coniperda</i> (Schwarz)	0	1	1	0	0	1	1	1	1	2	0.01	
Corthylini	<i>Conophthorus resinosa</i> Hopkins	1	14	11	8	3	3	12	11	15	26	0.16	
Corthylini	<i>Conophthorus</i> spp. Hopkins	1	0	0	0	0	1	0	1	0	1	0.01	
Cryphalini	<i>Cryphalus ruficollis</i> Hopkins	0	4	8	2	1	1	8	11	1	12	0.07	
Crypturgini	<i>Crypturgus borealis</i> Swaine	0	0	15	3	12	0	0	15	0	15	0.09	
Crypturgini	<i>Crypturgus pusillus</i> (Gyllenhal)	0	6	0	6	0	0	0	5	1	6	0.04	
Corthylini	<i>Corthylus punctatissimus</i> (Zimmerman)	0	3	21	3	9	3	9	16	8	24	0.14	
Tomcini	<i>Dendroctonus rufipennis</i> Kirby	0	0	4	3	1	0	0	4	0	4	0.02	
Tomcini	<i>Dendroctonus simplex</i> LeConte	0	6	1	6	0	1	0	7	0	7	0.04	
Tomcini	<i>Dendroctonus valens</i> LeConte	19	684	292	890	41	18	46	276	719	995	5.95	
Dryocoetini	<i>Dryocoetes affaber</i> (Mannerheim)	0	2	1	1	1	1	0	3	0	3	0.02	
Dryocoetini	<i>Dryocoetes autographus</i> (Ratzeburg)	2	23	5	25	1	1	3	25	5	30	0.18	
Dryocoetini	<i>Dryocoetes caryi</i> Swaine	0	88	49	101	34	0	2	135	2	137	0.82	
Dryocoetini	<i>Dryocoetes</i> spp. Eichhoff	0	72	130	106	83	6	7	149	53	202	1.21	
Corthylini	<i>Gnathotrichus materiarius</i> (Fitch)	6	108	68	112	31	4	35	153	29	182	1.09	
Hylastini	<i>Hylastes porculus</i> Erichson	6	962	700	1178	460	16	14	1335	333	1668	9.97	
Hylesinini	<i>Hylesinus aculeatus</i> Say	7	18	37	21	6	4	31	9	53	62	0.37	
Tomcini	<i>Hylurgopinus rufipes</i> (Eichhoff)	4	15	3	8	2	8	4	3	19	22	0.13	
Hylastini	<i>Hylurgops rugipennis pinifex</i> (Fitch)	0	899	82	933	39	4	5	967	14	981	5.86	
Ipini	<i>Ips grandicollis</i> (Eichhoff)	88	1427	2574	1909	1973	115	92	951	3138	4089	24.44	
Ipini	<i>Ips perroti</i> Swaine	2	0	0	0	0	0	2	1	1	2	0.01	
Ipini	<i>Ips pini</i> (Say)	1164	427	975	107	79	13	2367	1499	1069	2566	15.33	
Dryocoetini	<i>Lymanitor decipiens</i> (LeConte)	310	33	45	4	2	2	380	56	332	388	2.32	
Micracini	<i>Micracis suainei</i> Blackman	0	0	3	0	1	0	2	0	3	3	0.02	
Micracini	<i>Micracis</i> spp. LeConte	2	0	0	0	0	1	1	1	0	2	0.01	

Table 3. Continued.

Tribe	Species	Year			Lure			Region			% of Total	
		2006	2007	2008	$\alpha/\beta$ -pinene	EtOH+ EtOH	Ips 3- part	North- east	East- central	Total		
Corthylini	<i>Monanthrum mali</i> (Fitch)	1	6	5	3	3	5	1	0	12	12	0.07
Ipini	<i>Orithotomicus caelatus</i> (Eichhoff)	41	734	455	771	122	7	330	908	322	1230	7.35
Ipini	<i>Orithotomicus latidens</i> (LeConte)	0	11	2	8	0	0	5	13	0	13	0.08
Ipini	<i>Orithotomicus</i> spp. Ferrari	1	0	0	0	0	0	0	0	0	1	0.01
Phleotribini	<i>Phloeotribus piceae</i> Swaine	0	9	16	4	5	2	14	9	16	25	0.15
Ipini	<i>Pityogenes hopkinsi</i> Swaine	2	23	31	20	8	4	24	25	31	56	0.33
Ipini	<i>Pityogenes plagiatus</i> (LeConte)	0	1	2	1	2	0	0	2	1	3	0.02
Ipini	<i>Pityokteines sparsus</i> (LeConte)	0	5	97	17	43	0	42	101	1	102	0.61
Ipini	<i>Pityokteines</i> spp. Fuchs	1	0	1	1	0	0	1	1	1	2	0.01
Corthylini	<i>Pityophthorus consimilis</i> LeConte	3	0	0	0	0	1	2	0	3	3	0.02
Corthylini	<i>Pityophthorus lautus</i> Eichhoff	2	0	13	10	0	1	4	5	10	15	0.09
Corthylini	<i>Pityophthorus puberulus</i> (LeConte)	9	0	0	0	0	3	6	2	7	9	0.05
Corthylini	<i>Pityophthorus</i> spp. Eichhoff	129	731	596	978	211	102	165	670	786	1456	8.7
Polygraphini	<i>Polygraphus rufipennis</i> (Kirby)	2	52	48	64	8	10	20	90	12	102	0.61
Scolytini	<i>Scolytus multistriatus</i> (Marshall)	3	2	13	6	0	3	9	0	18	18	0.11
Scolytini	<i>Scolytus muticus</i> Say	0	1	2	1	2	0	0	0	3	3	0.02
Scolytini	<i>Scolytus piceae</i> (Swaine)	0	2	0	2	0	0	0	1	1	2	0.01
Scolytini	<i>Scolytus schweyrewi</i> Semenov	5	1	7	5	2	1	1	0	5	9	0.05
Scolytini	<i>Scolytus</i> spp. Geoffroy	0	11	1	3	0	5	0	0	5	5	0.03
Xyloterini	<i>Trypodendron betulae</i> Swaine	0	101	211	79	203	22	8	301	11	312	1.86
Xyloterini	<i>Trypodendron lineatum</i> (Olivier)	0	20	29	2	16	11	20	44	5	49	0.29
Xyloterini	<i>Trypodendron retusum</i> (LeConte)	1	74	585	41	423	40	156	214	446	660	3.94
Xyloterini	<i>Xyleborus</i> spp. Stephens	120	643	1	16	1	738	9	417	347	764	4.56
Xyloterini	<i>Xyloterinus politus</i> (Say)	0	38	2	0	0	38	2	2	38	40	0.24
<b>Total</b>		1975	7258	7500	7470	4063	1247	3980	8633	8102	16841	100

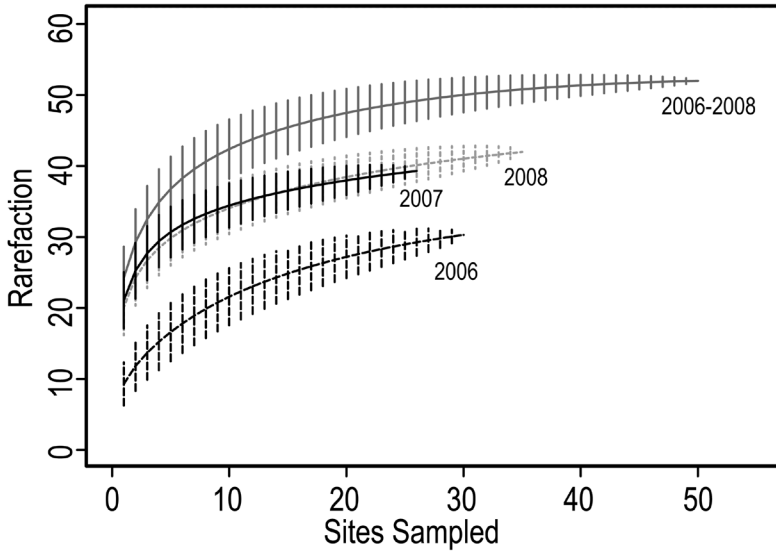


Figure 1. Rarefaction curves of all Scolytinae captured using all trap lure types ( $\alpha/\beta$ -pinene (NA 2006), EtOH+ $\alpha$ -pinene (NA 2006 and 2007), EtOH (NA 2008), and *Ips* 3-part) as accumulated by total sites sampled for 2006, 2007, 2008, and all sample years combined.

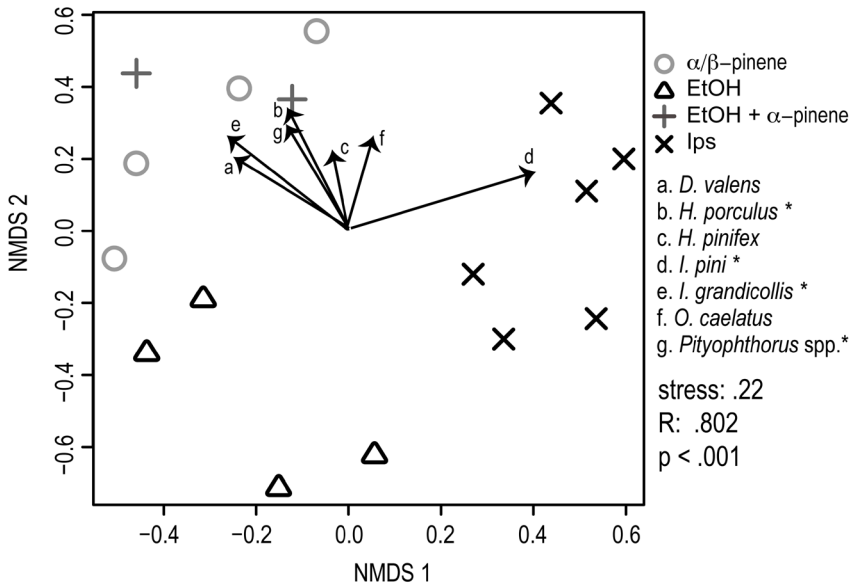


Figure 2. NMS plot of Scolytinae community composition using trap captures in the, Northeast and East-central regions of Minnesota from 2006-2008. Bray-Curtis resembled data are labeled by lure type ( $\alpha/\beta$ -pinene (NA 2006), EtOH+ $\alpha$ -pinene (NA 2006 and 2007), EtOH (NA 2008), and *Ips* 3-part). Species correlations are overlaid for the seven most abundant beetle species, significant correlations ( $P < 0.05$ ) are denoted with an asterisk.



(LeConte) were captured in higher numbers with *Ips* 3-part lures, *Trypodendron* spp. Stephens with EtOH+ $\alpha$ -pinene, and *Xyleborus* spp. Eichhoff with EtOH. Species vector correlations overlaid on the ordination in Figure 2 were significant for *Hylastes porculus* Erichson, *I. pini*, *I. grandicollis*, and *Pityophthorus* spp. Eichhoff ( $P < 0.050$ ) with *H. porculus*, *I. pini*, and *Pityophthorus* spp. trending towards  $\alpha/\beta$ -pinene and EtOH+ $\alpha$ -pinene lures, while *I. grandicollis* trended towards *Ips* lures (Fig. 2). Differences in species abundance between lure types were therefore primarily attributed to *H. porculus*, *I. grandicollis*, *I. pini*, and *Pityophthorus* spp. (Fig. 2).

Phenology curves for the seven most abundantly captured species indicated a high amount of intra- and inter-annual variation (Fig. 3). While we have standardized all the phenology curves by trap days, it is important to remember that not all lures were used in each year and caution must be taken to ensure direct comparison of phenologies between years are done within the framework of lure type. For example, it would not be appropriate to compare *Dendroctonus valens* LeConte captures with  $\alpha/\beta$ -pinene lure across all sample years, as  $\alpha/\beta$ -pinene was not sampled in 2006. *D. valens* populations were generally low except those captured with  $\alpha/\beta$ -pinene lure (Fig. 3A). Populations of *D. valens* peaked in late spring of 2007 versus fall in 2008 (Fig. 3A). *H. porculus* populations peaked in June each year and were two and a half times larger in 2007 than in 2008 as sampled by  $\alpha/\beta$ -pinene lure (Fig. 3B). *H. rugipennis pinifex* was rarely captured in 2006 or 2008, but populations were relatively high in 2007 on the  $\alpha/\beta$ -pinene lure (Fig. 3C). *I. pini* populations tended to peak in the fall, and were nearly four times as high in 2006 compared with 2007 and 2008 (Fig. 3D). *I. grandicollis* were most effectively captured on EtOH+ $\alpha$ -pinene lure, but also showed strong attractiveness to  $\alpha/\beta$ -pinene lure (Fig. 3E). *Orthotomicus caelatus* (Eichhoff) populations were variable, with peak flight occurring at a different time each year (Fig. 3F). *Pityophthorus* spp. generally peaked during June each year and were captured with a variety of lure types (Fig. 3G).

## Discussion

We captured 52 species of Scolytinae during three years of sampling. While rarefaction curves indicate we sampled a majority of the Scolytinae community (as possibly sampled by the study lure types)(Fig. 1), a catalog of Scolytinae in Michigan and species richness estimates from other temperate states (Idaho, Indiana, Maryland, Montana, Oregon and Washington) indicate that our captures probably approach half of the total Scolytinae richness in Minnesota (Cognato et al. 2009). A similar study in the Superior National Forest captured 34 species of Scolytinae from 2000-2003 (Gandhi et al. 2009).

Recent surveys sampling native bark and ambrosia beetle communities have captured at least 58% invasive and exotic species (Coyle et al. 2005, Miller and Rabaglia 2009, Gandhi et al. 2010). We trapped only two exotic species comprising only 0.16% of total captures in this study. While we feel confident in the robust nature of our protocol (Fig. 1), this lack of exotics is surprising considering the proximity of our sample regions to Lake Superior shipping ports and the increasing record of exotic bark beetle interceptions near U.S. ports-of-entry (Liebhold et al. 1995). The lack of establishment by exotic Scolytinae in Minnesota could be due, in part, to the relatively cold winter climate or less stand disturbances due to the presence of National Forest and the Boundary Waters National Park.

Individual Scolytinae species showed high inter-year and regional variation (i.e., *D. valens*) (Fig. 3). Our results concur with previous studies showing high geographic (Hulcr et al. 2008) and annual (Brockerhoff et al. 2006) variation in Scolytinae capture rates. Annual variation in Scolytinae captures is not uncommon, often due to long-term weather changes (Bentz et al. 2010),

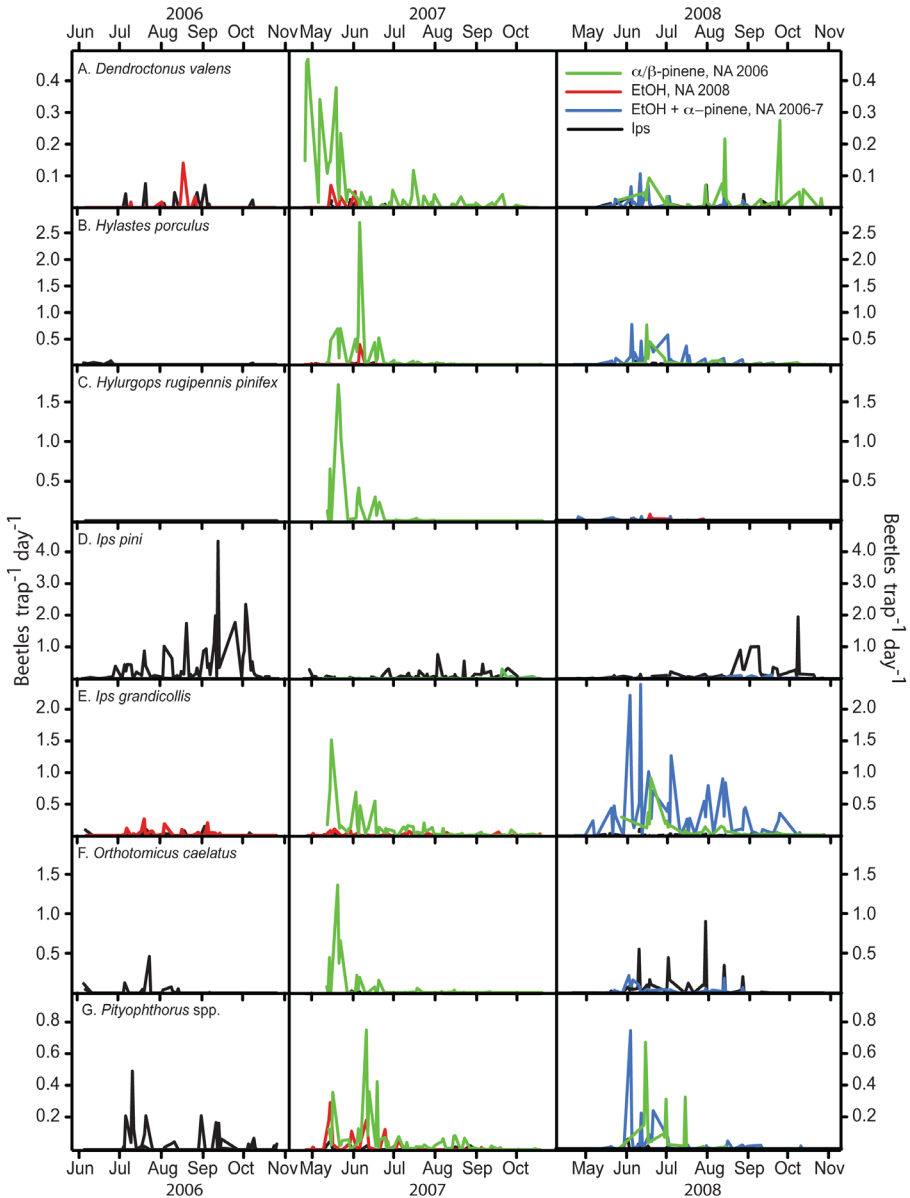


Figure 3. Phenology of the seven most abundant Scolytinae captured in Minnesota from 2006-2008: A) *Dendroctonus valens*, B) *Hylastes porculus*, C) *Hylurgops rugipennis pinifex*, D) *Ips grandicollis*, E) *Ips pini*, F) *Orthotomicus caelatus* and G) *Pityophthorus* spp. While we have standardized all the phenology curves, not all lures ( $\alpha/\beta$ -pinene (NA 2006), EtOH+ $\alpha$ -pinene (NA 2006 and 2007), EtOH (NA 2008), and *Ips* 3-part) were used in each year and caution must be taken to ensure direct comparison of phenologies between years are done within the framework of lure type.

severe weather events (Gandhi et al. 2007), and even regular weather variation (Aukema et al 2005). We were unable to detect any differences in Scolytinae community based on weather events most likely due to our course scale analyses of these factors. While we observed large variations in individual species abundances, the overall Scolytinae community we captured remained relatively static throughout the three-year study period.

We observed large variations in the Scolytinae community captured by each lure type (Fig. 2). This type of response to semiochemical lures has been well documented for  $\alpha$ -pinene, EtOH, and *Ips* lures (Gandhi et al. 2009); however, few studies have looked at this type of community response with the addition of other terpenoid lure components (Poland et al. 2004). We found strong variation in the Scolytinae community captured by  $\alpha/\beta$ -pinene lure.  $\alpha/\beta$ -pinene seems to be attractive to a much larger suite of Scolytinae than other lure types used in this study (Table 3). Gandhi et al. 2009 found similar attraction to  $\alpha/\beta$ -pinene in the Superior National Forest, Minnesota. However, we did not sample  $\alpha$ - or  $\beta$ -pinene independently and thus were unable to discern the full nature of  $\beta$ -pinene's effects.

Phenologies observed in this study were similar to previously published work. For instance, the phenology of *I. grandicollis* was nearly identical to that observed in Ohio (Gandhi et al. 2010). Flight of *D. valens* and *I. pini* was similar to that in Arizona (Gaylord et al. 2006). Flight of *H. porculus*, *I. grandicollis*, and *I. pini* was similar to that observed in Wisconsin red pine stands (Ayers et al. 2001; Erbilgin and Raffa 2002). Observations on *D. valens*, *H. pinifex* and *O. caelatus* presence on red pine in Michigan indicate similar emergence times, although our study indicates a longer flight period for both *D. valens* and *O. caelatus* (Kennedy and McCullough 2002).

In summary, exotic Scolytinae were uncommon in our study, and  $\alpha$ - and  $\beta$ -pinene were effective bait components. Phenologies for several Scolytinae indicated mostly univoltine life histories, with the possible exception of *D. valens* (Fig. 3A) and *I. grandicollis* (Fig. 3E). Insect surveys are an invaluable contribution to our knowledge of natural systems, yet they are unfortunately rarely published. This study contributes to the taxonomic and biodiversity knowledge of the Scolytinae of Minnesota, and studies such as these (e.g., Gandhi et al. 2010) could serve as a baseline for future work.

### Acknowledgments

We thank Nathan Goodell, Heidi Hagman, and Stephanie Visser (Minnesota Department of Agriculture) for field and laboratory assistance. Dennis Haugen (US Forest Service) provided valuable discussions and assistance in the early stages of this work. Claudio Gratton, Nicholas Keuler, Kenneth Raffa and Phil Townsend (UW-Madison) provided invaluable support and statistical assistance. Kamal Gandhi wrote a thorough and insightful review of this manuscript. This project was based on the non-target insects captured in surveys partially funded by the USDA Forest Service and the USDA Animal and Plant Health Inspection Service..

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