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Variation in Lepidopteran Occurrence in Hemlock-Dominated and Deciduous-Dominated Forests of Central Appalachia

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Abstract

Eastern hemlock, (*Tsuga canadensis* Carrière, Pinaceae), is threatened with extirpation by an exotic invasive herbivore, the hemlock woolly adelgid, (*Adelges tsugae* Annand, Homoptera: Adelgidae). Given this threat, a broader and more detailed knowledge of the community associated with eastern hemlock is merited. As Lepidoptera are important members of forest communities, this study was initiated to determine the relative occurrence of Lepidoptera in hemlock-dominated and deciduous-dominated habitats by evaluating abundance, species richness, temporal variation, and composition overlap. Lepidoptera were surveyed using blacklight traps from May – August 2010 at two collection sites in the Appalachian region of eastern Kentucky. The first collection site was within a forest stand dominated by mixed deciduous species, the second site possessed an overstory of eastern hemlock. Lepidoptera ≥ 20 mm in wingspan were identified and enumerated, yielding a total of 1,020 individuals of ≥ 137 species and 18 families. The total number of Lepidoptera captured in May and June was fewer than in July and August ($P \leq 0.05$). The composition of the assemblage varied between collection sites as well as seasonally; 85 species were identified at the deciduous site and 107 species were identified at the hemlock site. While 27 species were recorded only at the deciduous site, 49 species were unique to the hemlock site. Of those unique to the hemlock site, five species were either detritivores or conifer specialists. These data demonstrate the importance of both deciduous and hemlock-dominated forest habitats for many species of Lepidoptera in Appalachia. Our study forms a foundation for understanding species richness patterns of Lepidoptera in hemlock forests in North America and is a useful baseline for comparisons of richness and diversity post invasion by the hemlock woolly adelgid.

Lepidoptera are among the most abundant and conspicuous of forest insects. Defoliation by these insects is widespread in forests, with pestiferous species found throughout eastern North America (Covell 2005, Summerville and Crist 2008). Beyond the importance of these insects as forest herbivores, Lepidoptera also play a valuable role in the larger food web by serving as critical prey for both vertebrate and invertebrate predators (Dix et al. 1995, Lacki et al. 2007). These insects are found broadly across eastern North America and in mountain regions deciduous forests harbor high species diversity across a gradient of conditions (Dodd et al. 2008, Summerville and Crist 2008, Dodd et al. 2012). While species inventories for this group exist across North America's eastern deciduous forests (Summerville et al. 1999, Summerville and Crist 2001, Dodd et al. 2011) and northern boreal forests (Thomas and Thomas 1994, Thomas 2001, Pohl et al. 2004), specific knowledge of the Lepidoptera affiliated with forests dominated by eastern hemlock, (*Tsuga canadensis* Carrière, Pinaceae), is lacking. Eastern

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hemlock is a slow-growing, shade tolerant tree that serves as a foundation species in forests of eastern North America (Godman and Lancaster 1990). In the northern portions of its range eastern hemlock grows in large contiguous tracts, but in the south, including central and southern Appalachia, it is most often confined to riparian zones and moist cove sites (Godman and Lancaster 1990). Hemlock is often the only conifer present where it occurs, and it provides critical nesting habitat for birds (Tingley et al. 2002). The canopy is dense, regulating air and soil temperatures (Adams and Loucks 1971) and limiting light penetration to the forest floor. As a riparian tree it influences headwater stream habitat and benthic macroinvertebrate communities (Snyder et al. 2002) and supports unique fish communities (Ross et al. 2003). Hemlock litter decomposes slowly, and associated soils are poor in nutrients (Yorks et al. 2003), acidic, and with a characteristic species-poor understory community (Godman and Lancaster 1990). As a foundation species, eastern hemlock influences the composition and structure of arthropod communities (Snyder et al. 2002, Dilling et al. 2007, Rohr et al. 2009, Mallis and Rieske 2011).

In eastern North America eastern hemlock and its community associates are threatened with extirpation by an exotic invasive herbivore, the hemlock woolly adelgid, (*Adelges tsugae* Annand, Homoptera: Adelgidae). The adelgid is a xylem-feeding insect of Asian origin that depletes the starch reserves of its host plant. Eastern hemlock is highly susceptible, and is rapidly being colonized by the adelgid throughout its range. Ecosystems dominated by eastern hemlock are a critical, though uncommon component of the forest landscape throughout much of the central and southern Appalachians. Replacement of eastern hemlock by deciduous species will likely change nutrient cycling and the physical and chemical conditions of terrestrial habitats (Yorks et al. 2000). Given the threat posed to eastern hemlock and associated communities from adelgid-induced hemlock mortality, a broader and more in-depth knowledge of hemlock community associates is merited and timely (Buck et al. 2005, Dilling et al. 2007). To address this, the main objective of this study was to document the relative occurrence of Lepidoptera by determining abundance, species richness, temporal variation, and composition overlap in a hemlock-dominated and deciduous-dominated habitat.

Materials and Methods

Surveys were conducted at two sampling sites ca. 300 m apart in a contiguous forest tract in Bath County, Kentucky. These sites lay in the Cumberland District of the Daniel Boone National Forest at the juncture of Bath and Menifee counties, which is part of the Western Allegheny Plateau (Level III Ecoregion) and include portions of the Knobs-Lower Scioto Dissected Plateau and the Northern Forested Plateau Escarpment (Level IV Ecoregions) (Woods et al. 2002). The overstory of one site was dominated by eastern hemlock and the other was dominated by deciduous species (*Acer*, *Carya*, and *Quercus* spp.). The hemlock site was found at 38°1'1.26" N, 83°35'25.50" W; the deciduous site was found at 38°1'2.35" N, 83°35'15.25" W. Canopy height of the forest at these two sites were similar; midstory trees (< 12.7 cm DBH) in this area averaged 32 m in height and overstory trees (≥ 12.7 cm diameter at DBH) averaged 53 m in height. The two sites were at similar elevations (283 m and 279 m, respectively).

We sampled the macroarthropod community concurrently at each site over multiple nights in 2010 using 10 W blacklight traps (Universal Light Trap, Bioquip Products, Gardena, CA), focusing on Lepidoptera. A single blacklight trap was placed on the ground at each site and operated from dusk to dawn. Surveys were carried out from 6 May – 15 August and the two sites were each visited five times (n = 10 trap-nights). As per recommendations by Yela and Holyoak (1997), survey nights were fair with temperatures ≥ 16°C at sunset, no precipitation, and low wind. A cotton tuft soaked in ethyl acetate was placed

in each trap to subdue trapped insects. Following a trap night, specimens were sorted and placed in cold storage (4°C) for identification in the laboratory.

Specimens were enumerated and Lepidoptera identified to species (or genus in rarer cases) using Covell (2005), Holland (1903), and reference collections at the University of Kentucky. Voucher specimens were incorporated into existing reference collections. Reports of food habits from Covell (2005) were noted for the most common species as well as those unique to either collection site. Our classification of noctuiods follows that of LaFontaine and Schmidt (2010). We focused our efforts on macrolepidoptera and those microlepidoptera with wings ≥ 20 mm (i.e., some Oecophoridae, Yponomeutidae, Tortricidae, Megalopygidae, Limacodidae, and Pyralidae); thus, our study is not an exhaustive assessment of the assemblage.

We calculated Jaccard's and Sørensen's coefficients of similarity to report the degree of species overlap between the two sites (Southwood 1978). While limited replication across study sites prohibited a statistical test for differences in Lepidopteran occurrence between the deciduous and hemlock sites, repeated sampling permitted testing for seasonal differences in our data. We tested for differences in the abundance and species richness of Lepidoptera captured per trap using the Wilcoxon rank-sum test in SAS (v. 9.1). Additionally, we used EstimateS (v. 8.2) to generate ICE (Lee and Chao 1994) and Chao 2 (Chao 1987) species richness estimations for comparisons between survey sites. Estimations were based on 1,000 randomizations (Summerville and Crist 2005).

Results

A total of 1,020 Lepidoptera was captured. Of these, 559 individuals were captured from the hemlock site and 461 individuals were captured from the deciduous site. Fewer Lepidoptera were captured early in May and June compared to later July and August (Fig. 1).

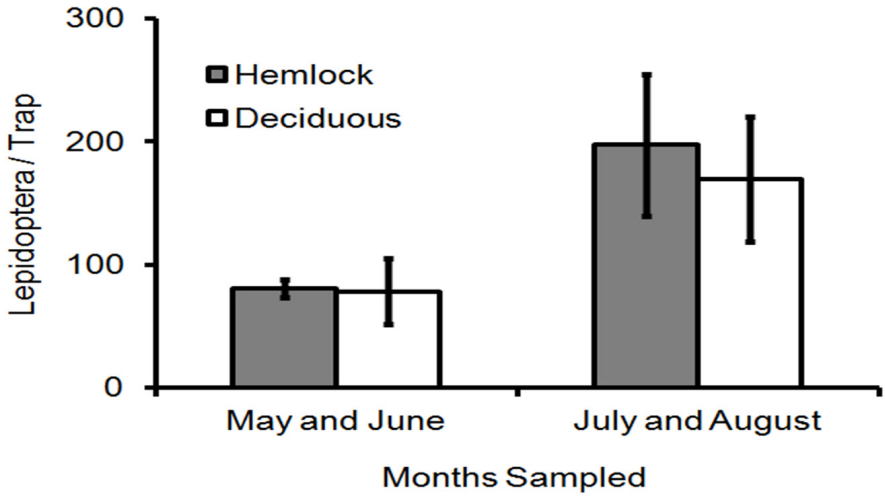

Figure 1. Mean abundance of Lepidoptera ± SE collected with blacklight traps from a hemlock-dominated and a deciduous-dominated forest in the Daniel Boone National Forest, Kentucky, during May-August of 2010. Fewer Lepidoptera were captured in May and June versus July and August ($W = 16.0$, df = 9, $P = 0.02$).

We identified 733 Lepidoptera (72%) beyond the family level, representing ≥ 137 species and 18 families (Table 1). Of these, ≥ 107 species were identified from the hemlock site and ≥ 85 were identified from the deciduous site. No difference in species richness was detected between the early (May and June) and late (July and August) portions of the season ($W = 21.0$, df = 9, $P > 0.05$). The ICE estimates of richness (mean ± std. dev.) were 245 ± 15 and 189 ± 12 species for the hemlock and deciduous forest, respectively. Chao 2 estimates of richness were more conservative, with 216 ± 32 and 162 ± 25 species for the hemlock and deciduous sites, respectively. Geometridae and Erebidae were the most speciose families overall, followed distantly by Noctuidae, Notodontidae, and Limacodidae (Fig. 2). These five families comprised > 75% of the Lepidoptera we identified.

There were 58 species from 13 families ubiquitous to both sites. Most were in the Geometridae and Erebidae (14 and 13 species, respectively). Sørensen's coefficient revealed 60% overlap in species similarity, whereas Jaccard's coefficient revealed a 43% overlap between sites. *Clemensia albata* Packard (Erebidae) was the most abundant species trapped (n = 40); larvae are fairly ubiquitous in mesic woods and feed on tree lichens. Thirty-four individuals were captured at the hemlock site, whereas only 6 were captured at the deciduous site. The second most commonly encountered species was *Palpita magniferalis* (Walker) (Pyralidae) (n = 38). Though larvae feed on ash (*Fraxinus* spp.), adults were captured in approximately equal numbers from both sites.

There were 49 species across 10 families that were unique to the hemlock site; most were in the Erebidae, Geometridae, and Noctuidae (14, 12, and 12 species, respectively). A total of three geometrid species known to specialize on hemlocks and other conifers were unique in their collection at the hemlock site; these included, *Lambdina fiscellaria* (Guenée), *Macaria fissinotata* (Walker), and *M. signaria* (Hübner). A number of erebid detritivores were likewise unique to the hemlock site: *Idia* spp., *Scoleocampa liburna* (Geyer), *Tetanolita mynesalis* (Walker), *Zanclognatha cruralis* (Guenée). Twenty seven species across 11 families were unique to the deciduous site; most were in the Erebidae and Geometridae (14 and 12 species, respectively). Neither unique detritivores, nor conifer specialists were noted in collections at the deciduous site.

Family and species composition shifted over the course of our surveys. Our trapping effort in May – June yielded 81 species, primarily Geometridae and Erebidae (27 and 15 species, respectively). There were three commonly captured species/genera: the geometrid genus, *Iridopsis* (n = 23), as well as the pyralid species, *Desmia funeralis* (Hübner) (n = 13) and *P. magniferalis*, (n = 10). *Iridopsis* spp. feed on a wide variety of herbaceous and woody plants. *D. funeralis* feeds on the eastern redbud (*Cercis canadensis* L., Fabaceae) and native grape (*Vitis* spp.). During July – August, 104 species were captured. While most of these were again Erebidae or Geometridae (27 and 23 species, respectively), the Notodontidae and Noctuidae were also common (14 and 13 species, respectively). This late season trapping yielded many common species/genera (n ≥ 10 individuals) from eight families, including: Drepanidae: *Drepana arcuata* Walker, *P. magniferalis*; Erebidae: *Halysidota tessellaris* (J. E. Smith); Geometridae: *Biston betularia* (L.), *Caripeta divisata* Walker, *C. albata*, *Iridopsis* sp., *Macaria* sp; Limacodidae: *Lithacodes* sp., *Nadata gibbosa* (J. E. Smith); Noctuidae: *Marimatha nigrofimbria* (Guenée), *Polygrammate hebraeicum* Hübner; Notodontidae: *Heterocampa obliqua* Packard, *Peridea basitriens* (Walker); Pyralidae: *D.* funeralis; Saturnidae: *Anisota stigma* (F.), *Datana angusii* Grote and Robinson, *Dryocampa rubicunda* (F.). Nearly twice as many species were exclusively captured during July – August (n = 63) versus those exclusively captured during May – June (n = 34).

Table 1. A checklist of Lepidoptera collected in blacklight traps from a hemlock-dominated and a deciduous-dominated forest in the Daniel Boone National Forest, Kentucky, during May-August of 2010. Values are the sum of individuals captured within specified months. Asterisks denote capture in both forest types, whereas a superscript denotes capture in only hemlock (h) or deciduous forest (d).

Taxon	**Hemlock**		**Deciduous**	
	May-June	**July-Aug.**	**May-June**	**July-Aug.**
APATELODIDAE				
Apatelodes torrefacta (J. E. Smith) *	1	1	3	6
Olceclostera angelica (Grote) *		1	1	
DREPANIDAE				
Drepana arcuata Walker *		11	3	7
Eudeilinia herminiata (Guenée) [h]		2		
Oreta rosea (Walker) *		2	1	1
ELACHISTIDAE				
Antaeotricha spp. [h]		1		
Antaeotricha schlaegari (Zeller) *		7	5	
EREBIDAE				
Allotria elonympha (Hübner) *		2		3
Apantesis sp. *	1	1		2
Cisseps fulvicollis (Hübner) [d]				5
Cisthene sp. [h]		3		
Clemensia albata Packard *	2	32	5	1
Crambidia pallida Packard [d]			2	
Crambidia sp. [h]		1		
Cycnia tenera Hübner *		2		2
Dasychira sp. *		1		8
Euparthenos nubilis (Hübner) [h]		1		
Halysidota tessellaris (J. E. Smith) *	3	11		4
Haploa clymene (Brown) *		3		6
Hypena scabra (F.) [h]	1	1		
Hypoprepia fucosa Hübner [h]	2			
Idia sp. [h]		1		
Orgyia leucostigma (J. E. Smith) *		2	2	1
Palthis sp. [h]		1		
Pangrapta decoralis Hübner [h]		3		
Panopoda carneicosta Guenée [h]	1			
Parallelia bistriaris Hübner [h]		1		
Ptichodis herbarum (Guenée) [d]				1
Pygarctia spraguei (Grote) [h]	4			
Pyrrharctia isabella (J. E. Smith) *	1	2		2
Scoleocampa liburna (Geyer) [h]	2	5		
Spilosoma congrua Walker *	3		1	1
Spilosoma sp. [h]		3		
Spilosoma virginica (F.) *		2		2
Tetanolita mynesalis (Walker) [h]		1		
Virbia opella (Grote) *	1	1	2	
Virbia sp. *		5	2	
Zale sp. [h]		1		
Zanclognatha cruralis (Guenée) [h]	3			

Table 1. Continued.

Taxon	Hemlock		Deciduous	
	May-June	July-Aug.	May-June	July-Aug.
GEOMETRIDAE				
Biston betularia (L.) *		17	1	
Caripeta divisata Walker *		1		12
Costaconvexa centrostrigaria (Wollaston) [h]	4			
Dyspteris abortivaria (Herrich-Schäffer) *	2	1		5
Ecliptoptera atricolorata (Grote & Robinson) *	2			1
Epimecis hortaria (F.) *	2	3	1	
Eubaphe mendica (Walker) [d]			1	
Eulithis diversilineata (Hübner) *		2	1	6
Eutrapela clemataria (J. E. Smith) *	3	4	2	
Euchlaena amoenaria (Guenée) *		1		1
Euchlaena pectinaria (Dennis & Schiffermüller) [h]	3			
Glena cognataria (Hübner) [h]	1			
Glena cribrataria (Guenée) [h]	3	1		
Iridopsis sp. *	8	12	15	
Lambdina fervidaria (Hubner) *	4	5	4	
Lambdina fiscellaria (Guenée) [h]		2		
Macaria sp. [h]		15		
Macaria fissinotata (Walker) [h]	4	1		
Macaria ocellinata (Guenée) [d]				1
Macaria promiscuata Ferguson *	1	1	5	
Macaria signaria (Hübner) [h]	2			
Metarranthis angularia Barnes & McDunnough [d]			1	
Metarrhanthis hypochraria (Herrich-Schäffer) [d]			1	
Metarrhanthis indeclinata (Walker) [h]	1			
Nemoria bistriaria Hübner *		6	2	
Plagodis alcoolaria (Guenée) [d]			1	
Plagodis fervidaria (Herrich-Schäffer) [d]				3
Plagodis phlogosaria (Guenée) [d]			1	1
Plagodis serinaria Herrich-Schäffer [h]	3			
Prochoerodes lineola (Drury) [h]	1	3		
Probole amicaria (Herrich-Schäffer) *		1		4
Speranza coortaria (Hulst) *		3		1
Tetracis sp. [d]			2	
Tetracis cachexiata Guenée [h]	4			
Tetracis crocallata Guenée [h]	2			
Trichodezia albovittata (Guenée) [d]				1
LASIOCAMPIDAE				
Artace cribraria (Ljungh) [d]			3	
LIMACODIDAE				
Apoda biguttata (Packard) *		1	3	
Apoda y-inversum (Packard) *		2	1	
Euclea delphinii (Boisduval) *	1	1	2	

Table 1. Continued.

Taxon	Hemlock		Deciduous	
	May-June	July-Aug.	May-June	July-Aug.
Lithacodes sp. [h]		18		
Lithacodes fasciola (Herrich-Schäffer) *	4		4	
Natada nasoni (Grote) *	1		2	
Parasa chloris (Herrich-Schäffer) [d]			2	
Prolimacodes badia (Hübner) [h]		8		
Torticidia flexuosa (Grote) [d]			2	
MEGALOPYGIDAE				
Lagoa crispata (Packard) [h]	3	8		
NOCTUIDAE				
Abagrotis alternata (Grote) [h]		1		
Acronicta americana (Harris) [h]	1			
Acronicta haesitata (Grote)[d]			6	
Acronicta inclara J. B. Smith [h]		1		
Acronicta funeralis Grote & Robinson [h]	2			
Agrotis ipsilon (Hufnagel) [h]		1		
Cosmia calami (Harvey) [h]		1		
Eudryas grata (F.) *	1	1		1
Feltia jaculifera (Guenée) [h]		1		
Lacinipolia renigera (Stephens) [d]			1	
Leuconycta diptheroides (Guenée) [h]		1		
Marimatha nigrofimbria (Guenée) *		9	1	1
Morrisonia confusa (Hübner) [d]			1	
Orthodes crenulata (Butler) [h]		1		
Polygrammate hebraeicum Hübner [h]		11		
Pseudeustrotia carneola (Guenée) [h]		1		
Spodoptera dolichos (F.) [h]		1		
Xestia dolosa Franclemont *		5		2
NOLIDAE				
Baileya australis (Grote) *	3		1	1
NOTODONTIDAE				
Cerura scitiscripta Walker [h]		2		
Datana angusii Grote & Robinson *	3	5	5	7
Datana contracta Walker *	3	2	1	2
Datana ministra (Drury) [d]				3
Datana perspicua Grote & Robinson [h]		3		
Heterocampa obliqua Packard *	3	4	2	14
Lochmaeus bilineata (Packard) [h]		1		
Lochmaeus manteo Doubleday [h]		1		
Macrurocampa marthesia (Cramer) [d]			2	4
Nadata gibbosa (J. E. Smith) *	3	6	4	8
Nerice bidentata Walker [h]		1		
Oligocentria lignicolor (Walker) [d]				3
Peridea basitriens (Walker) *	2	4	3	14
Symmerista albifrons (J. E. Smith) *	4		2	2

Table 1. Continued.

Taxon	Hemlock		Deciduous	
	May-June	July-Aug.	May-June	July-Aug.
OECOPHORIDAE				
Psilocorsis spp. *	5	2	3	
PYRALIDAE				
Blepharomastix ranalis (Guenée) [d]			1	
Desmia funeralis (Hübner) *	1	25	12	
Galleria mellonella (L.) [h]		3		
Palpita magniferalis (Walker) *	3	14	7	14
Pantographa limata (Grote & Robinson) *	1	6	2	1
SATURNIIDAE				
Actias luna (L.) [d]				2
Anisota stigma (F.) *		3		10
Automeris io (F.)*	2		1	
Callosamia angulifera (Walker) [d]				1
Dryocampa rubicunda (F.) *		1	4	12
Eacles imperialis (Drury) *		1		2
SPHINGIDAE				
Ceratomia undulosa (Walker) *	1		1	
Deidamia inscripta (Harris) [d]			1	
Paonias excaecatus (J. E. Smith) *		2		2
THYATIRIDAE				
Pseudothyatira cymatophoroides (Guenée) [d]			1	
TORTRCIDAE				
Argyrotaenia alisellana (Robinson) [h]		1		
Clepsis melaleucana (Walker) [d]			1	
YPONOMEUTIDAE				
Atteva aurea (Fitch) *		2		1

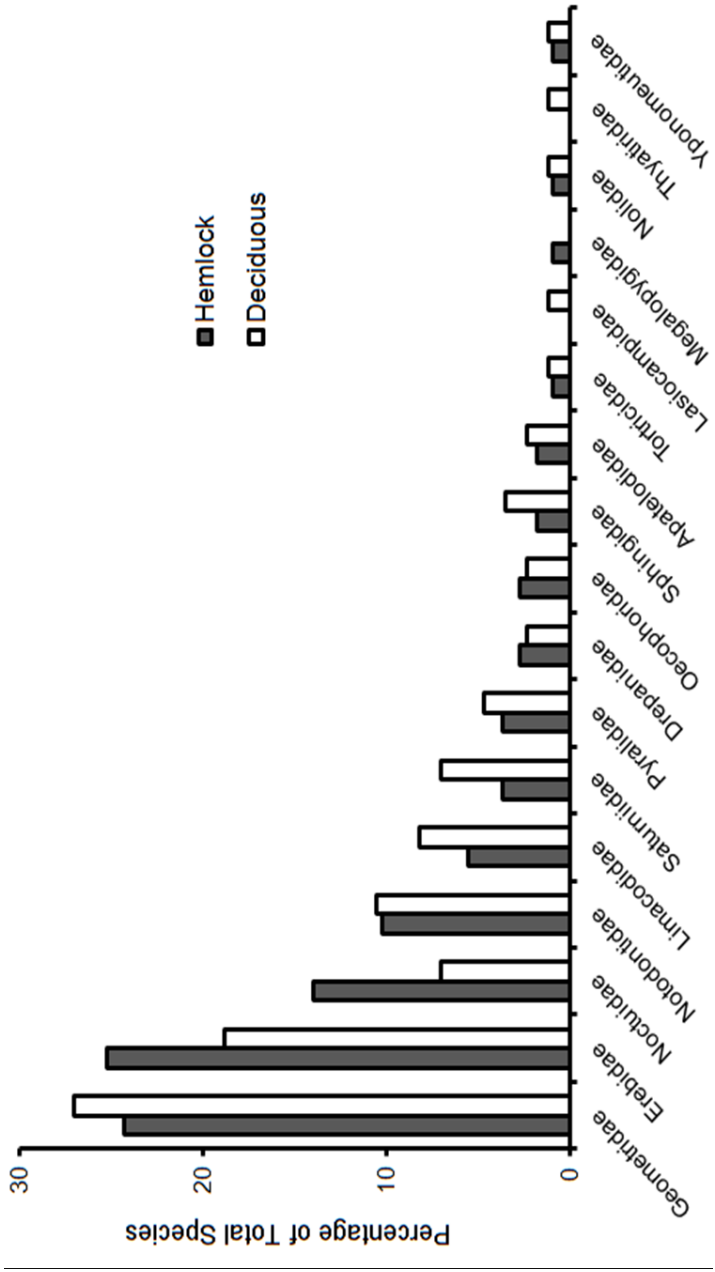

Figure 2. Percent composition of lepidopteran families collected with blacklight traps from a hemlock-dominated and a deciduous-dominated forest in the Daniel Boone National Forest, Kentucky, during May-August 2010.

Discussion

Our data demonstrate that the presence of eastern hemlock contributes significantly to the overall lepidopteran diversity of Appalachian forests. While our species richness estimates indicate that our survey was far from comprehensive, it is clear that both hemlock and deciduous forests possess rich lepidopteran assemblages. It is notable that nearly twice as many species were unique to our hemlock site than our deciduous site and that a number of these species were either detritivores or conifer specialists. This implies that on a limited spatial scale hemlock-dominated habitats may possess a suite of Lepidoptera not found in habitats with a deciduous overstory. This supports results from other studies. In its role as a foundation species in eastern North America, eastern hemlock maintains a distinct community of benthic, riparian and canopy arthropod associates. Over 200 insect and 33 mite species are reportedly associated with hemlock in central Appalachia (Wallace and Hain 2000, Buck et al. 2005, Dilling et al. 2007, Turcotte 2008, J. K. Adkins and L. K. Rieske *unpublished data*), and hemlocks support greater spider abundance, richness, diversity and evenness than do deciduous canopies (Mallis and Rieske 2011), including several species unique to hemlock (Aiken and Coyle 2000). Our results must be interpreted with caution, however, as many Lepidoptera are strong fliers and their appearance in traps associated with a given forest type may not indicate resident populations.

Dodd et al. (2012) found lepidopteran abundance and diversity in the hardwoods of Central Appalachia to be higher after May. While we found that Lepidoptera were more abundant later in the sampling period, we failed to detect differences in overall species richness. Even so, our data demonstrate a high amount of turnover in the occurrence of species over the sampling period. Further, we observed more common species in July and August, suggesting a more even lepidopteran assemblage later in the season. Our data underpin the recommendations by Summerville and Crist (2005), that in order to capture much of the local variation in lepidopteran occurrence studies must span a wide window of time in order to adequately inventory species.

Our study forms a foundation for understanding species richness patterns of Lepidoptera in hemlock forests in North America and is a useful baseline for comparisons of richness and diversity post invasion by the hemlock woolly aldegid. The adelgid is expanding its geographic range at an alarming rate, and hemlock forests in eastern North America are at risk. Given the potential for direct and indirect impacts of this invasion on Lepidoptera and other arthropods (Dilling et al. 2009), baseline knowledge of species occurrence is essential. Such knowledge can help land managers assess impacts and mitigate effects of current and future invasions on forest health and forest sustainability.

Acknowledgments

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