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ARTHROPOD DIVERSITY ASSOCIATED WITH OLD AND SECONDARY GROWTH EASTERN HEMLOCK (*TSUGA CANADENSIS*) IN THE GREAT SMOKY MOUNTAINS NATIONAL PARK

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Abstract: Prior to the introduction of the hemlock woolly adelgid (HWA), *Adelges tsugae* Annand, into the Great Smoky Mountains National Park (GSMNP), the diversity and seasonal abundance of arthropods (insects and spiders) associated with two old growth and two secondary growth stands of eastern hemlock, *Tsuga canadensis* (L.) Carrière, were assessed. A total of 8,071 insects and 191 spiders was sampled, and both groups were found to be more abundant in secondary growth than in old growth hemlock stands. Insect samples were dominated by the orders Diptera and Lepidoptera, accounting for over 75% of all insect specimens. Spider collections were dominated by three species (*Pirata montanus* Emerton, *Wadotes tennesseensis* Gertsch, and *W. hybridus* Emerton) that accounted for over 50% of all spider specimens. Shannon-Weiner diversity and evenness values for insect families and spider species did not differ greatly by hemlock stand type. Seasonal abundance of insect families in light traps was found to be highest in the summer while the abundance of insect families in pitfall traps varied little throughout the study.

Key Words: Eastern hemlock; *Tsuga canadensis*; Hemlock Woolly Adelgid; *Adelges tsugae*.

INTRODUCTION

Eastern hemlock, *Tsuga canadensis* (L.) Carrière, is a slow-growing, long-lived conifer whose native range extends throughout the eastern United States and Canada. It grows at elevations ranging from near sea level to more than 1,500 m and occupies multiple forest types from the Maritimes west to Minnesota and south along the Appalachian Mountain range from Maine to Georgia (Farjon 1990; Godman and Lancaster 1990). Although it was harvested routinely in the early 1900s, slow growth and mediocre wood quality limit its economic usefulness. However, eastern hemlock is widely recognized as an ecologically important and aesthetically pleasing species. Dense shade and acidic soil conditions under hemlock dominated forest canopies create a habitat where only a handful of herbaceous and woody plant species are adapted for survival (Quimby 1996). These areas are also ideal roosting and nesting sites for a number of avian species and provide an important source of forage and cover for wild turkey and deer (Quimby 1996; Ross et al. 2004; Lishawa et al. 2007). Eastern hemlock, where it occurs as a riparian species, plays a vital role in soil stabilization and helps maintain water quality and temperature at conditions optimal for native brook trout, aquatic insects, and amphibians (Brooks 2001; Snyder et al. 2002; Ross et al. 2003). Hemlocks are also an important component of many recreation and scenic areas throughout the Appalachian region (Quimby 1996), and with numerous cultivars available, they are of great value to the nursery industry (Swartley 1984).

A number of factors threaten the stability and long-term survival of hemlock ecosystems in the eastern United States, including exotic insects, periodic severe droughts, wildfires, suburban development, and climate change. Most important among these is the hemlock woolly adelgid (HWA), *Adelges tsugae* Annand, an exotic insect pest that in recent years has caused widespread mortality of eastern hemlock throughout the mid-Atlantic and southern Appalachian regions (McClure et al. 2001). The adelgid was first described from specimens collected on western hemlock (*T. heterophylla* Sargent) in California and Oregon (Annand 1924) where it now is thought to be native (Havill et al. 2006). It most likely was introduced to the eastern U.S. sometime between 1920 and 1950 on *T. sieboldii* nursery stock imported from Japan and planted in Richmond, Virginia (Souto et al. 1996; Stoetzel 2002). Since that time, HWA has spread to 17 eastern states from Maine to Georgia and currently infests approximately 50% of eastern hemlock ecosystems where it can kill trees in as little as four years (McClure et al. 2001).

The Great Smoky Mountains National Park (GSMNP) straddles a portion of the border between North Carolina and Tennessee, encompassing over 200,000 ha of forested habitat in the southern Appalachian Mountains and boasts the largest biodiversity of flora and fauna found in any one place in the eastern

U.S. This includes one of the largest pockets of both old and secondary growth eastern hemlock forest found within the species' native range. Hemlock grows, in total, on over 35,000 ha in multiple forest types with more than 2,000 ha occurring as pure hemlock (Johnson et al. 2005). The first infestations of HWA at GSMNP were found near Fontana Lake in 2002. Park resource managers, 10 yrs prior to this in 1992, initiated an effort to map the hemlock forests at GSMNP and document the associated flora and fauna in advance of the adelgid (Johnson et al. 2000). Included in this effort was a project to survey and identify the unknown community of arthropods that occupy the eastern hemlock ecosystems within the park. The goal was to develop fundamental knowledge of the seasonal abundance, natural variations, and locations of the species present to help guide decisions about the use of insecticides and biological controls once HWA arrived in the park. We report on a portion of this effort and present the results of light and pitfall trap field surveys to identify arthropods associated with old and secondary growth eastern hemlock stands within GSMNP.

MATERIALS AND METHODS

Survey Plots

Arthropod sampling plots were established in hemlock dominated forest stands at four locations within GSMNP, two in old growth stands (Inadu Knob and Cataloochee) and two in secondary growth stands (Elkmont and Cosby Creek). Inadu Knob, Cataloochee, and Cosby Creek are all located in the eastern portion of the park, and Elkmont is in the central portion. Within each of the four stands, 16 0.1-acre circular plot-monitoring stations were established at representative sites, each separated by a distance of 20 m. A total of 64 monitoring stations, 32 in old growth and 32 in secondary growth, were set. The design allowed sampling of all 64 stations within a one-week period. Arthropod surveys were conducted 5–8 June 1995, 19–21 July 1995, 3–8 September 1995, and 22–26 April 1996.

Survey Techniques

Light trap sampling consisted of placing one battery-powered UV light trap in one, centrally located monitoring station in each of the four hemlock stands on successive nights during each sampling week. Insects attracted to the light trap were captured for one hour after sunset with aerial nets or by hand from a white sheet hung near the light. Thereafter for the remainder of the night, insects attracted to the light were capture in a soapy water filled reservoir attached below the trap. Pitfall trap sampling consisted of placing five traps in an X-pattern in the center of each of the 64 monitoring stations. Insects were captured using soapy water, and traps were left in place for one 24 hr period during each sampling week.

Specimen Processing

Insect specimens captured at UV light traps by hand or aerial nets were pinned and labeled with the site, date, and method of collection. Those caught in the soapy water reservoirs were placed in similarly labeled vials of alcohol. Among specimens captured in pitfall traps, the larger hard-bodied insects were air dried and then pinned and labeled as above. Smaller soft-bodied insects and spiders were placed in labeled vials of alcohol. All insect specimens were identified at N.C. State University with assistance from taxonomic specialists in the NCSU Department of Entomology. Spider specimens, all of which were captured in pitfall traps, were sent to Dr. Frederick A. Coyle, now Professor Emeritus of Biology at Western Carolina University (Cullowhee, NC), for identification.

DATA SUMMARY AND ANALYSIS

A database of all arthropod specimen data was created using Microsoft Excel®. Data for insects consisted of order, family, sampling site, sampling date, sampling method, and number of specimens (Table 1). Spider data included family, genus, species, author, sampling site, sampling date, and number of specimens (Table 2). The insect database was sorted to determine the relative abundance of insect orders over all sampling sites, dates, and methods, and the total number of insect families captured at each sampling site on each sampling date in light (Fig. 1) and pitfall (Fig. 2) traps. The relative diversity (H') and evenness (E) of arthropods was estimated by the Shannon-Weiner Index using the Ecological Measures computer program (Kotila 1986). Insect diversity and evenness values were determined for each sampling site and method individually and for all sites and methods together (Table 3). Spider diversity and evenness were estimated for each site individually and all sites together (Table 3).

RESULTS AND DISCUSSION

Insect Diversity

Overall, 8,071 insect specimens were collected representing 142 families and 11 orders from hemlock stands in GSMNP during this survey (Table 1). The number of insects sampled from secondary growth stands (4,931 specimens from 123 families and 10 orders) was greater than from old growth stands (3,140 specimens from 85 families and 9 orders). The number of insects sampled

Table 1. Insect families associated with old and secondary growth eastern hemlock in the Great Smoky Mountains National Park.

Order	Family	Site[a]	Date[b]	Method[c]	*n*
Blattaria	Cryptocercidae	IK	2,3	PF	2
Coleoptera	Agyrtidae	Elk	1	PF	2
	Alleculidae	Cat,Elk	1, 2	LT	4
	Anobiidae	Cos	2	LT	1
	Anthribidae	IK	4	PF	2
	Byrrhidae	IK	2	PF	1
	Cantharidae	Cat,Cos,Elk,IK	1,2,4	LT	34
	Carabidae	Cat,Cos,Elk,IK	1,2,3,4	LT,PF	433
	Cerambycidae	Cat,Cos,Elk	1,2	LT	6
	Cerylonidae	Cos	3	LT	1
	Chrysomelidae	Cat,Cos,Elk,IK	1,2,3,4	LT,PF	26
	Cicindelidae	Elk	4	PF	1
	Cleridae	Elk,IK	1,2	LT	2
	Coccinellidae	Cos,Elk,IK	2,3,4	LT	4
	Curculionidae	Cat,Cos,Elk	2,3,4	LT,PF	12
	Dermestidae	Elk	3	PF	1
	Elateridae	Cat,Cos,Elk,IK	1,2	LT,PF	33
	Erotylidae	Cat,Cos,Elk	1,2,3	LT,PF	4
	Histeridae	Elk	2	PF	1
	Lampyridae	Cat,Cos,Elk,IK	1,2	LT,PF	32
	Lucanidae	Cat	2	LT	1
	Lycidae	Cat,IK	1,4	LT,PF	4
	Melandryidae	Cat,Cos	1,2	LT	5
	Mycetophagidae	Cos	2	LT	1
	Phalacridae	Cat	2	LT	1
	Pselaphidae	Elk	2	LT	3
	Pyrochroidae	Cos,Elk,IK	1,2	LT	7
	Rhysodidae	IK	2	PF	1
	Scarabaeidae	Cat,Cos,Elk,IK	1,2,3,4	LT,PF	25
	Silphidae	Cat,Cos,Elk,IK	1,2,4	LT,PF	43
	Staphylinidae	Cat,Cos,Elk,IK	1,2	LT,PF	8
Diptera	Anisopodidae	Cat,Cos,IK	2,4	LT,PF	18
	Anthomyiidae	Cat,Cos,Elk,IK	1,3,4	LT,PF	10
	Bombyliidae	IK	4	PF	1
	Calliphoridae	Cat,Elk,IK	2,3	LT,PF	9
	Camillidae	IK	4	LT	1
	Cecidomyiidae	Cat,Cos,Elk	2,3,4	LT	68
	Ceratopogonidae	Cat,Cos,Elk,IK	1,2,3,4	LT	147
	Chironomidae	Cat,Cos,Elk,IK	2,3,4	LT	2,167
	Conopidae	Elk	4	PF	1
	Culicidae	Cat,Cos,Elk	1,2,3	LT	9
	Dixidae	Cat	2,4	LT	18
	Dolichopodidae	Cat,Cos,Elk	1,2	LT	11
	Drosophilidae	Cat,Cos,Elk	1,2	LT	27
	Empididae	Cat,Cos,Elk,IK	1,2,3,4	LT	305
	Ephydridae	Elk	1	LT	29
	Heleomyzidae	Cos,Elk	1,2	LT	7
	Muscidae	Cat,Cos,Elk,IK	1,2,3,4	LT,PF	43
	Mycetophilidae	Cat,Cos,Elk,IK	1,2,3,4	LT	197
	Oestridae	Cos,Elk	1,2	LT,PF	3
	Phoridae	Cat,Cos,Elk,IK	1,2,3,4	LT,PF	137
	Pipunculidae	Cat,Elk	1,2,3	LT,PF	3
	Psychodidae	Cat,Cos	2,3,4	LT	20
	Rhagionidae	Cos,Elk,IK	1,2,3,4	LT,PF	16
	Sarcophagidae	Cos,Elk	2,4	PF	2
	Scathophagidae	Cos,Elk	2,3	LT,PF	4
	Sciaridae	Cat,Cos,Elk,IK	1,2,3,4	LT	195
	Sciomyzidae	Elk,IK	3	LT,PF	3
	Sepsidae	Elk	4	PF	1
	Simuliidae	Cos,Elk	1,2,3,4	LT	11
	Syrphidae	Cat	2	LT	1
	Tabanidae	Elk	2	LT	3

Table 1. Continued.

Order	Family	Site[a]	Date[b]	Method[c]	*n*
Diptera	Tachinidae	Cat,Cos,IK	2,4	LT,PF	6
	Tanyderidae	Elk	4	PF	3
	Therevidae	Elk	1,2	LT,PF	2
	Tipulidae	Cat,Cos,Elk,IK	1,2,3,4	LT	220
	Trichoceridae	IK	4	PF	1
	Xylophagidae	Elk	4	PF	1
Ephemeroptera	Heptageniidae	Cos,Elk	2,4	LT	2
	Leptophlebiidae	Cos	4	LT	2
Hemiptera	Aphididae	Elk,IK	1,2	LT	2
	Cercopidae	Elk	2	LT	7
	Cicadellidae	Cos,Elk	1,2,3	LT	3
	Cixiidae	IK	1,4	LT,PF	2
	Derbidae	Elk	1	LT	1
	Issidae	Elk	2	LT	1
	Lygaeidae	Elk	4	PF	2
	Miridae	Cos,Elk	1,2	LT,PF	4
	Pentatomidae	IK	2	LT	1
	Piesmatidae	Cos	4	PF	1
	Reduviidae	Cos,Elk	3,4	PF	2
Hymenoptera	Andrenidae	IK	4	PF	11
	Anthophoridae	Elk	4	PF	6
	Apidae	Elk	4	PF	1
	Bethylidae	Elk	3	PF	1
	Braconidae	Elk,IK	3	LT,PF	16
	Bradynobaenidae	Elk	3	PF	1
	Chalcididae	Elk	3	PF	5
	Colletidae	Cat,Cos,Elk	1,2,3,4	PF	5
	Cynipidae	Elk	1	LT	2
	Eucoilidae	Elk	3	PF	5
	Figitidae	Elk	3	PF	1
	Formicidae	Cat,Cos,Elk,IK	1,2,3,4	LT,PF	409
	Gasteruptiidae	Elk	3	LT	2
	Halictidae	Cos	1	PF	1
	Ichneumonidae	Cat,Cos,Elk,IK	1,2,3,4	LT,PF	22
	Megachilidae	Elk	4	PF	3
	Melittidae	Cat,Elk	3,4	PF	11
	Pompilidae	Elk	3	PF	1
	Scelionidae	Cos	3	PF	1
	Sphecidae	Elk	3,4	PF	9
	Tiphiidae	Elk,IK	1,3,4	PF	5
	Trigonalidae	Elk	2,4	PF	2
Lepidoptera	Apatelodidae	Cat	2	LT	1
	Arctiidae	Cat,Cos,Elk,IK	1,2,3,4	LT,PF	102
	Blastobasidae	Cos	2	LT	11
	Drepanidae	Cat,Cos,Elk,IK	1,2,3,4	LT	41
	Geometridae	Cat,Cos,Elk,IK	1,2,3,4	LT,PF	1,190
	Hepialidae	Cos,Elk	1	LT	2
	Hesperiidae	Elk	3	PF	1
	Hyblaeidae	Cos	2	LT	11
	Lasiocampidae	Cat,Cos,Elk,IK	1,2,3,4	LT	20
	Limacodidae	Cat,Cos,Elk,IK	1,2,3	LT	23
	Lymantriidae	Cat,Cos,Elk,IK	1,2,3,4	LT	32
	Noctuidae	Cat,Cos,Elk,IK	1,2,3,4	LT,PF	496
	Notodontidae	Cat,Cos,Elk,IK	1,2,3,4	LT	115
	Oecophoridae	Cat	2	LT	4
	Papilionidae	Cat,Cos,Elk	3,4	LT,PF	3
	Pyralidae	Cat,Cos,Elk,IK	1,2,3	LT,PF	271
	Saturniidae	Cat,Cos,Elk	1,2	LT	14
	Sphingidae	Cat,Cos,Elk,IK	1,2,3,4	LT	28
	Thyatiridae	Cat,Cos,Elk	1,2,4	LT	104

Table 1. Continued.

Order	Family	Site[a]	Date[b]	Method[c]	*n*
Lepidoptera	Tineidae	Cat,Elk	3	LT	2
	Tortricidae	Cat,Cos,Elk,IK	1,2,3,4	LT	32
	Zygaenidae	Cos	2	LT	1
Neuoptera	Corydalidae	Elk	1	LT	7
	Chrysopidae	Cos	2	LT	1
Orthoptera	Gryllacrididae	Cat,Cos,Elk,IK	1,2,3,4	LT,PF	323
	Gryllidae	Elk	2	LT	1
	Tettigoniidae	Cat,Cos,Elk,IK	2,3	LT	8
Plecoptera	Capniidae	Elk	1	LT	2
	Leuctridae	IK	3	LT	1
	Perlidae	Cat,Cos,Elk	1,2	LT	36
	Perlodidae	Cat,Elk	1,3	LT	2
Trichoptera	Hydropsychidae	Cat,Cos.Elk,IK	1,2,3	LT	36
	Leptoceridae	Elk	1	LT	3
	Limnephilidae	Cat,Cos,Elk,IK	1,2,3	LT	91
	Philopotamidae	Cat,Elk	1,2,3	LT	23
	Phryganeidae	Cat,Cos,Elk	1,2,3	LT	5
	Polycentropodidae	Cat,Cos,Elk	1,2,3	LT	43
	Psychomyiidae	Elk	1,2	LT	27
	Rhyacophilidae	Elk	1,3	LT	7

[a] Field Sites: Cat = Cataloochee (old growth); Cos = Cosby Creek (secondary growth); Elk = Elkmont (secondary growth); IK = Inadu Knob (old growth).
[b] Sampling Dates: 1 = 5–8 June 1995; 2 = 19–21 July 1995; 3 = 3–8 September 1995; 4 = 22–26 April 1996.
[c] Sampling Methods: LT = Light Trap; PF = Pitfall Trap.

from light traps (6,766 specimens from 106 families and 10 orders) was greater than from pitfall traps (1,305 specimens from 68 families and 7 orders). The orders Diptera and Lepidoptera dominated the survey, accounting for over 75% of all specimens collected. Other insect orders captured included Coleoptera (8.6%), Hymenoptera (6.44%), Orthoptera (4.1%), Trichoptera (2.91%), Plecoptera (0.51%), Hemiptera (0.32%), Neuroptera (0.10%), Ephemeroptera (0.05%), and Blattaria (0.02%).

Several studies have evaluated the insects associated with eastern hemlock with a focus on predators (Montgomery and Lyons 1996; Wallace and Hain 2000), guild structure (Dilling et al. 2007), and species abundance and diversity (Buck et al. 2005). Studies that focused on predators were conducted to evaluate the biological control potential of native and naturalized insects for HWA management in the eastern U.S. The most common natural enemies found feeding on the adelgid in these surveys were from the families Cecidomyiidae, Chrysopidae, Coccinellidae, Hemerobiidae, and Syrphidae, but none were present at high enough densities to provide effective control of HWA (Montgomery and Lyons 1996; Wallace and Hain 2000). All but one of these families, Hemerobiidae, were captured in our study, and for all but Cecidomyiidae fewer than five specimens were caught (Table 1). Interestingly, although native natural enemies are now recognized as ineffective for adelgid control, Dilling et al. 2007 found predators to be the third most common insect guild associated with eastern hemlock in the southern Appalachian Mountains.

Buck et al. 2005 also surveyed the insect associates of eastern hemlock at GSMNP and evaluated the seasonal abundance and diversity of insects associated with old growth and secondary growth stands. Overall, they collected fewer insect specimens (2,832) and families (101) and one less insect order using a combination of Malaise, pitfall, and direct sampling. Eight orders were common to both studies, with Psocoptera and Mecoptera unique to Buck et al. and Ephemeroptera, Plecoptera, and Trichoptera unique to ours (Table 1). Both studies found less insect diversity associated with pitfall traps than with other means of sampling. Buck et al. reported fewer specimens and significantly less species diversity captured in pitfall compared to Malaise traps and direct sampling. Similarly, in our survey the Shannon-Weiner index for the diversity of insect families captured in pitfall traps was lower than for light traps (Table 3).

Our study differed from Buck et al. 2005 in the seasonal abundance and numbers of insect specimens associated with old and secondary growth stands of eastern hemlock. Buck et al. found the seasonal abundance of insect species to be highest in the early spring and fall months. Our survey found the seasonal abundance of insect families associated with light traps to be highest during July and lowest in the fall and

Table 2. Spiders associated with old and secondary growth eastern hemlock in the Great Smoky Mountains National Park. All specimens were collected in pitfall traps.

Family	Genus	Species	Author	Site[a]	Date[b]	*n*
Amaurobiidae	*Callioplus*	*pantoplus*	(Bishop & Crosby)	Cos	1,3	2
	Coras	*aerialis*	Muma	Cat	4	2
	Wadotes	*calcaratus*	(Keyserling)	Cos,Elk	1,3,4	11
	Wadotes	*dixiensis*	Chamberlin	Cat,Elk	4	2
	Wadotes	*hybridus*	(Emerton)	Cos,Elk	3,4	19
	Wadotes	*tennesseensis*	Gertsch	Cat,Elk,IK	2,3	25
Antodiaetidae	*Antrodiaetus*	*unicolor*	(Hentz)	Cos	2,3	8
Araneidae	*Neoscona*	*arabesca*	(Walckenaer)	Cat	2	1
Corinnidae	*Scotinella*	*redempta*	(Gertsch)	Cat,Cos,Elk	1,3	3
Cybaeidae	*Cybaeus*	*patritus*	Bishop & Crosby	Cos,Elk	2,3	7
Dictynidae	*Cicurina*	*breviaria*	Bishop & Crosby	IK	4	1
	Cicurina	*arcuata*	(Keyserling)	Cos,Elk	1,2,4	3
Gnaphosidae	*Drassyllus*	*fallens*	Chamberlin	Elk	1	1
Leptonetidae	*Leptoneta*	sp.		Cos	2	1
	Leptoneta	*gertschi*	(Barrows)	Cos	2	2
Linyphiidae	*Bathyphantes*	*bishopi*	Ivie	Cat,Cos,IK	1,2,3	6
	Eperigone	*maculata*	(Banks)	Elk	3	1
	Lepthyphantes	*zebra*	(Emerton)	Elk	4	1
	Meioneta	sp.		Elk	4	7
	Pocadicnemis	*americana*	Millidge	IK	4	1
	Walckenaeria	*minuta*	(Emerton)	Elk	4	2
	Walckenaeria	*brevicornis*	(Emerton)	Elk	4	9
	Walckenaeria	*pallida*	(Emerton)	Elk	4	2
Linyphiidae	?	?		IK	4	2
Lycosidae	*Pirata*	*montanus*	Emerton	Cat,Cos,Elk	1,2,3	59
Nesticidae	*Nesticus*	*tennesseensis*	(Petrunkevitch)	Cat,Cos	1,2	2
Pisauridae	*Dolomedes*	*tenebrosus*	(Hentz)	Cat	3	1
Salticidae	*Habrocestum*	*parvulum*	(Banks)	Elk,IK	1,4	3
	Habrocestum	*pulex*	(Hentz)	Elk	1	1
Tengellidae	*Liocranoides*	sp.		Cat,Cos,Elk	1,3,4	4
Tetragnathidae	*Leucauge*	*venusta*	(Walckenaer)	Cos,IK	1,2	2

[a] Field Sites: Cat = Cataloochee (old growth); Cos = Cosby Creek (secondary growth); Elk = Elkmont (secondary growth); IK = Inadu Knob (old growth).

[b] Sampling Dates: 1 = 5–8 June 1995; 2 = 19–21 July 1995; 3 = 3–8 September 1995; 4 = 22–26 April 1996.

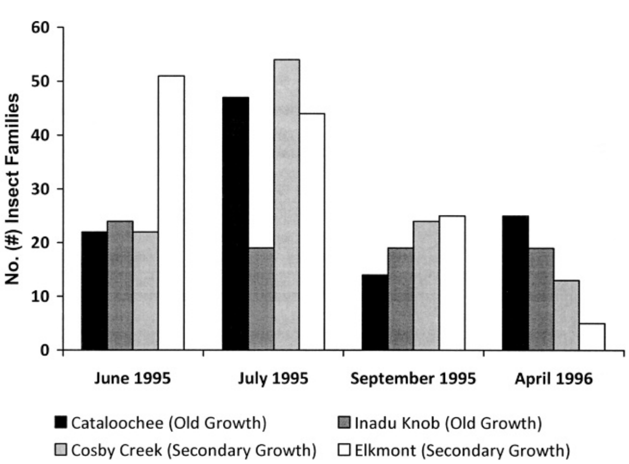

FIG. 1. Seasonal abundance of insect families captured in light traps associated with old and secondary growth stands of eastern hemlock in the Great Smoky Mountains National Park.

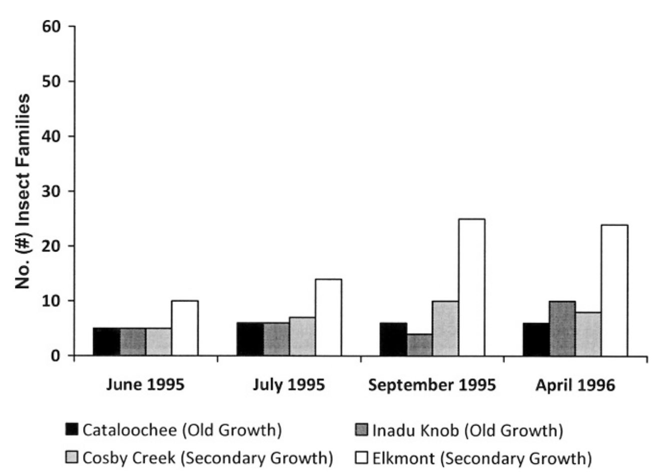

FIG. 2. Seasonal abundance of insect families captured in pitfall traps associated with old and secondary growth stands of eastern hemlock in the Great Smoky Mountains National Park.

Table 3. Shannon-Weiner diversity (H′) and evenness (E) values for insect families and spider species associated with eastern hemlock in the Great Smoky Mountains National Park.

	Shannon's H′	Shannon's E
Insect Families		
Cataloochee—Old Growth	1.192	0.655
Inadu Knob—Old Growth	1.048	0.597
Cosby Creek—Secondary Growth	1.070	0.569
Elkmont—Secondary Growth	1.443	0.709
Light Traps	1.192	0.589
Pitfall Traps	0.882	0.481
All Sites/Sampling Methods	1.306	0.607
Spider Species		
Cataloochee—Old Growth	0.826	0.866
Inadu Knob—Old Growth	0.490	0.630
Cosby Creek—Secondary Growth	0.908	0.815
Elkmont—Secondary Growth	0.828	0.687
All Sites	1.058	0.739

spring (Fig. 1). The seasonal abundance of insect families associated with pitfall traps varied little by site throughout the study (Fig. 2). Additionally, we captured greater numbers of insect specimens from secondary growth stands while Buck et al. sampled higher abundance of specimens in old growth stands. However, neither our study (Table 3) nor Buck et al. found the diversity and evenness of insects, as estimated by the Shannon-Weiner index, to differ greatly by hemlock stand type.

Shannon-Weiner diversity indices calculated for insects associated with eastern hemlock at GSMNP were much lower (0.882–1.306) in our study compared to those of Buck et al. 2005 (3.62–4.51). However, interpretation of this difference is difficult for two reasons. First the bulk of the insects sampled by Buck et al. were from Malaise traps, whereas light trap samples dominated our catch. Comparing subsets of specimens from different trap types is tenuous because of sampling biases resulting from insect behavior, activity, and size, among other factors. Second, our diversity indices were based on specimen identifications to the family level, whereas Buck et al. identified specimens to the species level, and breaking each family down to individual species would be expected to change the diversity estimate.

Further complicating comparisons between these complementary studies is the fact that our study was conducted seven years prior to the first report of HWA within the GSMNP and may better represent the arthropod associates of healthy hemlock stands within the park. Buck et al. 2005 made their arthropod surveys in 2002 and 2003, during the first two years of documented adelgid infestations (Johnson et al. 2005). The patterns of insect abundance and diversity that they report may be influenced by stand decline related to HWA and a second exotic pest of eastern hemlock, the elongate hemlock scale (*Fiorinia externa* Ferris), first discovered in the park during the same survey (Buck 2004).

Spider Diversity

Overall, 191 spider specimens were collected in pitfall traps located in hemlock stands at GSMNP (Table 2). Similar to our results for insect sampling, more spiders were captured in secondary growth (149) than in old growth (42). All but 14 individuals were identified to the species level (n = 27 species). Of those 14, two specimens were classified to the family level and 12 were identified to genus (Table 2). The most abundant species were *Pirata montanus* Emerton, *Wadotes tennesseensis* Gertsch, and *W. hybridus* Emerton that accounted for over 50% off all spiders sampled. Shannon-Weiner diversity and evenness values for the spiders did not differ greatly among old growth and secondary growth hemlock sites (Table 3).

Spider communities associated specifically with eastern hemlock in the United States have not been well studied, but the identities, habitat distribution, and life histories of many of those found in GSMNP have been documented (Aiken and Coyle 2000; Davis and Coyle 2001; Stiles and Coyle 2001). In total, 461 species of spiders have been identified in the park as part of the All Taxa Biodiversity Inventory (ATBI), and the 27 spider species identified in our survey are included in the GSMNP Spider Checklist maintained by DicoverLife.org.

CONCLUSIONS

Our survey of the arthropod associates of eastern hemlock in GSMNP yielded a total of 8,262 specimens (8,071 insects and 191 spiders) from a combination of light and pitfall traps, and all specimens and given to the park for cataloging in their permanent biological collection. More arthropods were captured in secondary growth hemlock stands than in old growth stands, although, analyses of community structure indicated that the diversity of insect families and spider species did not differ greatly by stand type. The GSMNP began the All Taxa Biodiversity Inventory (ATBI) in 1998 to identify, map, and catalog all flora and fauna within the park boundaries with an emphasis on endangered ecosystems. Our survey, augmenting those by Buck et al. 2005 and Dilling et al. 2007, provides a description of the arthropod fauna found in eastern hemlock ecosystems in the park that are currently threatened by HWA. These data can be used to guide management decisions for adelgid control at GSMNP through the evaluation of potential non-target effects of biological control agents and insecticides currently used to combat this invasive insect pest.

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