

SHENANDOAH NATIONAL PARK
ASSESSMENT OF BIODIVERSITY
ASSOCIATED WITH EASTERN HEMLOCK FORESTS

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Introduction

The eastern hemlock (*Tsuga canadensis*) is a shade-tolerant, late-successional conifer that provides unique riparian and upland habitat in the deciduous forest landscape (DeGraaf et al. 1992). Hemlocks influence microclimate, soil chemistry, and forest floor environment, and contribute to regional diversity (Benzinger 1994). The eastern hemlock may be particularly important in the mid-Atlantic region, where it is one of few native conifers found within the eastern deciduous forest and a major component of many remaining old-growth forest stands.

Because the eastern hemlock is a long-lived “climax” species, some plants and animals may have evolved in association with hemlock stands (Benzinger 1994). For example, several bird species, such as solitary vireo (*Vireo solitarius*), black-throated green warbler (*Dendroica virens*), and blackburnian warbler (*Dendroica fusca*) depend on, or strongly prefer, hemlock habitats (Benzinger 1994). Water shrews (*Sorex palustris*), a species of special concern in the northeast, also have been found to be closely associated with hemlock stands (Sciascia and Pehak 1995). At Shenandoah National Park (Shenandoah NP), the Federally-endangered Shenandoah salamander (*Plethodon shenandoah*) occurs in dense hemlock stands (Mitchell 1991, Watson et al. 1994). In addition, plant species, such as painted trillium (*Trillium undulatum*), grow primarily under the canopy of hemlock trees (Radford et al. 1968). Because riparian hemlocks shade adjacent waters and help to maintain cool instream temperatures, many streams that support naturally reproducing populations of brook trout (*Salvelinus fontinalis*) are associated with hemlock forests (Ross and Bennett 1993). Aside from their ecological qualities, eastern hemlock stands are highly valued for their aesthetic and recreational appeal.

At Shenandoah NP, the aesthetic, recreational, and ecological values of hemlock stands are threatened by the hemlock woolly adelgid (*Adelges tsuga* Annands; HWA). The HWA was first detected in Shenandoah NP in the winter of 1988 and now infests all eastern hemlock stands at Shenandoah NP, causing significant mortality of hemlock trees (Watson et al. 1992). Biodiversity associated with hemlock stands could be at risk if the current trend of HWA infestation and resulting mortality continues. The National Park Service endeavors to protect and maintain the natural heritage of its lands, particularly under the threat of an invasive exotic species such as the HWA.

Baseline information on the biotic components of hemlock ecosystems is fundamental to the protection and restoration of biodiversity and to the maintenance of ecosystem dynamics in hemlock stands at Shenandoah NP. The objectives of this study were to collect information on the biotic components of hemlock ecosystems at Shenandoah NP using the ecosystem profile method (Mahan et al. 1998), and to test the use of the ecosystem profile method.

Study Sites

Within Shenandoah NP, potential hemlock and hardwood forest stands were selected based on a sampling design method developed by researchers at the United States Geological Survey (USGS) Biological Resources Division (BRD) Leetown Science Center (Smith et al. 1996). Using this method, hemlock stands were clustered into three topographic types (clusters 1, 2, or 3) based on landscape attributes. Cluster 1 stands were termed bench stands and were relatively low gradient sites. Cluster 2 stands were termed ravine stands and were steep sites with a highly variable, often stepping, gradient. Cluster 3 stands were termed mid-slope stands and had a steep, but less variable, slope with a convex or only slightly concave shape in cross-section.

Selected hemlock stands then were paired with hardwood stands based upon similarities in elevation, slope, aspect, solar radiance, terrain shape, stand size and perimeter, and occurrence of first, second, and third order streams. Using this method seven pairs of stands, having similar physiographic characteristics but different forest composition, were identified. Because of funding constraints, only one pair of stands could be selected for sampling in 1997. We selected Limberlost (hemlock) (Fig. 1) and Matthew's Arm (hardwood) (Fig. 2) as our pair of study stands (Mahan 1997). We selected Limberlost because it is an important old-growth stand. In addition, it is the most highly visited hemlock stand in the park. We selected Matthew's Arm because it was the hardwood stand that most closely matched Limberlost physiographically. These stands were bench stands (cluster 1) that contained streams.



Figure 1. Location of Limberlost hemlock stand, Shenandoah National Park, Madison County, Virginia

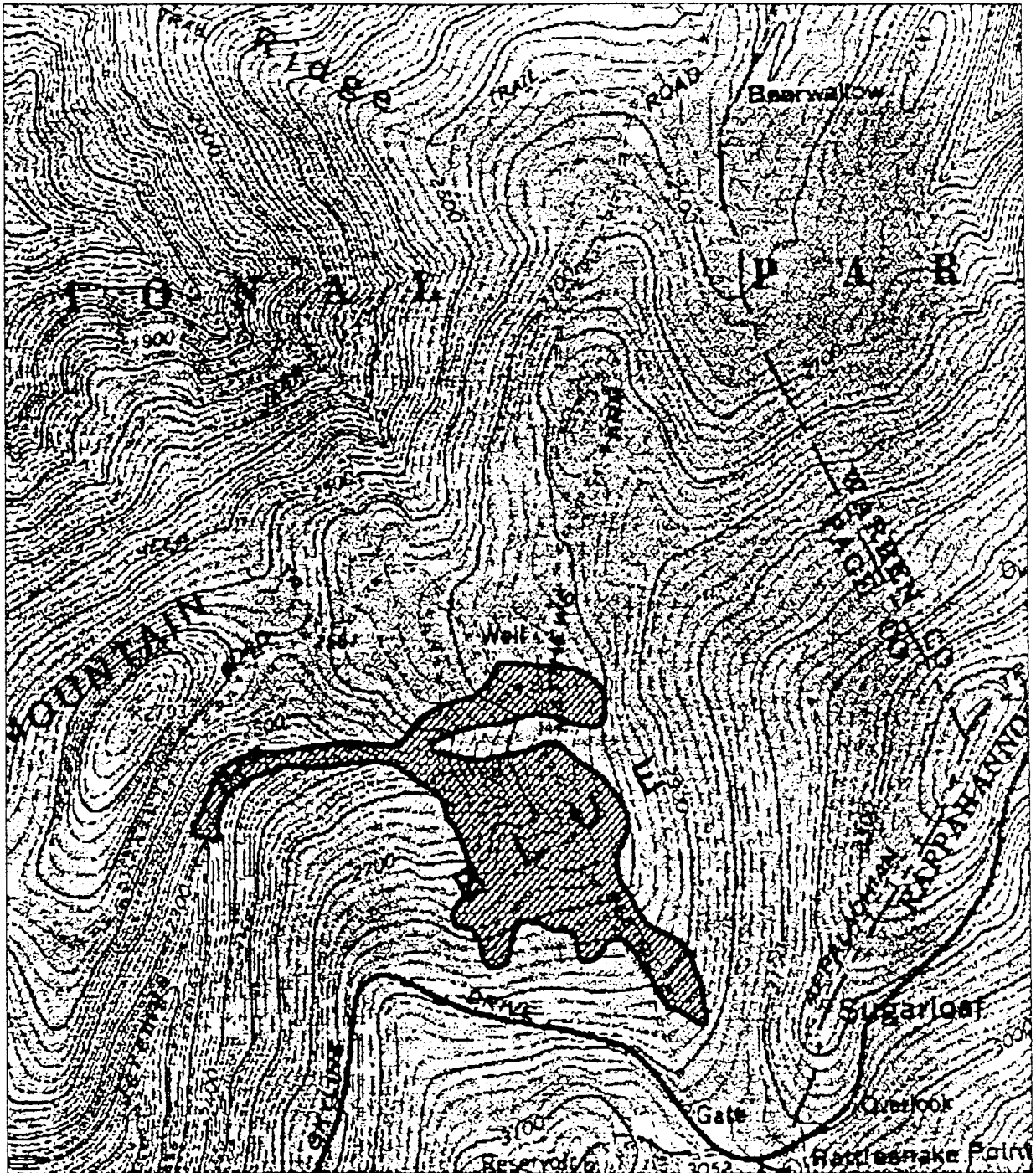


Figure 2. Location of Matthew's Arm hardwood stand, Shenandoah National Park, Page County, Virginia

Methods

A plot-based ecosystem profile inventory was conducted at both Limberlost and Matthew's Arm and was supplemented with more extensive stand-based sampling across a larger area (Kim 1993, Mahan et al. 1998). The ecosystem profile inventory included intensive sampling for multiple taxonomic groups (plants, flying insects, soil- and litter-dwelling invertebrates, trunk-dwelling invertebrates, mammals, and amphibians) from the forest floor to the forest canopy within a 20 x 20 m sampling plot (Mahan et al. 1998). More extensive sampling for mammals, amphibians, soil- and litter- dwelling invertebrates, and vascular plants was conducted throughout the forest stands.

Protocols used to sample each taxonomic group were described in detail by Mahan et al. (1998). A list of specific methods used to sample each taxonomic group, sampling locations, and the frequency or duration of sampling are presented in Table 1. Because of limited funding, we only were able to sample in August, 1997. Ideally, sampling should be conducted in spring, summer, fall, and winter, and include sampling protocols for birds, frogs and toads, owls, bats, non-vascular plants, and fungi.

Site Design

At Limberlost, we established two parallel transects that ran with the topographic contour of the stand (parallel to the slope) and transversed the entire length of the stand (Scott and Woodward 1994, Jaeger 1994, Sciascia and Pehek 1995, Battles et al. 1996) (Fig. 3). Two transversing transects were established on the south side of the stream. No transects were established along the north side of the stream because a well-traveled trail was present there and could have biased our sampling efforts. One transect was parallel to the streambed and was positioned 10 m from the edge of the stream (streamside transect). The second transect also paralleled the stream but was placed 35 m upslope of the edge of the stream and 25 m from the first transect (upslope transect).

We established 20 trapping stations (10 stations/transect for invertebrates, salamanders, and small mammals), at 25-m intervals along the two transects established in the stand. At Limberlost, trapping stations 11 and 10 were placed at the beginning of the transects because of a trail at the end of the transects that precluded their establishment there. However, at Matthew's Arm, the trapping stations were established in numerical order (Fig. 4).

We randomly established 5 of the 20, 0.04-ha square (20 x 20 m) vegetation plots along the two transversing transects. All vegetation plots were located at least 50 m from the edge of the stand in order to minimize any edge effects and were located at least 25 m from each other.

Once the trapping stations were established, we randomly chose one trapping station in each stand as the basis for creating an "ecosystem profile". Once the trapping station was randomly chosen, a 20 x 20 m plot was centered on the selected trapping station, then termed the ecosystem profile plot. The vegetation plot nearest the ecosystem profile plot was moved so that it overlapped, and became part of, the ecosystem profile plot.

Table 1. Methods used to sample major taxonomic groups at Shenandoah National Park, Virginia, 1997.

Taxonomic group	Sampling method	Sampling locations (E or B)*	Frequency or duration of sampling
Vascular plants	Seedling plot	B	One time
	Shrub plot	B	One time
	Sapling plot	B	One time
	Overstory tree plot	B	One time
Invertebrates	Soil cores	B	One time
	Leaf litter samples	B	One time
	Pitfall traps	B	One time
	Trunk traps	E	Four days
	Beating	E	One time
	Sweeping	E	One time
	Substrate search	B	One time
	Malaise traps	E	Four days
	Canopy malaise traps	E	Four days
	Branch clipping	E	One time
	Light traps	E	One night
Salamanders	Substrate search	B	One time
Mammals	Small live traps	B	Four trap-nights
	Large live traps	B	Four trap-nights
	Pitfall traps	E	Four trap-nights
	Deer pellet technique	B	One time
	Qualitative transect sample	B	One time

* E = sampling only was conducted in ecosystem profile plot, B = sampling was conducted both within the ecosystem profile plot and throughout the stand.

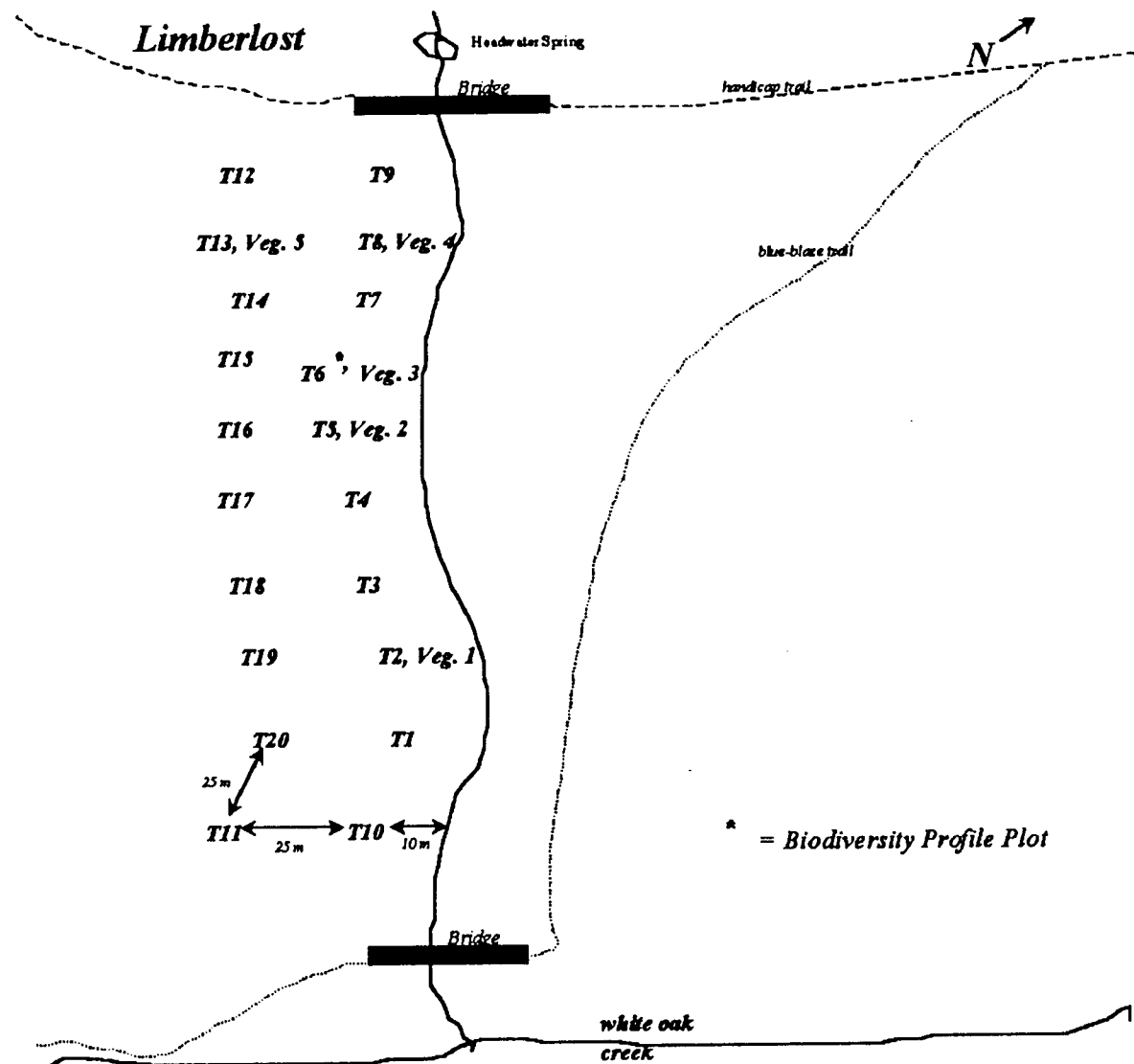
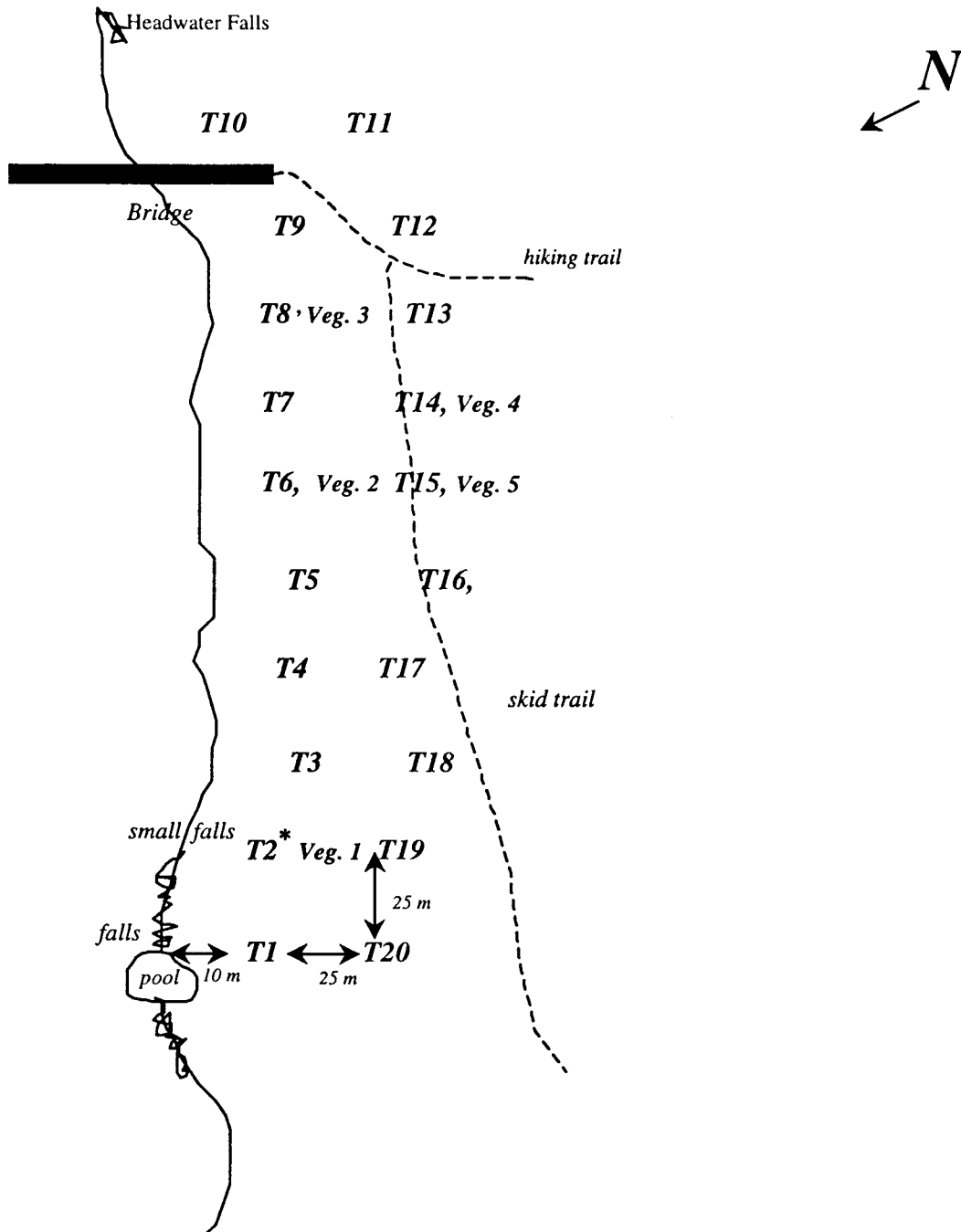


Figure 3. Sampling design at Limberlost hemlock stand, Shenandoah National Park, Madison County, Virginia, August 1997 T = trapping stations; veg. = vegetation plots

Matthew's Arm



* = Biodiversity Profile Plot

Figure 4. Sampling design at Matthew's Arm hardwood stand, Shenandoah National Park, Page County, Virginia, August, 1997. T = trapping stations; veg. = vegetation plots

Once we had established transects, trapping stations and vegetation plots at Limberlost, we established another study site at Matthew's Arm. Matthew's Arm was set up in exactly the same design as Limberlost.

Soil Samples

We collected one 5-cm diameter soil core at each trapping station at both Matthew's Arm and Limberlost. Soil cores were taken to a depth of 2-5 cm and kept intact for extraction. Soil samples were air-dried and then sent for testing to Agricultural Analytical Services Laboratory at The Pennsylvania State University. All soil samples were tested for soil pH, phosphorous, acidity, exchangeable cations of potassium, magnesium, and calcium, cation exchange capacity, and percent saturation by potassium, magnesium and calcium.

Plants

Overstory trees, saplings, shrubs, herbaceous plants, and seedlings were sampled within each of the five randomly selected vegetation plots at each stand (Mahan et al. 1998). Overstory trees were inventoried throughout the 20 x 20-m vegetation plot. The remaining vegetation classes were inventoried within smaller, square nested plots, centered within the vegetation plot (Table 2, Fig. 4).

To establish the nested plots, we delineated diagonal lines to connect the plot corners. The direction of each diagonal line passing through the vegetation plot was calculated by adding or subtracting 45 ° from the azimuth of the transversing transect. From the plot center, the corners of each nested plot were located by measuring along each diagonal the distance of the product of the length of the side of the nested plot and the square root of two (1.41) (Table 2, Fig. 5).

Within each plot, average slope and aspect were recorded and a photometer reading was taken at the center of the plot. Weather conditions were noted along with any distinctive landmarks on or near the site. A metal stake was driven into the plot center to permanently mark its position.

In the overstory plot, canopy cover was classified into one of three categories (gap, intermediate, or closed) based on percent cover (Table 3) (Daubenmire 1959). Also, the locations of any distinct gaps in an otherwise closed or intermediate canopy were noted.

Species, diameter at breast height (d.b.h.), and location of each overstory tree (> 11.4cm d.b.h.) were recorded. The location of each tree was determined by measuring its distance and azimuth from plot center. A tree was considered in the plot if the center of the tree at ground level was on or within the plot boundary. Snags were included in the inventory. Also, any insect infestations, fire scars, or damage to a tree were noted.

In the sapling and shrub plot, the number of individuals of each species was recorded. Percent cover of each species also was estimated to the nearest five percent within the nested plot. Individuals were considered in the plot if their stems originated within or on the plot boundary.

Table 2. Descriptions, plot sizes, square dimensions, and diagonal dimensions for vegetation classes.

Vegetation Class	Description	Plot Size	Square Dimension	Diagonal Dimension
Overstory	tree species >1.5 m tall and >11.4 cm dbh	0.04 ha (400m ²)	20m x 20m	28.28m
Saplings	woody plant >1.5 m tall and ≤11.4 cm	0.01 ha (100m ²)	10m x 10m	14.14m
Shrubs	woody stem 0.5-1.5 m tall and <2.5 cm dbh	0.01 ha (100m ²)	10m x 10m	14.14m
Herbaceous	plants whose exposed parts die at the end of the growing season	0.0025 ha (25m ²)	5m x 5m	7.07m
Seedling	woody plant <1.5 m tall	0.0004 ha (4m ²)	2m x 2m	2.83m

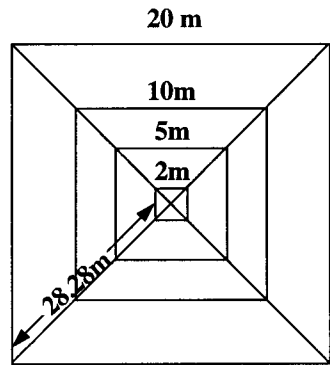


Fig. 5. Vegetation plot layout at Matthew's Arm and Limberlost, August, 1997.

Table 3. Classifications used to assess canopy cover at
Shenandoah National Park, August, 1997.

Canopy classification	Percent cover
Gap	0-30%
Intermediate	>30-70%
Closed	>70-100%

In the herbaceous plot, the species were field identified and their identifications were recorded. For those species that could not be identified in the field, specimens were collected and identified in the laboratory. Specimens complete enough to allow identification will be curated at the Carnegie Museum of Natural History. Many herbaceous specimens were not identifiable beyond the generic level.

The number of seedlings also was recorded for each species within the seedling plot. The number of individuals more than 1-year-old was tallied by looking for annual bud scars on the stem. Any evidence of browse was noted.

Invertebrates

Insects comprise at least 75% of all known species of animals, and yet they often are ignored in ecological studies. Because insects are a major driving force behind many ecosystem processes, without them, our present ecosystems would not function. Invertebrates perform many ecological functions, such as pollination and nutrient cycling, and serve as food for many other organisms. Therefore, they are valuable as indicators of many different kinds of environmental disturbance. Failure to include insects and other invertebrates in ecosystem inventories, monitoring, conservation, and management leads to a misrepresentation of ecosystem integrity and dynamics. Because of their diversity, insects provide the opportunity to detect smaller, more inconspicuous changes in ecosystems that might otherwise go undetected by focusing only on larger, more conspicuous vertebrate species (Danks 1996). The variety of methods that we used to sample invertebrates are described below.

Beating

To sample invertebrates associated with understory vegetation, we collected beating samples at five randomly chosen points within the ecosystem profile plot at both Matthew's Arm and Limberlost. A total of 10 beats on numerous branches constituted one sample (Mahan et al. 1998). Beatings were always conducted in the morning (0600 – 1000 h).

Branch Clipping

In order to inventory invertebrates that inhabit the forest canopy (Schowalter 1989), we collected branch clippings from two overstory trees within the ecosystem profile plot at both Matthew's Arm and Limberlost. Branches were sampled by quickly enclosing a 0.5-m length of foliage-bearing branch in a 60-liter plastic bag, clipping the branch, and sealing the bag (Mahan et al. 1998). Three branches constituted one sample, and each tree was sampled at upper crown level and lower crown level.

Canopy Malaise Traps

In order to inventory flying insects in the forest canopy, we placed two canopy malaise traps (Nyrop and Simmons 1986, Mahan et al. 1998) in each ecosystem profile plot. One trap was placed in the mid- to upper-canopy of each of two overstory trees (one trap per tree) within each ecosystem profile plot. Traps were placed a minimum of 5 m apart. Canopy malaise traps were set for a 4-day period and were checked and emptied daily.

Leaf Litter

We hand-collected leaf litter samples from the forest floor using a 0.25 x 0.25-m quadrant (Edwards 1991). Once collected, leaf litter samples were placed in sealed bags and stored at 5°C until the samples could be sorted through manually and invertebrates could be removed. We randomly collected five leaf litter samples within the ecosystem profile plot at both Matthew's Arm and Limberlost. In addition, we collected one leaf litter sample at each of 10 additional randomly selected trapping stations at both Mathew's Arm and Limberlost.

Light Traps

We used light trapping to inventory nocturnal flying insects. We placed one light trap, equipped with a 10-watt black light tube and tetra-chloroethane (an insect fumigant and preservative), on the ground within the ecosystem profile plot at both Matthew's Arm and Limberlost. Traps were run for one night, from dusk to dawn.

Malaise Traps

To sample flying insects, we set two malaise traps within each ecosystem profile plot in randomly selected locations (Mahan et al. 1998). Malaise traps were set for a 4-day period and were checked and emptied daily.

Natural Substrate Searches

We conducted a plot-based substrate search for invertebrates in each of 10 trapping stations (every other trapping station), including the ecosystem profile plot, at both Matthew's Arm and Limberlost (Mahan et al. 1998). This method was used in conjunction with a natural substrate search for salamanders. We established a 5-m radius plot centered on each trapping station. Within each substrate plot, all rocks and logs were overturned and checked for invertebrates. All invertebrates visually observed were collected by hand using forceps or gloves and placed in a jar containing 75% ethyl alcohol. Rocks and logs then were returned to their original positions. Two researchers searched simultaneously for inverts and salamanders for a standardized time of 10 minutes (20 person minutes) per plot.

Pitfall Traps

We placed six pitfall traps within each ecosystem profile plot, allowing at least 10 m between traps and forming a grid system within the plot. In addition, we placed one pitfall trap in the center of each of five randomly selected trapping stations at each site. Invertebrate pitfall traps were constructed from 9-cm diameter plastic drinking cups placed beneath the ground so that the top of the traps were level with the soil surface. We used table salt, placed to a depth of 1-2 cm in the bottom of the trap and covered with water, as a preservative. Pitfall traps were opened for a 4-day period and checked and emptied daily.

Soil Cores

We took five randomly selected soil core samples each within the ecosystem profile plot at both Matthew's Arm and Limberlost. In addition, we took one soil core sample at each of 10 randomly selected trapping stations at each site. Soil cores were taken to a depth of 2-5 cm and were kept intact for extraction (Edwards and Fletcher 1971, Mahan et al. 1998). Soil cores were maintained at 4-10° C until the invertebrates could be extracted. A modified Tullgren Funnel (Tullgren 1918) method was employed to extract invertebrates from the soil cores.

Sweeping

We collected five sweep samples to sample invertebrates on herbaceous vegetation within the ecosystem profile plot at both Matthew's Arm and Limberlost. We randomly chose the starting point of each sweep sample. Ten sweeps, one taken at each step, constituted one sample (Winchester and Scudder 1993, Mahan et al. 1998). Sweepings were always conducted in the morning (0600 – 1000 h).

Trunk Traps

In order to collect invertebrates from tree trunks (Moeed and Meads 1983), we attached trunk traps to five trees each within the ecosystem profile plot at both Matthew's Arm and Limberlost. Trunk traps were opened for 4 days.

Invertebrate Preservation and Identification

All invertebrate specimens were stored in 70 % ethyl alcohol and taken to the Frost Entomological Museum for identification and curation. Specimens were sorted first to the level of order, and subsequently to the family level. Most specimens, except for larvae, were identified to the family level. Although some specimens were identified to species level, limited funding precluded identification of all invertebrates to the species level. Therefore, invertebrate analyses were limited. For example, within one family of a particular order, it is possible to have species that are predators, as well as species that are herbivores or detritivores. Therefore,

without knowing the species, it was not possible to group many of the specimens into guilds for analyses.

Salamanders

Natural Substrate Searches

We conducted a plot-based natural substrate search for salamanders at each of 10 trapping stations (every other station), including the ecosystem profile plot, at both Matthew's Arm and Limberlost (Mahan et al. 1998). These plots corresponded to the plots where we conducted natural substrate searches for invertebrates. We established a 5-m radius plot centered on each of the 10 randomly-selected trapping stations. Within each substrate plot, all rocks and logs were overturned and checked for salamanders, then returned to their original positions. Two researchers searched for a standardized time of 10 minutes (20 person minutes) per plot. All salamanders were identified to species.

Mammals

Live and Pitfall Trapping

We set two small mammal live traps (8 x 8 x 26 cm) at each of the 20 trapping stations, one of which was the ecosystem profile plot, at Matthew's Arm and Limberlost. In addition, we set one wire-mesh mammal live trap (13 x 13 x 41 cm) at 10 of the 20 trapping stations (every other station), including the ecosystem profile plot at each study area. We also set one mammal pitfall trap (1-gallon metal can) at the center of each ecosystem profile plot. Small mammal live traps, pitfall traps, and wire mesh traps were opened on the evening of the first trap night, remained opened for 4 consecutive nights and days, and were checked and emptied each morning. All mammal live traps were placed at least 10 m from the center of the trapping station. Each trap was placed next to habitat structures such as rocks, logs, or trees. All mammals captured in the traps were assessed as to weight, sex, and presence of bot fly larva, marked with monel metal eartags, and then released.

Mammalian Transect Protocol

To provide information on species richness, we walked along the transects within the stands and recorded any mammalian sign. Mammal sign included direct observation of mammals, tracks, or scat.

Deer Pellet-Group Technique

We used a pellet-group technique (Neff 1968, Mahan et al. 1998) to determine relative use of the two stands by white-tailed deer (*Odocoileus virginianus*). At each trapping station, one 5-m

radius plot was cleared of all pellets in July 1997, and was re-visited August 1997. Deer pellets that had accumulated in the one-month time period were counted.

Statistical Analyses

We used a two-sample t-test (for unequal variance $\alpha=0.05$), to compare species parameters (abundance, richness, etc.) between Limberlost and Matthew's Arm. Because we only sampled one pair of stands during one season, statistical comparisons were often not possible. More statistical comparisons of abundance and richness of particular invertebrate guilds will be possible once more invertebrates have been identified to species. At this time, statements of differences in abundance for invertebrates are anecdotal and, except in specific instances, do not imply statistically significant differences.

Results and Discussion

Soil Samples

Soil samples collected from Limberlost had a significantly ($P \leq 0.05$) lower pH, higher acidity and higher cation exchange capacity than samples taken from Matthew's Arm (Table 4). In contrast, samples collected from Matthew's Arm had a significantly higher calcium percent saturation than samples collected from Limberlost. In addition, there were strong trends toward higher amounts of phosphorous and calcium, as well as magnesium percent saturation, at Matthew's Arm.

Our findings are consistent with observations made by other researchers. Hemlock soils are characterized by a lower pH and higher acidity than hardwood soils (Chandler 1943, Elliott et al. 1993). Hemlock needles, which are very acidic in reaction, accumulate beneath the trees and influence soil chemistry. Under acidic conditions nutrients, such as phosphorous and calcium, are leached from the soil. Although the cation exchange capacity, which refers to the number of sites available on soil particles for cations to adhere, was higher at Limberlost, in acidic forest soils these exchange sites are largely held by hydrogen ions. Thus, both amount and availability of nutrients were lower in soils of hemlock stands.

Plants

The mean number of overstory trees, snags, and one-year old seedlings per plot did not differ significantly between Matthew's Arm and Limberlost. We did not encounter enough two-year old seedlings in our plots to permit analyses for this vegetation class. However, the mean number of shrubs/saplings at Matthew's Arm was significantly higher than at Limberlost (Table 5). Eastern hemlock was the only overstory tree with basal area that differed significantly between stands. Hemlock had significantly more basal area ($t = 3.64$, d.f. = 4, $P = 0.02$) at Limberlost than at Matthew's Arm.

Dominant overstory tree associations differed between Matthew's Arm and Limberlost (Table 6). At Limberlost, eastern hemlock was by far the most dominant tree species, followed by black birch (*Betula lenta*), red maple (*Acer rubrum*), basswood (*Tilia americana*), northern red oak (*Quercus rubra*) and sugar maple (*Acer saccharum*). At Matthew's Arm, chestnut oak (*Quercus prinus*) was the most dominant tree species, followed by northern red oak, striped maple (*Acer pennsylvanicum*), red maple, pignut hickory (*Carya glabra*) and black oak (*Quercus velutina*).

Species richness of overstory trees and shrubs/saplings was significantly higher at Matthew's Arm than at Limberlost (Table 7). However, species richness of one-year old seedlings did not vary significantly between Matthew's Arm and Limberlost. We recorded eight species of overstory trees, 5 species of shrubs/saplings, 7 species of one-year old seedlings, and 13 herbaceous species at Limberlost (Table 8, Table 9, Table 10, and Table 11, respectively). At Matthew's Arm, we recorded 19 overstory tree species, 12 shrub/sapling, 13 one-year old seedling species, and 37 herbaceous plant species.

Table 4. Results of soil analyses from samples taken at Matthew's Arm (n=20) and Limberlost (n=20), August, 1997.

Soil Properties	Limberlost		Matthew's Arm		Statistical Comparisons	
	$\bar{x}$	SE	$\bar{x}$	SE	<i>t</i>	<i>P</i>
pH	4.48	0.06	4.82	0.09	-3.14	0.004
Phosphorous	12.55	0.70	15.40	1.30	-1.95	0.062
Acidity	15.70	0.89	11.95	1.10	2.58	0.014
Potassium	0.11	0.03	0.13	0.01	-0.82	0.420
Magnesium	0.35	0.06	0.51	0.10	-1.43	0.160
Calcium	1.21	0.21	2.12	0.45	-1.83	0.078
Cation Exchange Capacity	15.69	0.45	13.75	0.76	2.21	0.035
Potassium percent saturation	0.66	0.15	0.94	0.10	-1.54	0.130
Magnesium percent saturation	2.28	0.38	3.80	0.75	-1.81	0.082
Calcium percent saturation	7.67	1.40	15.60	3.30	-2.18	0.039

Table 5. Mean number and standard error of overstory trees, snags, shrubs/saplings, and 1-year old seedlings per plot at Matthew's Arm (n = 5) and Limberlost (n = 5), August, 1997.

	Matthew's Arm		Limberlost	
	$\bar{x}$	SE	$\bar{x}$	SE
Number of overstory trees per plot	16.6	1.25	20.5	2.10
Number of snags per plot	1.8	0.38	2.3	0.63
Number of shrubs/saplings per plot ^a	12.6	1.12	8.8	1.18
Number of one-year old seedlings per plot	22.0	7.22	28.3	9.4

^a Denotes significant difference between sites as determined by 2-sample t-test.

Table 6. Average number of overstory trees per ha for the six most dominant tree species at Limberlost and Matthew's Arm, August, 1997.

Limberlost Avg.: n = 5		Matthew's Arm Avg.: n = 5	
Tree species	Number/ha	Tree species	Number/ha
<i>Tsuga canadensis</i>	381.0	<i>Quercus prinus</i>	106.0
<i>Betula lenta</i>	62.5	<i>Quercus rubra</i>	93.8
<i>Acer rubrum</i>	25.0	<i>Acer pennsylvanicum</i>	37.5
<i>Tilia americana</i>	18.8	<i>Acer rubrum</i>	31.3
<i>Quercus rubrum</i>	12.5	<i>Carya glabra</i>	25.0
<i>Acer saccharum</i>	12.5	<i>Quercus velutina</i>	18.8

Table 7. Mean species richness and standard error of overstory trees, shrubs/saplings, and 1-year old seedlings per plot in Matthew's Arm (n = 5) and Limberlost (n = 5), August, 1997.

	Matthew's Arm		Limberlost	
	$\bar{x}$	SE	$\bar{x}$	SE
Species richness of overstory trees per plot ^a	8.0	1.25	4.0	2.10
Species richness of shrubs/saplings per plot ^a	4.6	0.68	1.8	0.25
Species richness of one-year old seedlings per plot	5.0	0.83	2.7	0.75

^a Denotes significant difference between sites as determined by 2-sample t-test.

Table 8. Overstory tree species found at Matthew's Arm and Limberlost, August, 1997.

Common Name	Scientific Name	Present at Limberlost	Present at Matthew's Arm
American chestnut	<i>Castanea dentata</i>		✓
White ash	<i>Fraxinus americana</i>	✓	✓
Basswood	<i>Tilia americana</i>	✓	✓
Bitternut hickory	<i>Carya cordiformis</i>		✓
Black birch	<i>Betula lenta</i>	✓	✓
Black gum	<i>Nyssa sylvatica</i>		✓
Black locust	<i>Robinia pseudoacacia</i>		✓
Black oak	<i>Quercus velutina</i>		✓
Chestnut oak	<i>Quercus prinus</i>	✓	✓
Eastern hemlock	<i>Tsuga canadensis</i>	✓	
Eastern hop-	<i>Ostrya virginiana</i>		✓
Eastern white pine	<i>Pinus strobus</i>		✓
Fire cherry	<i>Prunus pensylvanicum</i>		✓
Flowering dogwood	<i>Cornus florida</i>		✓
Northern red oak	<i>Quercus rubra</i>	✓	✓
Pignut hickory	<i>Carya glabra</i>		✓
Red maple	<i>Acer rubrum</i>	✓	✓
Striped maple	<i>Acer pensylvanicum</i>		✓
Sugar maple	<i>Acer saccharum</i>	✓	
Tulip poplar	<i>Liriodendron</i>		✓
Yellow birch	<i>Betula allegheniensis</i>		✓

Table 9. Shrub/sapling species found at Matthew's Arm and Limberlost, August, 1997.

Common Name	Scientific Name	Present at Limberlost	Present at Matthew's Arm
American chestnut	<i>Castanea dentata</i>		✓
Bitternut hickory	<i>Carya tomentosa</i>		✓
Black birch	<i>Betula lenta</i>		✓
Eastern hemlock	<i>Tsuga canadensis</i>	✓	
Eastern hop-hornbeam	<i>Ostrya virginiana</i>		✓
Flowering dogwood	<i>Cornus florida</i>		✓
Musclewood	<i>Carpinus caroliniana</i>		✓
Northern red oak	<i>Quercus rubra</i>		✓
Red maple	<i>Acer rubrum</i>	✓	
Serviceberry	<i>Amelanchier sp.</i>	✓	
Spicebush	<i>Lindera benzoin</i>		✓
Striped maple	<i>Acer pensylvanicum</i>	✓	✓
White ash	<i>Fraxinus americana</i>		✓
Witch hazel	<i>Hamamelis virginiana</i>	✓	✓
Yellow birch	<i>Betula allegheniensis</i>		✓

Table 10. One-year old seedling species found at Matthew's Arm and Limberlost, August, 1997.

Common Name	Scientific Name	Present at Limberlost	Present at Matthew's Arm
American chestnut	<i>Castanea dentata</i>		✓
Black birch	<i>Betula lenta</i>	✓	
Black cherry	<i>Prunus serotina</i>		✓
Black oak	<i>Quercus velutina</i>		✓
Chestnut oak	<i>Quercus prinus</i>		✓
Fire cherry	<i>Prunus pensylvanica</i>		✓
Flowering dogwood	<i>Cornus florida</i>		✓
Late low-bush blueberry	<i>Vaccinium angustifolium</i>		✓
Mountain laurel	<i>Kalmia latifolia</i>	✓	
Northern red oak	<i>Quercus rubra</i>	✓	✓
Red maple	<i>Acer rubrum</i>	✓	✓
Spicebush	<i>Lindera benzoin</i>		✓
Striped maple	<i>Acer pensylvanicum</i>	✓	✓
Sugar maple	<i>Acer saccharum</i>	✓	✓
White ash	<i>Fraxinus americana</i>	✓	✓

Table 11. Herbaceous plants found at Matthew's Arm and Limberlost, August, 1997.

Common Name	Scientific Name	Present at Limberlost	Present at Matthew's Arm
American polypody	<i>Polypodium virginianum</i>		✓
Aster	<i>Aster sp.</i>	✓	✓
Black cohosh	<i>Cimicifuga racemosa</i>		✓
Blackberry	<i>Rubus sp.</i>		✓
Black mustard	<i>Brassica nigra</i>		✓
Black raspberry	<i>Rubus sp.</i>		✓
Boston fern	<i>Polystichum acrostichoides</i>		✓
Buttercup	<i>Amaranthus sp.</i>		✓
Cinnamon fern	<i>Osmunda cinnamomea</i>		✓
False miterwort	<i>Tiarella cordifolia</i>		✓
Fragrant bedstraw	<i>Galium triflorum</i>	✓	✓
Garlic mustard	<i>Alliaria officinalis</i>		✓
Grass	<i>Poaceae sp.</i>	✓	
Hay-scented fern	<i>Dennstaedtia punctilobula</i>	✓	✓
Hepatica	<i>Hepatica sp.</i>		✓
Jack-in-the-pulpit	<i>Arisaema sp.</i>	✓	✓
Knotweed	<i>Polygonum sp.</i>	✓	
Maidenhair fern	<i>Adiantum pedatum</i>		✓
Northern bedstraw	<i>Galium boreale</i>		✓
Partridgeberry	<i>Mitchella repens</i>	✓	✓
Pipsissewa	<i>Chimaphila umbellata var. cisatlantica</i>		✓
Rattlesnake plantain	<i>Goodyera sp.</i>		✓
Rattlesnake root	<i>Prenanthes sp.</i>	✓	
Red trillium	<i>Trillium erectum</i>	✓	
Round-leafed hepatica	<i>Hepatica americana</i>		✓
Saxifrage	<i>Saxifragaceae sp.</i>		✓
Sedge	<i>Carex sp.</i>		✓
Self-heal	<i>Prunella vulgaris</i>		✓
Short-styled snakeroot	<i>Sanicula canadensis</i>		✓
Smooth false foxglove	<i>Gerardia laevigata</i>		✓
Solomon's seal	<i>Polygonatum sp.</i>		✓
Spotted touch-me-not	<i>Impatiens biflora</i>		✓
Starflower	<i>Trientalis borealis</i>	✓	✓
Stinging nettle	<i>Urtica dioica</i>	✓	✓
Switch grass	<i>Panicum sp.</i>		✓
Violet	<i>Viola spp.</i>	✓	✓
Virginia creeper	<i>Parthenocissus quinquefolia</i>		✓
White woods aster	<i>Aster divaricatus</i>		✓
Wild lily-of-the-valley	<i>Maianthemum canadensis</i>	✓	✓
Wild crane's bill	<i>Geraneum maculatum</i>		✓
Yam	<i>Dioscorea sp.</i>		✓

Lower species richness is typical of hemlock stands (Benzinger 1994). Overstory hemlock trees create a microhabitat that favors growth of hemlock over other species. Deep shade and acidic soils preclude other tree species from establishing and lead to low levels of shrub and herbaceous growth beneath hemlock trees. These trends were evident at Limberlost.

Canopy closure appeared to be greater at Limberlost than at Matthew's Arm. At Limberlost, two plots had a closed canopy, while two others had intermediate canopy closure. In contrast, four plots had intermediate canopy closure at Matthew's Arm and one plot had an open canopy.

Matthew's Arm was characterized by a higher species richness of overstory trees, shrubs/saplings and herbaceous species and a higher density of shrubs/saplings. We were unable to calculate densities for herbaceous plants due to inadequate sampling.

Invertebrates

Due to funding and expertise constraints, we only identified three invertebrate groups to the species level. All other groups were identified to the order or family level (Table 12). Approximately 2000 specimens have not been identified to the order level and are only sorted to phylum.

Using 12 sampling techniques, we collected 13,803 invertebrates from 30 orders at Shenandoah NP in August, 1997. We captured 6,338 specimens at Limberlost (Table 13) and 7,465 specimens at Matthew's Arm (Table 14). Diptera (flies) were the most abundant order at both Matthew's Arm and Limberlost, followed by Collembola (springtails) and Acari (mites). At Matthew's Arm, Hymenoptera (ants, bees, wasps) Araneae (spiders), Coleoptera (beetles), and Lepidoptera (moths) were most abundant following Acari. At Limberlost, however, Lepidoptera, Araneae, Hymenoptera and Julida (millipedes) were most abundant after Acari.

Of the 12 sampling techniques used, we collected the first, second, and third highest number of individuals using ground malaise traps, leaf litter samples, and light traps, respectively (Table 13, Table 14). We captured the greatest number of flies (Diptera) and ants, bees and wasps (Hymenoptera) using ground malaise traps. We captured the greatest number of moths (Lepidoptera) and numerous flies in light traps. However, we caught the greatest number of mites (Acari), spiders (Araneae), centipedes (Chordeumatida, Geomorphila, Lithiobiomorpha), beetles (Coleoptera), springtails (Collembola), millipede (Julida), and bark lice (Psocoptera) specimens in leaf litter samples.

Spiders

We collected 407 individuals from 17 spider families at Limberlost and Matthew's Arm (Table 15). In addition, we collected 75 individuals from the order Araneae that we were unable to identify to family. Five families, including the hunting spiders (Gnaphosidae), wolf spiders (Lycosidae), oecobiids (Oecobiidae), nursery-web and fishing spiders (Pisauridae), and crab spiders (Thomisidae) were found only at Matthew's Arm. A funnel-web spider (Amaurobiidae) was collected only at Limberlost. Individuals of the grass and funnel-web spiders (Agelenidae),

Table 12. Identification status of invertebrate specimens collected during August 1997 in a hemlock and hardwood forest stand at Shenandoah National Park

Araneae (spiders)

407 specimens all identified to family level (17 families)

Coleoptera (beetles)

226 specimens, 29 families, 78 spp. All specimens have been identified to species level

Collembola (springtails)

3317 specimens all identified to family level (6 families)

Diptera (flies)

5442 specimens, 40 families, one family identified to species level (83 specimens), 5360 specimens identified to family level only

Hymenoptera (ants, bees, wasps, etc.)

557 specimens, 23 families, one family identified to genus (183 specimens), 410 specimens identified to family level

Hemiptera (bugs)

26 specimens, 8 families, all identified to family level

Homoptera (scale insects)

196 specimens, 6 families, all identified to family level

Lepidoptera (butterflies and moths)

354 specimens, 13 families, 24 specimens identified to family level, 254 specimens identified to species level

Opiliones (harvestmen)

104 specimens, 2 families, 101 specimens identified to species level, 6 species in all

Psocoptera (bark lice)

137 specimens, 10 families, one family identified to species level (3 species, 39 specimens)

Chilopoda (centipedes)

263 specimens, 3 orders, 7 families, 237 identified to family level, 26 to species level

Diplopoda (millipedes)

380 specimens, 5 orders, 7 families, 379 specimens identified to family level

Table 13. Number of invertebrate specimens from each order collected at Limberlost, using 12 different sampling methods, August, 1997.

Order	Total no. of specimens	Beat sheet	Branch clip	Canopy malaise	Ground malaise	Invert. pitfall	Leaf litter	Light trap	Mammal pitfall	Soil core	Substrate search	Sweep net	Trunk trap
Unknown	11						6			5			
Acari	744	1	1	1		11	226	87	5	392	19	1	
Araneae	246	43	6		1	7	169	1	3		2	5	9
Blattaria	1										1		
Chordeumatida	48					1	46			1			
Coleoptera	70	1	1		3	14	30	5	1	6	7	2	
Collembola	1020	2				33	576		62	299	1	2	45
Diplura	3									3			
Diptera	2890	7		19	1670	19	30	1078	4	21		18	24
Ephemeroptera	7							7					
Geophilomorpha	4						4						
Hemiptera	5	1	1					1				1	1
Homoptera	41		1	2	17	1	1	14		1		2	2
Hymenoptera	202	2	1	1	54	4	60	55			10	4	11
Isopoda	1					1							
Julida	172					4	160			3	5		
Lepidoptera	260	11	9	2	24	1	9	198	1				5
Lithobiomorpha	107						71		1	32	3		
Neuroptera	4	3		1									
Opiliones	53	2	1		7	2	3	4	2		8	1	23
Orthoptera	4							1					3
Plecoptera	134	12	8	4	27			57					26
Polydesmida	15					2	10				3		
Polydesmidea	2									2			
Protura	13									13			
Pseudoscorpiones	19						14	1		4			
Psocoptera	107	17	26		2	3	42	16					1
Scolopendromorpha	12						4		1		7		
Segmented Worm	3									3			
Siphonaptera	3								3				
Thysanoptera	2		2										
Trichoptera	135			1	7			127					
TOTAL	6338	102	57	31	1812	103	1461	1652	83	785	66	36	150

Table 14. Number of invertebrate specimens from each order collected at Matthew's Arm, using a variety of trap methods, August, 1997.

Order	Total no. of specimens	Beat sheet	Branch clip	Canopy malaise	Ground malaise	Invert. pitfall	Leaf litter	Light trap	Mammal pitfall	Soil core	Substrate search	Sweep net	Trunk trap
Unknown	3						2		1				
Acari	464	9			11	17	154	9		263	1		
Araneae	236	23	8	1	3	9	147		2	2	8	23	10
Chordeumatida	72					1	65			2	4		
Coleoptera	234	8	9		30	27	93	15	10	11	11	3	17
Collembola	2297	4	1		9	166	1632		2	260	1	1	221
Diplura	2									2			
Diptera	2705	9		24	2057	204	48	227	4	47		61	24
Gastropoda	2						1		1				
Geomorphila	18						14			2	2		
Geophilomorpha	4						2			1	1		
Hemiptera	33	2	12	1	1	1	9	1				4	2
Homoptera	163	6	5	7	99	2	2	26	1	2		10	3
Hymenoptera	458	2	3	3	250	8	59	22		7	85	11	8
Julida	56					1	43		1		11		
Lepidoptera	229	7	24	3	53	5	23	93				5	16
Lithobiomorpha	86						54			31	1		
Mecoptera	4				3	1							
Neuroptera	4		1		3								
Opiliones	51	4			10	15	4				3		15
Orthoptera	8					5	3						
Plecoptera	27	1			15			6					5
Polydesmida	10					2	4			3	1		
Protura	9									9			
Pseudoscorpiones	45						36			9			
Psocoptera	72	47	1		4	1	18					1	
Scolopendromorpha	23						14			1	8		
Segmented Worm	4									4			
Siphonaptera	6					6							
Spirobolida	4					3	1						
Thysanoptera	7	2	1	1			1			2			
Trichoptera	129				18			110					1
TOTAL	7465	124	65	40	2566	474	2429	509	22	658	137	119	322

Table 15. Spider (order: Araneae) families and genera collected at Limberlost and Matthew's Arm, August, 1997.

Family	Scientific name	Total number of specimens	Limberlost	Matthew's Arm
Agelenidae		50	21	29
Amaurobiidae		1	1	
Antrodiaetidae	Antrodiaetus sp.	6	3	3
Araneidae		125	88	37
Clubionidae		24	9	15
Dictynidae		4	2	2
Erigonidae		39	17	22
Gnaphosidae		1		1
Hahniidae		41	27	14
Linyphiidae		32	12	20
Lycosidae		26		26
Oecobiidae		1		1
Philodromidae		20	9	11
Pisauridae		1		1
Salticidae		24	17	7
Theridiidae		6	2	4
Thomisidae		6		6
unknown-damaged or immature		75	38	37

folding-door tarantulas (Antrodiaetidae), orb weavers (Araneidae), two-clawed hunting spiders (Clubionidae), hackled-band weavers (Dictynidae), dwarf spiders (Erigonidae), hahniid sheet-web spiders (Hahniidae), sheet-web spiders (Linyphiidae), philodromids (Philodromidae), jumping spiders (Salticidae), and comb-footed spiders (Theridiidae) were captured in both stands.

Orb weavers were the most abundant family in our study, and more orb weavers were found at Limberlost than at Matthews Arm. A two-sample t-test on abundance of orb-weavers in leaf litter samples indicated a trend toward a higher abundance of orb weavers in Limberlost than in Matthews Arm ($t=2.07$, d.f. = 14, $P = 0.06$). Orb-weaving spiders construct snares in the form of an orb. Hatley and Macmahon (1980) suggested that vegetation structure may influence the composition of spider communities. Unlike many other web-building spiders, the orb weavers require a more open substrate for web attachment. Orb weavers may be more abundant at Limberlost because the dense hemlock canopy precludes development of a dense understory and shrub layer, resulting in more open substrate. In addition, microclimate characteristics also influence spider distribution (Turnbull 1973). A potentially cooler microclimate within hemlock stands (Benzinger 1994) may influence the presence and abundance of orb-weaving spiders as well as other spider families.

Spiders may serve as excellent indicators of hemlock ecosystem integrity. Hatley and Macmahon (1980) stated that spiders are ideal for ecological studies because they are locally abundant in terms of individuals and taxa. Macfadyen (1957) estimated that spider densities range from 175 to 650 individuals per square meter of soils. Spiders are ecologically important as predators of other invertebrates and as prey for small vertebrate predators, including shrews and birds (Fitch 1963). Different hunting strategies make some species more adept at capturing certain types of prey (e.g., flying insects versus non-flying insects) than others. In addition, although many species occupy a wide range of biotopes, species associations may be notably different among biotopes (Turnbull 1973). Therefore, the presence of certain species associations may be indicative of abundance of certain types of prey, quality of habitat for small vertebrate predators, microclimate conditions, and habitat structure.

Beetles

We collected 226 individuals from 29 beetle (order: Coleoptera) families (Table 16). In addition, we collected 48 individuals from the order Coleoptera that we were unable to identify due to funding and expertise constraints. Fifteen families were unique to Matthew's Arm, and one family was unique to Limberlost. Thirteen families were found in both stands. Matthew's Arm had a higher beetle species richness than Limberlost. Fifty-four (62%) of the 87 beetle species collected were unique to Matthew's Arm. Fifteen (17%) of the species collected were unique to Limberlost, and 18 (21%) species were found at both stands. Specimens that were known to be separate species but whose exact species identifications were not known were given species numbers to signify their identity (e.g., Species 1, Species 2).

At Matthew's Arm, a majority (60%) of beetles collected was predaceous (Fig. 6). Herbivorous beetles were next in abundance, followed by detritivorous beetles. In contrast, herbivorous,

Table 16. Beetle (order: Coleoptera) families, genera, and species collected at Limberlost and Matthew's Arm, August, 1997.

Family	Scientific name	Total number of specimens	Limberlost	Matthew's Arm
Alleculidae	Sp. 1	1		1
Anobiidae	<i>Caenocara</i> sp.	2		2
Anthribidae		1		1
Buprestidae		1		1
Cantharidae	Sp. 1	2	1	1
Carabidae	<i>Carabus goryi</i> (Dejean)	1		1
Carabidae	larvae	1	1	
Carabidae	<i>Platynus angustanus</i> (Dejean)	2	1	1
Carabidae	<i>Pterostichus coracinus</i> (Newman)	24	5	19
Carabidae	<i>Pterostichus diligendus</i> (Chaudoir)	1		1
Carabidae	<i>Pterostichus lachrymosus</i> (Newman)	1		1
Carabidae	<i>Scaphinotus ridingsi</i> (Bland)	3	2	1
Carabidae	<i>Scaphinotus viduus</i> (Dejean)	1		1
Carabidae	Sp. 1	1	1	
Carabidae	Sp. 2	1		1
Carabidae	Sp. 3	1	1	
Carabidae	Sp. 4	1	1	
Carabidae	<i>Sphaeroderus schaumii</i> (Chaudoir)	3	2	1
Carabidae	<i>Sphaeroderus stenostomus</i> (Weber)	2		2
Cerambycidae	<i>Pidona ruficollis</i> (Say)	1		1
Chrysomelidae	<i>Diabrotica undecimpunctata howardi</i> (Barber)	1	1	
Chrysomelidae	<i>Monocesta coryli</i> (Say)	3	1	2
Chrysomelidae	<i>Odontota dorsalis</i> (Thunbergii)	8	1	7
Chrysomelidae	Sp. 1	3		3
Chrysomelidae	Sp. 2	1	1	
Chrysomelidae	Sp. 3	1	1	
Chrysomelidae	Sp. 4	1		1
Coccinellidae	<i>Chilocorinae</i> sp. 1	1		1
Coccinellidae	Larvae	2		2
Coccinellidae	<i>Psyllobora</i> sp.	1		1
Coccinellidae	Sp. 2	1		1
Coccinellidae	Sp. 3	1		1
Cryptophagidae		1		1
Curculionidae	Cryptorhynchinae	3		3
Curculionidae	Cryptorhynchinae sp. 1	1		1
Curculionidae	Cryptorhynchinae sp. 2	2	1	1

Table 16. (cont.) Beetle (order: Coleoptera) families, genera, and species collected at Limberlost and Matthew's Arm, August, 1997.

Family	Scientific name	Total number of specimens	Limberlost	Matthew's Arm
Curculionidae	<i>Curculio</i> sp. 1	2		2
Curculionidae	<i>Curculio</i> sp. 2	1		1
Curculionidae	<i>Curculio</i> sp. 3	1		1
Curculionidae	<i>Curculio</i> sp. 4	13	12	1
Curculionidae	<i>Curculio</i> sp. 5	3	3	
Curculionidae	<i>Curculio</i> sp. 6	2		2
Dascillidae	Sp. 1	1		1
Elateridae	<i>Ctenicera</i> sp. 1	1		1
Elateridae	larvae	3		3
Elateridae	<i>Limonius</i> sp. 1	2		2
Elateridae	Sp. 1	4	1	3
Elateridae	Sp. 2	1		1
Leiodidae	Sp. 1	1		1
Leptinidae		1	1	
Leptodiridae	Sp. 1	8	1	7
Leptodiridae	Sp. 2	1		1
Lycidae	<i>Calopteron reticulatum</i> (Francouer)	1		1
Lycidae	<i>Plateros</i> sp. 1	3		3
Melandryidae	Sp. 1	4	1	3
Mordellidae	Sp. 1	3		3
Mordellidae	Sp. 2	2		2
Nitidulidae	<i>Psyllobora</i> sp.	1		1
Nitidulidae	Sp. 1	4		4
Nitidulidae	Sp. 2	1		1
Nitidulidae	Sp. 4	1		1
Phalacridae	Sp. 1	1		1
Pselaphidae	Sp. 1	5	2	3
Pselaphidae	Sp. 2	1	1	
Ptiliidae	Sp. 1	7		7
Scarabaeidae	<i>Aphodius</i> sp. 1	1		1
Scarabaeidae	<i>Aphodius</i> sp. 2	1	1	
Scarabaeidae	<i>Bolbocerus</i> sp.	2		2
Scarabaeidae	<i>Dialytes striatulus</i> (Say)	1		1
Scarabaeidae	<i>Dialytes truncatus</i> (Melsheimer)	1	1	
Scarabaeidae	<i>Geotrupes balyi</i> (Jekel)	3	3	
Scarabaeidae	<i>Geotrupes blackburnii blackburnii</i> (Fabricius)	5		5

Table 16. (cont.) Beetle (order: Coleoptera) families, genera, and species collected at Limberlost and Matthew's Arm, August, 1997.

Family	Scientific name	Total number of specimens	Limberlost	Matthew's Arm
Scarabaeidae	<i>Onthophagus</i> sp.	1		1
Scarabaeidae	<i>Trox</i> sp.	1	1	
Scolytidae	Sp. 1	1		1
Scydmaenidae	Sp. 1	10	2	8
Scydmaenidae	Sp. 2	2	1	1
Silphidae	<i>Nicrophorus orbicollis</i> (Say)	4	1	3
Silphidae	<i>Nicrophorus tomentosus</i> (Weber)	1	1	
Staphylinidae	Sp. 1	24		24
Staphylinidae	Sp. 2	2		2
Staphylinidae	Sp. 3	1		1
Staphylinidae	Sp. 4	1		1
Staphylinidae	Sp. 5	2		2
Staphylinidae	Sp. 6	1		1
Staphylinidae	Sp. 7	1		1
Staphylinidae	Sp. 8	1		1
Staphylinidae	Sp. 9	1		1
Staphylinidae	Sp. 10	22	1	21
Tenebrionidae	Sp. 1	3	3	
Tenebrionidae	Sp. 2	2	1	1
unknown-larvae or damaged		48	17	31

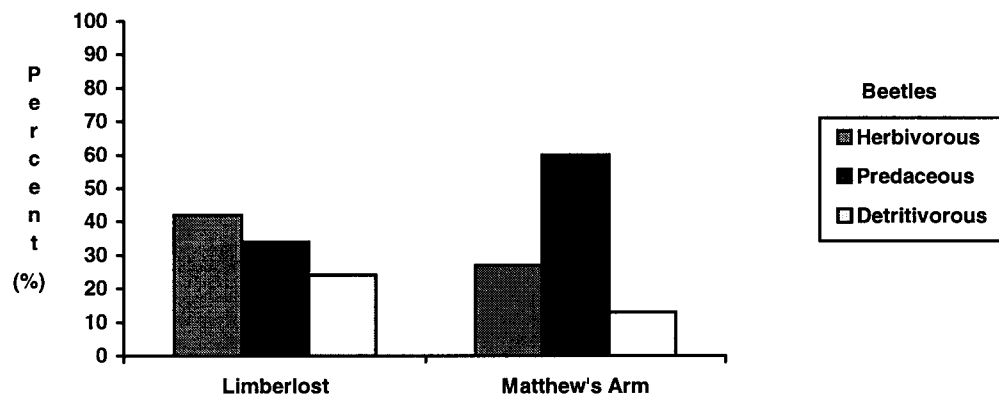


Figure 6. Percent of herbivorous, predaceous, and detritivorous beetle specimens collected at Limberlost and Matthew's Arm, August, 1997.

predaceous and detritivorous beetles were similarly abundant within Limberlost. We speculate that higher diversity and abundance of vegetation may support a greater abundance of invertebrate prey within hardwood stands than within hemlock stands. Subsequently, there may be more food available to support predatory invertebrates at Matthew's Arm.

Springtails

We collected 3,317 springtail (order:Collembola) specimens from six families at both stands (Table 17). Neelidae was the only family unique to Matthew's Arm.

Springtails live in soil, leaf litter, under bark, in decaying logs, and in fungi (Borror et al. 1989). They avoid dry habitats and, in moist habitats, may move above the surface of the ground into trees (Christiansen and Bellinger 1980). Most springtails feed on decaying plant material, fungi and bacteria.

Although springtails were collected using a variety of methods, they were most abundant in leaf litter samples. However, there was a 14 % difference in the number of springtails captured in leaf litter samples between stands (Fig. 7). Fifty-seven percent of springtail specimens collected at Limberlost were collected from leaf litter, whereas 71 % of springtail specimens collected at Matthew's Arm were collected from leaf litter. Comparatively, at Limberlost 29 % of springtails were collected in soil core samples, whereas only 11 % of springtails were collected in soil core samples at Matthew's Arm. These results suggest that a greater percentage of springtails may inhabit the soil in hemlock stands, whereas a greater percentage may inhabit leaf litter in hardwood stands.

Differences in the percentage of springtails that occupy leaf litter versus soils may be due to a difference in the location of available food. Hemlock needles decompose more slowly than hardwood leaves due to the presence of waxes and lignins and cooler microclimatic conditions associated with hemlock stands (Benzinger 1994). These factors encourage thicker litter layers in hemlock stands. In addition to thicker litter layers, hemlock litter typically is more acidic and has lower nutrient content than hardwood litter. Therefore, much of the available nutrients in hemlock stands may be located in the organic layer of the soil below the litter layer. Along with more nutrients, more fungi and bacteria may be located in the organic layer of the soil than in leaf litter in hemlock stands. Conversely, in hardwood stands decaying organic material may be most abundant in the leaf litter.

Another possible cause for a difference in the percentage of springtails occupying the leaf litter versus the soil in hardwood versus hemlock stands may be the type of food present in each type of stand. Fungi are twice as abundant in hemlock litter than in hardwood litter (Benzinger 1984). Conversely, bacteria are more abundant in hardwood litter. Identification of specimens to the species level may reveal that species that feed predominantly on fungi are more abundant in hemlock stands, whereas species that prefer bacteria and decaying plant material are more abundant in hardwood stands.

Table 17. Collembola families collected at Limberlost and Matthew's Arm, August, 1997.

Family	Total number of specimens	Limberlost	Matthew's Arm
Entomobryidae	2440	661	1779
Hypogastruridae	247	79	168
Isotomidae	255	119	136
Neelidae	1		1
Onychiuridae	323	140	183
Sminthuridae	51	21	30

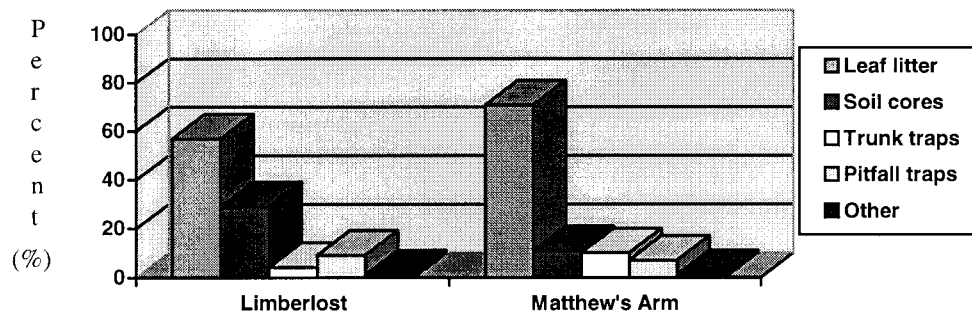


Figure 7. Percentage of springtails collected in leaf litter, soil core, trunk trap, pitfall trap and other samples at Matthew's Arm and Limberlost, August, 1997.

Table 18. Fly (order: Diptera) families, genera, and species collected at Limberlost and Matthew's Arm, August, 1997.

Family	Scientific name	Total number of specimens	Limberlost	Matthew's Arm
Agromyzidae		3	2	1
Agromyzidae	<i>Japanagromyza</i> sp.	8	8	
Anisopidae	<i>Mycetobia divergens</i>	1	1	
Anthomyiidae		16	7	9
Asilidae		2	2	
Bibionidae		120	120	
Calliphoridae		6	2	4
Camillidae		1		1
Cecidomyiidae		3088	1626	1462
Ceratopogonidae		196	96	100
Chironomidae		205	132	73
Chironomidae larvae		1		1
Chloropidae		4	3	1
Clusiidae		1		1
Culicidae		2		2
Diastatidae		1		1
Dixidae		38	20	18
Dolichopodidae		78	36	42
Dolichopodidae	<i>Chrysotus</i> sp.	1		1
Drosophilidae		48	26	22
Empididae		228	189	39
Lauxaniidae	<i>Camptoprosopella</i> sp.	5	5	
Lauxaniidae	<i>Homoneura fraterna</i>	3		3
Lauxaniidae	<i>Homoneura incerta</i>	14	14	
Lauxaniidae	<i>Homoneura philadelphica</i>	52	46	6
Micropezidae	<i>Calobatina geometra</i>	1	1	
Muscidae		183	81	102
Mycetophilidae		236	110	126
Phoridae		416	108	308
Pipunculidae		2		2
Psychodidae		29	15	14
Rhagionidae		1		1
Sarcophagidae		3	1	2
Scathophagidae		5		5
Sciaridae		230	92	138
Sciomyzidae		2		2

Table 18. (cont.) Fly (order: Diptera) families, genera, and species collected at Limberlost and Matthew's Arm, August, 1997.

Family	Scientific name	Total number of specimens	Limberlost	Matthew's Arm
Simuliidae		30	1	29
Sphaeroceridae		50	20	30
Stratiomyidae		2		2
Syrphidae		3	2	1
Tabanidae		3		3
Tachinidae		9	7	2
Tephritidae	<i>Trypeta</i> sp.	2		2
Tipulidae		109	61	48
Vermileonidae		3		3
Xylophagidae		1	1	
unknown -larvae or damaged		153	54	91

Diptera

We collected 5,442 individuals from 40 fly (order:Diptera) families (Table 18). In addition, we collected 153 individuals from the Order Diptera that we were unable to identify due to funding and expertise constraints. Twelve families were only found at Matthew's Arm and five families were only found at Limberlost. Twenty-three families were collected in both stands. All individuals of the Dipteran family Lauxaniidae were identified to species level. Of the four species of lauxaniids collected, two were only found at Limberlost, one was only found at Matthew's Arm and one was collected from both stands.

Several Dipteran families, including Bibionidae, Cecidomyiidae, Chironomidae, Empididae, and Lauxaniidae, were more abundant at Limberlost than at Matthew's Arm. Some or all members of these families share a dependence upon decaying organic matter, fungus, mould and dung. Bibionid, or march fly, larvae feed on most kinds of vegetable matter, including live plants and leaf mould (Oldroyd 1964). As adults, bibionids are flower-feeders. Most Cecidomyiidae, or gall-midge, larvae burrow into the tissues of living plants and cause formation of galls. However, others feed in rotting vegetable matter, dung, fungus, and mould. Most members of the family Chironomidae, or midges, are aquatic whereas others are terrestrial. Many larvae live in moss, humus, dung, and rotting vegetation that is wet and rich in organic matter (Borror et al. 1989). Like the Chironomids, the Empididae, or dance flies, have both aquatic and terrestrial species. Adults feed on nectar and are predaceous. Terrestrial larvae are predominantly predaceous and inhabit rich soil, humus, rotten wood, and decaying vegetation. Lauxaniidae larvae also inhabit decaying organic material and leaf mould, and feed primarily on microorganisms and fungi found on decaying plants. Members of this family are common in moist, shady places (Miller 1977).

Although flies that are dependent upon decaying organic matter seem to be favored in hemlock stands, several of the families that were most abundant in Matthew's Arm are also dependent upon decaying organic matter. For instance, individuals of the family Phoridae inhabit decaying vegetation as adults and occur in decaying organic matter and fungi as larvae. Individuals of the family Sciaridae, or fungus gnats, are dependent upon fungi.

At the family level, reasons for differences in abundance of particular flies in hemlock or hardwood stands were not apparent. Individuals of different families may play similar ecological roles within different ecosystems. Most of the families that were more abundant in Limberlost contain species that are aquatic or prefer moist, shady places. Perhaps individuals of these families are attracted to hemlock stands because of the cooler, moister microclimate that exists there. By further identifying the flies to species level, more differences may become apparent. For example, the lauxaniids were identified to species level, and had a higher species diversity at Limberlost than at Matthew's Arm. *Homoneura philadelphica*, the most abundant species, is the only *Homoneura* species recorded from eastern hemlock forests (Miller 1977).

Table 19. Ant, bee and wasp (order: Hymenoptera) families, genera, and species collected at Limberlost and Matthew's Arm, August, 1997.

Family	Scientific name	Total number of specimens	Limberlost	Matthew's Arm
Apidae		1		1
Braconidae		54	19	35
Ceraphronidae		6	2	4
Cynipidae		1		1
Diapriidae		136	13	123
Eucoilidae		6	2	4
Eulophidae		3	1	2
Eurytomidae		3	1	2
Formicidae		39	6	33
Formicidae	<i>Aphenogaster</i> sp.	57		57
Formicidae	<i>Camponotus</i> sp.	13	5	8
Formicidae	<i>Lasius</i> sp.	32	5	27
Formicidae	<i>Myrmecina</i> sp.	13		13
Formicidae	<i>Stenamma</i> sp.	68	53	15
Heloridae		2	1	1
Ichneumonidae		159	72	87
Ichneumonidae	<i>Gelis maculicollis</i>	1	1	
Megaspilidae		6	3	3
Ormyridae		1	1	
Platygastridae		6	3	3
Pompilidae		3	3	
Proctotrupidae		11	6	5
Pteromalidae		4	4	
Scelionidae		3		3
Sphecidae		1		1
Tenthredinidae		2	1	1
Tiphiidae		1		1
Torymidae		2		2
Vespidae		23		23
unknown-damaged		3		3

Hymenoptera

We collected 557 individuals from 23 Hymenoptera families (Table 19). In addition, we collected three individuals from the order Hymenoptera that we were unable to identify. Seven families were found only at Matthew's Arm, and four families were found only at Limberlost. Fifteen families were collected in both stands.

Members of the order Hymenoptera serve very important roles in ecosystem function. Many of its members are important pollinators. Many others are parasitic on other insects and invertebrates, and are valued for their role in regulating insect populations (Borror et al. 1989). We found a higher diversity and abundance of Hymenoptera specimens at Matthew's Arm than at Limberlost. Because Matthew's Arm had a higher diversity of plant species, as well as a greater abundance and diversity of invertebrates, we expected Hymenoptera to play a more important role in the hardwood stand. Although we recognize their importance, Hymenoptera may not serve as good indicators of hemlock ecosystem integrity. Identification of Hymenoptera to species level may elucidate differences in species composition in hemlock versus hardwood forests.

Lepidoptera

We collected 354 individuals from 15 moth (order:Lepidoptera) families (Table 20). In addition, we collected 135 individuals from the order Lepidoptera that we were unable to identify due to funding and expertise constraints. Three families were found only at Matthew's Arm and six families were found only at Limberlost. Six families were collected in both stands. Thirteen species were collected only at Matthew's Arm, whereas 37 species were collected only at Limberlost. Eleven species were collected in both stands.

The Lepidoptera specimens we captured are species typical of mixed hardwood habitats in the northeast. Although there are several moth species that are hemlock obligates in the northeast (e.g., *Semiothisa fissinotata*), we did not capture any of these species during our limited sampling effort. We were unable to identify any potential indicator species in 1997, however sampling at different times throughout the summer might yield species that are indicative of hemlock ecosystems.

Harvestmen

We collected 104 individuals from two harvestmen (order:Opiliones) families (Table 21). Both families were found in each stand. Two species were only collected at Matthew's Arm, whereas three species were collected in both stands.

Harvestmen are both predators and scavengers, feeding on live and dead insects. Harvestmen generally prefer shaded habitats with closed canopies (Jennings et al. 1984). *Odiellus pictus* prefers habitat of moderate to dense canopies, and was more abundant at Limberlost.

Table 20. Moth (order: Lepidoptera) families, genera, and species collected at Limberlost and Matthew's Arm, August, 1997.

Family	Scientific name	Total number of specimens	Limberlost	Matthew's Arm
Agonoxenidae	<i>Glyphipteryx linneella</i>	1	1	
Arctiidae	<i>Clemensia albata</i>	1	1	
Arctiidae	<i>Holomelina opella</i>	1	1	
Arctiidae	<i>Spilosoma virginica</i>	2	2	
Arctiidae larvae		6		6
Gelechiidae		5	5	
Geometridae larvae		1		1
Geometridae		2	2	
Geometridae	<i>Anacamptodes defectoria</i>	1	1	
Geometridae	<i>Besma quercivoraria</i>	2	1	1
Geometridae	<i>Biston betuloria</i>	28	16	12
Geometridae	<i>Coripeta divisata</i>	18	1	17
Geometridae	<i>Drepana arcuata</i>	9	9	
Geometridae	<i>Epimecis hortaria</i>	1	1	
Geometridae	<i>Epirrhoe alternata</i>	1	1	
Geometridae	<i>Euphyia unangulata intermedia</i>	11	8	3
Geometridae	<i>Hydrelia inornata</i>	2	2	
Geometridae	<i>Hypagrtis subatomoria</i>	11	11	
Geometridae	<i>Iridopsis larvaria</i>	33	27	6
Geometridae	<i>Itame pustularia</i>	22	21	1
Geometridae	<i>Melanolopha canadaria</i>	21		21
Geometridae	<i>Pero honestarica</i>	4	4	
Geometridae	<i>Plagodis alcoolaria</i>	2		2
Geometridae	<i>Prochoerodes transversata</i>	1	1	
Geometridae	<i>Scopula limboundata</i>	5	5	
Geometridae	<i>Semiothisa aemulataria</i>	1	1	
Geometridae larvae		22	18	4
Gracillariidae	<i>Caloptilia serotinella</i>	1	1	
Gracillariidae		3	3	
Limacodidae larvae		2		2
Lymantriidae	<i>Lymantria dispar</i>	3		3
Noctuidae	<i>Abagrotis alternata</i>	4	4	
Noctuidae	<i>Acronicta</i> sp. 2	1	1	
Noctuidae	<i>Acronicta</i> sp.1	1	1	

Table 20. (cont.) Moth (order: Lepidoptera) families, genera, and species collected at Limberlost and Matthew's Arm, August, 1997.

Family	Scientific name	Total number of specimens	Limberlost	Matthew's Arm
Noctuidae	<i>Amphipyra pyramidoides</i>	1		1
Noctuidae	<i>Anathix ralla</i>	2	2	
Noctuidae	<i>Anomogyna</i> sp.	1		1
Noctuidae	<i>Bomolocha edictalis</i>	2	1	1
Noctuidae	<i>Bomolocha palporia</i>	1	1	
Noctuidae	<i>Catocala</i> sp.1	1	1	
Noctuidae	<i>Catocala</i> sp.2	1	1	
Noctuidae	<i>Catocala ultronia</i>	1	1	
Noctuidae	<i>Colocasia propinquinelinea</i>	13	12	1
Noctuidae	<i>Euparthenos nubilis</i>	1	1	
Noctuidae	<i>Euplexia beuesimilis</i>	1	1	
Noctuidae	<i>Leucania</i> sp.	1		1
Noctuidae	<i>Ochropleura plecta</i>	1	1	
Noctuidae	<i>Pangroptia decoralis</i>	1	1	
Noctuidae	<i>Panopoda carneicosta</i>	1		1
Noctuidae	<i>Phalaenophana pyramusalis</i>	1	1	
Noctuidae	<i>Phalaenostola larentioides</i>	4	4	
Noctuidae	<i>Phlogophora periculosa</i>	1	1	
Noctuidae	<i>Xestia dolosa</i>	2	2	
Noctuidae	<i>Xestia smithi</i>	2	2	
Noctuidae larvae		35	7	28
Notodontidae		5		5
Notodontidae	<i>Cochmaeus manteo</i>	1	1	
Notodontidae	<i>Dasylophia anguina</i>	1	1	
Notodontidae	<i>Nadata gibbosa</i>	2	2	
Notodontidae	<i>Oligocentra semirufescens</i>	1	1	
Notodontidae	<i>Schizura ipomoeae</i>	1	1	
Notodontidae larvae		9		9
Oecophoridae		1	1	
Pyalidae		3	3	
Pyalidae	<i>Pantographa limata</i>	5	4	1
Pyalidae	<i>Pyrallis rostiferalis</i>	1	1	
Pyalidae	<i>Pyrausta</i> sp.	10	10	
Saturniidae	<i>Actias luna</i>	1		1

Table 20. (cont.) Moth (order: Lepidoptera) families, genera, and species collected at Limberlost and Matthew's Arm, August, 1997.

Family	Scientific name	Total number of specimens	Limberlost	Matthew's Arm
Thyatiridae larvae		1	1	
Tineidae		2	2	
Tineidae	<i>Swammerdamia caesiella</i>	1	1	
Tineidae larvae		1		1
Tortricidae		2	2	
Tortricidae	<i>Ancylis fuscociliana</i>	1	1	
Tortricidae	<i>Ptycholoma peritana</i>	2	2	
Unidentified larvae		24	7	17
unidentified		111	29	82

Table 21. Harvestmen (order: Opiliones) families and species collected at Matthew's Arm and Limberlost, August, 1997.

Family	Scientific name	Total number of specimens	Limberlost	Matthew's Arm
Phalangiidae	immature	3	2	1
Phalangiidae	<i>Odiellus pictus</i> (Wood)	47	29	18
Sclerosomatidae	<i>Leiobunum aldrichi</i> (Weed)	28	17	11
Sclerosomatidae	<i>Leiobunum calcar</i> (Wood)	20	5	15
Sclerosomatidae	<i>Leiobunum nigropalpi</i> (Wood)	1		1
Sclerosomatidae	<i>Leiobunum politum</i> (Weed)	5		5

Table 22. Bark lice (order: Psocoptera) families and species collected at Matthew's Arm and Limberlost, August, 1997.

Family	Scientific name	Total number of specimens	Limberlost	Matthew's Arm
Amphipsocidae		1		1
Caeciliidae		14	13	1
Ectopsocidae		38	8	30
Elipsocidae		3	3	
Epipsocidae		24	20	4
Lachesnillidae		1		1
Peripsocidae		6	6	
Peripsocidae	<i>Peripsocus madidus</i> (Hagen)	2	2	
Peripsocidae	<i>Peripsocus subfasciatus</i> (Rambur)	37	37	
Philotarsidae		3		3
Psocidae		3	2	1
Psoquillidae		5	3	2
Unknown-damaged or immature		42	13	29

Conversely, *Leiobunum calcar*, which was more abundant at Matthew's Arm, is a hardy species able to tolerate a wider range of habitat conditions (Edgar 1971). *Leiobunum politum* occurs in both fields and woods (Weed 1893). *Odiellus pictus* may prefer the dense canopy and microclimate conditions in hemlock stands, and may be useful as an indicator of hemlock ecosystem integrity.

Psocoptera

We collected 137 individuals from ten psocid (Psocoptera) families (Table 22). In addition, we collected 42 individuals from the order Psocoptera that we were unable to identify. Three families were only collected at Matthew's Arm, two families were only collected at Limberlost, and five families were collected at both stands.

Psocids are primarily herbivores and detritivores and may feed on algae, lichens, molds, fungi, and detritus (Mockford 1993). A few Psocids are partially predators, feeding on insect eggs and scale insects. They may inhabit bark, foliage, litter, or rock surfaces.

Psocids may serve as good indicators of hemlock ecosystem integrity. Individuals of the family Peripsocidae were only found at Limberlost. Three species of peripsocids, most of which were *Peripsocus subfasciatus* (Rambur), were identified. Mockford (personal communication) stated that *P. subfasciatus* is more common in hemlock stands than hardwood stands in Illinois. In addition, E. Mockford (Illinois State University) stated that *P. subfasciatus* has both a parthenogenetic (thelytoky) and a sexual form. Within the interior of the eastern United States, Mockford has only found the sexual form (males) in hemlock stands, although the reason for this is unknown. It is possible that the parthenogenetic form outcompetes the sexual form in other habitats, but that the increase in genetic diversity resulting from sexual reproduction is an advantage within hemlock ecosystems.

We captured two male *P. subfasciatus* at Limberlost and none at Matthew's Arm, further supporting Mockford's findings. These specimens constitute the first record of male *P. subfasciatus* known from Virginia. Therefore, hemlock stands may support unique psocid species as well as a greater amount of genetic diversity within species.

More individuals of the family Caecilidae and Epipsocidae also were captured at Limberlost. Many species of the family Caecilidae are known to inhabit coniferous trees (Mockford 1993). Species of Epipsocidae inhabit woodland litter, shaded rock outcrops, and coniferous trees.

Bugs

We collected 25 individuals from eight bug (order:Hemiptera) families and 194 individuals from six Homoptera families (Table 23). In addition, we collected 13 individuals from the Order Hemiptera, and 10 individuals from the order Homoptera, that we were unable to identify. Individuals from each of the eight hemiptera families were collected at Matthew's Arm, whereas only two families were represented at Limberlost. Bugs inhabit vegetation or reside on the ground. Some are predators, while others are herbivores.

Table 23. Bugs (Hemiptera), cicadas, hoppers, psyllids, whiteflies, aphids and scale insects (Homoptera) families collected at Matthew's Arm and Limberlost, August, 1997.

Order	Family	Total number of specimens	Limberlost	Matthew's Arm
Hemiptera	Acanthosomatidae	1		1
Hemiptera	Anthocoridae	1		1
Hemiptera	Aphididae	1		1
Hemiptera	Cyonidae	1		1
Hemiptera	Lygaeidae	2		2
Hemiptera	Miridae	12	4	8
Hemiptera	Pentatomidae nymph	1	1	
Hemiptera	Pentatomidae	2		2
Hemiptera	Reduviidae	4		4
Hemiptera	unknown - damaged or immature	13		13
Homoptera	Aphididae	27	5	22
Homoptera	Cercopidae	2		2
Homoptera	Cicadellidae	161	30	131
Homoptera	Delphacidae	1	1	
Homoptera	Membracidae	2	2	
Homoptera	Psyllidae	1	1	
Homoptera	unknown - damaged or immature	10	2	8

One Homoptera family was only collected at Matthew's Arm, three families were only collected at Limberlost, and two families were collected at both stands (Table 23). Aphids (Aphididae) and hoppers (Cicadellidae) were the most abundant families we captured, and many more individuals were collected from Matthew's Arm than from Limberlost. All Homoptera feed on plants. Therefore, we expected the number of Homoptera, as well as Hemiptera, to be higher at Matthew's Arm due to the higher diversity of tree and shrub species, as well as the higher density of shrubs, at Matthew's Arm.

Centipedes

We collected 254 individuals from three centipede (class Chilopoda) orders and six families (Table 24). Individuals from all three orders were found in both stands. Within the order Geophilomorpha, members of each family were found in both stands, however, *Strigamia bidens* and *Strigamia bothriopa* only were found at Matthew's Arm. Both Lithobiomorpha families were found at each stand. Within the order Scolopendromorpha, individuals of the family Cryptopidae were found in both stands whereas individuals of the family Chilopodae were found only at Limberlost.

We collected five specimens of *Arctogeophilus fulvus*, one at Limberlost and four at Matthew's Arm (Table 24). *A. fulvus* is a very rare northern species (Hoffman, personal communication). This species has been only collected at elevations above 909 meters, indicating that *A. fulvus* has a sub-boreal range in the Appalachians (Hoffman 1995). The southernmost known record is for Roan Mountain, TN, at 1,515 meters. Our specimens constitute the first known records of this rare species from Shenandoah NP.

Our specimens of *Strigamia bidens* also constitute a new county record. Previously, *S. bidens* was only recorded from eight western counties of Virginia (Hoffman 1995). However, it is considered to be more widespread; its limited known range due to lack of collection in other areas (Dr. Richard Hoffman, Virginia Museum of Natural History, October, 1998, personal communication).

Millipedes

We collected 380 individuals from four Diplopoda orders and ten families (Table 25). Individuals from the orders Chordeumatida, Julida, and Polydesmida were collected at both stands. Spirobolida specimens were only collected at Matthew's Arm. Within the order Chordeumatida, specimens of the families Branneridae and Cleidogonidae were found in both stands. Polydesmidae specimens were only collected at Limberlost, and Striariidae specimens were only collected at Matthew's Arm. One Julidae specimen was collected at Matthew's Arm, and Parajulidae and Polydesmidae specimens were collected in both stands. Xystodesmidae and Polydomidae specimens were only collected from Limberlost, and Spirobolidae specimens were only collected from Matthew's Arm.

The biology of millipedes is poorly known, in part because their taxonomy is incomplete. Shear (1972) speculated that less than one quarter of millipedes in the United States have been

Table 24. Centipede orders, families and species collected at Matthew's Arm and Limberlost, August, 1997.

Order	Family	Scientific name	Total number of specimens	Limber-lost	Matthew's Arm
Geophilomorpha	Chilenophilidae	<i>Arctogeophilus fulvus</i> (Wood)	5	1	4
Geophilomorpha	Dignathodontidae	<i>Strigamia bidens</i> (Wood)	2		2
Geophilomorpha	Dignathodontidae	<i>Strigamia bothriopa</i> (Wood)	1		1
Geophilomorpha	Dignathodontidae	<i>Strigamia cf. branneri</i> (Bollman)	18	3	15
Geophilomorpha	immature		10	9	1
Lithobiomorpha	Henicopidae		31	18	13
Lithobiomorpha	immature		3		3
Lithobiomorpha	Lithobiidae		159	89	70
Scolopendromorpha	Chilopodae		4	4	
Scolopendromorpha	Cryptopidae		30	8	22
Scolopendromorpha	Cryptopidae	<i>Cryptops</i> sp.	1		1

Table 25. Millipede orders, families and species collected at Matthew's Arm and Limberlost, August, 1997.

Order	Family	Scientific name	Total number of specimens	Limberlost	Matthew's Arm
Chordeumatida	Branneridae		38	17	21
Chordeumatida	Cleidogonidae		78	30	48
Chordeumatida	Polydesmidae		1	1	
Chordeumatida	Striariidae	<i>Striaria</i> sp.	3		3
Julida	Julidae		1		1
Julida	Parajulidae		227	172	55
Polydesmida	Polydesmidae		25	15	10
Polydesmida	Xystodesmidae	<i>Semionellus placidus</i> (Wood)	1	1	
Polydesmida	Polydomidae		2	2	
Spirobolida	Spirobolidae		4		4

described. Shear (1972) also stated that hardwood forests are the most productive habitats for millipedes, while coniferous forests are considered to support relatively few millipedes. Hartman (1977), however, found a greater abundance of millipedes and centipedes in hemlock stands than in hardwood stands in Connecticut. In addition, Dirks-Edmunds (1947) found five times as many millipedes and centipedes in Douglas fir-hemlock communities than in oak communities in Oregon.

We captured more millipedes in the hemlock stand than in the hardwood stand. The greater abundance of millipedes at Limberlost was due to the abundance of the family Parajulidae. Leaf litter in hemlock stands may be more moist, and therefore better feeding habitat for saprophagous invertebrates such as millipedes (Hartman 1977). However, according to R. Hoffman of the Virginia Museum of Natural History, (personal communication) Parajulidae generally inhabit open fields. Identification of millipede specimens to species may reveal further differences in the millipede communities between hemlock and hardwood stands. Millipedes may be useful as indicators of hemlock ecosystem integrity.

Other Invertebrate Orders

We collected specimens from a number of other invertebrate orders including mites (Acari), cockroaches (Blattaria), diplurans (Diplura), scorpionflies (Mecoptera), lacewings (Neuroptera), crickets (Orthoptera), proturans (Protura), pseudoscorpions (Pseudoscorpiones), fleas (Siphonaptera), and thrips (Thysanoptera) (Table 26). We collected relatively few specimens from most of these orders. Although we collected many mites, they were not identified due to lack of funding and expertise. More mites were collected at Limberlost than at Matthew's Arm.

Several orders of aquatic insects were also captured (Table 26). These included mayflies (Ephemeroptera), stoneflies (Plecoptera), and caddisflies (Trichoptera). Stoneflies of the family Leuctridae were more abundant at Limberlost than at Matthew's Arm. Snyder et al. (1998) found that *Leuctra* spp. (Leuctridae) were strongly associated with streams in hemlock stands.

Salamanders

Seventy-six salamanders of three species were captured at Limberlost (Table 27). Seventy salamanders were captured during the substrate search, four were inadvertently captured in invertebrate pitfall traps, and two were captured in the mammal pitfall trap. Forty-nine salamanders of six species were captured at Matthew's Arm (Table 27). Twenty-five salamanders were captured during the substrate search, 22 were captured in invertebrate pitfall traps, and two were captured in the mammal pitfall trap. Salamanders captured during the substrate search were identified and released. Individuals captured in invertebrate or mammal pitfall traps were identified and curated at the Vertebrate Museum of Shippensburg University, Shippensburg, Pennsylvania.

The red-backed salamander was the only species with a sample size large enough to allow statistical comparisons. Sixty-eight red-backed salamanders were captured at Limberlost during the substrate search, with a mean of 6.18 (SE = 0.83, $n = 11$) salamanders per plot. Nineteen red-

Table 26. Mite, cockroach, dipluran, mayfly, lacewing, scorpionfly, cricket, stonefly, proturan, pseudoscorpion, flea, thrip, and caddisfly orders and families collected at Matthew's Arm and Limberlost, August, 1997.

Order	Family	Total number of specimens	Limberlost	Matthew's Arm
Acari		1208	744	464
Blattaria	Cryptoceridae	1	1	
Diplura	Campodeidae	2		2
Diplura	Japygidae	3	3	
Ephemeroptera		7	7	
Mecoptera	Meropeidae	3		3
Mecoptera	Panorpidae	1		1
Neuroptera	Hemerobiidae	6	4	2
Neuroptera	Nymph	2		2
Orthoptera	Acrididae	4	4	
Orthoptera	Gryllacrididae	8		8
Plecoptera	Chloroperlidae	1	1	
Plecoptera	Leuctridae	119	101	18
Plecoptera	Nemouridae	19	17	2
Plecoptera	Perlidae	19	14	5
Plecoptera	Perlodidae	3	1	2
Protura		22	13	9
Pseudoscorpiones		64	19	45
Siphonaptera		9	3	6
Thysanoptera	Immature	1		1
Thysanoptera	Phlaeothripidae	4		4
Thysanoptera	Thripidae	4	2	2
Trichoptera	Lepidostomatidae	32	11	21
Trichoptera	Limnephilidae	77	48	29
Trichoptera	Philopotamidae	4	2	2
Trichoptera	Polycentropodidae	9	8	1
Trichoptera	Psychomyiidae	106	53	53
Trichoptera	Rhyacophilidae	36	13	23

Table 27. Salamanders captured at Matthew's Arm and Limberlost, August, 1997.

Common name	Scientific name	Number of salamanders captured at Limberlost	Number of salamanders captured at Matthew's Arm	Total
Jefferson salamander	<i>Ambystoma jeffersonianum</i>	0	1	1
Red-backed salamander	<i>Plethodon cinereus</i>	73	33	106
Slimy salamander	<i>Plethodon glutinosus</i>	0	4	4
Spring salamander	<i>Gyrinophilus porphyriticus</i>	2	1	3
Two-lined salamander	<i>Eurycea bislineata</i>	1	9	10
Valley and Ridge salamander	<i>Plethodon hoffmani</i>	0	1	1

backed salamanders were captured at Matthew's Arm during the substrate search, with an average of 1.73 (SE = 0.60, $n = 11$) salamanders per plot. Red-backed salamanders were significantly ($t = 4.66$, d.f. = 18, $P = 0.001$) more abundant at Limberlost than at Matthew's Arm.

Frisbie and Wyman (1992) stated that, in their study site in New York, the red-backed salamander was four to five times more abundant in beech than in hemlock forest. They hypothesized that differences in soil chemistry (more acidic soil in hemlock) might affect rates of sodium loss in red-backed salamanders, and thus favor hardwood habitats. However, differences in soil chemistry did not explain differences in red-backed salamander abundance in their study. Wyman (1988) found red-backed salamanders in quadrats with a soil pH of 4.2 but did not find red-backed salamanders in quadrats with a pH of 3.9. Although soil pH was significantly lower at Limberlost than at Matthew's Arm (Table 5), the mean soil pH of Limberlost was 4.48, well above the apparent limiting level in Wyman's study.

The red-backed salamander is an important predator of large invertebrate decomposers (Wyman and Hawksley-Lescault 1987). Therefore, a greater abundance of large invertebrate decomposers (e.g. millipedes) in the leaf litter and soil of hemlock stands may support greater numbers of salamanders. In a study conducted by National Audubon Society in Pennsylvania, researchers also detected a trend toward higher number of red-backed salamanders in coniferous forests (Ross, unpublished data). Therefore, red-backed salamanders potentially may be used as indicators of hemlock ecosystem integrity, although more sampling should be conducted in a number of hemlock and hardwood stands to confirm the trend of higher numbers in hemlock versus hardwood. In addition, the mechanisms that favor higher numbers of red-backed salamanders in hemlock stands should be identified.

Mammals

Live Trapping

No mammals were captured in the wire mesh traps during the trapping period at either study area. For the small mammal traps, we reached a total of 143 and 62 trap nights for the entire trapping period at Matthew's Arm and Limberlost, respectively. Because many small mammal traps were frequently disturbed or damaged by a black bear (*Ursus americanus*) sow and cub at Limberlost, trapping effort was not consistent throughout the trapping period (Table 28).

Four species of small mammals, the white-footed mouse (*Peromyscus leucopus*), deer mouse (*Peromyscus maniculatus*), red-backed vole (*Clethrionomys gapperi*), and meadow vole (*Microtus pennsylvanicus*) were captured at both study areas combined (Table 28). However, only one meadow vole was captured and, therefore, not included in the statistical analyses.

Higher mean numbers of red-backed voles, deer mice and white-footed mice were captured per trap night at Limberlost than at Matthew's Arm, although these differences were not statistically significant ($P > 0.05$) (Table 29). Perhaps the high variability in capture rate and the number of trap nights precluded the statistical detection of differences between the study areas (Table 29). Finally, there was a slight trend in the percent of *P. leucopus* infested with bot flies between the

Table 28. Total and mean ($\pm$ SE) number of trap nights per night for small mammal traps at Matthew's Arm and Limberlost, August, 1997.

Study Area	Date	Trap-nights	Disturbed/damaged traps (lost trap-nights)
Matthew's Arm	8/19	34	6
	8/20	40	0
	8/21	29	11
	8/22	40	0
Total =		143	17
Limberlost	8/19	31	9
	8/20	16	24
	8/21	2	38
	8/22	13	27
Total =		62	98

Table 29. Comparison of mean number of small mammal captures per trap night ($\pm$ SE) at Limberlost (n = 62) and Matthew's Arm (n = 143), August, 1997.

Species	Mean number captures/trap night			
	Limberlost		Matthew's Arm	
	$\bar{x}$	SE	$\bar{x}$	SE
<i>Peromyscus leucopus</i> ^a	0.258	0.169	0.187	0.043
<i>Peromyscus maniculatus</i> ^b	0.141	0.132	0.033	0.039
<i>Clethrionomys gapperi</i> ^c	0.154	0.209	0.006	0.012

^aNo significant difference between study areas; $t = 3.18$, $df = 3$, $P = 0.47$

^bNo significant difference between study areas; $t = 2.77$, $df = 3$, $P = 0.19$

^cNo significant difference between study areas; $t = 3.18$, $df = 3$, $P = 0.25$

two study areas ($t = 2.44$, $df = 6$, $P = 0.10$), with a higher percentage infested at Matthew's Arm ($\bar{x} = 25\%$) than at Limberlost ($\bar{x} = 6\%$).

We expected to find a significantly higher number of red-backed voles in the hemlock stand than in the hardwood stand. Red-backed voles require moist habitat and consume more water than other small mammal species (Getz 1968, Nurdyke and Buskirk 1991). In addition, although they will eat a variety of plant and insect foods, red-backed voles consume a higher proportion of fungi than most other small mammal species and can be a major dispersal agent of fungi (Ovaska and Herman 1986, Ure and Maser 1982). Red-backed voles also may play an important role in inoculating woody plants with mycorrhizal fungi, thereby aiding the establishment of trees and the maintenance of forest health (Maser et al. 1978). The roots of most vascular plants have an obligatory relationship with nitrogen-fixing fungi. Small mammal burrowing activities transport these fungi to the roots of plants.

We also expected to find a significantly higher number of white-footed mice in the hardwood stand than in the hemlock stand. White-footed mice consume more mast than other small mammal species, and are dependent upon acorns for over-winter survival (Goodrum et al. 1971, Hamilton 1941, Martin 1951). Although we did not find a significantly higher number of white-footed mice at Matthew's Arm, we did find a strong trend toward a higher number of white-footed mice infested with bot fly (*Cuterebra sp.*) larvae at Matthew's Arm. Host parasitism rates may be density dependent (Dunaway et al. 1967). If parasitism rates are density dependent, we would expect white-footed mice to be more abundant at Matthew's Arm than at Limberlost. However, other factors, including soil conditions and the microenvironment near the soil surface, may determine habitat suitability for bot fly eggs and young larvae (Dunaway et al. 1967). Bot fly larvae can cause reduced reproductive success and cause anemia, leucocytosis and plasma protein imbalances in their hosts (Dunaway et al. 1967, Sabrosky 1986). These factors, in addition to reduced mobility and subsequent increased susceptibility to predation, may reduce the fitness of infested populations. Therefore, rates of bot fly parasitism may influence small mammal community composition and structure.

We believe the lack of significant results in August 1997 was due to interference by a black bear sow and cub at Limberlost. Not only did we lose over one-half of our trap nights at Limberlost, but the remaining trap nights were biased by bear activity. For example, in the beginning of the week it appeared that all of the traps that the bears came upon were disturbed. However, some of the traps only were opened in the back, while others were torn completely open with all bait missing. The traps that were opened in the back but not torn apart had fresh mammal urine and droppings, indicating that they had contained small mammals at the time they were opened. We suspected that either the small mammals frightened the bears when they jumped out, or the smell of urine made the peanut butter unattractive to them and they moved on to the next trap. By the last morning, however, almost every trap that was undisturbed held a small mammal. We concluded that the bears had learned to smell whether the traps contained small mammals or not, and left the full traps unmolested. This biased the number of mammals per trap night at Limberlost and led to higher numbers of all small mammals per trap night in that stand.

Pitfall Trapping

Only one small mammal was captured in the mammal pitfall traps. One red-backed vole was captured in the mammal pitfall trap at Limberlost. In addition, two juvenile white-footed mice were captured in invertebrate pitfalls.

Mammalian Transect Protocol

Mammals determined to be present within Limberlost and Matthew's Arm, Shenandoah NP, according to the transect protocol are listed below:

<u>Limberlost</u>	<u>Matthew's Arm</u>
Black bear	Bobcat (<i>Lynx rufus</i>)
Raccoon (<i>Procyon lotor</i>)	Eastern chipmunk (<i>Tamias striatus</i>)
Squirrel (<i>Sciurus sp.</i>)	Raccoon
White-tailed deer	Squirrel
	White-tailed deer

Deer Pellet-Group Technique

The mean number of pellet groups per plot at Limberlost was 0.20 (SE = 0.09) At Matthew's Arm, the mean number of pellet groups per plot was 0.25 (SE = 0.14). The mean number of pellet groups per plot did not differ significantly ($t = -0.29$, $P = 0.77$) between Limberlost and Matthew's Arm.

Although preferential use of hemlock over hardwood stands by deer was not evident from pellet counts conducted in August, we expect that use of hemlock stands by deer would be greater in the winter. Hemlock stands provide excellent thermal cover for wildlife during the winter months.

Summary

Biotic Components of Hemlock and Hardwood Ecosystems

Matthew's Arm was characterized by soils with higher levels of available nutrients and lower acidity than Limberlost. In addition, Matthew's Arm had a higher species richness of herbaceous vegetation, shrubs/saplings and overstory trees, and a higher density of shrubs/saplings. Dominant overstory trees at Matthew's Arm were chestnut oak, northern red oak, striped maple, red maple, pignut hickory, and black oak.

Overall, invertebrate species (or family) richness was higher at Matthew's Arm than at Limberlost. These results were expected, as a higher density and diversity of plants may provide food for more invertebrates.

We found twice as many species of salamanders at Matthew's Arm than at Limberlost, although the number of red-backed salamanders captured at Matthew's Arm was significantly less than the number captured at Limberlost. Small mammals did not exhibit any significant differences in abundance between the two sites, although there was a strong trend toward a higher infestation of bot fly larvae in white-footed mice at Matthew's Arm.

Limberlost was characterized by more acidic soils with lower available nutrients. Eastern hemlock was by far the most dominant overstory tree species at Limberlost. Other associated overstory species included black birch, red maple, basswood, northern red oak, and sugar maple. The understory and shrub layer at Limberlost was relatively sparse compared with that of Matthew's Arm.

Invertebrate species (or family) richness was generally lower at Limberlost than at Matthew's Arm. However, although Matthew's Arm had a greater variety of invertebrates, the invertebrate community at Limberlost seemed to be unique in several ways. Although further collecting in a number of stands and in different seasons is needed to verify a difference in invertebrate communities, many families of invertebrates only were present at Limberlost. In addition to differing species composition, the structure of hemlock and hardwood invertebrate communities may differ. For example, orb-weaving spiders, which require open habitat structure, were more abundant at Limberlost. Several families of flies that depend upon decaying organic material and fungi also seemed to be more abundant at Limberlost, as did *Odiellus pictus*, a species of harvestmen. Individuals of the bark lice family Peripsocidae were unique to Limberlost and are known to be more abundant in hemlock forests than hardwood forests. Specimens of the millipede family Parajulidae also were more abundant at Limberlost. Further identification of invertebrate specimens to the species level will undoubtedly reveal more differences in the invertebrate communities between the two stands.

The red-backed salamander, which feeds on large detritivorous insects, such as millipedes, was significantly more abundant at Limberlost than at Matthew's Arm. Finally, although no statistically significant differences were detected in the mammal communities due to lost trap nights, we suspect that the red-backed vole (*C. gapperi*) may be more abundant at Limberlost.

The red-backed vole consumes a high proportion of fungi, which are known to thrive in hemlock ecosystems.

Although preliminary results suggest that hardwood forests are more diverse than hemlock forests, hemlock forests do seem to have unique species composition and structure. Therefore, hemlock stands may contribute significantly to the regional biodiversity of otherwise hardwood landscapes in the northeast.

Ecosystem Profile Approach

We found the ecosystem profile approach to be a useful tool for inventorying biodiversity, formulating future research hypotheses, and providing a more complete (multi-taxonomic) understanding of hemlock ecosystem structure and function. Within a 4-day sampling period we documented the presence of 70 plant species, and collected 13,803 invertebrates from 30 orders and 168 families. As the invertebrate specimens are further identified, the total number of invertebrate species will likely be in the thousands. Of the few specimens that were identified to species, two centipede species are new records for Shenandoah NP and new county records for Virginia. In addition, males of *P. subfasciatus* (Peripsocidae) had never before been documented in Virginia. Prior to our collection, only the parthenogenetic form of that species had been collected in the state. As identification proceeds, many more new county and state records are likely to be documented from our collection. New, previously undescribed species also may be found. In addition to plants and invertebrates, we documented six species of salamanders and 10 species of mammals within Matthew's Arm and Limberlost.

Although limited funding precluded sampling at more than one pair of stands or more than one time per year, the information we gathered can be used to formulate future research hypotheses. For example, specific research projects on the abundance of red-backed salamanders in hardwood versus hemlock forests, diet of the red-backed salamander (e.g., their reliance on detritivorous insects), differences in the detritivorous invertebrate communities, abundance of the red-backed vole, and role of spiders in hemlock communities are all projects which may help us to better understand hemlock ecosystem function. With more information about their roles in hemlock ecosystems, red-backed salamander, red-backed vole, orb-weaving spiders, *P. subfasciatus*, and detritivorous insects may be identified as indicator species (or guilds) for hemlock ecosystem health. Fungi in hemlock versus hardwood stands should be investigated as well, as fungi serves as food for many detritivorous invertebrates and the red-backed vole.

Future Research

In August 1997, we tested the ecosystem profile approach at Shenandoah NP. Based on our results, we believe the ecosystem profile approach, implemented in several pairs of stands, during spring, summer and fall, would generate enough information to allow statistical comparisons of the biota of hemlock and hardwood stands. Detailed information about hemlock ecosystem structure and function may elucidate which factors make some hemlock stands more susceptible to the hemlock woolly adelgid than others or help identify potential native biological controls.

Using the ecosystem profile approach, functional guilds and species that are particularly representative of hemlock ecosystem integrity can be identified and used as ecological indicators to monitor hemlock health. Baseline information gathered using the ecosystem profile approach could also provide the foundation upon which future restoration efforts can be developed. If hemlock ecosystems are eliminated before we understand their components, we will never know how to successfully restore them.

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