Colby Hill Ecological Project

A Survey of Surface-Active Terrestrial Invertebrates at the Guthrie-Bancroft Farm in Lincoln and Bristol, Vermont

Submitted by
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Executive Summary

Terrestrial invertebrates constitute an important component of faunal biodiversity and provide an attractive alternative to larger animals for ecosystem monitoring. In this study, we examined the surface-active terrestrial invertebrate diversity in three different forest ecosystems (rich hardwood forest, transition hardwood forest, and spruce-fir forest) at the Guthrie-Bancroft Farm in Lincoln and Bristol, Vermont.

We collected 6158 specimens belonging to 21 orders in 53 samples (35 pitfall and 18 litter) taken at two times during the 1999 field season. We identified 2014 specimens to the family level and sorted them into 84 invertebrate families. Using extrapolation techniques, we generated three estimates of overall family richness for surface-active invertebrates, which ranged from 120-159 families.

Non-statistical comparisons of the family richness and the distinctness of the invertebrate assemblages for each of the three forest ecosystems suggested that the rich hardwood forest was the most diverse. In addition to having several uncommon species, this ecosystem had the highest number of observed families, the highest estimates of family richness, and the highest number of unique families. Two factors that may account for the higher diversity of the rich hardwood forest are moisture and nutrients. The transition hardwood forest appeared to be the least diverse of the three ecosystems, having the lowest estimates of family richness and the lowest number of unique families. The results of these ecosystem comparisons, however, should be treated as preliminary.

We selected three focal groups (spiders, ground beetles, and ants) and identified a total of 333 specimens (191 spiders, 112 ground beetles, and 30 ants) to the species level. We identified 19 species of ground beetles and generated an overall ground beetle species richness estimate of 27 for Guthrie-Bancroft Farm. This represents approximately 50 % of the surface-active ground beetles known to occur in the nearby Green Mountain National Forest. We identified 30 species of spiders and estimated that the overall surface-active species richness for the three forest ecosystems ranged from 39-42 species. This represents about 6% of the spider fauna (for the families collected) known from the northeastern states and Canadian provinces.

Finally, our species identifications turned up several uncommon specimens from the rich hardwood forest. We found two individuals of the ground beetle species, *Pterostichus lachrymosus*. This uncommon species has a state rank of S3 and is included on Vermont's list of rare and uncommon animals. We found two unusual spider specimens belonging to the genera *Bathyphantes* and *Ceraticelus* that likely represent undescribed species. One unusual specimen from outside of the focal groups was identified as *Crosbycus dasycnemus*, the lone member of the Ceratolasmatidae family found in our fauna. Although known from Vermont, it has only rarely been collected here.

The findings of this study suggest that the protection of the overall biodiversity of surface-active invertebrates at Guthrie-Bancroft Farm should involve the preservation and management of all three forest ecosystems that were examined. In each of the forest ecosystems we found families and species that were not found in either of the other two ecosystems. Therefore the loss of any one ecosystem might result in the local extinction of species. Furthermore, the findings suggest that special attention be paid to the preservation of the rich hardwood forest ecosystem. Its comparatively high diversity, together with the presence of several uncommon species, warrants concern for any intensive management practices that could potentially damage it.

Introduction

Terrestrial invertebrates, which include insects, spiders, centipedes, millipedes, and a few other groups, constitute an enormous percentage of the planet's biological diversity. Insects alone comprise more than three-fourths of the known animal species in the world (Freeman, 1979). Despite their important contribution to biological diversity, however, terrestrial invertebrates have generally received little attention in conservation planning. This can be attributed, in part, to the fact that a thorough inventory of invertebrates to the species level in any ecosystem is usually both a time- and cost-prohibitive endeavor, which requires the dedication of numerous taxonomic specialists.

Recently, however, invertebrates have begun to receive more attention from conservationists and ecological planners (Kremen et al., 1993) both for their contribution to biodiversity and for their potential usefulness in biomonitoring. Invertebrates can provide an attractive alternative to larger animals in ecosystem monitoring for several reasons. Invertebrates are: 1) abundant and highly diverse, 2) found in a wide variety of habitats and ecological niches, 3) of small size and wide distribution relative to vertebrates, 4) subject to rapid population turnover, and 5) easily sampled in statistically significant numbers (Kremen et al., 1993). Furthermore, terrestrial invertebrates are low on the food chain and thus respond more rapidly to subtle environmental changes than vertebrate groups. Finally, in small preserves, invertebrates offer a way of monitoring ecological integrity that may not be feasible with relatively small vertebrate populations.

Some efforts have been made by ecologists (Oliver and Beattie, 1996a; Colwell and Coddington, 1994; Hammond, 1994) to establish time- and cost-effective shortcut methods for the estimation of invertebrate species richness and diversity. The use of focal groups, extrapolation, and morphospecies are among the methods that have thus far been developed. The "focal group" method (Hammond, 1994) uses selected taxonomic groups as surrogates for larger invertebrate assemblages. In this approach, a subgroup of the collection is identified to species and its species richness is then correlated with the richness of the larger group to which it belongs (for example, the wolf spider richness could represent the richness of all spiders). A second method for estimating species richness is to extrapolate from a small sample size in which all specimens are identified to species (Colwell and Coddington, 1994). A third shortcut involves separating specimens into "morphospecies" (Oliver and Beattie, 1996b) by grouping specimens that look alike regardless of their scientific names. This method does not require specialists for taxonomic identification and in at least one case (Oliver and Beattie,1996b) morphospecies were used to generate estimates of species richness that were very similar to exact species identification. The utility of these methods is currently being debated, however, and studies that test their effectiveness are scarce.

In this study, we examined the terrestrial invertebrate diversity in three different forest ecosystems at the Guthrie-Bancroft Farm in Lincoln and Bristol, Vermont. The ecosystems targeted were: a rich, moderately well drained, seepy, northern hardwood forest (RHF); a well drained, beech-red maple-red oak-sweet birch transition hardwood forest (THF); and a somewhat poorly drained, red spruce-balsam fir-hemlock-yellow birch forest (SF). We focused our study on surface-active invertebrates by using sampling methods that would capture those species primarily active on the ground surface or within the forest litter. All adult specimens collected were identified to the family level. Since both richness and distinctness are key components of biodiversity, we estimated the family richness and the distinctness of the invertebrate assemblages in each forest type. We also estimated the overall family richness of the three ecosystems taken as a whole. A few select "focal groups" were then identified to species. We estimated the species richness and distinctness of the focal groups for each forest ecosystem and overall. Finally, we reported on rare and uncommon species collected at the Guthrie-Bancroft Farm.

Methods

In each of the three forest ecosystems (Figure 1), six pitfall traps were set approximately 5 m apart and left open for one week. When the traps were recovered, three 4-L samples of forest litter were collected near the pitfall traps. The litter samples were placed into Berlese funnels to extract the litter-dwelling invertebrates. All specimens were stored in 80% ethanol with 1% glycerin. This collecting schedule was completed twice: once in early May and again in late July-early August. The first round of pitfall traps and litter samples was collected on May 13, 1999. Pitfall traps were again collected on July 25, 1999, but because several of the traps at the transition hardwood forest site (THF) had been disturbed (probably by a bird or mammal), the disturbed traps were reset and collected on August 1, 1999. One pitfall trap from the rich hardwood

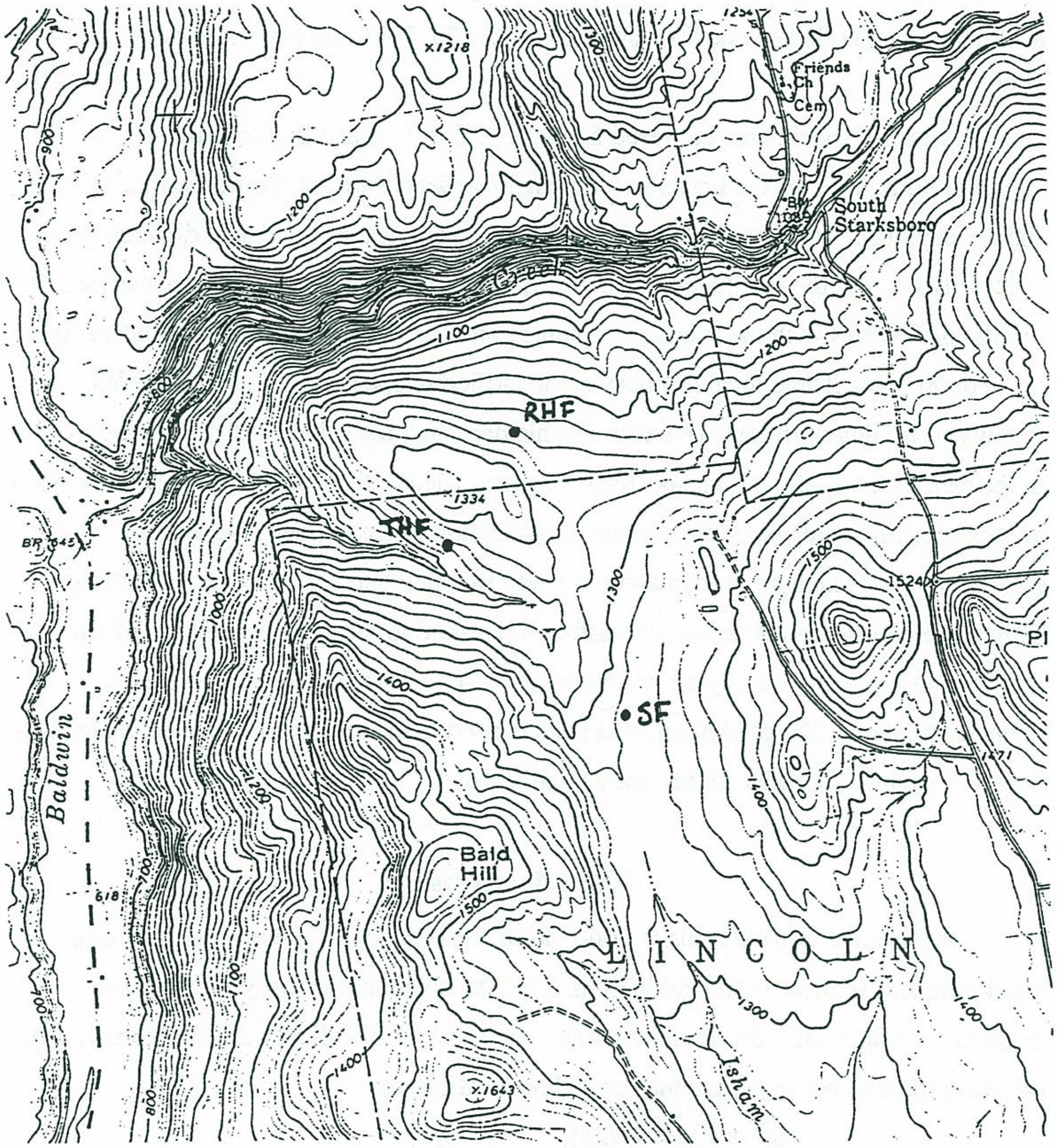

Figure 1. Approximate sampling locations in three forest ecosystems at Guthrie-Bancroft Farm in Lincoln/Bristol, Vermont, 1999. RHF = Rich hardwood forest; SF = Spruce-fir forest; THF = transition hardwood forest.

forest was also disturbed, but a new trap was not put out. In each of the three forest ecosystems, we collected one litter sample on July 25, 1999 and two more on August 7, 1999.

All adult specimens recovered from the pitfall traps and litter samples were identified to family, except for three problematic orders (Acarina, Pseudoscorpionida, and Psocoptera). The Acarina, despite their abundance, are an extremely difficult group to identify even to the family level and are typically lumped by order in data analyses. Similar difficulties with the Pseudoscorpionida and the Psocoptera forced us to treat them at the order level. Three focal groups were identified to species: the ground beetles (Family: Carabidae), the ants (Family: Formicidae), and the spiders (Order: Areneida). In the case of the spiders, each specimen was identified to the finest level of classification possible. In almost all cases, this meant identification to the species level (some specimens were immature or damaged in a way that prevented species identification). Only those specimens that were successfully identified to the species level, or which belonged to a genus or family not otherwise represented, were used in the species richness estimates. The total number of spiders used in the species richness estimates was therefore slightly smaller than the number collected.

Data Analysis

We used "non-parametric methods for the estimation of species richness from small samples" (Colwell and Coddington, 1994) to obtain both family and species richness estimates. Of the several methods reviewed by Colwell and Coddington (1994), we chose three to use in generating our richness estimates:

$$S_1^* = S_{obs} + (a^2/2b), \qquad (1)$$

$$S_2^* = S_{obs} + (L^2/2M), \qquad (2)$$

$$S_3^* = S_{obs} + L\ (n\text{-}1/n), \qquad (3)$$

where:

S_1^*, S_2^*, and S_3^* are estimates of the true species richness in an assemblage;

S_{obs} is the observed number of species in the sample;

a is the number of species represented by a single individual;

b is the number of species represented by exactly two individuals;

L is the number of species that occur in only one subsample;

M is the number of species that occur in exactly two subsamples;

and n is the number of subsamples.

Two of these formulas, (1) and (2), were first employed by Chao (1984) and the third (3), was first used by Burnham & Overton (1979).

We utilized modified forms of equations (1), (2), and (3) to estimate the family richness at each of the three forest ecosystems and overall:

$$F_1^* = F_{obs} + (a^2/2b), \qquad (4)$$

$$F_2^* = F_{obs} + (L^2/2M), \qquad (5)$$

$$F_3^* = F_{obs} + L\,(n\text{-}1/n), \qquad (6)$$

where:

F_1^*, F_2^*, and F_3^* represent estimates of the family richness;

F_{obs} is the observed number of families in the sample;

a is the number of families represented by a single individual;

b is the number of families represented by exactly two individuals;

L is the number of families that occur in only one subsample;

M is the number of families that occur in exactly two subsamples;

and n is the number of subsamples.

In our study, a subsample corresponded to one pitfall trap or one litter collection.

As our measure of ecosystem distinctness, we simply used the number of families or species that were "unique" to that ecosystem (i.e. not found in either of the other two). The number of unique families or unique species approximates the degree to which a particular ecosystem differs from the other two and represents the contribution that the ecosystem makes to the overall biological diversity of the site.

Results

Family Richness Estimates

Overall Family Richness

We collected 6158 specimens at the Guthrie-Bancroft Farm in 53 subsamples (n = 53; 35 pitfall traps and 18 litter samples). The specimens represented seven classes and

21 orders (Table 1). Some general information on the orders and families found is summarized in an appendix. The order with the largest number of collected specimens was Acarina; its 4031 specimens comprised approximately 2/3 of all collected specimens. The two orders with next highest number of specimens were the springtails (Collembola) and the beetles (Coleoptera). The order Coleoptera was represented by the largest number of families (17).

We identified 2014 specimens to the family level and sorted them into 84 invertebrate families (Table 1). The three problematic orders were each treated as a single family for a minimum of 87 families ($F_{obs} = 87$). We found 27 families that were represented by a single individual ($a = 27$) and 11 families that were represented by only two individuals ($b = 11$). Thirty-six families occurred in only one subsample (L = 36) and 9 families occurred in only two subsamples (M = 9). We calculated three different estimates of overall family richness for the site (Table 2). The overall family richness values ranged from 120-159 families.

Within-Ecosystem Family Richness and Ecosystem Distinctness

We identified 60 families at RHF and 50 families at both THF and SF (Table 1). The within-ecosystem family richness values (Table 2) ranged from 87-104 families for RHF, from 67-104 families for SF and from 67-75 families for THF. Non-statistical comparisons of the within-ecosystem family richness estimates (Table 2) showed that the rich hardwood forest had the highest family richness value for all three estimators (for F_2^*, RHF and SF shared the highest value). The transition hardwood forest had the lowest family richness value (Table 2) for all three estimators (for F_3^*, THF and SF shared the lowest value).

Thirty families were common to all three sites. Each forest ecosystem had a number of "unique families" (Table 1) that were not found at any other site. The rich hardwood forest had the highest number of unique families (15) and the transition hardwood forest (THF) had the lowest (10).

The rich hardwood forest had the largest number of Coleoptera families (12) with six of them being unique to that ecosystem (Table 1). RHF also had a higher diversity of land snails (Order: Styllommatophora) than the other two forests. Although we collected

Table 1. A list of the classes (italics), orders (bold), and families of invertebrates collected from three forest ecosystems at Guthrie-Bancroft Farm in Lincoln/Bristol Vermont, 1999 including specimen counts from 84 families and 3 unsorted orders. RHF = Rich hardwood forest; SF = Spruce-fir forest; THF = Transition hardwood forest.

	RHF	SF	THF	Total
Arachnida				
Acarina	**523**	**2160**	**1348**	**4031**
Areneida				
Amaurobiidae	4	7	14	25
Dictynidae	4	10	13	27
Gnaphosidae		1		1
Hahniidae	13	9	6	28
Liocranidae	1	1	9	11
Linyphiidae	27	11	34	72
Lycosidae	7	3	2	12
Salticidae	6	2	3	11
Theridiidae			2	2
Theridiosomatidae		1		1
Thomisidae		1		1
Phalangida				
Caddidae		6		6
Ceratolasmatidae	1			1
Phalangidae	10	18	14	42
Sabaconidae			2	2
Pseudoscorpionida	**15**	**10**	**14**	**39**
Chilopoda				
Geophilomorpha				
Dignathodontidae	3			3
Geophilidae	9	6	18	33
Schendylidae	5		18	23
Lithobiomorpha				
Lithobiidae	2	2	3	7
Diplopoda				
Chordeumida				
Conotylidae		7	33	40
Julida				
Julidae	71	65	3	139
Parajulidae	4	3	25	32
Polydesmida				
Polydesmidae	15	24	4	43
Oligochaeta				
Lumbricida				
Lumbricidae	2	1	1	4
Gastropoda				
Stylommatophora				
Arionidae		15		15
Cionellidae	1			1
Endodontidae	1			1
Pupillidae	2			2
Vallonidae	6			6
Zonitidae	6		1	7
Symphala				
Scutigerella				
Scutigerellidae	2			2
Insecta				
Coleoptera				
Carabidae	50	46	16	112
Chrysomelidae	1			1
Cryptophagidae	4			4
Cupedidae			1	1
Curculionidae	1	6	4	11
Dermestidae	1			1

Table 1. (Continued)

	RHF	SF	THF	Total
Lampyridae	1			1
Leiodidae			1	1
Leptodiridae			20	20
Mycetophagidae	2			2
Pselaphidae	1			1
Ptiliidae	13	1		14
Scaphidiidae	2	1	1	4
Scarabeidae			23	23
Scolytidae		1		1
Scydmaenidae	3	5	1	9
Staphylinidae	25	32	10	67
Collembola				
Entomobryiidae	257	186	152	595
Hypogastruridae	34	115	13	162
Isotomidae	70	28	17	115
Sminthuridae	42	29	5	76
Diptera				
Anisopodidae		1		1
Anthomyiidae		1		1
Cecidomyiidae	3	9	6	18
Chironomidae		5	1	6
Chloropidae			1	1
Calliphoridae		1		1
Dolichopodidae	1	1		2
Drosophilidae		1		1
Mycetophilidae		2		2
Phoridae	21	3	11	35
Psychodidae	1		1	2
Sarcophagidae			1	1
Scathophagidae			1	1
Sciaridae	1	6	5	12
Xylophagidae	1			1
Hemiptera				
Aphididae	7	2		9
Dipsocoridae	8			8
Coccoidea (superfamily)	4			4
Lygaeidae	1			1
Miridae	1		1	2
Reduviidae		1		1
Hymenoptera				
Aphelinidae		1		1
Ceraphronidae			2	2
Chalcidoidea (superfamily)	1			1
Diapriidae	1			1
Formicidae	19	3	8	30
Ichneumonidae		1	1	2
Megaspilidae	1			1
Scelionidae	11	1	2	14
Lepidoptera				
Tineidae			1	1
Orthoptera				
Gryllacrididae	13	5	9	27
Psocoptera	11		63	74
Thysanoptera				
Thripidae	3			3
Number of specimens	1356	2857	1945	6158
Number of specimens identified to family (excludes Acarina, Pseudoscorpionida, and Psocoptera)	807	687	520	2014
Number of families	60	50	50	87
Number of unique families	15	13	10	38

a similar number of specimens from this order at RHF (16) and SF (15), all specimens from SF belonged to a single family of slugs while those from RHF belonged to five families of land snails, four of which were unique to this ecosystem. The spruce-fir forest exhibited the highest number of spider families (10), and unique spider families (3), despite having a lower number of specimens than either of the other forest ecosystems.

Table 2. The parameters and family richness estimates of surface-active invertebrates for three forest ecosystems at the Guthrie-Bancroft Farm, Lincoln/Bristol Vermont, 1999. RHF = Rich hardwood forest; SF = Spruce-fir forest; THF = Transition hardwood forest; F_1^*, F_2^*, and F_3^* = family richness estimators; F_{obs} = number of observed families; a=number of families represented by a single individual b = number of families represented by exactly two individuals; L = number of families in only one subsample; M = number of families in only two subsamples; n = number of subsamples.

	RHF	SF	THF	Overall
$F_1^* = F_{obs} + (a^2/2b)$	87	86	75	120
$F_2^* = F_{obs} + (L^2/2M)$	104	104	96	159
$F_3^* = F_{obs} + L\ (n\text{-}1/n)$,	82	67	67	122
N	17	18	18	53
a	18	17	14	27
b	6	4	4	11
L	23	18	18	36
M	6	3	7	9
F_{obs}	60	50	50	87

Species Identifications and Species Richness Estimates

Spiders (Order: Areneida)

We collected a total of 191 spiders from 11 families (Table 1) and representing 30 species (Table 3). Six species were found in all three ecosystems. Each ecosystem had several "unique species" that were not found at either of the two other sites, but no ecosystem had a remarkably higher number of unique species than any other (Table 3) and appear to be statistically identical without even testing. The transition hardwood forest had both the largest number of specimens and the highest number of species (Table 3). Despite this however, the range of species richness values for this ecosystem (24-26) was not noticeably higher than those calculated for the other

Table 3. Spider species collected in pitfall and litter samples from three forest ecosystems at the Guthrie-Bancroft Farm, Lincoln/Bristol Vermont, 1999. RHF = Rich hardwood forest; SF = Spruce-fir forest; THF = Transition hardwood forest.

Species name	RHF	SF	THF	Total
Agroeca ornata			1	1
Amaurobius boralis	1		1	2
Bathyphantes pallidus (Banks)		1		1
Bathyphantes sp. A (nr yukon)	1			1
Callobius sp.			1	1
Centromerus persolutus	4	2	4	10
Ceraticelus sp. A	1			1
Ceratinella brunnea (Emerton, 1882)	2			2
Cicurina arcuata	1		1	2
Cicurina brevis	1	1	2	4
Cicurina pallida	2	8	1	11
Cryphoeca sp.			1	1
Cybaeopsis sp.			3	3
Eperigone maculata (Banks)			2	2
Erigonid sp.	13	4	26	43
Lepthyphantes zebra (Emerton, 1882)	2			2
Misumena vatia		1		1
Neoantistea magna	10	7	3	20
Neon nellii	1		1	2
Phrurotimpus alarius (Hentz, 1847)	1		4	5
Pirata sp.	7	3	2	12
Robertus riparius (Keyserling, 1886)			2	2
Sisicottus montanus		1		1
Tapinocyba simplex (Emerton)		2	1	3
Theridiosomatidae (imm.)		1		1
Tunagyna debilis		2		2
Wadotes calcaratus	3	5	7	15
Wadotes hybridus		1		1
Walckaeneria directa	1			1
Zelotes fratris		1		1
Number of specimens	51	40	63	154
Number of species	16	15	18	30
Number of unique species	5	7	6	18

Table 4. The parameters and species richness estimates of spiders in three forest ecosystems at the Guthrie-Bancroft Farm, Lincoln/Bristol Vermont, 1999. RHF = Rich hardwood forest; SF = Spruce-fir forest; THF = Transition hardwood forest; S_1^*, S_2^*, and S_3^* = species richness estimators; S_{obs} = number of observed species; a=number of species represented by a single individual b = number of species represented by exactly two individuals; L = number of species in only one subsample; M = number of species in only two subsamples; n = number of subsamples.

	RHF	SF	THF	Overall
$S_1^* = S_{obs} + (a^2/2b)$	27	23	26	39
$S_2^* = S_{obs} + (L^2/2M)$	30	21	24	39
$S_3^* = S_{obs} + L\ (n\text{-}1/n)$,	24	22	26	42
N	17	18	18	53
a	8	7	8	12
b	3	3	4	8
L	9	7	8	12
M	3	4	5	8
S_{obs}	16	15	18	30

ecosystems (Table 4).The estimates of spider species richness for the three ecosystems taken as a whole ranged from 39 – 42 species (Table 4). There are approximately 704 spider species in the northeastern states and Canadian provinces from the eight families that we collected with more than one species (Dan Jennings, pers. comm.). If our overall spider species richness estimates are accurate, Guthrie-Bancroft Farm hosts approximately 6% of the surface-active spider fauna known for the entire region.

Ground Beetles (Family:Carabidae)

We collected a total of 112 ground beetles representing 19 species (Table 5). Only two species were common to all three ecosystems. RHF and SF each had five unique species, while THF had two. The rich hardwood forest had the highest number

Table 5. Ground beetle species (Family: Carabidae) collected in pitfall and litter samples from three forest ecosystems at the Guthrie-Bancroft Farm, Lincoln/Bristol Vermont, 1999. RHF = Rich hardwood forest; SF = Spruce-fir forest; THF = Transition hardwood forest.

Species name	RHF	SF	THF	Totals
Agonum fidele	1			1
Agonum mutatum	1			1
Agonum retractum	2		3	5
Calathus ingratus		1		1
Cymindis cribricollis	1		1	2
Gastrellarius honestus		1		1
Notiophilus aeneus		1		1
Platynus decentis	21	25		46
Pterostichus adoxus			1	1
Pterostichus adstrictus		1		1
Pterostichus coracinus	10	2		12
Pterostichus diligendus	2	5		7
Pterostichus lachrymosus	2			2
Pterostichus pensylvanicus		1	1	2
Pterostichus rostratus			1	1
Pterostichus stygicus	4	2	1	7
Sphaeroderus canadensis	2			2
Sphaeroderus lecontei	4			4
Synuchus impunctatus	1	7	8	16
Total Count	50	46	16	112
Number of species	**12**	**10**	**6**	**19**
Number of unique species	5	5	2	12

of specimens and species while the transition hardwood forest yielded the lowest number of both (Table 5). The ranges of within-ecosystem species richness values (Table 6) varied considerably for SF and THF (it was impossible to compute a value of S_1^* for THF because $b = 0$) and made it difficult to see any obvious trends between the three ecosystems. When taken as a whole, however, all three estimators of species richness yielded a value of 27 for overall ground beetle species richness at the Guthrie-Bancroft Farm. Approximately 55 species of surface-active ground beetles are known to occur in the nearby Green Mountain National Forest of Vermont (Ross Bell, pers. comm.). If our ground beetle species richness estimates are correct, Guthrie-Bancroft Farm hosts approximately 50 % of the surface-active ground beetles known for this nearby large region.

Table 6. The parameters and species richness estimates of ground beetles in three forest ecosystems at the Guthrie-Bancroft Farm, Lincoln/Bristol Vermont, 1999. RHF = Rich hardwood forest; SF = Spruce-fir forest; THF = Transition hardwood forest; S_1^*, S_2^*, and S_3^* = species richness estimators; S_{obs} = number of observed species; *a*=number of species represented by a single individual; *b* = number of species represented by exactly two individuals; L = number of species in only one subsample; M = number of species in only two subsamples; *n* = number of subsamples.

	RHF	SF	THF	Overall
$S_1^* = S_{obs} + (a^2/2b)$	20	16		27
$S_2^* = S_{obs} + (L^2/2M)$	21	28	18	27
$S_3^* = S_{obs} + L\,(n\text{-}1/n)$,	17	16	11	27
N	17	18	18	53
a	4	5	5	8
b	4	2	0	4
L	6	6	5	8
M	2	1	1	4
S_{obs}	12	10	6	19

Ants (Family: Formicidae)

We collected a total of 30 ants representing four species (Table 7). Only one species was common to all three ecosystems. RHF and SF each had one unique species that was not collected in either of the other ecosystems. The rich hardwood forest had the highest number of both specimens and species (Table 7). The small number of specimens collected at each site was insufficient to calculate meaningful estimates of within-ecosystem species richness. Similarly, it was impossible to estimate overall species richness using the S_1^* or S_2^* estimators (because both $b = 0$ and $M = 0$). The S_3^* estimator yielded a dubious overall ant species richness value of 5 species, only one species more than we collected.

Table 7. Ant species (Family: Formicidae) collected from three forest ecosystems at the Guthrie-Bancroft Farm, Lincoln/Bristol Vermont, 1999. RHF = Rich hardwood forest; SF = Spruce-fir forest; THF = Transition hardwood forest.

Species name	RHF	SF	THF	Total
Aphaenogaster rudis subsp. *picea*	2		4	6
Camptonotus sp.		1		1
Lasius niger subsp. *neoniger*	10			10
Tetramorium caespitosum	7	2	4	13
Number of specimens	**19**	**3**	**8**	**30**
Number of species	3	2	2	4
Number of unique species	1	1		2

Rare and Uncommon Species

We found one species on the list of rare and uncommon animals in Vermont (Nongame and Natural Heritage Program, 1996). Two individuals of the ground beetle species, *Pterostichus lachrymosus*, were collected in pitfall traps in the rich hardwood forest. One of the individuals was taken in May and one in July. The species has a state rank of S3 (Nongame and Natural Heritage Program, 1996), which means that it is uncommon in Vermont and worthy of occurrence-tracking and monitoring. The global status of this species is unknown. *Pterostichus lachrymosus* has not been collected from many locations in Vermont and, unlike many other ground beetles, its ecology is not well understood (Ross Bell, pers. comm.). Three field seasons (1994, 1998, and 1999) of intensive ground beetle collecting (more than 10,000 specimens) in the Green Mountain National Forest yielded only one individual of this species (Rykken, 1995 and Catherine Dickert, unpublished results).

Our species identifications also turned up two unusual spider specimens belonging to the genera *Bathyphantes* and *Ceraticelus* in the family Linyphiidae. Consultation with an arachnologist revealed that they likely represent undescribed species (Dan Jennings, pers. comm.). Both specimens were found in the rich hardwood forest and were referred to as *Bathyphantes* sp. A and *Ceraticelus* sp. A (Table 3).

Several unusual specimens from outside of the focal groups were also noted, but because most of these were not identified to the species level, it is difficult to say much about their significance. One exception was a single specimen of the family Ceratolasmatidae found at RHF. This family has only one species in our fauna, *Crosbycus dasycnemus*, and although the species is known from Vermont, it has rarely been collected here (Ross Bell, pers. comm.).

Discussion

Family Richness Estimates

The wide range of estimated values (120-159) for overall family richness (Table 2) at Guthrie-Bancroft reflected some uncertainty in the ability of the estimators to reliably approximate the actual family richness value. Several factors may have contributed to inconsistent family richness estimates. In general, extrapolation techniques underestimate actual richness values (Colwell and Coddington, 1994). Moreover, this effect may have been compounded by treating the problematic orders (Acarina, Pseudoscorpionida, and Psocoptera) as single families. On the other hand, the family richness estimates may have been inflated by the collection of a number of families that are not considered to be surface-active (most notably those families in the order Diptera). Finally, the reliability of the family richness estimates may have suffered from undersampling. A high percentage of the families found (44%) contained only one or two individuals (Table 2), suggesting that many new families were still being found.

Ecosystem Comparisons

Non-statistical comparisons of the three forest ecosystems suggest that the rich hardwood forest stood out as the most diverse. This ecosystem had the highest number of observed families, highest estimates of family richness, highest number of unique families, and the highest diversity of land snails. Furthermore, we found the uncommon ground beetle species, *Pterostichus lachrymosus*, two undescribed spider species, and the rarely-collected Ceratolasmatid, *Crosbycus dasycnemus*, in RHF. The transition hardwood forest site was apparently the least diverse of the three ecosystems; it had the lowest estimates of family richness and the lowest number of unique families. The spruce-fir forest exhibited diversity characteristics that were intermediate between those of the rich hardwood forest and the transition hardwood forest, except in the case of spiders. The spruce-fir forest showed the highest diversity of spider families with both the highest number of observed spider families (10), and the highest number of unique families (3).

Two factors that may contribute to the apparently higher diversity at the rich hardwood forest are moisture and nutrients. The rich hardwood forest has a number of seeps that supply moisture even under extremely dry conditions (like those encountered during the 1999 field season), and therefore may be a preferred habitat for many families that inhabit moist environments (see Appendix). Furthermore, the suspected presence of calcium carbonate in the soil of this ecosystem, although not directly tested, would likely contribute to higher diversity. Calcium carbonate is an important component in the exoskeleton construction of some invertebrates (e.g. Diplopoda) and it is essential to the shell building capacity of land snails, which accounts nicely for the high diversity of land snails in this ecosystem.

Even though ecosystem comparisons suggested small differences between forest types, these data should be treated as preliminary for several reasons. The comparisons were based primarily on family level identifications (since this information was essentially complete for the specimens we collected), not on species identifications. The identification of all specimens to the species level would provide a stronger basis for ecosystem comparison. Undersampling may also have exaggerated ecosystem differences. In general, undersampling tends to overestimate distinctness (Colwell and Coddington, 1994). We may have undersampled the ecosystems by collecting specimens only twice from a small proportion of the land in each ecosystem. In one study (Hammond, 1994), modest differences in between-site species richness estimates disappeared with increased sampling effort through time. Finally, statistical analyses of these data could reveal that the differences were not statistically significant.

Species Richness Estimates

Species richness estimates were limited to the focal groups. We estimated the percentage of species richness for these focal groups at Guthrie-Bancroft Farm, by comparing the data for two of the focal groups with known distribution information.

We intended to use the information gathered from the focal groups to estimate the species richness for all surface-active invertebrates at Guthrie-Bancroft Farm. We decided, however, that with the information available to us, any attempt to do so would have been mere speculation. All methods for making calculations of this sort rely on ratios of known values of species richness to estimate unknown values and on the assumption that the ratios employed are constant among the entities compared (Colwell and Coddington, 1994). We found that the ratio of ground beetle species richness at Guthrie-Bancroft to that of the Green Mountain National Forest was approximately 1:2, and that the ratio of spider species richness at Guthrie-Bancroft to that of the northeastern states and Canadian provinces was approximately 1:17. Using these ratios to estimate overall invertebrate species richness would have meant employing non-hierarchical ratios to do so (i.e. using the ratio of spider species richness to predict the richness of a taxonomically unrelated group like centipedes). In general, the use of non-hierarchical ratios only makes sense when there is some functional, ecological reason to suppose that such a ratio might be roughly constant (Colwell and Coddington, 1994). Furthermore, such ratios need to be calibrated before being used to predict the species richness of unknown groups (Hammond, 1994). To our knowledge, no previous work of this sort has been attempted in Vermont, and well-calibrated predictive ratios do not exist. Further identification work on the specimens that we have already collected could serve as a test to determine which ratios might serve this function in Vermont (see Recommendations for Future Study section in this document).

Rare and Uncommon Species

We found one species on the list of rare and uncommon animals in Vermont (Nongame and Natural Heritage Program, 1996), but this may not accurately reflect the number of rare invertebrate species at Guthrie-Bancroft Farm. The Vermont list includes 115 invertebrate species (81 beetles, 1 crayfish, 2 amphipods, 1 isopod, 20 moths and butterflies, and 10 mussels and snails). The list would undoubtedly be longer, but reliable distribution and abundance data for most terrestrial invertebrates is lacking. The disproportionately high number of beetles on the list can be attributed to Dr. Ross Bell at the University of Vermont who has extensively studied this group. In other words, the Vermont list of rare and uncommon animals reflects what we do know about rarity for the few well-studied invertebrates, but does not reflect how little we know about rarity for most invertebrates. Therefore, Guthrie-Bancroft may have other rare invertebrate species (including possibly the two undescribed spider species), whose names do not appear on the state list.

Significance of Findings

The findings of this study suggest that the protection of the overall biodiversity of surface-active invertebrates at Guthrie-Bancroft Farm should involve the preservation and management of the three forest ecosystems that were examined. In each forest ecosystem, we found families and species that were not found in either of the other two ecosystems. Therefore the loss of any one ecosystem might result in the local extinction of species from the property. Furthermore, the findings suggest that special attention be paid to the preservation of the rich hardwood forest ecosystem. Its comparatively high diversity together with the presence of the uncommon ground beetle species, *Pterostichus lachrymosus*, and the two undescribed spider species, warrant concern for any intensive management practices that could potentially damage it.

It should be emphasized that this study focused on only a small cross-section of all invertebrates at the site (i.e. those active on the ground or found within the litter). Nevertheless, it sampled invertebrates that were found in a number of habitat niches (within leaf litter, under stones, in fungi, in decaying bark, etc.) and that represented a variety of trophic levels (e.g. scavengers, decomposers, predators, etc). The appendix contains information on habitat niches and trophic levels of most families and orders found in this study. The management of biodiversity at a site should involve careful consideration of the various habitat niches and trophic levels for incorporation into a monitoring protocol. We recommend that a subset of invertebrates encompassing different habitat niches, trophic levels, and rarity be chosen for incorporation into a monitoring strategy used to indicate environmental change.

Recommendations for Future Study

An inventory of invertebrate species in small, natural preserves like Guthrie-Bancroft Farm is important to the conservation community for several reasons. First, there is a great need to understand the structure and variation of biodiversity on small park-sized scales, because most land-use decisions are made at this scale (Colwell and Coddington, 1994). Second, site inventories in areas of the world where the invertebrate fauna is reasonably well-known play an important role in the honing of sampling methods and the calibration of sample data (Hammond, 1994). Finally, a modest-sized invertebrate inventory can be used as a local test of rapid, cost-effective biodiversity assessment techniques.

For these reasons, we recommend a continuation of invertebrate inventorying efforts at Guthrie-Bancroft Farm and outline some possible directions for those inventories to take. We also recommend the incorporation of carefully chosen invertebrates into an overall ecological monitoring scheme.

A Test of Rapid Biodiversity Assessment Techniques

The need to develop a rapid and cost-effective biodiversity assessment technique in Vermont was recently demonstrated by the U.S. Fish and Wildlife Service. Their plans to survey invertebrates on lands acquired from Champion Paper Co. in northeastern Vermont were halted by the financial investment required in the absence of field-tested, shortcut protocols. Similarly, our own efforts to use focal groups in this study as surrogates for overall invertebrate species richness were thwarted by the absence in Vermont of calibrated predictive ratios. The development of a reliable rapid assessment technique would serve to advance and inform conservation planning in the northeast by providing a locally-established, cost-effective strategy for incorporating information about the most diverse animal group into inventory, monitoring, and management plans.

Further analysis of the specimens already collected offers the potential to test two promising methods for rapid biodiversity assessments in Vermont: morphospecies and focal groups. It would entail having non-specialists sort the specimens thus far identified to the family level into morphospecies and then having specialists identify them to species. The authors of this study could do most of the species identifications, with consultation from various specialists for problematic species. The richness and diversity of the morphospecies and species identifications could then be compared, to see if morphospecies reliably predicts species richness. From the same data set, a variety of focal groups could be examined to see which serve as the best surrogates for the prediction of overall invertebrate diversity.

Further Inventory Work

The sampling done thus far on the Guthrie-Bancroft Farm represents only a small component of the invertebrate fauna there. A more complete inventory of the invertebrate community, would include the following:

1. Aquatic sampling. Well-established protocols for sampling aquatic invertebrates and monitoring water quality make this effort straightforward. An examination of the aquatic fauna will gauge the relative health of the streams on this parcel compared to those in the rest of Vermont and establish baseline data for future water quality monitoring efforts. Aquatic sampling is best conducted in early spring just after ice break and again in September.
2. Additional terrestrial sampling. Surface-active invertebrates represent only a subset of all terrestrial invertebrates. Significant numbers of invertebrates live in tree canopies, under tree bark, on shrubs, herbs or grasses. Many invertebrates are active in flight. A survey of terrestrial invertebrates that utilized different sampling techniques, such as sweep-netting, malaise traps, and light traps would target many groups not collected in pitfall traps or litter samples. These techniques would provide more information on the presence of rare, threatened or endangered butterflies and moths. Additional terrestrial sampling could include the following:
    a. further collection of specimens from the previously sampled ecosystems using different sampling techniques. The goal of such work would be to more completely characterize these ecosystems.
    b. collection of surface-active invertebrates from other ecosystems. The goal of this work would be to make further comparisons between ecotypes.

Monitoring

A comprehensive ecological monitoring plan for Guthrie-Bancroft Farm should include a variety of plants and animals. As part of these efforts a subset of invertebrates useful as indicators of ecological change should be chosen and monitored regularly. We recommend that a group of invertebrates encompassing different habitat niches, trophic levels, and rarity be chosen for incorporation into a monitoring strategy. Baseline data provided by the inventories will permit detection of directional change in these ecosystems with the decline or expansion of carefully chosen indicator species over time.

<u>Permission to Publish</u>

Data about distribution and ecosystem associations of invertebrates in Vermont is sparse. We request permission to share what we have found with the scientific community by submitting our report for publication in a scientific journal.

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Appendix

General Information on the Identification and Ecology of the Terrestrial Invertebrate Families of Guthrie-Bancroft Farm

Bold=Class
Underline=Order
Indented and italicized=Superfamily
Indented=Family

Arachnida

Acarina (mites)—tiny, usually eight-legged; inhabit damp soil and shady places; most live on plant or animal fluids; the most numerous invertebrates in forest humus.

Phalangida ("daddy long legs")— long-legged spider-like arachnids with a broadly fused abdomen and cephalothorax; a single pair of simple eyes on top.

- Caddidae
- Ceratolasmatidae
- Phalangidae
- Sabaconidae

Areneida (spiders)

- Amaurobiidae—often found under stones or in leaf litter; many catch their prey by means of snares that contain "hackle bands."
- Dictynidae—generally small spiders that possess large poison glands; build snares in foliage and underneath stones and leaves on the ground.
- Gnaphosidae—spin a tubular retreat under stones or in rolled leaves, from which they hunt.
- Hahniidae—small spiders that build delicate sheet webs, near the ground, usually in damp or moist places.
- Liocranidae
- Linyphiidae (line-weaving spiders)--most species construct a snare without a retreat for hunting.
- Lycosidae (wolf spiders)—active on the surface often at night; female carries the egg sack attached to her spinnerets and after emergence the young as well.
- Salticidae (jumping spiders)—unusually large eyes make this family of spiders exceptionally keen visual hunters; prey in daylight; commonly in well-lighted areas.
- Theridiidae (comb-footed spiders)—build irregular snares on which they suspend themselves upside down while awaiting prey.
- Theridiosomatidae (ray spiders)—weave snares of concentric rings, puntuated by rays; found in dark and damp situations.
- Thomisidae (crab spiders)—spiders with forward–facing crab-like front legs; wanderers, not weavers, that secure prey by stealth.

Pseudoscorpionida (pseudoscorpions)—small arachnids that give the impression of scorpions, but lack the narrow tail and sting; found in soil, litter, and under logs and rocks; often prey on mites and springtails.

Chilopoda (centipedes)—many-legged, segmented invertebrates; first segment is equipped with poison claws for capturing and killing prey; nocturnal creatures that live in damp, dark places under stones, leaves, logs, and bark.

- Dignathodontidae
- Geophilidae
- Lithobiidae
- Schendylidae

Diplopoda (millipedes)—detritivores that feed on leaf litter and probably play an important role in tranformation to humus; typically inhabit the litter in mesic deciduous forests; abundance and diversity may be correlated to the presence of calcareous substances which they use to make their exoskeleton.

- Julidae
- Parajulidae
- Conotylidae
- Polydesmidae

Symphala—common inhabitants of the deeper soil horizons; only surface to feed or when conditions are favorable; important in breaking down organic matter.

Scutigerellidae

Gastropoda

Stylommatophora (land snails and slugs) – most snails require moisture, shelter, and an abundant source of lime; readily available lime generally leads to an abundant and varied fauna in this order.

Arionidae (slugs)—all those found in the eastern U.S. are introduced from Europe; several native species in the western U.S.

Cionellidae – small elongate glossy shells; only one species in the U.S.

Endodontidae – worldwide distribution; shells variable, but often ribbed.

Pupillidae –large family of worldwide distribution; small to minute pupa-shaped shells.

Vallonidae – small; usually with depressed shells sculptured with fine cuticular ribs.

Zonitidae – medium to small land snails of nearly worldwide distribution; shell generally with a depressed spire.

Annelida

Oligochaeta (Segmented worms)

Lumbricidae (earthworms) – occur in a variety of habitats with adequate moisture; major agents in the breakdown of organic matter and its mixture with mineral soil. Most (except for two genera) are considered to be non-native.

Insecta (insects)

Coleoptera (beetles)

Carabidae (ground beetles) – predaceous and scavenger beetles; most are nocturnal, live under debris, wood, and rocks; some eat insects, slugs, snails, caterpillars, grass seeds; members of one genus can spray a hot water vapor cloud at aggressors.

Chrysomelidae (leaf beetles) – very common, brightly colored; feed on flowers and foliage, bore into stems and roots; many important agricultural pests.

Cryptophagidae (cryptophagid beetles) – live beneath leaves and wood chips, in rotting logs, and on fungi and flowers.

Cupedidae (reticulated beetles)—most primitive beetle family; larvae feed in moist, rotting wood.

Curculionidae (weevils or snout beetles) – largest family of beetles (40,000 species worldwide); feed on all parts of plants; important pests.

Dermestidae (dermestid beetles) – most are scavengers; larvae feed on leather, woolen and silk-products, rugs, stored foods, and carrion.

Lampyridae (fireflies) – color and flash vary by species and associated with mating; most that fly at night are males; predaceous on insect larvae, slugs, and snails.

Leiodidae (round fungus beetles) – adults and larvae common on fungi but also live in decaying vegetation or under bark; adults can roll themselves up into a tight ball.

Leptodiridae (small carrion beetles) – scavengers of moist forests that are generally found in carrion, humus, dung and fungi, but may also be found in forest litter.

Mycetophagidae (hairy fungus beetles) – occur on shelf fungi and under moldy bark and vegetation; feed on fungi.

Pselaphidae (short-winged mold beetles) – occur under stones, loose bark, moss, forest litter, and in ant nests; feed on mold, mites, and ant larvae; those in ant nests secrete a substance which attracts ants.

Ptiliidae (feather-winged beetles) – smallest of all beetles; they live in moist, rotting organic matter where they eat molds and fungi.

Scaphidiidae (shining fungus beetles) – feed on fungi and occur in decaying leaves and wood and under loose bark.

Scarabeidae (scarab beetles) – generally nocturnal, attracted to lights; one group feeds on carrion, dung, skin, and feathers; another group feeds on leaves and flowers (this group has many agricultural pests).

Scolytidae (bark beetles) – live under tree bark and either mine the wood's surface and underside of bark, bore into and feed on wood, or bore deeply into wood to cultivate and feed on fungi; often considered the most destructive group of forest insects; one species transmits Dutch elm disease.

Scydmaenidae (antlike stone beetles)—nocturnal beetles of moist places such as under bark or other objects; sometimes large numbers may fly at dusk but otherwise rarely observed.

Staphylinidae (rove beetles) – run with tip of abdomen curved up over the body; predators and scavengers of carrion, dung, fungi, and decomposing plants; some are parasitic on insects or live in bird or mammal nests.

Collembola (springtails)– a primitive order; wingless, with a "tail" curled under the body that is flung to the ground causing them to spring into the air; feed on plant debris and other organic material in the soil, algae, lichens, pollen, and fungal spores.

Entomobryiidae
Hypogastruridae
Isotomidae
Sminthuridae

Diptera (true flies)

Anisopodidae (wood gnats)—mosquito-like appearance; occur in moist places with abundant vegetation; larvae found in decaying material.

Anthomyiidae – often predacious on other insects; larvae feed on roots and other plant parts; adults resemble houseflies.

Calliphoridae (blow flies) – metallic, larger than houseflies; frequent carrion and manure and can spread disease; some deposit eggs in wounds, sores, or nostrils of other animals.

Cecidomyiidae (gall midges) – each species causes a unique plant gall.

Chironomidae (midges) – mosquito-like but do not bite; occur in large swarms, attracted to lights; adults live 5-10 days; most larvae aquatic.

Chloropidae – most common in grass or other low vegetation; wide variety of habitats.

Dolichopodidae (longlegged flies) – metallic; frequent shaded areas near water; predaceous; larvae chiefly aquatic.

Drosophilidae (vinegar flies) – common around ripe fruit and decaying vegetation; some larvae are external parasites or predators of other insects.

Mycetophilidae (fungus gnats) – common in dark places around damp, decaying vegetation.

Phoridae (humpbacked flies) – occur near decaying vegetation; larvae live in fungi, decomposing plant material, ant or termite nests, or are parasitic.

Psychodidae (moth flies) – occur in damp, shady areas; most do not bite (sand flies are the exception); larvae breed in moist, decaying organic matter, moss, mud, and water.

Sarcophagidae (flesh flies) – females deposit larvae (not eggs) on carrion; some larvae parasitic on grasshoppers and beetles.

Scathophagidae – larvae have varied habits some feed on plants, but the most common genus feeds on dung; adults are predacious on insects and other invertebrates.

Sciaridae (darkwinged fungus gnats) – occur in moist, shaded areas; larvae feed on fungi and some damage crops such as mushrooms and potatoes.

Xylophagidae – larvae live under bark and in decaying wood and are considered to be predacious; adults occur in wooded or forested areas especially near water.

Hemiptera (plant bugs, cicadas, aphids, scale insects, etc.)

Aphididae (aphids or plantlice) – occur clustered on stems or leaves of plants; produce "honeydew," a sugary secretion often seen as a shiny coating on leaves; ants often feed on honeydew and aphids alike; many species are serious plant pests; some transmit plant viruses.

Coccoidea (scale insects) – a large superfamily with many minute and highly specialized forms.

Dipsocoridae – live in ground litter and among stones; presumably are predacious. Small family with only two genera that occur north of Mexico.

Lygaeidae (seed bugs) – feed on mature seeds; some feed on sap or are predaceous on other insects; some are agricultural pests.

Miridae (plant bugs) – feed on plant juices; many are serious pests, some predaceous on other insects; some wingless species are ant mimics.

Reduviidae (assassin bugs) – predators of other insects; many will bite humans.

Hymenoptera (ants, bees, wasps)

Aphelinidae – common parasites of other insects.

Ceraphronidae—1-3mm long wasps; poorly understood; some are parasitoids of flies, thrips, and moths.

Chalcidoidea—very diverse superfamily; most are small (3-5mm) and are parasitoids of insects, spiders and mites.

Diapriidae—2-4mm long wasps; primarily parasites of fly larvae and pupae.

Formicidae (ants) – social insects, live in colonies on the ground or in decomposing wood; some feed on flower nectar, plant secretions, insect honeydew (which they farm), seeds, leaves and blossoms, dead insects, or are predaceous. Three castes: workers (sterile females), females (queens), and males.

Ichneumonidae – stinging wasps; one of the largest insect families (8000 species in North America); larvae major parasites of other immature insects, mostly moths and butterflies.

Megaspilidae—2-3mm long wasps; poorly understood; some are parasitoids of scale insects and fly pupae.

Scelionidae – minute wasps; larvae parasitic on insect or spider eggs; female may ride around on top of the host until ready to deposit her eggs.

Lepidoptera (moths and butterflies)

Tineidae (clothes moths) – larvae are scavengers or feed on fungi; some species are pests that feed on wool clothing, hair, fur, silk, and other animal products.

Orthoptera (Grasshoppers, locusts, and crickets)

Gryllacrididae (cave and camel crickets) – most are wingless, nocturnal; occur in moist habitats, under logs and stones, in hollow trees or burrows of other animals.

Psocoptera (book lice) – most found on tree trunks or under bark. This group can wreak havoc on the paste and bindings of books stored in damp places.

Thysanoptera (thrips) – females have saw-like ovipositor for slicing into leaves to deposit eggs; eat flowers, leaves, buds, and fruit, and many are pests of crops; some transmit plant viruses.

Thripidae – this family contains most of the species of economic importance.

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