Banisteria 23: 26-37

Arthropod Community Heterogeneity in a Mid-Atlantic Forest Highly Invaded by Alien Organisms

Daniel Kjar and Edward M. Barrows

Laboratory of Entomology & Biodiversity
Department of Biology
Reiss Building, Suite 406
Georgetown University
Washington, DC 20057-1229

ABSTRACT

Pitfall traps obtained 11,611 arthropods of 255 species and morphospecies in seven classes, 28 orders, and 72 families at four sites in a low forest in Dyke Marsh Wildlife Preserve, Virginia, USA, during 2000 and 2001. The study sites had a total of 41 plant species, ranging from 10 to 33 species per site. Alien plant cover among the four sites ranged from 10-89%. Three alien plant species covered an average of 58% of the study sites. Abundance of arthropods varied significantly in some taxonomic groups below the phylum level. Ants, mites, spiders, and springtails were the more diverse and abundant arthropods captured. Spider and ant species richness was highest in a site with 89% alien plant cover. This site also had the highest abundance of collembolans and alien millipeds. Ant abundance was highest in two sites dominated by Asian bittersweet and Japanese honeysuckle. Ant diversity is a possible indicator for the diversity of the entire arthropod community on the forest floor. Our study suggests that alien invasive plants are altering terrestrial arthropod abundance and diversity in this national park.

Key words: terrestrial arthropods, biodiversity, community heterogeneity, eastern deciduous forest, alien invasive plants, *Ampelopsis brevipedunculata, Celastrus orbiculatus, Lonicera japonica*.

INTRODUCTION

Arthropods are highly diverse and live in nearly every habitat on Earth. Trillions of them are alive at any one time. Class Insecta alone may have 5-30 million species (Erwin, 1982; Novotny et al., 2002). Although arthropods are major parts of many communities, to our knowledge there are no comprehensive studies of overall arthropod biodiversity (in terms of species richness and abundances) in particular communities, except for Borges' (1999) study in the Azores. Published community studies often have limited arthropod species lists that are dependent on the local researchers' fields of interest, or the presence of an endangered species, or both (Bossart & Carlton, 2002).

Many papers address the biodiversity of one or only a few selected arthropod taxa. For the North American Mid-Atlantic Region, such studies include those by Erwin (1981), Barrows (1986), Smith & Barrows (1987), Butler et al. (1999), Brown (2001), Kalhorn et al. (2003), and many references therein. There are a number of comprehensive, annotated lists of certain large arthropod taxa for particular regions including: Christiansen & Bellinger (1980), Henry & Froeschner (1988), and Krombien et al. (1984). Examples of lists that treat most insect groups are Britton (1920) for Connecticut, Leonard (1928) for New York, Proctor (1946) for Acadia National Park, Wray (1967) for North Carolina, Weissman & Kondratieff (1999) for Great Sand Dunes National Monument, and Haarstad (2003) for central Minnesota.

In view of the paucity of knowledge of arthropod communities worldwide, we examined the forest-floor arthropod community and its associated plants in a Mid-Atlantic forest.

METHODS

We conducted our study in the Dyke Marsh Wildlife Preserve (DMWP), Fairfax County, Virginia, USA, 38^{o} 46' N, 77^{o} 03' W, which contains a freshwater tidal

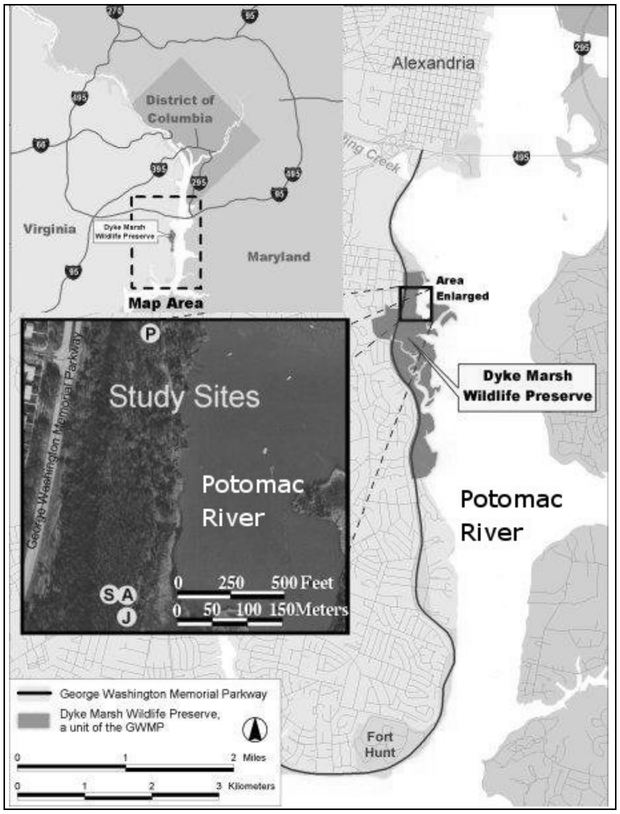

Fig. 1. Map of Dyke Marsh Wildlife Preserve showing locations of study sites.

marsh and bordering low deciduous forest and swamp forest along the Potomac River (Fig. 1). We sampled arthropods in four sites: three dominated by one of three species of alien plants**,** and one site dominated by native plants (Barrows & Kjar, 2004; keyword: DMWPss1). The alien Asiatic bittersweet (*Celastrus orbiculatus*) was the most common plant cover in site A; alien Japanese honeysuckle (*Lonicera japonica*), site J; alien porcelainberry (*Ampelopsis brevi-pedunculata*), site P; and the native sensitive fern (*Onoclea sensibilis*), site S. In August 2000 we delineated a 10 x 10-m grid at each site with 100 1-m^2 plots using stakes and string. Each site had a 3-m-wide peripheral buffer zone with a flora similar to its central area. We censused each plot for all plants, including seedlings, using Brown & Brown (1984, 1992) and lists for DMWP in Xu (1991) and Haug (1993). Each plot was divided into four 0.5-m^2 quadrats. We determined plot plant coverage by counting the number of quadrats in which each plant species was rooted or by recording the presence or absence of a particular vine species in plots with dense vine cover.

To determine which arthropod species were present and test our null hypothesis that arthropod taxa did not differ in their abundances among the study sites, we used pitfall traps to collect arthropods on a warm, dry day during the third week of August, September, and October 2000 and June, July, August, September, and October 2001. During a trapping bout, we ran all traps during the same 24 h. Each site had 10 traps, each being in the central area of a randomly chosen 1-m^2 plot within the site. The trap comprised a large plastic cup (11.5-cm diameter x 13 cm deep), a small plastic cup (8-cm diameter x 10 cm deep), a funnel (11-cm top diameter and 2-cm bottom diameter), a thin plastic collar (16-cm outside diameter and 9.5-cm inside diameter), and a 32-cm^2 square wooden cover with four legs (2.5 x 2.5 x 4 cm). We closed the large cups with tightly fitting lids between trapping bouts. To prepare a trap for collecting arthropods, we opened its large cup, placed a small cup with 25 ml of 95% ethanol inside it, placed the collar over the large cup, placed a funnel on the collar, added a 5-mm deep layer of local soil over the collar, and centered the cover over the collar.

Although pitfall trapping cannot be used for absolute abundance estimates, it is the most accepted and time-efficient way to compare terrestrial arthropods among sites (Uetz et al., 1979; Porter & Savignano, 1990; Oliver & Beattie, 1996; Holway, 1998; Burger et al., 2001). Pitfall-trap catches of ants do not give a comprehensive view of the true abundance or diversity of ants within a site due to the social and behavioral differences in ant species. However, the random selection of plots within each site and the identical trapping regimes for each site allowed us to compare each site's trap catches within species and larger groups (e.g., Formicidae). Litter and vegetation architecture may also be a confounding factor when comparing pitfall catches in different habitats and must be taken into account (Greenslade, 1964).

We identified arthropods with the help of lab technicians and specialists, keys including those in Blatchley (1910, 1926), Bolton (1994), Borror et al. (1981), Christiansen & Bellinger (1980), Creighton (1950), Downie & Arnett (1996), and Henry et al. (1988), and digital images that we put online during specimen processing helped in rapid identification of common species (Barrows & Kjar, 2004). We excluded Acari from all quantitative analyses because their abundance depended on the amount of soil that inadvertently fell into a trap cup. Voucher specimens were deposited in the Arthropod Collection of the Laboratory of Entomology and Biodiversity at Georgetown University.

To test our null hypothesis, we used parametric and nonparametric analyses of variance (ANOVAs). For parametric analyses, we used raw or $\log_{10}(x+1)$-transformed data and the *post hoc* multiple-comparison Student-Newman-Keuls (SNK test). For nonparametric analyses, we used the Kruskal-Wallis test and the *post hoc* multiple-comparison Tukey test on rank sums (for Diplopoda and *Ponera pennsylvanicus*). We used SPSS version 10.1.0 (SPSS 2000) for all tests except for the Tukey test which we performed using Zar's (1984) method. Each trap's catch for both years is combined to produce the total for a trap. Within each site the totals from the 10 traps were used to produce the mean number of a particular taxon per trap for that site.

To ascertain arthropod diversities, we used the 2-yr cumulative arthropod abundances per site and all sites combined to calculate the Shannon index, $H' = -\Sigma (p_i \ln p_i)$, where p_i is the frequency of the *i*th species (Krohne, 1998) and an index of evenness, $E = H'/\ln S$, where S is the number of species. E approaches 1.0 as total abundance becomes more evenly distributed among all species. To compare species diversity between sites, we used the Community Coefficient of Similarity, CC = $2\Sigma C/(A+B)$ (Uetz, 1976), which we modified with an additional term where $C = 1-|(pC_a - pC_b)|$ for abundance weighting; pC_a and pC_b are the proportions of each species shared by both sites, and A or B are the number of species at each site.

RESULTS

Each site varied in plant species richness and identity of its dominant plant species (Table 1). Site P had the most alien plant coverage (89%), followed, in descending order, by sites A, J, and S (Table 1). We could find no area of 10 x 10 m without alien plants in the forest. Site S had the most diverse plant community (H' = 2.63), followed by sites J, A, and P (Table 1). Twenty-nine plant species occurred in site S, with no species exceeding 25% of the total site coverage. One species (*A. brevipedunculata)* covered 71% of site P, which had the lowest H' and evenness (*E)* of the four sites. Site A had the highest species richness, but only three species (*C. orbiculatus*, *L. japonica*, and *Toxicodendron radicans,* Poison Ivy) totaled 67% of its coverage. This resulted in a 19% lower H' and 21% lower E than site S, although site S had four fewer species than site A.

Pitfall traps collected 11,611 individual arthropods of 255 species and morphospecies in seven classes, 28 orders, and 72 families (Appendix 1). Images of most species are in Barrows & Kjar (2004). Thirteen taxa (Araneae, Coleoptera, Collembola, Diplopoda, Formicidae, Isopoda, Orthoptera, five formicid species, and one hahniid spider species) had significantly different mean abundances among sites (Tables 2-4). Sites P and S had more spiders (Araneae) and beetles (Coleoptera) than sites A and J. Each site had a significantly different number of springtails (Collembola) in its traps than the other sites ($P \leq 0.05$, SNK test, Table 2). Millipeds and isopods were predominantly caught in site P (Table 2). All but four of the trapped millipeds were the alien, invasive julid *Ophyiulus pilosus*, native to Europe. Sites A and J had significantly higher numbers of ants than sites P and S ($P \leq 0.05$, SNK test, Table 2). Orthoptera had similar abundances at sites A, P, and S, but site J had significantly fewer individuals ($P \leq 0.05$, SNK test, Table 2).

Site P pitfalls caught the most ant species (16) and had the highest ant H' and E (Table 5). This site also yielded four ant species not caught at the other sites: *Amblyopone pallipes, Crematogaster pilosa, Myrmica emeryana,* and *M. punctiventris*. *Crematogaster cervasi* was captured only at site J and the only *Proceratium silaceum* were captured at site A. *Prenolepis imparis* accounted for >50% of all captured ants for sites A and J and 44% of the ants caught at site S. However, at site P 50% of all captured ants were *Paratrechina faisonensis*, whereas only 5% were *P. imparis* (Table 3).

The majority of captured arthropod groups did not vary significantly in abundance among sites ($P > 0.05$, ANOVA, Table 2). One-third of all groups had fewer than 20 representatives in the traps (Table 2). The total abundance of all arthropod groups did not vary significantly among sites ($P > 0.05$, ANOVA, Table 2). Of the 13 groups on which *post hoc* multiple comparisons tests could be run (excluding Formicidae as a group), six groups demonstrated that sites A and J are more similar to each other than to either site P or S (Tables 2-4).

Exclusion of ants from the diversity indices resulted in a 30% H' increase for sites A and J, compared to a 5% and 9% H' decrease for sites S and P, respectively (Table 5). Formicid Community Coefficient of Similarity (CC) mirrored the combined CCs of plant, spider, and higher taxa (Table 6). Sites A, J, and S were more similar to each other in species identity for Formicidae and plants than they were to site P. Plant and spider species composition differed greatly among sites (Tables 1, 4).

Spiders were diverse at all sites, although only two species were abundant (Table 4). Less than 60% of the spider species were caught at more than one site. The lycosid *Pirata zelotes* was the most abundant spider, followed by the hahniid *Neoantistea agilis* (Table 4). Sites A and J did not differ significantly in abundance of *N. agilis* and total spiders, but were significantly different from site S with regard to these taxa ($P \leq 0.05$, SNK test, Table 4). Site P had significantly more *N. agilis*, but not significantly more spiders as a group, than sites A and J ($P \leq 0.05$, SNK test, Table 4).

Table 1. Plant composition and diversity in four study sites, Dyke Marsh Wildlife Preserve, Virginia. Bolded names and values indicate alien plants. Underlined values indicate the most dominant plant in each site.

		Estimated percent cover per site (n = 10)			
Species	Common name	A	J	P	S
Acer rubrum	red maple	0.64	0.11	0	0.88
Ampelopsis brevipedunculata	**porcelainberry**	**0**	**0.46**	**<u>71.25</u>**	**1.32**
Aster sp.	aster	0	0	1.00	0
Berberis thunbergii	**Japanese barberry**	0	0	0	0.22
Botrychium virginianum	rattlesnake fern	0	0.34	0	0.66
Campsis radicans	trumpet creeper	0	0.23	0	0.22
Carya cordiformis	bitternut hickory	0.80	0.69	0	0
Carya sp.	hickory	1.29	0	0	0
Celastrus orbiculatus	**Asiatic bittersweet**	**<u>51.13</u>**	**13.97**	**10.07**	**8.33**
Celtis occidentalis	hackberry	0.16	0	0	0
Clematis terniflora	**Asian clematis**	**0.64**	**5.50**	0	**0.88**
Cornus florida	flowering dogwood	0	0	0.18	0.44
Dioscorea villosa	wild yam	0	0.11	0	1.75
Duchesnea indica	**Asian strawberry**	**0**	**0.46**	**0**	**0**
Eupatorium rugosum	snakeroot	0	0.57	0	3.29
Fraxinus americana	white ash	0	0.11	0	0
Fraxinus pennsylvanica	green ash	0	0.11	0	0
Galium obtusum	stiff bedstraw	0	0.23	0	0
Galium triflorum	sweet-scented bedstraw	0	0.69	0	0
Geum canadense	white avens	0	0.23	0	0
Ligustrum sp.	**privet**	**0**	**0.23**	**0**	**0.66**
Lindera benzoin	spicebush	5.31	4.70	0	6.36
Liquidambar styraciflua	sweetgum	0.48	0.34	0	0.44
Lonicera japonica	**Japanese honeysuckle**	**8.36**	**<u>37.57</u>**	**10.44**	**7.02**
Lonicera maackii	**Amur honeysuckle**	**1.29**	**1.15**	**0**	**0.44**
Lysimachia ciliata	fringed loosestrife	0	0	0	1.75
Onoclea sensibilis	sensitive fern	0	0.46	0	<u>25.00</u>
Parthenocissus quinquefolia	Virginia creeper	0.16	4.93	0	3.95
Prunus serotina	wild black cherry	0.48	3.78	0.55	1.32
Quercus phellos	willow oak	0.16	0.46	0	1.10
Quercus velutina	black oak	0	0.11	0	0.22
Rosa multiflora	**multiflora rose**	**1.29**	**0.23**	**0**	**2.63**
Rubus argutus	serrated-leaf blackberry	0.16	0.11	5.86	1.54
Sambucus canadensis	common elder	0	0	0.18	0.22
Sassafras albidum	sassafras	0	0.11	0	0
Smilax rotundifolia	round-leaf greenbrier	0	0	0	0.44
Toxicodendron radicans	poison ivy	8.84	16.15	0.73	8.33
Ulmus americana	American elm	0.32	0.80	0	1.97
Viburnum molle	smooth arrowwood	16.88	4.70	0.55	12.94
Viburnum prunifolium	black haw	1.45	0.23	0	5.70
Vitis sp.	grape	0.16	0.11	0	0
Total percent invasion†		77 ± 13	47 ± 21	89 ± 14	10 ± 12
Number of species		20	33	10	29
Shannon index of diversity (*H*′)		1.68	2.13	1.04	2.63
Shannon index of evenness (*E*)		0.56	0.61	0.45	0.78

† Percent invasion (mean ±1SD) for each site determined from plant survey information. n = 100 plots per site.

Table 2. Number of arthropods (mean ± 1 SD) captured per pitfall trap (n = 10) at four study sites in Dyke Marsh Wildlife Preserve, Virginia.†

		Site			
Taxon	**Common name**	**A**	**J**	**P**	**S**
Araneae‡	Spiders	7.3 ± 4.4a	5.6 ± 2.7a	9.8 ± 3.8a,b	10.1 ± 2.8b
Blattaria	Cockroaches	0.2 ± 0.4	0.6 ± 1.1	0.3 ± 0.5	0.5 ± 0.7
Chilopoda	Centipedes	1.5 ± 1.9	2.7 ± 1.8	2 ± 2.6	0.9 ± 0.6
Coleoptera‡	Beetles	14 ± 3.6a	11 ± 2.2b	9.1 ± 3.1b	9.3 ± 1.7b
Collembola‡	Springtails	34.6 ± 9.4a	48.1 ± 11.9b	121.5 ± 28.2c	85.6 ± 17.1d
Dermaptera	Earwigs	0	0.2 ± 0.4	0	0.2 ± 0.6
Diplopoda‡	Millipedes	0.8 ± 1.0a	0.5 ± 1.0a	6.8 ± 3.8b	0.7 ± 0.7a
Diplura	Diplurans	1 ± 1.4	1.4 ± 1.8	0	0.6 ± 1.0
Diptera	Flies	6.1 ± 2.0	7.1 ± 2.7	9.2 ± 4.4	6.6 ± 2.8
Formicidae‡	Ants	152 ± 41.4a	137.6 ± 62.0a	40.1 ± 17.4b	58.5 ± 27.9b
Hemiptera	Bugs	1.4 ± 1.3	0.8 ± 0.9	0.7 ± 0.9	0.3 ± 0.7
Homoptera	Bugs	1.1 ± 0.6	1.3 ± 1.2	0.5 ± 0.5	1.5 ± 1.6
Hymenoptera§	Bees, Sawflies, Wasps	5.1 ± 2.3	9.1 ± 3.1	7.5 ± 5.8	6.6 ± 3.2
Isopoda‡	Sowbugs, Pillbugs, and kin	1.1 ± 0.7a	1.3 ± 0.9a	6.9 ± 6.3b	2.2 ± 1.5a
Isoptera	Termites	0.4 ± 0.7	0	0.1 ± 0.3	0
Lepidoptera	Butterflies, Moths	0.3 ± 0.7	0.2 ± 0.6	0.3 ± 0.5	0.3 ± 0.5
Neuroptera	Dustywings	0	0.1 ± 0.3	0	0
Opiliones	Harvestmen	9.2 ± 3.6	12.6 ± 5.6	9.7 ± 2.9	9.3 ± 3.4
Orthoptera‡	Crickets, Grasshoppers, and kin	19.9 ± 4.9a	13.9 ± 2.6b	22.3 ± 9.8a	23.6 ± 5.2a
Pseudoscorpiones	Pseudoscorpions	0.2 ± 0.4	0.8 ± 0.9	0	0.3 ± 0.5
Psocoptera	Barklice	0	0.6 ± 0.8	0	0.2 ± 0.4
Symphyla	Symphylans	0.4 ± 0.7	0.3 ± 0.7	0	0.3 ± 0.7
Thysanura	Bristletails	0.2 ± 0.4	0	0	0.1 ± 0.3
Thysanoptera	Thrips	0.4 ± 0.7	0.7 ± 0.7	0.1 ± 0.3	0.5 ± 0.5
Trichoptera	Caddisflies	0	0.2 ± 0.4	0	0.1 ± 0.3
Total Arthropods		257 ± 82.5	256 ± 106.3	246.9 ± 91.1	218.3 ± 74.7

† Within rows, means followed by different letters are significantly different from one another. We used a Tukey test for Diplopoda.
‡ $P \leq 0.05$.
§ Exclusive of Formicidae.

Table 3. Numbers of ants (mean ± 1 SD) captured per pitfall trap (n = 10) at four study sites in Dyke Marsh Wildlife Preserve, Virginia.

	Site			
Taxon	**A**	**J**	**P**	**S**
Acanthomyops sp.	0	0.2 ± 0.4	0	0.1 ± 0.3
Amblyopone pallipes	0	0	0.2 ± 0.4	0
Aphaenogaster rudis†	39.2 ± 37.2b	25.5 ± 9.4b	4.7 ± 5.4a	9.7 ± 7.3a
Camponotus castaneus	0.1 ± 0.3	0.2 ± 0.4	0.1 ± 0.3	0
Camponotus nearcticus	0.1 ± 0.3	0	0.1 ± 0.3	0
Camponotus pennsylvanicus	0.2 ± 0.4	0	0	0.1 ± 0.3
Camponotus subbarbartus	0.1 ± 0.3	0	0.1 ± 0.3	0
Crematogaster cerasi	0	0.1 ± 0.3	0	0
Crematogaster pilosa	0	0	1.2 ± 1.2	0
Lasius alienus†	1.8 ± 1.3b	5.6 ± 4.7a	6.6 ± 4.8a	5.0 ± 3.8a
Leptothorax curvispinosis	0.4 ± 0.7	1.3 ± 1.2	0.8 ± 1.0	0.8 ± 0.8
Myrmecina americana	1.1 ± 1.1	0.5 ± 0.5	1.3 ± 1.6	0.5 ± 1.0
Myrmica emeryana	0	0	0.3 ± 0.7	0
Myrmica punctiventris	0	0	0.7 ± 1.3	0
Paratrechina faisonensis†	25.5 ± 5.5b	20.2 ± 6.2a,b	19.7 ± 8.4a,b	12.6 ± 7.6a
Ponera pennsylvanicus†	0.5 ± 1.1	0.2 ± 0.6	1.9 ± 1.4	1.9 ± 1.7
Prenolepis imparis†	79.4 ± 40.2b	80.2 ± 55.7b	2.1 ± 1.8c	25.9 ± 15.4a
Proceratium silaceum	0.1 ± 0.3	0	0	0
Pyramica ohioensis	0	0.4 ± 1.3	0	0.1 ± 0.3
Pyramica rostrata	1.1 ± 1.0	1.7 ± 3.1	0.2 ± 0.4	0.2 ± 0.4
Stenamma brevicorne†	1.6 ± 1.8a	1.1 ± 0.9a	0.1 ± 0.3b	1.4 ± 1.6a
Stenamma impar	0.4 ± 0.7	0.4 ± 0.5	0	0.2 ± 0.6
Total ants	151 ± 41.4b	137 ± 62.0b	40 ± 17.4a	58 ± 27.9a

† $P \leq 0.05$. Within rows, means followed by different letters are significantly different from one another; *Ponera pennsylvanicus* sample size was too small for a *post hoc* analysis.

DISCUSSION

We found that abundances of some arthropod taxa were highly variable among sites. There were large differences in arthropod abundance and plant species richness between site P and the other three sites, and formicid CC may be a good indicator of changes in the entire terrestrial arthropod community in the forest. Small samples may have prevented us from finding many possible differences in arthropod abundance among sites (Table 2).

Site P, a forest opening evidently caused by a large tree fall, is markedly different from the other three sites and had the lowest plant *H′* and *E* (Table 2). A dense mat of the vigorous, alien vine *A. brevipedunculata* comprised 71% of the site's plant cover and appears to be maintaining the forest opening by excluding new tree seedlings and out-competing other plants for light, space, and other resources. Further, this vine may be excluding arthropods present in typical forest succession in the DMWP.

Plants can change soil chemistry by adding nutritive matter from their fallen parts and ectocrine substances and by removing soil nutrients and water. For example, in the Netherlands, the chemistry of decomposing leaves on a forest floor explained much of the variation in a collembolan community (Pinto et al., 1997). The abundance of litter-associated taxa such as Collembola, Diplopoda, Formicidae, and Isopoda in site P varied significantly from their abundances in the other sites. Site P had 359 more Collembola, and 60 more alien, invasive millipeds (*O. pilosus)* than any other site. Our ongoing DMWP research may identify which factors determine the distribution of *O. pilosus.* The presence of this milliped may be associated with the presence of *A. brevipedunculata* and its environmental effects.

Although ant abundance at site P was low, its ant diversity (H') was the highest of all four sites (Table 5). We caught four ant species unique to site P, possibly because the highly competitive False Honey Ant (*P. impairs*) was rare at this site, although an associated increase in other ant abundance is not apparent (Table 3). Based on our methodology, we cannot rule out the possibility that this ant was more common at site P than our traps indicated. This ant may have been foraging mostly on *A. brevipedunculata* and other plants not on the ground where the traps could collect it. Decreases in normally abundant ant species may be a sign of change in the ecology of an area according to Lynch et al. (1980). In eastern Maryland, they found that this usually common ant is sensitive to high temperatures and often becomes inactive when temperatures exceed 26^o C. Site P is noticeably warmer than the other sites when there is direct sunlight (pers. obs.), and the ground temperature may sometimes exceed that tolerated by *P. imparis*.

Sites P and S had low numbers of *Aphaenogaster rudis* and *P. imparis,* although there were significantly more *P. imparis* in the latter site. Site S is near a tidal channel and was periodically flooded during our study. The wet ground may have reduced the numbers of *P. imparis* and affected the arthropod community in other ways as well.

Composite CC values (where Formicidae are excluded) were nearly identical to formicid CC values (Table 6), and this may have important implications for future studies. We are currently working on a more comprehensive study of both soil and terrestrial arthropods and plan to evaluate whether a species-level

Table 4. Number of spiders (mean ± 1 SD) captured per pitfall trap (n = 10) at four study sites in Dyke Marsh Wildlife Preserve, Virginia.

	Site			
Species	**A**	**J**	**P**	**S**
Agelenopsis sp.	0.1 ± 0.3	0	0	0
Agroeca pratensis	0.1 ± 0.3	0	0	0
Anyphaena sp.	0	0	0	0.1 ± 0.3
Anyphaenidae spp.	0	0.1 ± 0.3	0.1 ± 0.3	0
Araneidae spp.	0.1 ± 0.3	0	0.1 ± 0.3	0.2 ± 0.4
Castianeira variata	0	0.2 ± 0.4	0.2 ± 0.4	0
Crustulina altera	0.1 ± 0.3	0.2 ± 0.4	0	0
Crustulina sp.	0.1 ± 0.3	0.1 ± 0.3	0	0.1 ± 0.3
Dictyna sp.	0	0.1 ± 0.3	0	0.3 ± 0.5
Drassyllus sp.	0.2 ± 0.4	0.6 ± 0.7	0.4 ± 0.5	0.2 ± 0.4
Dysdera crocata	0.1 ± 0.3	0	0.4 ± 0.7	0.1 ± 0.3
Eidmannella pallida	0.1 ± 0.3	0	0.3 ± 0.6	0
Erigoninae spp.	0.2 ± 0.4	0.2 ± 0.6	0.1 ± 0.3	0.2 ± 0.6
Euryopis argentea	0.2 ± 0.4	0.1 ± 0.3	0	0
Habrocestum pulex	0.2 ± 0.4	0.1 ± 0.3	0.4 ± 0.5	0.3 ± 0.5
Linyphiidae sp. a	0	0	0	0.1 ± 0.3
Linyphiidae sp. b	0.2 ± 0.4	0	0	0.5 ± 0.7
Linyphiidae sp. c	0	0	0.9 ± 1	0
Linyphiidae sp. d	0	0.1 ± 0.3	0	0
Linyphiidae sp. e	0	0	0.2 ± 0.4	0
Linyphiidae sp. f	0.1 ± 0.3	0	0.3 ± 0.5	0
Linyphiidae sp. g	0	0	0.1 ± 0.3	0
Linyphiinae spp.	0.8 ± 0.8	0.5 ± 0.5	0.8 ± 1.0	0.4 ± 0.5
Neoantistea agilis†	0.4 ± 0.7a	0.4 ± 0.7a	1.7 ± 1.1b	1.9 ± 1.4b
Neoscona domiciliorum	0	0	0	0.1 ± 0.3
Pardosa sp.	0	0.2 ± 0.4	0	0
Phrurotimpus borealis	0.1 ± 0.3	0.6 ± 0.5	0.4 ± 0.5	0
Phrurotimpus sp.	0	0.1 ± 0.3	0	0.3 ± 0.5
Pirata zelotes	3.1 ± 2.0	1.7 ± 1.5	2.5 ± 1.3	3.6 ± 1.7
Pisaurina sp.	0	0	0.1 ± 0.3	0
Schizocosa ocreata	0	0	0.1 ± 0.3	0
Scotinella redempta	0.5 ± 0.7	0.1 ± 0.3	0.3 ± 0.5	0.7 ± 0.5
Scotinella sp.	0.2 ± 0.4	0.1 ± 0.3	0.2 ± 0.4	0.2 ± 0.4
Sergiolus sp.	0	0.1 ± 0.3	0	0
Theridiidae sp.	0	0	0	0.1 ± 0.3
Xysticus sp.	0.4 ± 0.7	0	0.1 ± 0.3	0.7 ± 0.7
Zelotes sp.	0	0	0.1 ± 0.3	0
Total spiders†	7.3 ± 4.4a	5.6 ± 2.7a	9.8 ± 3.8a,b	10.1 ± 2.8b

† $P \leq 0.05$. Within rows, means followed by different letters are significantly different from one another.

Table 5. Shannon index of diversity (H') and Shannon index of evenness (E) for arthropod classes and orders, spiders, and ants caught at each site in Dyke Marsh Wildlife Preserve, Virginia.

	Site			
Arthropoda*	**A**	**J**	**P**	**S**
Arthropod abundance	2,568	2,567	2,469	2,183
No. of classes/orders (25 total)	20	22	16	22
H'	1.25	1.35	1.37	1.44
E	0.42	0.44	0.50	0.47
H' excluding Formicidae	1.73	1.77	1.24	1.36
E excluding Formicidae	0.57	0.57	0.44	0.43
Araneae (Spiders)				
Spider abundance	73	56	98	101
Number of species (37 total)	20	19	22	19
H'	2.23	2.44	2.53	2.23
E	0.74	0.83	0.82	0.76
Formicidae (Ants)				
Ant abundance	1,516	1,376	401	585
Number of species (22 total)	14	15	16	13
H'	1.26	1.24	1.68	1.57
E	0.48	0.46	0.64	0.61

*Includes all orders and classes listed in Table 2 except for Acari.

formicid CC is a good indicator for a total arthropod CC at a particular site. Ants may be ideal organisms for examining terrestrial community changes, although Alonso's (2000) review did not find them useful for this purpose. Ants make up a large portion of pitfall catches, are easy to separate from other taxa, are relatively easy to identify to the species level with a reference collection and a database such as the BDWA (Barrows & Kjar, 2004), and are inexpensive to preserve.

Sites A and J had lower abundances of isopods, orthopterans, spiders, and springtails, but nearly three times more ants than sites P and S combined (Table 2). Predaceous generalist and specialist ants may be reducing the abundance of some of these groups. For example, 32 of the 37 individuals of *Pyramica* ants, which prey upon springtails, were in sites A and J, and may have caused the low springtail abundances in these sites. Sites A and J had lower evenness among ants species compared with the other two sites. Site A had the lowest ant diversity (15 species), and 10 of these species each comprised less than 1% of the site's total ant abundance; 78% of the ants were *A. rudis* and *P. imparis* (Table 3).

All sites had very different and diverse spider assemblages, and most spider species did not show any trend in relation to the plant CCs (Tables 4 and 6). There were significantly fewer *N. agilis* (Hahniidae) in sites A and J than in the other two sites (Table 4). Heterogeneity of ground cover may have influenced the distribution of these spiders among these sites (Uetz, 1979). Sites P and S both have dense, low vegetation, while sites A and J do not. Low ground cover can affect diversity and abundance of ground-hunting spider species, and this may explain the much lower abundance of spiders caught in sites with little or no ground cover (Uetz, 1976).

Table 6. Community Coefficient of Similarity (CC) among four study sites in Dyke Marsh Wildlife Preserve, Virginia.

	Site comparison					
Taxa	**S x J**	**S x A**	**S x P**	**J x A**	**J x P**	**A x P**
Plants	0.740	0.626	0.410	0.640	0.265	0.360
Ants	0.757	0.859	0.596	0.744	0.697	0.589
Spiders	0.557	0.649	0.520	0.593	0.660	0.441
Higher taxa†	0.862	0.861	0.888	0.775	0.937	0.567
Rank combined‡	2	1	5	3	4	6
Rank ants	2	1	5	3	4	6
Rank combined without ants	1	2	5	3	4	6

† Higher taxa refers to all groups in Table 2.
‡ Ranks combined is a ranked average of data from all plants and ant, spider, and higher arthropod taxa. This scale is from 1-6, with 1 indicating the two sites most similar and 6 the two sites that are least similar.

Arthropod and plant diversities varied greatly among our study sites, and these animals and plants are likely to influence one another's diversities. Previous studies have demonstrated that insect abundance and diversity can be affected by changes in plant species abundance and diversity. An extensive study in Minnesota found that changes in plant species richness and plant functional-group diversity affect arthropod abundance (Haddad et al., 2001) as well as the stability of natural systems (Tilman et al., 1997). The proportion of native plants in a prairie reserve near Chicago, Illinois, explained nearly half of the variance in species richness of insects found in the reserve but absent from neighboring non-reserve areas (Panzer & Schwartz, 1998). A New Zealand study found that the percentage of native beetle species was positively correlated with the proportion of native plants in study sites (Crisp et al., 1998). Plant community changes, such as artificial monocultures in tropical agroecosystems, cause large changes in arthropod biodiversity and abundance (Perfecto & Snelling, 1995). Alien invasive plants can form monocultures, or near-monocultures, which are likely to change original arthropod communities. Such plants are major weeds in nature preserves, for example, Rock Creek Park in Washington, D.C. (Salmons, 2000).

In conclusion, we found 255 species and morphospecies of arthropods in a low forest that is highly invaded by alien plants. The abundance of 10 arthropod taxa varied significantly among four study sites. Future studies should examine possible relationships between arthropod biodiversity and invasive alien plants. On one hand, these plants may increase population sizes of native arthropods that feed on their nectar, pollen, and other parts. In the DMWP, many native bee, butterfly, fly, and wasp species obtain food from flowers of alien plants (pers. obs.), and some of these animals might have become more common due to these plants. On the other hand, alien plants can decrease population sizes of native arthropods. These plants can invade and change natural habitats and reduce population sizes of native plants used as food by native arthropods, and in turn reduce the numbers of these animals. Alien plants such as *Alliaria petiolata* (garlic mustard), *A. brevipedunculata, C. orbiculatus, Hedera helix* (English ivy), and *L. japonica* reduce the number of native plants used as food by native arthropods.

Among the 41 plant species in this study, three aliens, *A. brevipedunculata, C. orbiculatus*, and *L. japonica* had a mean total plant cover in the four study sites of 58%. Some of the variability of the arthropods in this study may result from changes in the plant community induced by alien plants. We are currently working on a new large-scale study with 60 replicate sites in the DMWP to test several hypotheses: Changes in terrestrial arthropod diversity are associated with the level of invasion by alien invasive plants; there are indicator groups of the diversity of the terrestrial and soil arthropod community; and native plant species richness is inversely related to level of alien plant invasion. To protect biodiversity, resource managers must know many things about native and alien arthropod species, including their identities, relative abundances, microhabitats, and other resource uses, as well as how alien, invasive organisms affect them.

ACKNOWLEDGMENTS

We thank Maya R. Patel (for field work and moral support); Joseph E. Barrows (field work); Alex Chang (field and laboratory help); Ru San Chen (statistical advice); David G. Furth (general help); Eric E. Grissell (small wasp identifications); Richard L. Hoffman (myripod identifications); Melissa C. Kangas (permit help); Christopher P. McManus (field work); Diane Pavek (research advice); Ed Cohen (insect identifications); Warren E. Steiner, Jr. (beetle identifications); David R. Smith (ant identifications); Theodore W. Sumon (spider identifications); Philip Sze and Martha R. Weiss (scientific advice); other arthropod specialists who are acknowledged on pages of the Biodiversity Database of the Washington, D.C., Area; Georgetown University, the Friends of Dyke Marsh, the National Park Service, and the Washington Biologists' Field Club (encouragement and funding).

LITERATURE CITED

Alonso, L. E. 2000. Ants as indicators of diversity. Pp. 80-88 *In* D. Agosti, J. D. Majer, L. E. Alonso, & T. R. Schultz (eds.), Ants. Standard Methods for Measuring and Monitoring Biodiversity, Smithsonian Institution Press, Washington, DC. 280 pp.

Barrows, E. M. 1986. A hornet, paper wasps, and yellowjackets (Hymenoptera: Vespidae) in suburban habitats of the Washington, D.C., area. Proceedings of the Entomological Society of Washington 88: 237–243.

Barrows, E. M., & D. S. Kjar. 2004. Biodiversity Database of the Washington, D.C., Area. http://biodiversity.georgetown.edu (5 February 2004)

Blatchley, W. S. 1910. An Illustrated and Descriptive Catalogue of the Coleoptera or Beetles (Exclusive of Rhynchophora) Known to Occur in Indiana. Nature Publishing Company, Indianapolis, IN. 1,385 pp.

Bolton, B. 1994. Identification Guide to the Ant Genera of the World. Harvard University Press, Cambridge, MA. 222 pp.

Borges, P. A. V. 1999. A list of arthropod species of sown and semi-natural pastures of three Azorean islands (S. Maria, Terceira and Pico) with some conservation remarks. Açoreana 9: 13–34.

Borror, D. J., D. M. De Long, & C. A. Triplehorn. 1981. An Introduction to the Study of Insects. Fifth Edition. Saunders College Publishing, Philadelphia, PA. 827 pp.

Bossart, J. L., & C. E. Carlton. 2002. Insect conservation in America: status and perspectives. American Entomologist 48: 82–92.

Britton, W. E. 1920. Check-list of the Insects of Connecticut. Connecticut State Geological and Natural History Survey, Hartford, CT. 397 pp.

Brown, J. W. 2001. Species turnover in the leafrollers (Lepidoptera: Tortricidae) of Plummers Island, Maryland: Assessing a century of inventory data. Proceedings of the Entomological Society of Washington 103: 673–685.

Brown, M. L., & R. G. Brown. 1984. Herbaceous Plants of Maryland. Port City Press, Baltimore, MD. 1,127 pp.

Brown, R. G., & M. L. Brown. 1992. Woody Plants of Maryland. Port City Press, Baltimore, MD. 347 pp.

Burger, J. C., M. A. Patten, T. R. Prentice, & R. A. Redak. 2001. Evidence for spider community resilience to invasion by non-native spiders. Biological Conservation 98: 241–249.

Butler, L., V. Kondo, E. M. Barrows, & E. C. Townsend. 1999. Effects of weather conditions and trap types on sampling for richness and abundance of forest macrolepidoptera. Environmental Entomology 28: 795–811.

Christiansen, K., & P. Bellinger 1980. The Collembola of North America, north of the Rio Grande. Grinnell College, Grinnell, IA. 1,322 pp.

Creighton, W. S. 1950. The Ants of North America. Bulletin of the Museum of Comparative Zoology 104. 569 pp.

Crisp, P. N., K. J. M. Dickinson, & G. W. Gibbs. 1998. Does native invertebrate diversity reflect native plant diversity? A case study from New Zealand and implications for conservation. Biological Conservation 83: 209–220.

Downie, N. M., & R. H. Arnett, Jr. 1996. The Beetles of Northeastern North America. 2 Vol. Sandhill Crane Press, Gainesville, FL. 1,720 pp.

Erwin, T. L. 1981. Natural history of Plummers Island, Maryland. XXVI. The ground beetles of a temperate forest site (Coleoptera: Carabidae): An analysis of fauna in relation to size, habitat selection, vagility, seasonality, and extinction. Bulletin of the Biological Society of Washington 5: 106–224.

Erwin, T. L. 1982 Tropical forests: their richness in Coleoptera and other arthropod species. Coleopterists' Bulletin 36:74–75.

Greenslade, P. J. M. 1964. Pitfall trapping as a method for studying populations of Carabidae (Coleoptera). Journal of Animal Ecology 33: 301–310.

Haarstad, J. A. 2003. The insects of Cedar Creek. http://cedarcreek.umn.edu/insects/insects.html (1 June 2003)

Haddad, N., D. Tilman, J. Haarstad, M. Ritchie, & J. M. H. Knops. 2001. Contrasting effects of plant richness and composition on insect communities: A field experiment. American Naturalist 158: 17–35.

Haug, E. 1993. Protecting botanical natural resources at Dyke Marsh. Unpublished report. 8 pp., 9 maps, 2 tables.

Henry T. J., & R. C. Froeschner (eds). 1988. Catalog of the Heteroptera, or True Bugs, of Canada and the Continental United States. E. J. Brill, Leiden, The Netherlands. 958 pp.

Holway, D. A. 1998. Effect of Argentine ant invasions on ground-dwelling arthropods in northern California riparian woodlands. Oecologia 116: 252–258.

Kalhorn, K. D., E. M. Barrows, & W. E. LaBerge. 2003. Bee (Hymenoptera: Sphecoidea: Apiformes) diversity in an Appalachian shale barrens. Journal of the Kansas Entomological Society 76: 455–468.

Krohne, D. T. 1998. General Ecology. Wadsworth Publishing Company, New York, NY. 722 pp.

Krombein, K. V., P.D. Hurd, Jr., D. R. Smith, & B. D. Burks. 1979. Catalog of the Hymenoptera in America North of Mexico. 3 Vol. Smithsonian Institution Press, Washington, DC. 2,735 pp.

Leonard, M. D. 1928. A list of the insects of New York with a list of the spiders and certain other allied groups. Cornell University Agricultural Experiment Station Memoir 101: 5-1121.

Lynch, J. F., E. C. Balinsky, & S. G. Vail. 1980. Foraging patterns in three sympatric species, *Prenolepis imparis*, *Paratrechina melanderi,* and *Aphaenogaster rudis*. Ecological Entomology 5: 353–371.

Novotny, V., Y. Basset, G. D. Weiblen, B. Bremer, L. Cizek, & P. Drozd. 2002. Low host specificity of herbivorous insects in a tropical forest. Nature 416: 841–844.

Oliver, I., & A. J. Beattie. 1996. Designing a cost-effective invertebrate survey: A test of methods for rapid assessment of biodiversity. Ecological Applications 6: 594–607.

Panzer, R., & M. W. Schwartz. 1998. Effectiveness of a vegetation-based approach to insect conservation. Conservation Biology 12: 693–702.

Perfecto, I., & R. Snelling. 1995. Biodiversity and the transformation of a tropical agroecosystem: Ants in coffee plantations. Ecological Applications 5: 1084–1097.

Pinto, C., J. P. Sousa, M. A. S. Graca, & M. M. da Gama. 1997. Forest soil Collembola. Do tree introductions make a difference? Pediobiologia 41: 131–138.

Porter, S. D., & D. A. Savignano. 1990. Invasion of polygyne fire ants decimates native ants and disrupts arthropod community. Ecology 71: 2095–2106.

Procter, W. 1946. Biological survey of the Mount Desert Region. Part VII. The insect fauna. Winstar Press, Philadelphia, PA. 556 pp.

Salmons, S. 2000. Rock Creek Park Invasive Non-Native Plant Mitigation Program. Final Report. National Park Service, Washington, D.C. (http://www.nps.gov/rocr/natural/final.htm) (9 September 2002)

Smith, D. R., & E. M. Barrows. 1987. Sawflies (Hymenoptera: Symphyta) in urban environments in the

Washington, D.C. area. Proceedings of the Entomological Society of Washington 89: 147–156.

SPSS, Inc. 2000. SPSS for Windows, Rel. 10.1.0. Chicago, IL.

Tilman, D., J. Knops, D. Wedin, P. Reich, M. Ritchie, & E. Siemann. 1997. The influence of functional diversity and composition on ecosystem processes. Science 277: 1300–1302.

Uetz, G. W. 1976. Gradient analysis of spider communities in a streamside forest. Oecologia 22: 373–385.

Uetz, G. W., 1979. The influence of variation in litter habitats on spider communities. Oecologia 40: 29–42.

Weissman, M. J., & B. C. Kondrateiff. 1999. An inventory of arthropod fauna at Great Sand Dunes National Monument, Colorado. University of Kansas Natural History Museum Special Publications 24: 57–68.

Wray, D. W. 1967. Insects of North Carolina. Third Supplement. North Carolina Department of Agriculture, Division of Entomology, Raleigh, NC. 181 pp.

Xu, Z. 1991. Final report on inventories of plant species and communities in Dyke Marsh, Alexandria, Virginia. George Mason University, Fairfax, VA. 68 pp. Unpublished report.

Zar, J. H. 1984. Biostatistical Analysis. Fourth Edition. Prentice Hall, Englewood Cliffs, NJ. 718 pp.

Appendix 1. Arthropod taxa from pitfall-trap samples from the low forest of Dyke Marsh Wildlife Preserve, Virginia, 2000–2001. Figures in parentheses denote the number of morphospecies that were not identified beyond the taxonomic level indicated.

- Arachnida
  - Acari (13)
    - Ixodidae (1)
  - Araneae (see Table 4)
  - Pseudoscorpiones (2)
  - Opiliones
    - Phalangiidae
      - *Hadrobunus maculosus*
      - *Leiobunum* sp.

- Chilopoda
  - Geophilomorpha
    - Dignathodontidae
      - *Strigamia bothriopa*
      - *Strigamia branneri*
    - Geophilidae
      - *Arctogeophilis umbraticus*
      - *Geophilus varians*
      - *Pachymerium ferrugineum*
  - Lithobiomorpha
    - Lithobiidae (2)
      - *Goribius* sp.
      - *Sigibius* sp.

- Crustacea (Malacostraca)
  - Isopoda (2)

- Diplopoda
  - Julida
    - Julidae
      - *Ophyiulus pilosus*
    - Parajulidae
      - *Ptyoiulus impressus*
  - Chordeumatida
    - Cleidogonidae
      - *Cleidogona* sp.

- Entognatha
  - Collembola
    - Dicyrtomidae
      - *Dicyrtoma fusca*
    - Entomobryidae
      - *Homidia sauteri*
      - *Homidia socia*
      - *Lepidocyrtus* sp.
    - Poduridae
      - *Friesea* sp.
    - Sminthuridae
      - *Symphypleona* sp.
    - Tomoceridae (1)
  - Diplura
    - Campodeidae (1)

Appendix 1 (continued)

Insecta
- Coleoptera
  - Anthicidae
    - *Tomoderus constrictus*
  - Anthribidae (1)
  - Biphyllidae (1)
  - Carabidae
    - *Chlaenius erythropus*
    - *Cyclotrachelus sodalis*
    - *Galerita bicolor*
    - *Harpalus* sp.
    - *Platynus decentis*
    - *Poecilus lucublandus*
    - *Polyderis* sp.
  - Chrysomelidae
    - *Multipunctata bigsbyana*
  - Colydiidae
    - *Paha laticollis*
  - Cryptophagidae (1)
  - Curculionidae
    - *Acalles carinatus*
    - *Acalles porosus*
    - *Callirhopallus bifasciatus*
    - *Oedophrys hilleri*
    - *Ostiorhynchus rugostriatus*
  - Elateridae (1)
  - Endomychidae (1)
  - Histeridae (1)
  - Lampyridae
    - *Photinus* sp.
    - *Photuris* sp.
  - Leiodidae (3)
  - Nitidulidae
    - *Epuraea rufa*
    - *Stelidota geminata*
  - Pselaphidae
    - *Adranes lecontei*
    - *Brachygluta* sp.
  - Scarabaeidae (1)
    - *Anomola marginata*
    - *Onthophagus hecate*
    - *Serica brunnea*
  - Scolytidae (3)
  - Silphidae (2)
  - Silvanidae (1)
  - Staphylinidae (10)
- Dermaptera
  - Forficulidae
    - *Forficula auricularia*
- Dictyoptera
  - Blatellidae
    - *Parcoblatta* sp.
- Diptera (25)
- Heteroptera (3)
  - Lygaeidae
    - *Drymus crassus*
    - *Ozophora picturata*
  - Miridae
    - *Fulvius slateri*
  - Pentatomidae
    - *Amaurochrous cinctipes*
    - *Brochymena quadripustulata*
  - Reduviidae (1)
- Homoptera
  - Aphididae (1)
  - Cicadellidae (5)
  - Flattidae (1)
  - Pseudococcidae (1)
  - Psyllidae (1)
- Hymenoptera
  - Bethylidae (8)
  - Braconidae (1)
  - Diapriidae
    - *Basalys* spp. (2)
    - *Belyta* sp.
    - *Coptera* sp.
    - *Trichopria* spp. (4)
  - Formicidae (see Table 3)
  - Mymaridae (3)
  - Pteromalidae
    - *Alotera* sp.
    - *Dipara* spp. (2)
  - Scelionidae (18)
  - unknown micro-wasp family (3)
- Isoptera
  - Rhinotermitidae
    - *Reticulitermes flavipes*
- Lepidoptera (6)
- Mecoptera
  - Meropeidae
    - *Merope tuber*
- Neuroptera
  - Coniopterygidae (1)
- Orthoptera (3)
  - Gryllidae
    - *Hapithus agitator*
    - *Neonemobius palustris*
    - *Pictonemobius ambitosus*
  - Raphidophoridae
    - *Tachycines asynamorus*
- Psocoptera
  - Lepidopsocidae (1)
  - Liposcelidae
    - *Liposcelis* sp.
  - Polypsocidae (1)
  - Psyllipsocidae (1)
- Mycrocoryphia
  - Machilidae (1)
- Thysanoptera (2)
  - Aelopthripidae (2)
  - Thripidae (1)
- Trichoptera (1)

Symphyla (1)