Discovering the Potential for Natural Control of Arthropod Pests on Christmas Trees in Pennsylvania

A Report of Research Funded by the
Pennsylvania Christmas Tree Growers Association
2004

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Project Summary

The current control measures for arthropod pests of Christmas tree species in Pennsylvania include chemical application of insecticide(s) or miticide(s). The complete reliance on chemical control carries with it a moderate financial burden in the cost of supplies and equipment and in the person hours to scout fields, but more so, it chronically exposes both the applicator and the non-target environment in which they are applied to potentially unhealthy active chemical agents. Also, the EPA continues to apply more stringent restrictions on the use of agricultural chemicals and there are increasing concerns of chemical resistance among arthropod pest species of all major crops across the world. Integrated pest management strategies, incorporating biological control agents, or the complete reliance of biological control agents have shown the potential to reduce or negate the use of chemical control in artificial stands of Christmas tree species in other states and I hope that these measures might bear fruit in Pennsylvania. This project was a preliminary step in investigating the potential for natural control of pest species in Pennsylvania Christmas tree farms.

I conducted a manageable insect survey to measure both the possible presence of arthropod pests and potential arthropods for natural control of Christmas tree pests. I sampled arthropods in a managed plot of multiple species where chemical application was administered based on scouting and where the ground cover in the area was subject to regular mowing. I also sampled arthropods from a nearby area containing similar, but unmanaged, tree species where neither mowing nor pesticide application occurred. I sorted the samples to try and locate species of Christmas tree pests as well as any potential natural control organisms. In addition, I quantified the samples to compare the overall diversity of collected arthropods between the sites.

Introduction

Insect Pests of Christmas Trees in Pennsylvania

Cornell University lists over a dozen arthropod pest species of Christmas Trees (http://ppathw3.cals.cornell.edu/Trees/TreePests.html), all of which occur in Pennsylvania, but the most prevalent and damaging of these locally are the Cooley Spruce Gall Aphid (*Adelges cooleyi*), the White Pine Weevil (*Pissodes strobi*), and the Balsam Twig Aphid (*Mindarus abietinus*) (Dr. Lawrence Kuhns, pers. comm.). All of these pests cause cosmetic damage, which is very detrimental to the yield of the Christmas tree. In addition, damage from these pests can cause decreased health, thus increasing the chance of needle drop.

The Native Pest Paradox – In today's agricultural market, reports on damage to native or imported crops by exotic pest species that generate out of control populations due to the high availability of food resources in a monoculture community are common place and increasingly frequent. Means for the control of these pests motivate research into their native habitats, often foreign countries, to find those factors that keep the populations in check. This research entails searching for those biological agents or social practices (predators, parisitoids, farming practices, etc.) that keep the pest species' populations at low, manageable numbers. In contrast, the pests of Christmas trees are native to the regions where they have become pests, the northern U.S. and Canada. This makes the Christmas tree farm a rare, and arguably more prosperous, community in which to search for the natural factors that may maintain a dynamic equilibrium in pest species populations.

Biological Control in Christmas Trees

There is a paucity of information in the literature regarding the use of biological agents to control pests in Christmas trees (Hulme 2000, Kenis 1997, Kenis & Mills 1994), which is noted and lamented:

> "Biocontrol in Christmas tree production probably holds more potential than is currently being realized. There is a scarcity of information on effectiveness of biocontrol agents, and the proper timing and density for agents that will be released in fields. To-date, there are few specialized biocontrol agents for Christmas tree pests available commercially." (http://ipmworld.umn.edu/chapters/mccull.htm, http://www.tricity.wsu.edu/~cdaniels/profiles/chritree.pdf, http://pestdata.ncsu.edu/cropprofiles/docs/orwachristmastrees.html)

This information is in no way discouraging, however, as there are over ten "groups" of potential biocontral agents of Christmas tree pests. Below is a short list of organisms already recognized as potential or realized natural enemies of Christmas tree pests by the University of Connecticut: (http://www.canr.uconn.edu/ces/ctpep/CTXMSINS.htm#_ednref12)

Some natural enemies to watch for and their target pests:	
Predators/Parasitoids	**Target Pest(s)**
Neoseiulus (Amblyseius) fallacis:	Spider mites[18]
Orius spp. (insidious flower bugs, minute pirate bugs):	Aphids, mites, insect eggs, small larvae and small nymphs.[19]
Ladybird beetles:	Aphids, mites, lepidoptera eggs[20] and exposed stages of adelgids.[21]
Entomopathogenic fungi:	Aphids, adelgids[21] mites and many other pest insects[20].
Stethorus spp.	Spider mites[22].
Potter wasps (*Eumenes fraternis*)	Caterpillars and sawfly larvae[23].
Other vespid wasps:	All types of exposed insects[23].
Sphecid wasps (*Ammophila* spp.):	Caterpillars and sawfly larvae[23].
Pentatomid stink bugs:	Caterpillars, sawfly larvae and other insects[23].
Chilocorus spp.:	Scales[20].

This list is not comprehensive in terms of the potential biological agents that may be utilized in stands of Christmas trees as there may be dozens or more still waiting to be recognized, which is a very optimistic prognosis. This optimism, however, is tempered with the disclaimer:

> "Obviously, it is important to minimize insecticide use and drift to help conserve these natural enemies." (http://ipmworld.umn.edu/chapters/mccull.htm, http://www.tricity.wsu.edu/~cdaniels/profiles/chritree.pdf, http://pestdata.ncsu.edu/cropprofiles/docs/orwachristmastrees.html)

Chemical Control in Christmas Trees

The monetary cost of chemical control in Christmas trees is not negligible amounting to as much as $40-50/acre for granular and $100-300/acre for liquid insecticide applications (http://www.ces.ncsu.edu/nreos/forest/xmas/growing/ag95.pdf), however, the cost associated with labor for scouting and application vary considerably with the practices of the individual farms' management. The Pennsylvania State University currently lists 49 active ingredients in 17 chemical classes that have been recommended for the control of Christmas tree pests (http://www.pested.psu.edu/insecticides.html#restrict) from low risk microbials and botanicals to highly toxic carbamates and organophosphates. Chemical applications come with associated health risks, for example:

> **Montgomery County, Pennsylvania**-- September, 1994: Following an application of Dursban (chlorpyrifos insecticide), 17 children were sent home with headaches, nausea, vomiting, and low-grade fevers. (See *Law Targets School Pesticide Use*, The Morning Call (Allentown, PA.) Jan. 26, 1994).

Dursban is a chemical on the recommended list for Christmas tree pests and is included in the long list of chemicals with potential health hazards from acute and chronic exposure provided by The Pennsylvania State University: "Toxicity and Potential Health Effects of Pesticides" (http://pubs.cas.psu.edu/FreePubs/pdfs/uo198.pdf). In addition to the personal health concerns of the chronically exposed applicators and any others who may inadvertently be exposed acutely, there is a growing consciousness among the "non-farming" community that chemical means of control are not worth the perceived potential damage to the health of people and the environment. Accuracy aside, these views often drive the political motivation for removal of these chemicals from the market by the EPA. And finally, the growing awareness of insect adaptability and genetic resistance to chemical controls is also prompting discussion among the academic and at large communities as to the growing risk of reliance on these singular control measures. Despite their current effectiveness and availability, the attitude of continued reliance on chemical control is precocious.

Method of Study

The methodology for the study was simple, straightforward, and exploratory. It entailed field collecting events to measure the presence of possible biological control agents in Christmas tree stands. Field collecting was performed at two sites, one managed (site M) and one unmanaged (site U). Site M is a Christmas Tree farm in Centre County Pennsylvania where collecting was completed with the permission, supervision, and guidance of the owner. The owner was questioned about likely points of pest outbreak and spots where chemical application had taken place. Site M is characterized as a well manicured farm with regularly spaced and regularly trimmed trees. The caretakers of site M manage the farm with acute applications of chemical control as needed and regular mowing in and around the trees to control the Christmas tree understory and unwanted herbaceous growth. Site U is a parcel of property owned by The Pennsylvania State University's horticulture department also located in Centre County. The section of site U I studied contained Christmas tree species that were left in an unmanaged section for at least 10 years. Site U is characterized by irregularly spaced trees of varying ages and size that received no chemical applications or trimming. Site U is essentially a wild site with an irregular schedule of mowing of the adjacent areas and little or no attention paid to the Christmas tree under-story.

Collecting events initially included several trapping modalities ranging from Malaise traps to hand collecting as well as initial plans to conduct light trapping. Malaise traps proved untenable due to high winds and inadequate sites for setting up traps, especially as the set-up of these traps was potentially damaging to the Christmas trees themselves. I ultimately determined through knowledge of other sampling projects, that light traps would be inappropriate as they would attract flying insects not associated with the Christmas tree ecosystem from adjacent ecosystems. Hand collecting (i.e., by hand net) was conducted only by myself so was limited in an attempt to remove investigator bias towards insects within my specialty. The majority of the insects surveyed were obtained using pan traps. Specimens attracted to pan traps represent only the local arthropod community as the attraction (color) has a very localized effect and will not attract species from afar via other sensory stimuli. Pan trap samples should also represent a community with little bias towards specific groups of organisms and produce manageable samples for a project of this scope. Pan traps of three different colors (red, yellow, and blue) were loaded with a low concentration of soapy water. Traps were placed randomly at site U and along tree rows at site M. The three primary colors were used as there is considerable published and anecdotal evidence that different arthropod species are attracted to different parts of the visible color spectrum (Frank Parker, pers. comm.). I used 10 pans of each color (30 total) for each sampling event at both sites U and M. At site M, the pan colors were alternated along three different rows of 10 pans. With the random placement of pans at site U and the alternate scheme at site M, I considered the site methodology equitable and independent and subject to possible quantification with either parametric or non-parametric statistics if the chance arose.

Insect specimens were initially sorted, pinned, and labelled by a student hourly worker who was trained in basic curatorial techniques. I provided the final resolution to the sorting of these specimens to species. Specimens were determined to the species level where possible, but this is severely limited in the class Insecta (see Discussion). Indeterminable species were sorted to morphotypes (specimens determined to be different species, but without an identification) with the most resolved level of classification possible (most commonly, the family level). The samples were evaluated for species with possible impact on biocontrol in a Christmas tree ecosystem, presence or absence of Christmas tree pests, and the two sites were compared in terms of diversity and community make-up. Diversity indices and statistics were calculated using EstimateS version 6.0b1 (Colwell 2000).

Results

The specimens recorded from the sampling events are listed in Tables 1 and 2. Some specimens collected that were of a condition impossible to distinguish their order (or family in the case of most insect specimens) were not included in the list or in comparative analyses. The total number of specimens that fell within that category was 23, or less than 2% of the grand total. A grand total of 1,603 specimens were curated, labeled, and sorted to morphotypes represented by 185 species in 67 families and 8 orders.

Christmas Tree Pests and Potential Biocontrol Organisms

Only one specimen collected in the entire survey could be determined accurately as a Christmas tree pest; a single specimen of the White Pine Weevil (*Pissodes strobi*) was collected at site M. Five species of Aphididae were collected (2 species only at site M, 2 species only at site U, and one species found at both sites), but were determined not to be either of the common Christmas tree pests. One specimen of a species of Tenthridinidae (sawfly) was collected (at site M), but was determined not to be a species pestiferous on Christmas trees or pine. Occasional interviews with the owner and/or manager of site M suggested that they suffered very little from pest infestations in recent history with the most problematic pest being mites, which they controlled through chemical means. It should be noted that I did not collect one specimen of mite and that the primary sampling modality (pan traps) is not appropriate for mite sampling. Pest infestations at site U were not observed and the history of the site was not accurately determined other than that one grower considered the trees at site U to be, “not suffering,” despite no management.

The presence of possible organisms of control was much more extensive. This list includes both known predators of Christmas tree pests such as Coccinellidae and potential predators such as ichneumonid wasps, which contain species with diverse biologies that may or may not have any association with Christmas tree pests. I will note here that some predatory or parasitic species I collected that are known not to be associated with Christmas tree pests were not included in the following list of potential biocontrol species. For example a large number of specimens of a sphecid wasp species which is know to prey on spiders were collected at both sites, but was not included in the following list. I sorted 5 spiders (Aranaea) (all from site U), 2 species of ladybird beetles (Coccinellidae) (both from site M), 2 species of predatory flies (Empidae) (both from site M), 4 species of hoverflies (Syrphidae: Syrphinae) (3 only at site M and one at both sites), 1 species of predatory bug (Nabidae) (from site M), 3 species of braconid wasps (Braconidae: Aphidiinae) (2 from site M and one from site U), 1 species of microparasitic wasp (Eulophidae) (from site M), 3 species of ichneumonid wasps (Ichneumonidae) (2 from site M and one from site U), 1 species of fairy wasp (Mymaridae) (from site U), 3 species of sphecid wasps (Sphecidae) (2 from both sites and 1 only at site M), and 1 vespid wasp (Vespidae) (from site U). In summary, I collected a total of 26 species (14% of the measured diversity!) (14 from site M, 9 from site U, and 3 occurring at both sites) with either known or potential deleterious impact on Christmas tree pests.

Comparing Site Diversity

Despite both sites being dominated by Christmas trees, they were quite different ecosystems. This is demonstrated by the arthropod communities sampled from each site as they shared only 40 species. Each site, therefore, had 64-65% of the sampled arthropod diversity exclusive to that site as compared to each other! Site M had a slightly higher diversity with 115 species counted, but the number of specimens was significantly lower with only 597 specimens collected throughout the project. Only 10 species (10%) at site M were represented by ten or more specimens and one species, *Toxomerus marginatus*, represented 17% of the total number of specimens. Of the 115 species collected at site M, 49 were represented by only one specimen. Site U had slightly fewer species sorted (112 species), but had almost twice the numbers of specimens (1,006 specimens). There were 21 species (19%) at site U that were represented by ten or more specimens and the most abundant species represented 12% of the total number of specimens. Still, site U had 52 species that were represented by only one specimen. Although the abundances of species at site U were greater, site M was measured as having higher diversity as indicated by four indices (Table 3).

Discussion

It has been an extremely arduous task for the entomological community to conduct studies involving species diversity. The estimates for the number of species of insect in the world range from just over one million to over 100 million (Erwin 1988, 1997; Stork 1997). Each species has its own biology and natural history that must be studied before specific characterization can be placed on the impact of the presence of that particular species in an ecosystem. This incredible diversity of organisms is compounded by the shear mass of numbers of many insect species that occur per any given volume sampled. The phylum Arthropoda is like no other group of organisms known in that with its diversity comes the added difficulty that the group contains numerous undescribed species; which is true not only for the New World tropics, but even for the North American continent for even some well studied groups such as Diptera. This incredible taxonomic hurdle dictates practical management of projects of this type, which, if go unconsidered often prevent project completion (Danks 1996). During the short duration of this project, I could have easily collected hundreds of thousands of insects with minimal effort. The processing of these specimens (i.e., curating, sorting, identifying, storage, etc.), however, would have entailed a budget in the hundreds of thousands of dollars to cover the cost of the material resources and the person hours of work towards completion. It is with these caveats that the reader be aware when considering the results of a project of this magnitude.

Despite the potential for disaster, the management plan for this project was successful. The results of this survey clearly indicate that there is some potential for biocontrol of Christmas tree pests and that this should be pursued further for reasons outlined in the introduction. Perhaps most promising is the presence of four different species of hoverflies in the family Syrphinae. These species are voracious predators of soft-bodied Homoptera as larvae, with at least one species earning the nickname "aphid lion," feeding on as many as 50 prey items per hour. Two of these species, *Toxomerus geminatus* and *Toxomerus marginatus*, were collected in high numbers in this project and as adults are common visitors to low growing flowers such as dandelion. One species of syrphine hoverfly, *Episyrphus balteatus*, is already being used widely for commercial biocontrol (http://www.eppo.org/STANDARDS/biocontrol/diptera.htm#episyr) and others are being considered (Dahlsten et al. 1993, Singh & Mishra 1988, Symondson et al. 2002 and references therein). Both adult and larval Ladybird beetles (Coccinellidae) are also extremely fond of aphids as a prey item. Several species of ladybird beetles, both native and exotic, are ubiquitous in the northeastern United States, but very few were collected in this study. Pan traps, however, are not the most effective method for collecting beetles in general nor ladybird beetles specifically. By comparison, the remaining species listed as possible biocontrol agents is less impressive. Still, some of the very small Hymenoptera I collected, such as species in Mymaridae, are know to be parasites of insect eggs and could very well impact Christmas tree pests.

I observed very low levels of pest activity at both sites. This is an especially important observation at site U where there had been no management and no chemical application for at least a decade. Centre County is part of a contiguous biome across central Pennsylvania so shares its species and its ecology in general, but as noted by the assemblage of arthropods collected, can be quite different locally. Sites M and U are separated by only 8 miles and separated by less distance from other Christmas tree farms. Regardless of the geography and the local ecosystem differences, these Christmas trees should be subject to the same pests as the Christmas trees in the rest of central Pennsylvania. The 2003 growing season was extremely wet and very cold in the late spring and early Summer, but reports from the Pennsylvania Department of Agriculture suggested that pest activity on Christmas trees was still rampant (http://ctrees.cas.psu.edu/scouting_reports.htm). Pest sightings came as early as March and continued through the summer despite the cooler temperatures and heavy rainfall. Site M is a well managed site that follows well regimented IPM (integrated pest management) strategies including local application of pesticides in response to early scouting (as opposed to general spraying). Site U is not managed at all. It would be precocious to make too strong a suggestion, but it is possible that the IPM strategy being conducted at site M is allowing a more balanced ecosystem to occur, more in tune with that at site U where no pests were observed at all. For example, the localized spraying at site M may be allowing the predator and parasite population to remain vital in adjacent refuges. This observation alone is very encouraging for an industry with a potential to decrease its reliance on chemical control should it so desire.

There is still a considerable amount of work to do in studying the dynamics of the Christmas tree ecosystem. This study sponsored by the PCTGA should be considered a pioneering step in promoting a more ecological sound and "public health" minded industry. As mentioned above, this study can only be a first small step (of many small steps) for an industry that is almost completely reliant on chemical pest control. It is one thing to collect species associated with a Christmas tree ecosystem, but it is quite another to accurately identify each species and, if necessary, describe any species unknown to Science. It is another incredibly big step to study the biology of any of these arthropods, whether known or unknown species, to measure the impact of their presence or absence in the Christmas tree ecosystem. Although Christmas tree species are very familiar organisms and the ecosystems in which they grow can be perceived as very simple, the reality is that the associated ecological dynamics demand respect and study. Some parallel studies might investigate generalist predators, such as the syrphine flies, that may benefit the Christmas tree industry serendipitously. Specialist predators on pests of specific Christmas tree species require a more spearheaded approach that can only come from a concerted effort of either a dedicated few or an organized collective. Some conifer pest species have wiped out entire populations in the eastern United States, notably the balsam woolly adelgid in the high elevation Appalachians, so the potential exists for the Christmas tree industry to be greatly impacted by an arthropod pest in the future. It is for this reason, the reasons put forth in this study, and the distinct potential for finding a solution to this ecological problem that the industry should strive to support further research.

Acknowledgements

I would like to extend my extreme gratitude to Ms. Denise Calabrese and the Pennsylvania Christmas Tree Growers Association for the resources and patience needed to conduct this research; Drs. Gary Felton and K.C. Kim, Department of Entomology, The Pennsylvania State University, for providing me a short term position in which to initiate this research; Dr. Robert Byers, Frost Entomological Museum, The Pennsylvania State University, for his honest insight into some of the practical considerations for this research, his help with the museum, and things in general; Mss. Jennifer Heindl and Krista Kahler for their help in the Frost Entomological Museum and camaraderie; and to several students of The Pennsylvania State University from both the University Park and Altoona campuses who contributed in one way or another.

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Table 1. List of the number and species of arthropods collected at site M. Site M was represented by 597 total specimens and 115 species.

Count	Order	Family	Genus	Species
1	Coleoptera	Chrysomelidae	*?*	*1*
12	Coleoptera	Chrysomelidae	*?*	*2*
1	Coleoptera	Coccinellidae	*?*	*1*
1	Coleoptera	Coccinellidae	*?*	*2*
1	Coleoptera	Curculionidae	*?*	*1*
1	Coleoptera	Curculionidae	*Pissodes*	*strobi*
1	Coleoptera	Nitidulidae	*?*	*2*
5	Coleoptera	Nitidulidae	*?*	*1*
2	Coleoptera	Staphylinidae	*?*	*1*
2	Coleoptera	Staphylinidae	*?*	*2*
2	Diptera	Agromyzidae	*?*	*2*
4	Diptera	Agromyzidae	*?*	*1*
3	Diptera	Anthomyiidae	*?*	*2*
5	Diptera	Anthomyiidae	*?*	*3*
72	Diptera	Anthomyiidae	*?*	*1*
1	Diptera	Calliphoridae	*?*	*4*
3	Diptera	Calliphoridae	*?*	*1*
4	Diptera	Calliphoridae	*?*	*3*
7	Diptera	Calliphoridae	*?*	*2*
1	Diptera	Ceratopogonidae	*?*	*1*
1	Diptera	Chironomidae	*?*	*5*
2	Diptera	Chironomidae	*?*	*2*
7	Diptera	Chironomidae	*?*	*4*
1	Diptera	Chloropidae	*?*	*2*
1	Diptera	Chloropidae	*?*	*4*
1	Diptera	Chloropidae	*?*	*5*
1	Diptera	Chloropidae	*?*	*6*
2	Diptera	Chloropidae	*?*	*1*
23	Diptera	Chloropidae	*?*	*8*
1	Diptera	Dolichopodidae	*?*	*3*
2	Diptera	Dolichopodidae	*?*	*1*
2	Diptera	Dolichopodidae	*?*	*6*
3	Diptera	Dolichopodidae	*?*	*4*
6	Diptera	Dolichopodidae	*?*	*5*
12	Diptera	Drosophilidae	*Drosophila*	*melanogaster*
2	Diptera	Empidae	*?*	*1*
2	Diptera	Empidae	*?*	*2*
1	Diptera	Ephydridae	*?*	*2*
1	Diptera	Ephydridae	*?*	*5*
2	Diptera	Ephydridae	*?*	*1*
3	Diptera	Ephydridae	*?*	*3*
1	Diptera	Muscidae	*?*	*6*
1	Diptera	Muscidae	*?*	*7*
1	Diptera	Muscidae	*?*	*9*
2	Diptera	Muscidae	*?*	*1*
2	Diptera	Muscidae	*?*	*4*

3	Diptera	Muscidae	*?*	*3*
4	Diptera	Muscidae	*?*	*2*
7	Diptera	Mycetophilidae	*?*	*2*
8	Diptera	Mycetophilidae	*?*	*1*
1	Diptera	Otitidae	*?*	*1*
1	Diptera	Phoridae	*?*	*3*
2	Diptera	Phoridae	*?*	*4*
5	Diptera	Phoridae	*?*	*1*
5	Diptera	Phoridae	*?*	*2*
2	Diptera	Rhagionidae	*Rhagio*	*mystaceaus*
3	Diptera	Sarcophagidae	*?*	*1*
4	Diptera	Sarcophagidae	*?*	*2*
7	Diptera	Sarcophagidae	*?*	*3*
1	Diptera	Scathophagidae	*?*	*1*
1	Diptera	Sciaridae	*?*	*2*
2	Diptera	Sciaridae	*?*	*3*
5	Diptera	Sepsidae	*?*	*1*
14	Diptera	Sepsidae	*?*	*2*
4	Diptera	Sphaeroceridae	*?*	*2*
4	Diptera	Sphaeroceridae	*?*	*3*
1	Diptera	Syrphidae	*Paragus (Paragus)*	*1*
1	Diptera	Syrphidae	*Sphaerophoria*	*brevipilosa*
3	Diptera	Syrphidae	*Toxomerus*	*geminatus*
99	Diptera	Syrphidae	*Toxomerus*	*marginatus*
1	Diptera	Tipulidae	*?*	*1*
1	Hemiptera	Lygaeidae	*Blissus*	*leucopterus (Say)*
1	Hemiptera	Miridae	*?*	*1*
1	Hemiptera	Nabidae	*?*	*1*
1	Homoptera	Aphididae	*?*	*2*
2	Homoptera	Aphididae	*?*	*1*
2	Homoptera	Aphididae	*?*	*3*
1	Homoptera	Cicadellidae	*?*	*8*
2	Homoptera	Cicadellidae	*?*	*1*
2	Homoptera	Cicadellidae	*?*	*2*
2	Homoptera	Cicadellidae	*?*	*4*
2	Homoptera	Cicadellidae	*?*	*5*
28	Homoptera	Cicadellidae	*?*	*3*
8	Homoptera	Psyllidae	*Trioza*	*tripunctata*
2	Hymenoptera	Andrenidae	*Andrena*	*1*
1	Hymenoptera	Braconidae (Aphidiinae)	*?*	*2*
2	Hymenoptera	Braconidae (Aphidiinae)	*?*	*1*
3	Hymenoptera	Colletidae	*Hylaeus*	*1*
3	Hymenoptera	Diapriidae (Belytinae)	*?*	*3*
64	Hymenoptera	Diapriidae (Belytinae)	*?*	*1*
1	Hymenoptera	Eucharitidae	*?*	*1*
1	Hymenoptera	Eulophidae	*?*	*1*
17	Hymenoptera	Formicidae	*Camponotus*	*1*
1	Hymenoptera	Formicidae	*Formica*	*1*
4	Hymenoptera	Formicidae	*Lasius*	*1*
1	Hymenoptera	Halictidae	*?*	*3*

1	Hymenoptera	Halictidae	?	6
1	Hymenoptera	Halictidae	?	7
3	Hymenoptera	Halictidae	?	1
8	Hymenoptera	Halictidae	?	12
10	Hymenoptera	Halictidae	?	10
1	Hymenoptera	Ichneumonidae	?	2
5	Hymenoptera	Ichneumonidae	?	3
1	Hymenoptera	Megachilidae	*Megachile*	1
1	Hymenoptera	Megachilidae (Lithurgini)	?	1
1	Hymenoptera	Mutillidae	?	1
1	Hymenoptera	Scelionidae	?	1
1	Hymenoptera	Sphecidae	?	1
2	Hymenoptera	Sphecidae	?	3
3	Hymenoptera	Sphecidae	*Ammophila*	2
1	Hymenoptera	Tenthridinidae	?	1
1	Lepidoptera	Hesperidae	?	1
1	Orthoptera	Acrididae	?	1
1	Orthoptera	Acrididae	?	2
1	Orthoptera	Tetrigidae	?	1

Table 2. List of the number and species of arthropods collected at site U. Site U was represented by 1,006 total specimens and 112 species.

Count	Order	Family	Genus	Species
1	Araneae	?	?	1
1	Araneae	?	?	2
1	Araneae	Salticidae	?	2
2	Araneae	Salticidae	?	3
3	Araneae	Salticidae	?	1
5	Coleoptera	Chrysomelidae	?	3
19	Coleoptera	Nitidulidae	?	1
3	Diptera	Agromyzidae	?	2
2	Diptera	Anthomyiidae	?	2
3	Diptera	Anthomyiidae	?	1
4	Diptera	Bibionidae	?	2
9	Diptera	Bibionidae	?	1
10	Diptera	Calliphoridae	?	3
1	Diptera	Chironomidae	?	1
17	Diptera	Chironomidae	?	3
110	Diptera	Chironomidae	?	4
1	Diptera	Chloropidae	?	3
5	Diptera	Chloropidae	?	2
8	Diptera	Chloropidae	?	8
19	Diptera	Chloropidae	?	7
1	Diptera	Dolichopodidae	?	1
1	Diptera	Dolichopodidae	?	2
2	Diptera	Dolichopodidae	?	6
5	Diptera	Dolichopodidae	?	3
7	Diptera	Dolichopodidae	?	4
10	Diptera	Dolichopodidae	?	5
1	Diptera	Drosophilidae	*Drosophila*	*melanogaster*
1	Diptera	Ephydridae	?	3
1	Diptera	Muscidae	?	2
1	Diptera	Muscidae	?	5
1	Diptera	Muscidae	?	8
10	Diptera	Mycetophilidae	?	2
2	Diptera	Phoridae	?	1
3	Diptera	Phoridae	?	2
51	Diptera	Rhagionidae	?	1
1	Diptera	Rhagionidae	?	2
2	Diptera	Rhagionidae	*Rhagio*	*mystaceaus*
2	Diptera	Rhinophoridae	?	1
1	Diptera	Sarcophagidae	?	2
2	Diptera	Sarcophagidae	?	4
4	Diptera	Sarcophagidae	?	3
1	Diptera	Sciaridae	?	2
1	Diptera	Sciaridae	?	1
1	Diptera	Sphaeroceridae	?	1
1	Diptera	Sphaeroceridae	?	2
1	Diptera	Syrphidae	*Eristalis*	1

1	Diptera	Syrphidae	*Eristalis*	2
80	Diptera	Syrphidae	*Toxomerus*	*marginatus*
1	Diptera	Tachinidae	?	2
2	Diptera	Tachinidae	?	1
1	Hemiptera	Lygaeidae	?	1
1	Hemiptera	Lygaeidae	?	2
13	Hemiptera	Lygaeidae	*Blissus*	*leucopterus* (Say)
1	Hemiptera	Thyreocoridae	*Corimelaena*	1
1	Homoptera	Aphididae	?	3
1	Homoptera	Aphididae	?	4
1	Homoptera	Aphididae	?	5
20	Homoptera	Cercopidae	?	1
1	Homoptera	Cicadellidae	?	9
1	Homoptera	Cicadellidae	?	10
2	Homoptera	Cicadellidae	?	7
2	Homoptera	Cicadellidae	?	11
4	Homoptera	Cicadellidae	?	5
4	Homoptera	Cicadellidae	?	6
19	Homoptera	Cicadellidae	?	4
54	Homoptera	Cicadellidae	?	3
61	Homoptera	Cicadellidae	?	2
81	Homoptera	Cicadellidae	?	1
125	Homoptera	Cicadellidae	?	12
1	Hymenoptera	Andrenidae	*Andrena*	2
1	Hymenoptera	Andrenidae	*Andrena*	3
1	Hymenoptera	Apidae	*Apis*	*mellifera*
1	Hymenoptera	Apidae	*Bombus*	*fervidus fervidus*
1	Hymenoptera	Apidae	*Bombus*	*insularis*
1	Hymenoptera	Bethylidae	*Goniozus*	1
1	Hymenoptera	Braconidae	?	1
1	Hymenoptera	Braconidae	?	2
1	Hymenoptera	Braconidae (Aphidiinae)	?	3
3	Hymenoptera	Colletidae	*Hylaeus*	2
20	Hymenoptera	Colletidae	*Hylaeus*	1
1	Hymenoptera	Diapriidae (Belytinae)	?	1
5	Hymenoptera	Diapriidae (Belytinae)	?	2
1	Hymenoptera	Diapriidae (Diapriinae)	?	1
1	Hymenoptera	Diapriidae (Diapriinae)	?	2
1	Hymenoptera	Eupelmidae	?	1
1	Hymenoptera	Eupelmidae	?	3
35	Hymenoptera	Eupelmidae	?	2
1	Hymenoptera	Formicidae	*Camponotus*	2
1	Hymenoptera	Formicidae	*Formica*	2
4	Hymenoptera	Formicidae	*Formica*	3
3	Hymenoptera	Formicidae	*Lasius*	1
3	Hymenoptera	Formicidae	*Prenolepis*	*imparis*
11	Hymenoptera	Formicidae	*Temnothorax*	1
1	Hymenoptera	Halictidae	?	2
1	Hymenoptera	Halictidae	?	5
1	Hymenoptera	Halictidae	?	6

2	Hymenoptera	Halictidae	?	8
3	Hymenoptera	Halictidae	?	4
8	Hymenoptera	Halictidae	?	9
8	Hymenoptera	Halictidae	?	11
14	Hymenoptera	Halictidae	?	12
2	Hymenoptera	Ichneumonidae	?	1
2	Hymenoptera	Megachilidae	?	1
1	Hymenoptera	Mymaridae	?	1
1	Hymenoptera	Pompilidae	?	1
5	Hymenoptera	Sphecidae	?	3
34	Hymenoptera	Sphecidae	?	1
1	Hymenoptera	Vespidae	?	1
2	Lepidoptera	Hesperidae	?	1
2	Orthoptera	Acrididae	?	2
2	Orthoptera	Gryllidae	?	1
1	Orthoptera	Tetrigidae	?	1

Table 3. Calculated indices of diversity from the two sample sites. For all indices, a higher number indicates greater diversity.

	Site U	Site M
Richness	112	115
Alpha	56.7	77.6
Shannon	3.8	4.2
Simpson	19.1	28.7