

AN ABSTRACT OF THE THESIS OF

Karen R. Wetherill for the degree of Master of Science in Entomology presented on January 26, 2000. Title: Structure, Function, and Analysis of Coleoptera and Heteroptera Assemblages on Two Species of Hazelnut in Oregon.

Abstract approved: _____
Redacted for Privacy

Mohammed T. AliNiasee

The European hazelnut, *Corylus avellana* L., was imported into the U.S. in the late 1800's and is now grown throughout the Willamette Valley in Oregon. A native species of hazelnut, *C. cornuta* Marshall, is a common shrub found in forested areas of the Pacific Northwest. Foliage of both *C. avellana* and *C. cornuta* was sampled using beating sheets. The objectives of the study were as follows: 1. To compile a complete list of the Coleoptera and Heteroptera fauna of both species of hazelnut. 2. To determine the amount of overlap across host plants. 3. To measure arthropod abundance and species diversity within functional groups across a forest-edge-orchard gradient. 4. To use ordination techniques to determine where peak abundance of individual taxa occur along the forest-edge-orchard gradient. One hundred and thirty-two species of Coleoptera and forty-nine species of Heteroptera were identified on Hazelnut foliage. The most abundant Heteroptera in the orchards studied is a newly introduced mirid predator, *Malacocoris chlorizans* (Panzer). There is a great deal of overlap between the two hazelnut species. Most differences are attributed to rare species. Diversity and

abundance of predaceous Coleoptera and Heteroptera were severely hindered by IPM management practices, involving insecticide usage, within the orchards. However, the organic orchards retained high levels of diversity and abundance of predaceous Coleoptera and Heteroptera in the centers of the orchards. The organic orchards had higher diversity of phytophagous Coleoptera and Heteroptera as compared to IPM orchards, but the abundance of those insects was not different between the IPM and organic orchards. The ordinations of the Coleoptera data show that the peak abundances of individual species often shift along the forest-edge-orchard gradient over time and that the organic orchards retain peak abundances of predaceous Coleoptera even in late season. The ordinations of the Heteroptera data show that several mirid predators are at their peak abundances within the orchards of both IPM and organic orchards.

©Copyright by Karen R. Wetherill
January 26, 2000
All Rights Reserved

Structure, Function, and Analysis of Coleoptera and Heteroptera Assemblages on Two
Species of Hazelnut in Oregon

by

Karen R. Wetherill

A THESIS

Submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Master of Science

Presented January 26, 2000
Commencement June 2000

Master of Science thesis of Karen R. Wetherill presented on January 26, 2000

APPROVED:

Redacted for Privacy

Major Professor, representing Entomology

Redacted for Privacy

Chair of Department of Entomology

Redacted for Privacy

Dean of Graduate School

I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Redacted for Privacy

Karen R. Wetherill, Author

ACKNOWLEDGEMENTS

I would like to thank Dr. M.T. AliNiazee and the Hazelnut Commission for making this study possible. I would like to thank Gary Parsons and Dr. Jack Lattin for sharing their expertise in taxonomy. I would like to thank Dr. Bruce McCune and Dr. Timothy Schowalter for representing my committee. I would like to thank Andy, Darlene, Christine, Tim, Rick and Gator for guidance and moral support.

TABLE OF CONTENTS

	<u>Page</u>
INTRODUCTION.....	1
Objective 1. To compile a complete list of Coleoptera and Heteroptera fauna of <i>C. avellana</i> and <i>C. cornuta</i>	3
Objective 2. To determine the amount of overlap across host plants.....	4
Objective 3. To measure arthropod abundance and diversity across a forest-edge- orchard gradient on organic and IPM orchards	4
Objective 4. To use ordination techniques to determine where peak abundance of individual taxa occur.....	5
MATERIALS AND METHODS.....	6
Study Sites	7
Sampling Method	9
Analysis.....	10
RESULTS.....	16
Coleoptera Results.....	16
Functional Groups.....	16
Multi-Response Permutation Procedure (MRPP).....	18
Objective 1. To compile a complete list of Coleoptera and Heteroptera fauna of <i>C. avellana</i> and <i>C. cornuta</i>	20
Objective 2. To determine the amount of overlap across host plants	26
Diversity measures.....	27
Objective 3. To measure arthropod abundance and diversity across a forest-edge- orchard gradient on organic and IPM orchards	29
Objective 4. To use ordination techniques to determine where peak abundance of individual taxa occur	37

TABLE OF CONTENTS (Continued)

	<u>Page</u>
Heteroptera Results.....	84
Functional Groups.....	84
MRPP.....	84
Objective 1. To compile a complete list of Coleoptera and Heteroptera fauna of <i>C. avellana</i> and <i>C. cornuta</i>	84
Objective 2. To determine the amount of overlap across host plants.....	88
Objective 3. To measure arthropod abundance and diversity across a forest-edge- orchard gradient on organic and IPM orchards	89
Objective 4. To use ordination techniques to determine where peak abundance of individual taxa occur	93
DISCUSSION	105
Integrated Pest Management.....	105
Natural Biological Control.....	106
Refugia.....	108
Edge Effects.....	110
Diversity Studies.....	111
BIBLIOGRAPHY.....	116

LIST OF FIGURES

<u>Figure</u>	<u>Page</u>
1a. NMS ordination of dates in species space on the Bush farm	11
b. NMS ordination of dates in species space on the Corricello farm	11
c. NMS ordination of dates in species space on the Dorris farm.....	12
d. NMS ordination of dates in species space on the Wiebe farm.....	12
2. Proportion of total abundance of Coleoptera in each Functional Group for each farm over the entire season.....	17
3. NMS ordination of sample units in Functional space with Predator overlay.....	39
4. NMS ordination of sample units in Functional space with Herbivore overlay.....	40
5. NMS ordination of sample units in Species space with <i>M. picta</i> overlay.....	41
6. NMS ordination of sample units in Species space with <i>Malthodes</i> overlay.....	42
7. NMS ordination of sample units in Species space with <i>C. polita</i> overlay.....	43
8. NMS ordination of sample units in Species space with <i>D. impressicollis</i> overlay.....	44
9. NMS ordination of sample units in Species space with <i>T. sericeus</i> overlay.....	45
10. NMS ordination of sample units in Species space with <i>S. obscurus</i> overlay.....	46
11. NMS ordination of sample units in Species space with <i>S. albida</i> overlay.....	47
12. NMS ordination of sample units in Species space with <i>T. inornata</i> overlay.....	48
13. NMS ordination of sample units in Functional space with Herbivore overlay.....	50
14. NMS ordination of sample units in Species space with <i>L. lecontei</i> overlay.....	51
15. NMS ordination of sample units in Species space with <i>N. horni</i> overlay.....	51
16. NMS ordination of sample units in Species space with <i>S. obscurus</i> overlay.....	52

LIST OF FIGURES (Continued)

<u>Figure</u>	<u>Page</u>
17. NMS ordination of sample units in Species space with <i>S. horridus</i> overlay.....	53
18. NMS ordination of sample units in Species space with <i>S. albida</i> overlay.....	53
19. NMS ordination of sample units in Functional space with Predator overlay.....	54
20. NMS ordination of sample units in Species space with <i>Scymnus</i> overlay.....	55
21. NMS ordination of sample units in Species space with <i>T. sericeus</i> overlay.....	56
22. NMS ordination of sample units in Species space with <i>M. picta</i> overlay.....	57
23. NMS ordination of sample units in Species space with <i>S. nebulosus</i> overlay.....	58
24. NMS ordination of sample units in Species space with <i>C. polita</i> overlay.....	59
25. NMS ordination of sample units in Species space with <i>P. piniphilus</i> overlay.....	59
26. NMS ordination of sample units in Functional space with Predator overlay.....	61
27. NMS ordination of sample units in Functional space with Herbivore overlay.....	62
28. NMS ordination of sample units in Species space with <i>I. nitidulus</i> overlay.....	63
29. NMS ordination of sample units in Species space with <i>Scymnus</i> overlay.....	64
30. NMS ordination of sample units in Species space with <i>H. axyridis</i> overlay.....	65
31. NMS ordination of sample units in Species space with <i>C. polita</i> overlay.....	66
32. NMS ordination of sample units in Species space with <i>C. septempunctata</i> overlay.....	67
33. NMS ordination of sample units in Species space with <i>T. sericeus</i> overlay.....	68
34. NMS ordination of sample units in Species space with <i>S. nebulosus</i> overlay.....	69
35. NMS ordination of sample units in Species space with <i>D. auratus</i> overlay.....	70
36. NMS ordination of sample units in Functional space with Herbivore overlay.....	72

LIST OF FIGURES (Continued)

<u>Figure</u>	<u>Page</u>
37. NMS ordination of sample units in Functional space with Predator overlay.....	73
38. NMS ordination of sample units in Species space with Malthodes overlay.....	74
39. NMS ordination of sample units in Species space with T. sericeus overlay.....	74
40. NMS ordination of sample units in Species space with H. axyridis overlay.....	75
41. NMS ordination of sample units in Species space with C. quatuordecimguttata overlay.....	76
42. NMS ordination of sample units in Species space with Scymnus overlay.....	77
43. NMS ordination of sample units in Species space with C. polita layover.....	78
44. NMS ordination of sample units in Species space with S. obscurus overlay.....	79
45. NMS ordination of sample units in Species space with T. inornata overlay.....	80
46. NMS ordination of sample units in Species space with A. fuscirostre overlay.....	81
47. NMS ordination of sample units in Species space with A. sparsus overlay.....	81
48. NMS ordination of sample units in Species space with L. nitidulus overlay.....	82
49. NMS ordination of sample units in Species space with S. albida overlay.....	82
50. NMS ordination of sample units in Species space with D. auratus overlay.....	83
51. NMS ordination of sample units in Species space with M. chlorizans overlay.....	95
52. NMS ordination of sample units in Species space with P. nigrinervis overlay.....	96
53. NMS ordination of sample units in Species space with C. salicellum overlay.....	97
54. NMS ordination of sample units in Species space with C. virgula overlay.....	98
55. NMS ordination of sample units in Species space with B. angulatus overlay.....	99
56. NMS ordination of sample units in Species space with E. pacifica overlay.....	99
57. NMS ordination of sample units in Species space with Orius spp. overlay.....	100

LIST OF FIGURES (Continued)

<u>Figure</u>		<u>Page</u>
58.	NMS ordination of sample units in Species space with <i>D. brevis</i> overlay.....	101
59.	NMS ordination of sample units in Species space with <i>B. provancheri</i> overlay.	101
60.	NMS ordination of sample units in Species space with <i>D. hesperus</i> overlay.....	102
61.	NMS ordination of sample units in Species space with <i>H. merioptera</i> overlay..	103
62.	NMS ordination of sample units in Species space with <i>L. rubidus</i> overlay.....	103
63.	NMS ordination of sample units in Species space with <i>H. harti</i> overlay.....	104
64.	NMS ordination of sample units in Species space with <i>C. salicata</i> overlay.....	104

LIST OF TABLES

<u>Table</u>	<u>Page</u>
1. Multi-Response Permutation Procedure, grouping by treatment. Coleoptera data.....	19
2. Multi-Response Permutation Procedure. Grouping by transect.....	20
3. Adult Coleoptera identified from beating sheet samples of <i>Corylus</i> spp.....	21
4. Functional Groups of Coleoptera.....	23
5. Total numbers of individuals and species for Coleoptera data.....	26
6. Diversity indices for Coleoptera of entire season.....	28
7. Diversity indices for Coleoptera of early season.....	28
8. Diversity indices for Coleoptera of late season.....	29
9a. Species Richness for all Coleoptera over entire season.....	31
b. Species Richness for Phytophagous Coleoptera over entire season.....	31
c. Species Richness for Predaceous Coleoptera over entire season.....	31
10a. Species Abundance for all Coleoptera over entire season.....	32
b. Species Abundance for Phytophagous Coleoptera over entire season.....	32
c. Species Abundance for Predaceous Coleoptera over entire season.....	32
11a. Species Richness for all Coleoptera over early season.....	33
b. Species Richness for Phytophagous Coleoptera over early season.....	33
c. Species Richness for Predaceous Coleoptera over early season.....	33
12a. Species Abundance for all Coleoptera over early season.....	34
b. Species Abundance for Phytophagous Coleoptera over early season.....	34
c. Species Abundance for Predaceous Coleoptera over early season.....	34
13a. Species Richness for all Coleoptera over late season.....	35
b. Species Richness for Phytophagous Coleoptera over late season.....	35
c. Species Richness for Predaceous Coleoptera over late season.....	35
14a. Species Abundance for all Coleoptera over late season.....	36
b. Species Abundance for Phytophagous Coleoptera over late season.....	36
c. Species Abundance for Predaceous Coleoptera over late season.....	36

LIST OF TABLES (Continued)

<u>Table</u>	<u>Page</u>
15. Multi-Response Permutation Procedure. Heteroptera data.....	84
16. Adult Heteroptera identified from beating samples of <i>Corylus</i> spp.....	86
17. Functional Groups of Heteroptera.....	87
18. Total numbers of individuals and species for Heteroptera data.....	89
19a. Species Richness for all Heteroptera.....	91
b. Species Richness for Phytophagous Heteroptera.....	91
c. Species Richness for Predaceous Heteroptera.....	91
20a. Species Abundance for all Heteroptera.....	92
b. Species Abundance for Phytophagous Heteroptera.....	92
c. Species Abundance for Predaceous Heteroptera.....	92

Structure, Function, and Analysis of Coleoptera and Heteroptera Assemblages on Two Species of Hazelnut in Oregon

INTRODUCTION

Integrated Pest Management (IPM) is the combined effort of many disciplines to efficiently manage the crop production system with minimal adverse environmental impact while maintaining maximal production (Kogan 1998). The basis of IPM is in understanding the ecology of the system. However, the ecological aspect is often the last component studied, if it is studied at all (Geier and Clark 1978). Fortunately, this trend is shifting. As fewer broad-spectrum pesticides are available on the market each year and the demand for sustainable agriculture increases, IPM and organic management practices are becoming more common and the need to understand the entire crop-ecosystem is pronounced.

The dynamic nature of the crop-ecosystem suggests the need to study both the agro-ecosystem and the surrounding environment (Colunga-Garcia et al. 1997). Understanding the entire system is even more important when the environment contains a wild relative of the crop that could serve as a refuge or reservoir for both beneficial species and pests (Haynes et al. 1980). Pimentel (1961) compared the arthropod assemblage of wild and cultivated Cruciferae. He noted that herbivorous arthropods preferred the cultivated over the wild plant, possibly due to the domestication process that encourages plant resources to be dedicated to production rather than to defense (Rosenthal and Dirzo 1997).

Three species of hazelnut occur in the U.S.A. The domesticated European hazelnut, *Corylus avellana* L., was introduced in the late 1800s and has been grown commercially in the Willamette Valley of Oregon since the turn of the 20th century. *C. avellana* is native to the Mediterranean region surrounding the Black Sea where it grows in dense thickets. These unmanaged areas are often adjacent to commercial orchards and the insects associated with these areas have been studied in Turkey (Ural et al. 1973, Ecevit et al. 1996).

Two species of hazelnut are native to North America. *Corylus americana* Marshall is found in the eastern United States and *Corylus cornuta* Marshall is found in the west. The latter is divided again into two varieties, *Corylus cornuta* var. *cornuta* and *Corylus cornuta* var. *californica*. *C. c. cornuta* is located in the drier, western regions where it grows in dense thickets and is typical of disturbed areas. *C. c. californica* is the wild type found in the wetter Pacific Northwest (Mehlenbacher 1991, Thompson et al. 1996). Clumps of *C. c. californica* can be found in many different habitats including clear-cuts, other disturbed sites, briar patches, deciduous forests and coniferous forests.

C. cornuta, also known as the beaked hazelnut, is typified by a long husk and a thick nut shell. The distribution of branches, leaves, and nuts of the wild shrub is sparse compared to that of the European hazelnut. *C. avellana* has also been found mixed with wild vegetation adjacent to older hazelnut orchards (personal observation). These escaped cultivars have similar structure to the wild shrubs although their leaves are slightly denser and the nuts grow in clusters rather than individually as on *C. cornuta*.

Hazelnut orchards in the U.S. are often bordered by forested areas that contain many native hazelnut shrubs. Current edge effect theory suggests that the assemblages of

an ecotone should be different than the assemblages of the interior of each adjacent area (Ozanne et al. 1997). The edge between the orchard and the forest should be more diverse than either the forest or the center of the orchards. However, commercial hazelnut orchards are single-age monocultures with no understory. The adjacent forests contain many ages and species of trees with a very diverse understory. *C. cornuta* is only one of many small shrubs in the forest. The increased floral heterogeneity of the forest may supercede the edge effect, making the arthropod assemblage of the forest more diverse than the edge or the orchard. In the case of IPM orchards, insecticide application would transform the orchard into a sink of both diversity and abundance of arthropods.

There is an obvious lack of information about the insect assemblage of the native hazelnut in the United States and how it affects commercial hazelnut orchards. This study was designed to provide baseline information about the insect assemblage associated with the native hazelnut, compared to the insect assemblage of commercial hazelnut orchards, and to assess changes in diversity and abundance of arthropods across a forest-edge-orchard gradient.

Objective 1. To compile a complete list of Coleoptera and Heteroptera fauna of *C. avellana* and *C. cornuta*.

In the U.S., the pest and beneficial insect fauna of hazelnut orchards has been studied extensively (AliNiazee 1980, AliNiazee 1994, AliNiazee and Messing 1995, AliNiazee 1998, Messing 1982, Messing and AliNiazee 1985). However, little is known about the community ecology of the commercial hazelnut system and its surrounding environment that contains a wild species of hazelnut (AliNiazee 1998).

Objective 2. To determine the amount of overlap across host plants.

According to Strong et al. (1984), host switching onto a novel host is relatively rapid when the new host is introduced and then should slow down within 100 years as the host switching events reach an asymptote. This occurs when the pool of possible colonizers is depleted. It is arbitrary to set a time limit on when the asymptote is reached. Furthermore, many factors affect host switching. The colonization of prey species may be affected by the amount and quality of enemy free space (Berdegue, 1996). *C. avellana* has been in the Pacific Northwest for over 100 years. Regardless of the arbitrary time limit, the majority of host switching events should already have occurred. The resultant community should resemble that of the native hazelnut, considering that most insects are not host specific at the species level (Kitching et al. 1997).

Objective 3. To measure arthropod abundance and diversity across a forest-edge-orchard gradient on organic and IPM orchards.

Since the two host plants are within the same genus, species abundance and diversity in organic farms should not change drastically over the forest-edge-orchard (FEO) gradient. Chemical applications in the IPM orchards would effect the arthropod assemblage within the orchard. As species respond differentially to chemical sprays, it follows that species diversity would decrease in sprayed orchards, leaving only resistant or highly mobile organisms. The abundance of pesticide resistant herbivores, however, should increase within the sprayed orchards as they are released from competition and predation.

Objective 4. To use ordination techniques to determine where peak abundance of individual taxa occur.

Since this was not a mark and recapture study, movement of individual organisms cannot be implied. However, growers are interested in where and when peak abundances of predators and herbivores occur. Some arthropods may be host specific at the species level and would be restricted to a single species of hazelnut. Other arthropods may be habitat specific and prefer an orchard habitat or a forested habitat, and this preference may change over the season. Effective natural control agents would be predators that are evenly distributed across the FEO gradient because they could control pests over the entire area. Knowledge of the suite of natural biological control agents is becoming more important as the trend towards sustainable agriculture progresses.

MATERIALS AND METHODS

The surveys were conducted at four separate farms (Bush, Dorris, Wiebe, and Corricello). The Bush and Dorris farms used the insecticide Asana (esfenvalerate), a synthetic pyrethroid, for control of the filbert worm, *Cydia latiferreanus* (Walsingham). The Wiebe and Corricello farms used none. For the remainder of this paper, Bush and Dorris will be referred to as IPM orchards and the Wiebe and Corricello orchards will be referred to as organic orchards. On a broad scale each farm could represent a replicate. However, the many differences and potentially confounding factors should be noted (see description of study sites).

Three transects were established at each farm, except the Corricello farm that only had one for logistical reasons. The transects were all at least 200m apart. Each transect had three plots, one in the orchard, one on the edge of the orchard, and one in the forest. Few studies have addressed edge effects on canopy arthropods. Ozanne et al. (1997) found that edge effects are most pronounced within 10m of the edge. However, response differed by taxon and some taxa show edge effects up to 25m. The orchard plots were at least 50m into the orchard. The edge plots were all directly on the edge of the orchard. The forest plots were all at least 50m into the forest. Each plot had five trees. The arthropod assemblages were sampled at each farm every two weeks using beating sheets. Sampling started March 29 and continued through September, 1998. This time frame represents most of the growing season. As this was a mensurative (observational) experiment, the forest, edge and orchard were not experimentally manipulated treatments. However, the term 'treatment' will be used for ease of discussion.

Study Sites:

The Bush farm is owned and operated by Dwayne Bush near Junction City, Oregon. The trees are mostly around 43 years old and have been managed by Mr. Bush since 1963. The main cultivar is Barcelona with Daviana and Hall's Giants for pollenizers. Mr. Bush uses IPM methods for pest control. In 1998, he applied Urea as fertilizer, Roundup® and Simazene® (July 19) as herbicides, Dermoxon against sucker growth, and a single application of Asana® (July 29) for filbert worm control. He considers the four most important insect pests to be the filbert worm, *Cydia latiferreanus* (Walsingham), the syneta beetle, *Syneta albida* LeConte, and the leaf rollers, *Archips rosanus* (L.) and *Choristoneura rosaceana* (Harris). He considers the aphid parasitoid *Trioxys pallidus* Halliday to be the most important beneficial insect. The forest adjacent to the orchard is primarily coniferous and contains many *C. c. californica*.

The Dorris Ranch, located in Springfield, Oregon, is owned by the Willamalane Park and Recreation Facility and has been managed by Gary Rodakowski since 1993. The ranch is a historical site and a wildlife refuge. It is the oldest commercial hazelnut orchard in Oregon with trees over one hundred years old. The main cultivar is Barcelona with Daviana for a pollenizer. The ranch is managed using IPM methods. In 1998, Dermoxon was applied for sucker growth on April 8th and Asana® was applied for filbert worm control on August 4th. Mr. Rodakowski views the filbert worm and leaf rollers as the most important pests, and recognizes *Trioxys pallidus* as the most important beneficial. The forest adjacent to the orchard contains some escaped *C. avellana* and several *C. c. californica*. It is a mixed hardwood-conifer forest next to the McKenzie River.

The Wiebe farm is owned and operated by David and Martha Wiebe in Monmouth, Oregon. They have been managing the farm since the trees were planted, eight years prior to this study. The main variety is Casina with Hall's Giants for pollinizers. They use Roundup[®] herbicide and urea fertilizer, but no insecticides. Mr. Wiebe does not consider any of the insects to be pests yet. Nineteen ninety-seven was the first harvest year. He considers lady beetles and spiders as the best predators. The forest is a mixed hardwood-conifer stand with many *C. c. californica* and only a few escaped *C. avellana*.

The Corricello farm, south of Crow, Oregon, has been owned and operated by Ken Corricello since the trees were planted thirteen years prior to this study. They are mostly Ennis variety with Hall's Giant pollinizers. The farm is organically managed using only organically certified pest control chemicals such as Boron, copper sulfate, and Safer Soap. They also use black light and pheromone traps for moths. Mr. Corricello considers the filbert big bud mite to be the worst pest and has used Safer Soap this spring (1998) to control them. He considers lady beetles and praying mantises to be the best arthropod predators but gives most of the credit to swallows and bats. The forest surrounding the Corricello farm is a twenty year-old stand of conifers with many *C. c. californica*.

Sampling Method:

Beating sheet samples were collected by beating three limbs per tree, three beats per limb. The numbered beating gives the same amount of effort to each tree, but does not eliminate the effects of the size and shape of the tree (Southwood 1978). Therefore, data in this study were relativized by sample unit total, since they could not be standardized.

Specimens were collected from the sheets and preserved in 75% ethanol. The beating sheet samples represent a snap-shot collection of relatively sessile arthropods. Only the Coleoptera (beetles) and the Heteroptera (true bugs) were analyzed. Specimens were identified by Gary Parsons, Dr. Jack Lattin, and myself to the lowest taxonomic level possible. Ten specimens of each species (when available) were deposited in the Oregon State Arthropod Collection (OSAC). All specimens were identified to genus and most to species except for the Staphylinidae of which the Aleocharinae, Omaliinae and Tachyporinae could only be identified to subfamily. The Staphylinidae as a whole were eliminated from the analysis. Four other Coleoptera specimens could not be identified and were also eliminated. Of the Heteroptera, 19 individuals were not identified. One sample unit was lost and was replaced with averages of the other four sample units at that plot on that sampling date.

Because an insect's functional group is of more interest to the applied entomologist than is its taxon, information on host preference and feeding habits was collected from the literature. Information on the family or genus was not used unless the reference stated that it applied to all species of the respective group. The functional groups used include; detritivore (D), pollen and nectar feeder (Fl), fungivore (Fu),

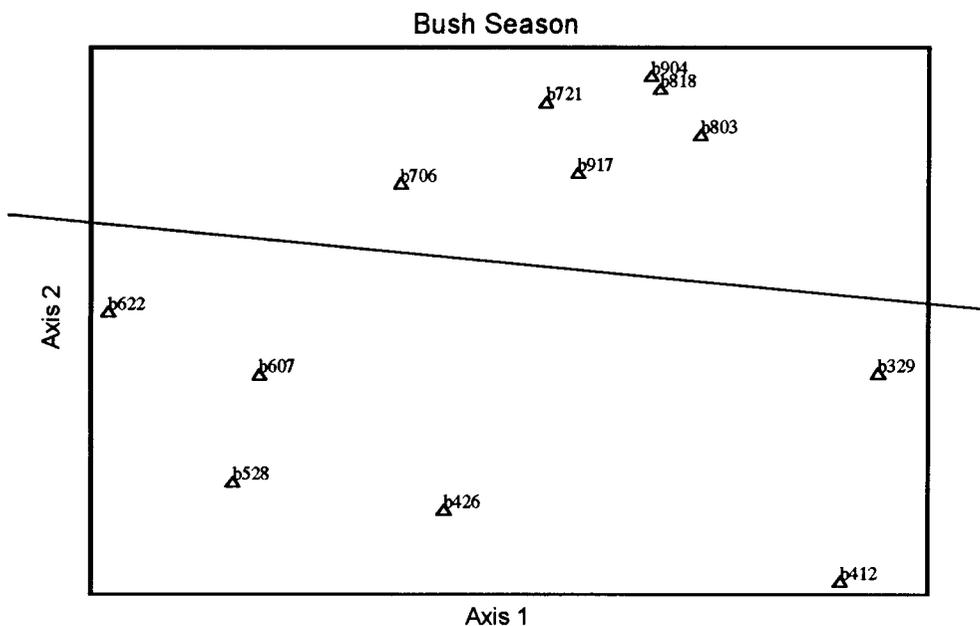
herbivore (H), non-feeding (nf), parasite or parasitoid (Pa), predator (Pr), seed feeder (Sd), sap feeder (Sp), scavenger (Sv) and xylophagous (X) as used and described by Parsons et al. (1991). For the Heteroptera, the additional category of tourist (T) was added. Tourists are those species that reportedly do not actively forage on *Corylus*.

Analysis:

The assemblages studied are defined as the adult Coleoptera and the adult Heteroptera of hazelnut foliage taken by beating. Each order was analyzed separately. The Coleoptera data were analyzed on two levels. First, on a taxonomic level which retains the information that each species contributes and second, on a functional level in which each species has been assigned to one or more functional groups. This stage loses the information that each species contributes, but reduces the information to a form that is more intuitive and useful in applied entomology. In this case, the Coleoptera data were reduced from 134 species to 11 functional groups. The Heteroptera were only analyzed on the taxonomic level because there were only three functional groups. The functional groups of important taxa are discussed.

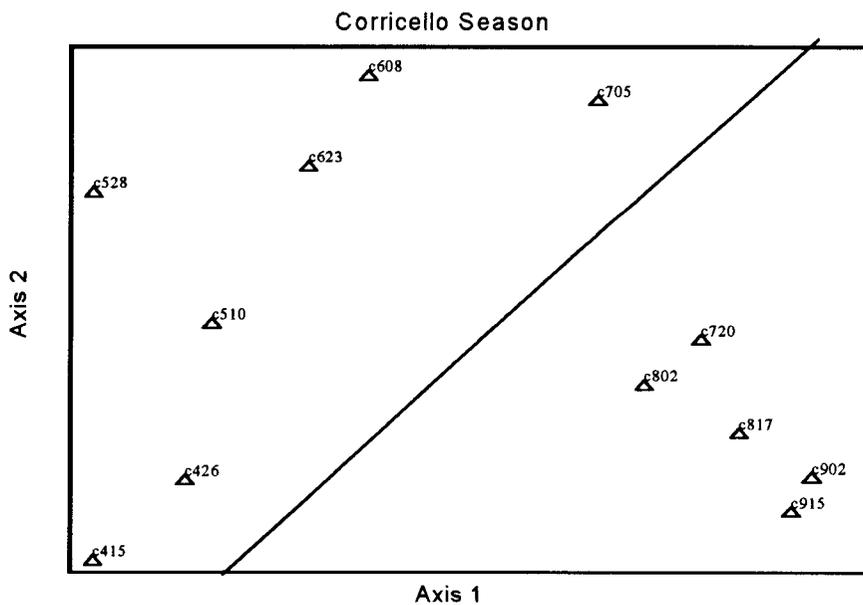
The Coleoptera data were also split into two subgroups representing the early and late season. All the data from each date were combined and the dates were ordinated using Non-metric Multidimensional Scaling (NMS) to determine a non-arbitrary cut-off for early and late seasons. On all four farms, an obvious division between the dates occurred. Early season includes all sampling dates from March 29, 1998 to July 5, 1998. Late season includes all sampling dates from July 6, 1998 to September 17, 1998. (Figure 1a-d).

Figure 1a. NMS ordination of dates in species space on the Bush farm.



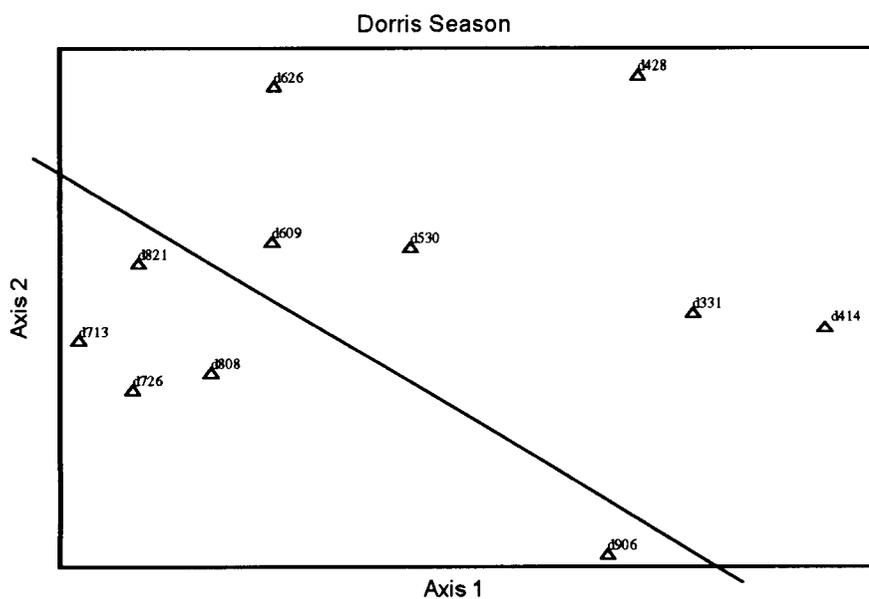
Line represents division between early and late season. Sample units represent the sum of all data from that sampling date.

Figure 1b. NMS ordination of dates in species space on the Corricello farm.



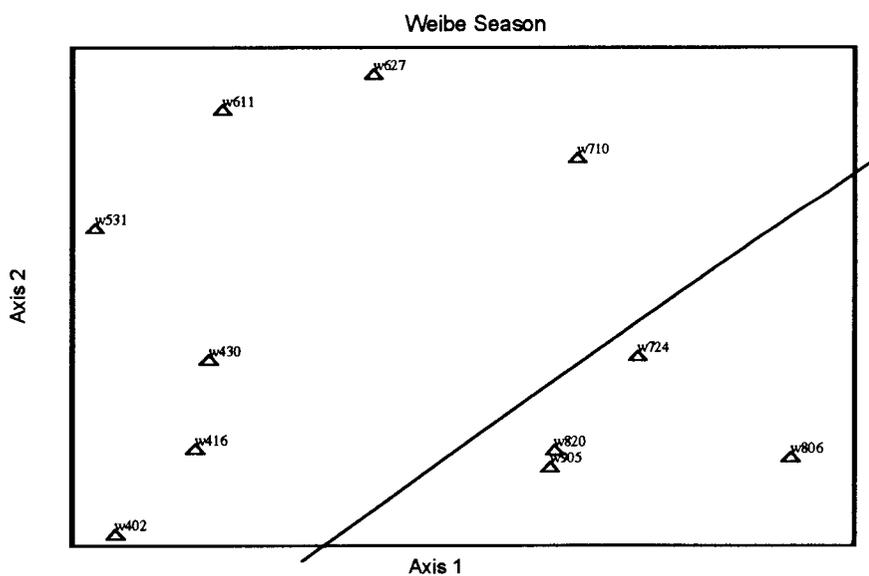
Line represents division between early and late season. Sample units represent the sum of all data from that sampling date.

Figure 1c. NMS ordination of dates in species space on the Dorris farm.



Line represents division between early and late season. Sample units represent the sum of all data from that sampling date.

Figure 1d. NMS ordination of dates in species space on the Weibe farm.



Line represents division between early and late season. Sample units represent the sum of all data from that sampling date.

The Heteroptera data were only analyzed over the entire season. Also, since the Heteroptera data were more similar in species assemblage than were the Coleoptera data across farms, the Heteroptera data from the two organic farms and the two IPM farms were lumped.

Since arthropod assemblage data (species abundance) do not fall into a normal distribution, a non-parametric multivariate method was used for testing the significance of differences between the assemblages. Multi-Response Permutation Procedure (MRPP) is one test that can show significance without violating assumptions of normality because no such assumptions are made (McCune and Mefford 1999).

For diversity comparisons, traditional indices including species richness (S), evenness (E), Shannon's (H) and Simpson's (D) indices, and Beta diversity were calculated. Raw species abundances were used for these calculations. S is the average number of species found per sample unit. Each sample unit refers to the arthropods beaten from a particular tree over the specified time period. S is sensitive to sample size. However, the same amount of effort was given for each sample and should therefore be comparable. E, H, and D all assume that all species are present in all sample units (Magurran 1988). As this was not the case for the data in question, these measurements should be considered with caution. Species richness is a measure of inventory diversity or the diversity within a habitat. Differentiation diversity (Beta diversity) is a measure of difference between habitats (Magurran 1988). The scale on which these measures work is variable. In this case, inventory diversity was used to measure the diversity within each treatment (the forest, the edge and the orchard). Beta diversity measures the diversity across those three treatments.

Species richness in this paper refers to the average number of species per sample unit and species abundance is the average number of individuals per sample unit, over a specified time period. The data from the IPM farms and the organic farms were pooled to make comparisons between management practices. Differences were tested using one-way analysis of variance (ANOVA) and Tukey-Kramer HSD with a significance level of 0.05. Tukey's procedure is similar to the Student-Newman-Keuls (SNK) test in that it uses only one test statistic to compare each mean, but Tukey's is more conservative. Tukey's creates a test statistic for the highest and lowest mean and uses that statistic for all comparisons (Jones 1984). Tukey's technique makes it harder to be statistically significant, which is desired in noisy data sets such as those in community level comparisons.

Analysis with ordination was used to describe differences across the FEO gradient by placing the sample units along multidimensional gradients in species composition space. Non-metric Multidimensional Scaling (NMS) is an ordination technique that works best for assemblage data because it deals well with sparse data sets. The number of empty cells (zero values) in the taxonomic matrices ranged from 68 to 93 per cent. The functional matrices ranged from 38 to 63 per cent empty. Other techniques such as Principle Component Analysis and Canonical Correspondence Analysis do not work well with large numbers of zeros (sparse data sets) and do not perform well with discrete data sets (such as community data) which are by nature truncated at zero. All ordinations were run in PC-ORD version 4.0 using the autopilot slow and thorough mode and Sorensen distance (McCune and Mefford 1999).

The data matrices were transformed by taking the square root of each value in the matrix, which helps to reduce the coefficient of variation (CV) of sums and the skewness of the data. Because of the inconsistencies and perhaps systematic errors produced in using beating sheet data from different tree structures, all data from this sampling technique were relativized, expressing density of a taxon as a proportion of the total for each sample unit. Finally, in the ordinations of the taxonomic matrices, the data were relativized by species maximum, which equalizes the importance of each species. Relativization by species maximum retains information on the peak occurrence of each species while alleviating the disparities between species abundance.

Kendall's rank correlations (Tau) and overlays of peak abundances were used to assess the importance of each species or functional group in positioning the sample units along the ordination axes. Tau was considered important if it was in the extreme 10% of the range of tau and was considered evenly distributed if it was in the middle 20% of the range of tau. An overlay is a graph of relative abundance data within the ordination framework. The relative size of each sample unit is the relative abundance of the species being overlaid. The ordination was rotated by treatment to place the maximum amount of variation explained (R-squared) on the X-axis which allowed more intuitive conclusions to be drawn from a single axis. Extreme outliers (greater than two standard deviations away from the mean) were removed if the removal allowed easier interpretation of the ordination. Only species that comprised at least 1% of the total abundance and which belong to either the predator or herbivore functional group were considered in detail.

RESULTS

Coleoptera Results:

Functional Groups:

Bush Farm (IPM): Overall, fungivorous beetles were the most abundant functional group comprising 38% of all beetles. Herbivores and predators made up 26 and 21%, respectively, pollen and nectar feeders made up 12%, and xylophagous beetles and scavengers made up the remaining 3%.

Dorris Farm (IPM): Again fungivores dominated the community at 52% of the total beetle assemblage, while herbivores and predators made up 17 and 12%, respectively. Pollen and nectar feeders made up 12% and xylophagous beetles and seed feeders made up the remaining 7%.

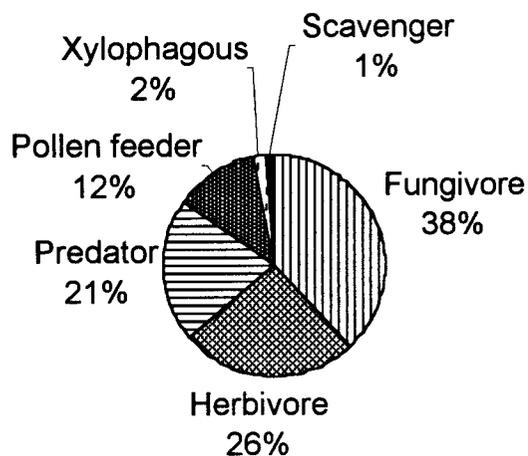
Wiebe Farm (Organic): Fungivores again dominated the community at 62%. Predators made up 18%, pollen and nectar feeders made up 9%, scavengers 8% and herbivores made up only 3% of the total beetle assemblage.

Corricello Farm (Organic): Fungivores were relatively more abundant on the Corricello ranch. They comprised 73% of the beetle assemblage. Herbivores and predators each made up 12% and pollen and nectar feeders made up the remaining 3%.

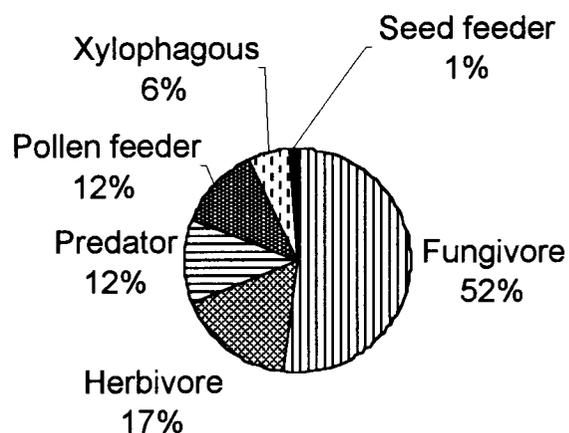
(Figure 2).

Figure 2. Proportion of total abundance of Coleoptera in each Functional Group for each farm over the entire season.

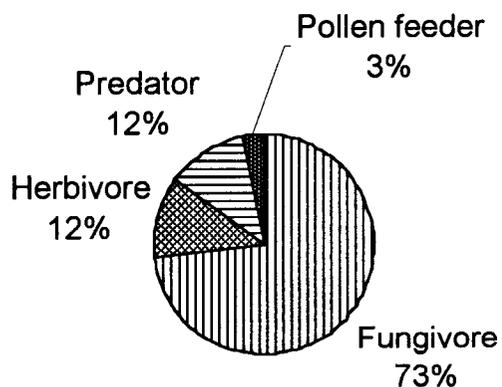
Bush Functional Groups



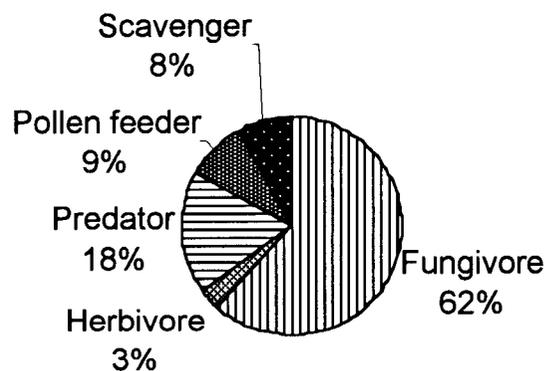
Dorris Functional Groups



Corr. Functional Groups



Wiebe Functional Groups



Multi-Response Permutation Procedure (MRPP):

MRPP is a non-parametric statistical method that tests differences among groups. MRPP was used to test for significant differences between the arthropod assemblages across the FEO gradient on both the taxonomic and the functional data for the Heteroptera and the Coleoptera from both early and late season. MRPP grouping by treatment gave all significant differences ($p < 0.05$) for all data sets except one. The Coleoptera from the Dorris Farm on the functional level in the late season gave no significant differences between treatments ($p = 0.226$). This data set had the fewest number of functional groups (five) and was 66% empty. Many of the sample units had the same contents, eg. only one fungivore. All of the A-values were above zero which indicates that there was less heterogeneity within each treatment than was expected by chance alone (Table 1).

Table 1. Multi-Response Permutation Procedure, grouping by treatment. Coleoptera data.

Farm	Taxon or functional group	Total season/ Early/late	A-value	p-value
Bush	taxonomic	total	0.192	$<10^{-8}$
Bush	taxonomic	early	0.152	$<10^{-8}$
Bush	taxonomic	late	0.191	$<10^{-8}$
Bush	functional	total	0.220	$<10^{-7}$
Bush	functional	early	0.253	$<10^{-7}$
Bush	functional	late	0.333	$<10^{-6}$
Corricello	taxonomic	total	0.184	$<10^{-5}$
Corricello	taxonomic	early	0.173	$<10^{-4}$
Corricello	taxonomic	late	0.126	$<10^{-3}$
Corricello	functional	total	0.234	$<10^{-4}$
Corricello	functional	early	0.122	0.008
Corricello	functional	late	0.199	$<10^{-3}$
Dorris	taxonomic	total	0.072	$<10^{-7}$
Dorris	taxonomic	early	0.063	$<10^{-6}$
Dorris	taxonomic	late	0.051	0.031
Dorris	functional	total	0.164	$<10^{-6}$
Dorris	functional	early	0.152	$<10^{-6}$
Dorris	functional	late	0.024	0.226
Wiebe	taxonomic	total	0.112	$<10^{-8}$
Wiebe	taxonomic	early	0.070	$<10^{-8}$
Wiebe	taxonomic	late	0.164	$<10^{-8}$
Wiebe	functional	total	0.335	$<10^{-8}$
Wiebe	functional	early	0.129	$<10^{-5}$
Wiebe	functional	late	0.349	$<10^{-8}$

The p-value is the probability of Type I error for the hypothesis of no difference between treatments. The A-value is the chance-corrected within group agreement.

MRPP was repeated using transect as a grouping variable. Some of the transects were significantly different ($p < 0.05$). This suggests that there is within-farm variation in the Coleoptera assemblage that should be addressed in future studies. (Table 2).

Table 2. Multi-Response Permutation Procedure. Grouping by transect.

Farm	Taxon or functional group	Total season/ Early/ late	A-value	p-value
Bush	tax	Total	0.004	0.288
bush	tax	Early	0.013	0.092
bush	tax	Late	-0.004	0.535
bush	fun	Total	0.010	0.223
bush	fun	Early	0.003	0.341
bush	fun	Late	-0.014	0.640
corr	***	***	***	***
dorr	tax	Total	0.017	0.023
dorr	tax	Early	0.026	0.004
dorr	tax	Late	-0.009	0.610
dorr	fun	Total	0.026	0.074
dorr	fun	Early	0.026	0.072
dorr	fun	Late	-0.035	0.833
weib	tax	Total	0.010	0.090
weib	tax	Early	0.013	0.029
weib	tax	Late	0.008	0.176
weib	fun	Total	0.007	0.278
weib	fun	Early	0.033	0.028
weib	fun	Late	0.017	0.173

***The Corricello farm only has one transect.

The p-value is the probability of Type I error for the hypothesis of no difference between treatments.

The A-value is the chance-corrected within group agreement.

Objective 1. To compile a complete list of Coleoptera and Heteroptera fauna of *C. avellana* and *C. cornuta*.

Of the Coleoptera data, 40 families, 129 genera and 132 species of beetles were identified. Nineteen beetle species are non-native. Information on abundance and host are also included in Table 3.

A complete list of the Coleoptera taken from beating sheets is found in Figure 4. *Clambus vulneratus* LeConte is a new species of Clambidae to Oregon. Many of the organisms in this study may well be incidental to hazelnut foliage, especially those taken from the native hazelnut in the forest as the hazelnuts are surrounded by alternate hosts. A list of the assigned functional group of each species is listed in Table 4 with references.

Table 3: Adult Coleoptera identified from beating sheet samples of *Corylus* spp.

AGYRTIDAE	<i>Ipelates latus</i> (Mannerheim) [u,c]	<i>Scymnus</i> sp. [a,b]
ALLECULIDAE		<i>Scymnus nebulosus</i> LeConte [a,b]
	<i>Mycetochara procera</i> Casey [s,c]	* <i>Stethorus punctillum</i> Weise [s,v]
ANOBIIDAE		COLYDIIDAE
	<i>Ernobius pallitarsis</i> Fall [u,c]	<i>Namunaria pacifica</i> (Horn) [s,c]
	<i>Ernobius punctulatus</i> (LeConte) [u,b]	CORYLOPHIDAE
	<i>Hemicoelus gibbicollis</i> (LeConte) [s,v]	<i>Orthoperus scutellaris</i> LeConte [s,c]
	<i>Vrilletta decorata</i> VanDyke [u,c]	<i>Sericoderus lateralis</i> (Gyllenhal) [u,b]
ANTHICIDAE		CRYPTOPHAGIDAE
	<i>Ischyropalpus nitidulus</i> (LeConte) [a,b]	<i>Anchicera kamschatica</i> Motschulsky [u,b]
ARTEMATOPODIDAE		<i>Anchicera nebulosa</i> Casey [s,c]
	<i>Macropogon testaceipennis</i> Motschulsky [s,v]	<i>Anchicera ochracea</i> (Zimmerman) [s,v]
BOSTRICHIDAE		<i>Anchicera pusilla</i> Schonherr [u,b]
	<i>Scobicia declivis</i> (LeConte) [s,v]	<i>Cryptophagus tuberculosus</i> Maklin [s,c]
BRUCHIDAE		CURCULIONIDAE
	<i>Acanthoscelides pauperculus</i> LeConte [u,c]	* <i>Amalus scortillum</i> (Herbst) [s,c]
	* <i>Bruchus brachialis</i> Fahraeus [u,v]	<i>Apion cordatum</i> Smith [u,v]
BUPRESTIDAE		* <i>Apion fuscirostre</i> Fabricius [u,b]
	<i>Anthaxia deleta</i> LeConte [s,c]	* <i>Ceutorhynchus assimilis</i> Paykull [s,v]
BYTURIDAE		<i>Dorytomus mucidus</i> (Say) [s,v]
	<i>Xerasia grisescens</i> (Jayne) [u,b]	* <i>Gymnaetron pascuorum</i> (Gyllenhal) [u,b]
CANTHARIDAE		<i>Lepesoma decorata</i> (LeConte) [u,c]
	<i>Cultellunguis larvalis</i> (LeConte) [u,b]	<i>Lepesoma granicollis</i> (LeConte) [u,c]
	<i>Malthodes</i> sp. [a,b]	<i>Lepesoma lecontei</i> (Casey) [u,c]
	<i>Podabrus piniphilus</i> (Eschscholtz) [u,b]	<i>Lignyodes horridulus</i> (Casey) [u,b]
	<i>Podabrus pruinosis</i> LeConte [u,v]	* <i>Mecinus pyraeter</i> (Herbst) [u,b]
	<i>Silis lutea</i> LeConte [u,b]	<i>Nemocoestes horni</i> VanDyke [u,c]
	<i>Silis spinigera</i> LeConte [s,c]	* <i>Otiorhynchus rugosostriatus</i> (Goeze) [u,c]
CARABIDAE		<i>Peritelinus oregonus</i> VanDyke [s,v]
	<i>Bradycellus congener</i> LeConte [s,v]	<i>Proctorus decipiens</i> (LeConte) [s,c]
	<i>Dromius piceus</i> Dejean [u,c]	<i>Rhyncolus brunneus</i> Mannerheim [u,b]
	<i>Lebia moesta</i> LeConte [s,c]	<i>Sciopithes obscurus</i> Horn [a,b]
CERAMBYCIDAE		<i>Scythropus californicus</i> Horn [s,v]
	<i>Eumichthus oedipus</i> LeConte [u,c]	* <i>Sitona lineatus</i> (Linnaeus) [s,v]
	<i>Leptalia macilenta</i> (Mannerheim) [s,v]	<i>Sthereus horridus</i> (Mannerheim) [u,c]
	<i>Phymatodes aeneus</i> LeConte [u,b]	<i>Tachyerges niger</i> (Horn) [s,c]
	<i>Phymatodes nitidus</i> LeConte [s,v]	<i>Thricolepsis inornata</i> Horn [a,b]
	<i>Pidonia scripta</i> (LeConte) [s,c]	* <i>Tychius picirostris</i> (Fabricius) [u,b]
	<i>Plectura spinicauda</i> Mannerheim [u,c]	* <i>Tychius stephensi</i> Schonherr [s,c]
CHRYSOMELIDAE		ELATERIDAE
	<i>Acalymma trivittata</i> (Mannerheim) [s,v]	<i>Agriotes sparsus</i> LeConte [u,b]
	<i>Altica ambiens</i> LeConte [s,v]	<i>Ampedus oregonus</i> (Schaeffer) [s,c]
	* <i>Chrysolina quadrigemina</i> (Suffrian) [s,v]	<i>Athous vittiger</i> LeConte [s,c]
	<i>Crepidodera nana</i> (Say) [u,v]	<i>Ctenicera mendax</i> (LeConte) [u,b]
	<i>Diabrotica undecimpunctata</i> (Mannerheim) [u,b]	<i>Dalopius</i> sp. [u,v]
	<i>Diachus auratus</i> (Fabricius) [a,b]	<i>Hemicrepidius pallidipennis</i> (Mannerheim) [s,v]
	<i>Orsodacne atra</i> (Ahrens) [s,c]	<i>Limonium infuscatus</i> Motschulsky [s,v]
	<i>Phyllotreta</i> sp. [u,b]	<i>Limonium nitidulus</i> Horn [u,b]
	<i>Phyllotreta albonica</i> (LeConte) [u,b]	<i>Megapenthes caprella</i> (LeConte) [s,c]
	<i>Psylliodes punctulata</i> Melsheimer [u,v]	<i>Melanotus longulus</i> (LeConte) [u,v]
	<i>Syneta albida</i> LeConte [a,b]	<i>Neopristiphorus cribrata</i> (LeConte) [s,c]
CLAMBIDAE		<i>Selatosomus cruciata</i> (Linnaeus) [u,v]
	<i>Clambus vulneratus</i> LeConte [s,c]	LAMPYRIDAE
COCCINELLIDAE		<i>Ellychnia hatchi</i> Fender [u,c]
	<i>Adalia bipunctata</i> (Linnaeus) [u,b]	LATRIDIIDAE
	<i>Calvia quatuordecimguttata</i> (Linnaeus) [u,v]	<i>Aridius nodifer</i> (Westwood) [u,b]
	<i>Calvia duodecim-maculata</i> (Geb.) [u,v]	<i>Corticarina</i> sp. [a,b]
	* <i>Coccinella septempunctata</i> (Linnaeus) [a,b]	<i>Latridius</i> sp. [a,b]
	<i>Coccinella trifasciata</i> Linnaeus [u,b]	<i>Melanophthalma</i> sp. [a,b]
	<i>Cycloneda polita</i> Casey [a,b]	MELANDRYIDAE
	* <i>Harmonia axyridis</i> (Pallas) [a,b]	<i>Prothalia holmbergii</i> (Mannerheim) [u,c]
	<i>Hippodamia convergens</i> Guerin-Meneville [s,v]	MELYRIDAE
	<i>Hippodamia sinuata</i> Mulsant [u,v]	<i>Amecocerus</i> sp. [s,v]
	<i>Mulsantina picta</i> (Randall) [u,b]	<i>Anthocomus moerens</i> (LeConte) [s,c]
	<i>Psyllobora 20-maculata</i> Say [a,b]	<i>Dasyrhadus impressicollis</i> Fall [u,b]
	<i>Psyllobora borealis</i> Casey [a,b]	<i>Hoppingiana nitida</i> Hatch [s,c]
		<i>Malachius auritus</i> LeConte [s,v]

Table 3. Continued

MYCETOPHAGIDAE

**Typhaea stercoria* (Linnaeus) [s,v]

NITIDULIDAE

Epuraea avara Randall [s,c]

Glischrochilus quadrisignata (Say) [s,v]

**Meligethes nigrescens* Stephens [u,b]

OEDEMERIDAE

Asclera discolor LeConte [s,c]

Xanthochroina bicolor (LeConte) [s,v]

PHALACRIDAE

Phalacrus penicillatus Say [s,v]

Stilbus apicalis (Melsheimer) [u,v]

PTINIDAE

Ptinus fallax Fall [s,c]

PYROCHROIDAE

Dendroides ephemeroides (Mannerheim) [s,c]

Pedilus cavatus Fall [s,v]

SALPINGIDAE

Rhinosimus viridiaeneus (Randall) [u,c]

SCARABAEIDAE

Dichelonyx backi (Kirby) [s,c]

SCIRTIDAE

Cyphon brevicollis LeConte [u,b]

Cyphon variabilis (Thunberg) [u,b]

SCOLYTIDAE

Pseudopityophthorus pubipennis (LeConte) [s,v]

**Xyleborinus saxeseni* (Ratzeburg) [u,b]

**Xyleborus dispar* (Fabricius) [u,b]

SCRAPTIIDAE

Anaspis duryi Lilj. [s,v]

Anaspis rufa Say [u,c]

SILVANIDAE

**Ahasverus advena* (Waltl) [u,v]

**STAPHYLINIDAE

Aleocharinae spp.

Astenus californicus (Austin)

Eusphalerum sp.

Gabrius sp.

Haida keeni Keen

Omaliinae spp.

Oxytelus laqueatus (Marsham)

Pelecomalium sp.

Platystethus americanus Erichson

Quedius limbifer Horn

Stenus sp.

Tachyparinae spp.

Tachyporus sp.

TENEBRIONIDAE

Helops pernitens LeConte [u,b]

THROSCIDAE

Pactopus horni LeConte [u,b]

Throscus sericeus LeConte [a,b]

TROGOSSITIDAE

Eronyxa pallidus (Motschulsky) [s,c]

*NON-NATIVE

**Not included in analysis

s = singleton (only one individual found)

u = uncommon (<50 individuals)

a = abundant (>50 individuals)

c = *C. cornuta*

v = *C. avellana*

b = both

Table 4. Functional Groups of Coleoptera

	D	Fl	Fu	Gl	H	nf	Pa	Pr	Sd	Sp	Sv	X	UNK	Exot	References
Iliatus	0	0	0	0	0	0	0	0	0	0	1	0	0	0	Parsons et al. in prep
Mprocera	0	1	0	0	0	0	0	0	0	0	0	0	0	0	Parsons et al. 1991
Epatar	0	0	0	0	0	0	0	0	0	0	0	1	0	0	Powell 1979
Epunctulatus	0	0	0	0	0	0	0	0	0	0	0	1	0	0	Powell 1979
Hgibbicollis	0	0	0	0	0	0	0	0	0	0	0	1	0	0	Powell 1979
Vdecorata	0	0	0	0	0	0	0	0	0	0	0	1	0	0	Essig 1958; Jaques 1951
Initidulus	0	1	1	0	0	0	0	1	0	0	1	0	0	0	Parsons et al. 1991
Mtestaceipe	0	1	0	0	0	0	0	0	0	0	0	0	0	0	Johnson 1999
Sdeclivis	0	0	0	0	0	0	0	0	0	0	0	1	0	0	Essig 1958; Jaques 1951
Apauperculus	0	1	0	0	0	0	0	0	1	0	0	0	0	0	Parsons et al. 1991
Bbrachialis	0	1	0	0	1	0	0	0	1	0	0	0	0	1	Beirne 1971; Arnett 1968
Adeleta	0	1	0	0	0	0	0	0	0	0	0	0	0	0	Parsons et al. 1991
Xgrisescens	0	0	0	1	0	0	0	0	0	0	0	0	0	0	Arnett 1968
Ciarvalis	0	0	0	0	0	0	0	1	0	0	0	0	0	0	Parsons et al. In prep
Malthodes	0	0	0	0	0	0	0	1	0	0	0	0	0	0	Parsons et al. In prep
Ppiniphilus	0	0	0	0	0	0	0	1	0	0	0	0	0	0	Parsons et al. In prep
Ppruinus	0	0	0	0	0	0	0	1	0	0	0	0	0	0	Parsons et al. In prep
Slutea	0	0	0	0	0	0	0	1	0	0	0	0	0	0	Arnett 1985
Sspinigera	0	0	0	0	0	0	0	1	0	0	0	0	0	0	Arnett 1985
Bcongener	0	0	0	0	1	0	0	1	1	0	0	0	0	0	Parsons et al. In prep
Dpiceus	0	0	0	0	0	0	0	1	0	0	0	0	0	0	Parsons et al. In prep
Lmoesta	0	0	0	0	0	0	1	0	0	0	0	0	0	0	Parsons et al. In prep
Eoedipus	0	1	0	0	0	0	0	0	0	0	0	0	0	0	Parsons et al. In prep
Lmacilenta	0	1	0	0	0	0	0	0	0	0	0	0	0	0	Parsons et al. In prep
Paeneus	0	0	0	0	0	0	0	0	0	0	0	1	0	0	Essig 1958
Pnitidulus	0	0	0	0	0	0	0	0	0	0	0	1	0	0	Essig 1958
Pscripta	0	1	0	0	0	0	0	0	0	0	0	0	0	0	Parsons et al. In prep
Pspinicauda	0	0	0	0	0	0	0	0	0	0	0	1	0	0	Parsons et al. In prep
Atrivittat	0	1	0	0	1	0	0	0	0	0	0	0	0	0	Jolivet & Cox 1996
Aambiens	0	0	0	0	1	0	0	0	0	0	0	0	0	0	Parsons et al. In prep
Cquadrigemin	0	1	0	0	1	0	0	0	0	0	0	0	0	1	Jolivet & Cox 1996
Cnana	0	0	0	0	1	0	0	0	0	0	0	0	0	0	Parsons et al. In prep
D11punctata	0	1	0	0	1	0	0	0	0	0	0	0	0	0	Powell 1979
Dauratus	0	0	0	0	1	0	0	0	0	0	0	0	0	0	Beller & Hatch 1932
Oatra	0	1	0	0	1	0	0	0	0	0	0	0	0	0	Parsons et al. In prep
Phyllotreta	0	0	0	0	1	0	0	0	0	0	0	0	0	0	Beirne 1971
Palbonica	0	0	0	0	1	0	0	0	0	0	0	0	0	0	Beirne 1971
Ppunctulata	0	0	0	0	1	0	0	0	0	0	0	0	0	0	Beirne 1971
Salbida	0	1	0	0	1	0	0	0	0	0	0	0	0	0	Beller & Hatch 1932
Cvulneratus	1	0	1	0	0	0	0	0	0	0	0	0	0	0	Parsons et al. In prep
Abipunctata	0	0	0	0	0	0	0	1	0	0	0	0	0	0	Parsons et al. In prep
C14-guttata	0	0	0	0	0	0	0	1	0	0	0	0	0	0	Semjanov 1982
C12-maculata	0	0	0	0	0	0	0	1	0	0	0	0	0	0	Parsons et al. In prep
C7punctata	0	0	0	0	0	0	0	1	0	0	0	0	0	1	Parsons et al. In prep
Ctrifasciata	0	0	0	0	0	0	0	1	0	0	0	0	0	0	Parsons et al. In prep
Cpolita	0	0	0	0	0	0	0	1	0	0	0	0	0	0	Essig 1958
Haxyridis	0	0	0	0	0	0	0	1	0	0	0	0	0	1	Parsons et al. In prep
Hconvergens	0	0	0	0	0	0	0	1	0	0	0	0	0	0	Parsons et al. In prep
Hsinuata	0	0	0	0	0	0	0	1	0	0	0	0	0	0	Parsons et al. In prep
Mpicta	0	0	0	0	0	0	0	1	0	0	0	0	0	0	Chapin 1985
Psyllobora	0	0	1	0	0	0	0	0	0	0	0	0	0	0	Parsons et al. In prep
Scymnus	0	0	0	0	0	0	0	1	0	0	0	0	0	0	Parsons et al. In prep
Snebulosus	0	0	0	0	0	0	0	1	0	0	0	0	0	0	Essig 1958
Spunctillum	0	0	0	0	0	0	0	1	0	0	0	0	0	1	Parsons et al. In prep
Npacifica	0	0	1	0	0	0	0	1	0	0	0	0	0	0	Parsons et al. 1991; Arnett 1968
Oscutellaris	0	0	0	0	0	0	0	1	0	0	0	0	0	0	Parsons et al. 1991
Slateralis	0	0	0	0	0	0	0	1	0	0	0	0	0	0	Arnett 1968
Akamtschatic	0	0	1	0	0	0	0	0	0	0	0	0	0	0	Parsons et al. In prep
Anebulosa	0	0	1	0	0	0	0	0	0	0	0	0	0	0	Parsons et al. In prep
Aochracea	1	0	1	0	0	0	0	0	0	0	0	0	0	0	Parsons et al. 1991
Apusilla	0	0	1	0	0	0	0	0	0	0	0	0	0	0	Parsons et al. In prep
Ctuberculosis	1	0	1	0	0	0	0	0	0	0	1	0	0	0	Parsons et al. 1991; Arnett 1968

Table 4. Continued

	D	Fl	Fu	Gl	H	nf	Pa	Pr	Sd	Sp	Sv	X	UNK	Exot	References
Ascortillum	0	0	0	0	1	0	0	0	0	0	0	0	0	1	Arnett 1985
Acordatum	0	1	0	0	1	0	0	0	0	0	0	0	0	0	Parsons et al. In prep
Afuscirostre	0	1	0	0	1	0	0	0	0	0	0	0	0	1	Jolivet & Cox 1996; Rees et al. 1996
Cassimilis	0	1	0	0	1	0	0	0	0	0	0	0	0	1	Booth et al. 1990
Dmucidus	0	0	0	0	1	0	0	0	0	0	0	0	0	0	Parsons et al. 1991
Gpascuorum	0	0	0	0	1	0	0	0	0	0	0	0	0	1	Parsons et al. In prep
Ldecorata	0	0	0	0	1	0	0	0	0	0	0	0	0	0	Parsons et al. In prep
Lgranicollis	0	0	0	0	1	0	0	0	0	0	0	0	0	0	Parsons et al. In prep
Llecontei	0	0	0	0	1	0	0	0	0	0	0	0	0	0	Parsons et al. In prep
Lhorridulus	0	0	0	0	1	0	0	0	0	0	0	0	0	0	Arnett 1985
Mpyraster	0	0	0	0	1	0	0	0	0	0	0	0	0	1	Parsons et al. In prep
Nhorni	0	0	0	0	1	0	0	0	0	0	0	0	0	0	Parsons et al. In prep
Orugosostratus	0	0	0	0	1	0	0	0	0	0	0	0	0	1	Parsons et al. In prep
Poregonus	0	0	0	0	1	0	0	0	0	0	0	0	0	0	Parsons et al. In prep
Pdeciens	0	0	0	0	1	0	0	0	0	0	0	0	0	0	Arnett 1985
Rbrunneus	0	0	0	0	0	0	0	0	0	0	0	1	0	0	Parsons et al. 1991
Sobscurus	0	0	0	0	1	0	0	0	0	0	0	0	0	0	Essig 1958
Scalifornicus	0	0	0	0	1	0	0	0	0	0	0	0	0	0	Parsons et al. In prep
Slineatus	0	0	0	0	1	0	0	0	0	0	0	0	0	1	Beirne 1971
Shorridum	0	0	0	0	1	0	0	0	0	0	0	0	0	0	Arnett 1985
Tniger	0	0	0	0	1	0	0	0	0	0	0	0	0	0	Parsons et al. In prep
Tinornata	0	0	0	0	1	0	0	0	0	0	0	0	0	0	Essig 1958
Tpicrostris	0	1	0	0	1	0	0	0	1	0	0	0	0	1	Beirne 1971; Parsons et al. 1991
Tstephensi	0	1	0	0	1	0	0	0	1	0	0	0	0	1	Beirne 1971; Parsons et al. 1991
Asparsus	0	0	0	0	1	0	0	0	0	0	0	0	0	0	Beirne 1971; Borrer et al. 1989
Aoregonus	0	0	0	0	1	0	0	0	0	0	0	0	0	0	Borrer et al. 1989
Avitteger	0	0	0	0	1	0	0	0	0	0	0	0	0	0	Borrer et al. 1989
Cmedax	0	0	0	0	1	0	0	0	0	0	0	0	0	0	Borrer et al. 1989
Dalopius	0	0	0	0	1	0	0	0	0	0	0	0	0	0	Borrer et al. 1989
Hpallidipennis	0	0	0	0	1	0	0	0	0	0	0	0	0	0	Borrer et al. 1989
Linfuscatus	0	0	0	0	1	0	0	0	0	0	0	0	0	0	Borrer et al. 1989
Lnitidulus	0	0	0	0	1	0	0	0	0	0	0	0	0	0	Borrer et al. 1989
Mcaprellus	0	0	0	0	1	0	0	0	0	0	0	0	0	0	Borrer et al. 1989
Mlongulus	0	0	0	0	1	0	0	0	0	0	0	0	0	0	Borrer et al. 1989
Ncribosa	0	0	0	0	1	0	0	0	0	0	0	0	0	0	Borrer et al. 1989
Scruciata	0	0	0	0	1	0	0	0	0	0	0	0	0	0	Borrer et al. 1989
Ehatchi	0	1	0	0	0	1	0	1	0	0	0	0	0	0	Arnett 1968; Booth et al. 1990
Anodifer	0	0	1	0	0	0	0	0	0	0	0	0	0	0	Parsons et al. In prep
Corticarina	0	0	1	0	0	0	0	0	0	0	0	0	0	0	Parsons et al. In prep
Latridius	0	0	1	0	0	0	0	0	0	0	0	0	0	0	Parsons et al. In prep
Melanopthalma	0	0	1	0	0	0	0	0	0	0	0	0	0	0	Parsons et al. In prep
Pholmbergii	0	0	1	0	0	0	0	0	0	0	0	1	0	0	Arnett 1968
Amecocerus	0	1	0	0	0	0	0	1	0	0	0	0	0	0	Parsons et al. 1991
Amoerens	0	0	0	0	0	0	0	1	0	0	0	0	0	0	Parsons et al. 1991
Dimpressicollis	0	0	0	0	0	0	0	1	0	0	0	0	0	0	Parsons et al. 1991
Hnitida	0	0	0	0	0	0	0	1	0	0	0	0	0	0	Parsons et al. 1991
Mauritia	0	0	0	0	0	0	0	1	0	0	0	0	0	0	Arnett 1985
Tstercoria	0	0	1	0	0	0	0	0	0	0	0	0	0	1	Parsons et al. In prep
Eavera	0	0	1	0	0	0	0	1	0	1	0	0	0	0	Winkler 1964; Parsons et al. 1991
Gquadrisignata	0	0	1	0	0	0	0	1	0	1	0	0	0	0	Winkler 1964
Mnigrescens	0	1	0	0	0	0	0	0	0	0	0	0	0	1	Parsons et al. 1991
Adicolor	0	1	0	0	0	0	0	0	0	0	0	0	0	0	Parsons et al. 1991
Xbicolor	0	1	0	0	0	0	0	0	0	0	0	0	0	0	Arnett 1968
Ppenicillatus	0	0	1	0	0	0	0	0	0	0	0	0	0	0	Parsons et al. 1991
Sapicalis	1	0	1	0	0	0	0	0	0	0	0	0	0	0	Parsons et al. 1991
Pfallax	0	0	0	0	0	0	0	0	0	0	1	0	0	0	Parsons et al. 1991
Dephemeroides	0	0	0	0	0	0	0	0	0	0	0	0	1	0	No references
Pcavatus	0	0	0	0	0	0	0	0	0	0	0	0	1	0	No references

Table 4. Continued

	D	Fl	Fu	Gl	H	nf	Pa	Pr	Sd	Sp	Sv	X	UNK	Exo	References
Dbacki	0	0	0	0	1	0	0	0	0	0	0	0	0	0	Parsons et al. 1991
Cbrevicollis	0	0	0	0	0	0	0	0	0	0	0	0	1	0	Merrit & Cummins 1984
Cvariabilis	0	0	0	0	0	0	0	0	0	0	0	0	1	0	Merrit & Cummins 1984
Ppubipennis	0	0	0	0	0	0	0	0	0	0	0	1	0	0	Wood 1982
Xsaxeseni	0	0	1	0	0	0	0	0	0	0	0	1	0	1	Arnett 1985; Wood 1982
Xdispar	0	0	1	0	0	0	0	0	0	0	0	1	0	1	Arnett 1985; Wood 1982
Aduryi	0	1	0	0	0	0	0	0	0	0	0	0	0	0	Parsons et al. 1991
Arufa	0	1	0	0	0	0	0	0	0	0	0	0	0	0	Parsons et al. 1991
Aadvena	0	0	1	0	0	0	0	0	0	0	0	0	0	1	Parsons et al. In prep
Hpernitens	0	0	0	0	1	0	0	0	0	0	0	0	0	0	Booth et al. 1990
Phorni	0	0	0	0	0	0	0	1	0	0	0	0	0	0	Yensen 1970; Arnett 1985
Tsericeus	0	0	0	0	0	0	0	1	0	0	0	0	0	0	Yensen 1970; Arnett 1985
Epadus	0	1	0	0	0	0	0	0	0	0	0	0	0	0	Parsons et al. 1991

D = detritivore
 Fl = pollen feeder
 Fu = fungivore
 Gl = gall former
 H = herbivore
 nf = non-feeding
 Pa = parasitoid
 Pr = predator
 Sd = seed feeder
 Sp = sap feeder
 Sv = scavenger
 X = xylophagous
 UNK = unknown
 Exot = non-native

Objective 2. To determine the amount of overlap across host plants.

A total of 90 species of Coleoptera were found on the wild hazelnut, *C. cornuta*. Forty-four species were found exclusively on the native hazelnut and not on the introduced hazelnut. Of these, 26 species were singletons. Only eight species restricted to the forest had three or more individuals. A total of 87 species of Coleoptera were found on *C. avellana*. Forty-one species of beetle were only found on the European hazelnut. Of these, 28 species were singletons. Only eight species restricted to the orchard had three or more individuals. Forty-six species were found on both species of hazelnut.

The arthropod community of *C. avellana* is similar to that of *C. cornuta*. Most differences were attributed to rare species (Table 5).

Table 5. Total numbers of individuals and species for Coleoptera data.

	Forest	Edge	Orchard
IPM: Bush			
Total individuals	550	185	183
Total species	25	12	9
Unique	8	2	1
IPM: Dorris			
Total individuals	311	79	47
Total species	25	14	9
Unique	10	2	0
Org: Wiebe			
Total individuals	2063	1664	1409
Total species	41	45	41
Unique	4	0	1
Org: Corricello*			
Total individuals	399	522	512
Total species	23	19	24
Unique	2	1	5

*Corricello farm has only one transect (15 sample units rather than 45).

Diversity measures (Tables 6-8):

Beta diversity was higher for both IPM farms because of the drastic differences between the forest, the edge and the orchard.

IPM farms: Species richness, Shannon's H and Simpson's D all indicated higher diversity in the forest, second highest diversity on the edge and lowest diversity in the center of the orchard at both the Bush farm and the Dorris farm when calculated for the entire season, the early season and the late season.

Wiebe Farm (Organic): The general trend was that diversity was higher in the orchard and on the edge than in the forest. However, when evenness was accounted for, as in both Simpson's and Shannon's indices, diversity was lowest on the edge and highest in the orchard and the forest for the early season. The late season corresponded with the general trend. Therefore, although species richness was highest on the edge, the community was unevenly distributed in the early season.

Corricello Farm (Organic): The general trend was that diversity was highest in the orchard and lower on the edge and in the forest. However, species richness indicated that diversity increased at the edge in the late season. Simpson's index suggested that, over the entire season, diversity was higher in the forest than in the edge. Shannon's index suggested that the forest was more diverse than the edge in the early season and overall, but was less diverse than the edge in late season.

Table 6. Diversity indices for Coleoptera of entire season.

Farm	Treatment	Beta diversity	Species Richness (S)	Evenness (E)	Shannon's Diversity Index (H)	Simpson's Diversity Index (D)
Bush	Total	8.89	6.3	0.82	1.40	0.693
Bush	Forest		9.6	0.76	1.69	0.73
Bush	Edge		4.9	0.87	1.31	0.67
Bush	Orchard		4.3	0.85	1.22	0.65
Dorr	Total	11.59	4.3	0.75	1.05	0.54
Dorr	Forest		7.8	0.84	1.65	0.74
Dorr	Edge		3.0	0.67	0.81	0.45
Dorr	Orchard		2.2	0.75	0.70	0.44
Weib	Total	6.12	14.0	0.64	1.68	0.69
Weib	Forest		12.7	0.49	1.23	0.53
Weib	Edge		15.1	0.68	1.83	0.73
Weib	Orchard		14.3	0.75	1.98	0.80
Corr	Total	3.66	13.1	0.67	1.70	0.72
Corr	Forest		13.0	0.70	1.79	0.75
Corr	Edge		11.8	0.60	1.48	0.65
Corr	Orchard		14.4	0.69	1.84	0.77

Table 7. Diversity indices for Coleoptera of early season.

Farm	Treatment	Species Richness (S)	Evenness (E)	Shannon's Diversity Index (H)	Simpson's Diversity Index (D)
Bush	Total	5.2	0.85	1.28	0.65
Bush	Forest	7.7	0.76	1.50	0.67
Bush	Edge	4.1	0.91	1.20	0.65
Bush	Orchard	3.9	0.86	1.14	0.63
Dorr	Total	3.6	0.71	0.91	0.49
Dorr	Forest	6.2	0.85	1.43	0.69
Dorr	Edge	2.8	0.67	0.79	0.45
Dorr	Orchard	1.8	0.62	0.50	0.33
Weib	Total	10.8	0.76	1.78	0.75
Weib	Forest	9.0	0.84	1.80	0.77
Weib	Edge	11.8	0.66	1.62	0.67
Weib	Orchard	11.7	0.79	1.92	0.80
Corr	Total	10.4	0.73	1.69	0.71
Corr	Forest	9.8	0.74	1.64	0.71
Corr	Edge	9.8	0.66	1.49	0.62
Corr	Orchard	11.6	0.80	1.93	0.80

Table 8. Diversity indices for Coleoptera of late season.

Farm	Treatment	Species Richness (S)	Evenness (E)	Shannon's Diversity Index (H)	Simpson's Diversity Index (D)
Bush	Total	2.5	0.54	0.62	0.35
Bush	Forest	4.3	0.78	1.08	0.57
Bush	Edge	1.9	0.47	0.48	0.28
Bush	Orchard	1.3	0.37	0.31	0.20
Dorr	Total	1.3	0.32	0.32	0.19
Dorr	Forest	2.8	0.75	0.82	0.47
Dorr	Edge	0.5	0.13	0.09	0.07
Dorr	Orchard	0.5	0.07	0.05	0.03
Weib	Total	8.2	0.67	1.40	0.63
Weib	Forest	6.9	0.43	0.80	0.38
Weib	Edge	9.0	0.79	1.79	0.75
Weib	Orchard	8.5	0.79	1.68	0.75
Corr	Total	6.7	0.70	1.30	0.64
Corr	Forest	6.0	0.69	1.22	0.59
Corr	Edge	7.0	0.65	1.24	0.62
Corr	Orchard	7.0	0.75	1.45	0.71

Objective 3. To measure arthropod abundance and diversity across a forest-edge-orchard gradient on organic and IPM orchards.

Entire Season (Tables 9 and 10): In IPM orchards, species richness of both predators and herbivores decreased significantly from the forest to the orchard for the entire season, as did predator abundance. Yet herbivore abundance did not change significantly over the FEO gradient. In organic orchards, the species richness and abundance of herbivores was not significantly different over the FEO gradient. However, the species richness and abundance of predators was significantly higher in the orchard and on the edge, than in the forest.

Early Season (Tables 11 and 12): Species richness of herbivores was significantly lower in the IPM orchards than in the organic orchards. However, herbivore abundance

was not significantly different between the two management types. Species abundance and richness of predators were significantly higher in the orchards of the organic farms than in the forests of both farms and were significantly lower in the orchards of IPM farms.

Late season (Tables 13 and 14): Species richness and abundance of herbivores were significantly reduced in both organic and IPM orchards. However, species richness and abundance of predators remained significantly higher in the organic orchards, while both dropped close to zero in IPM orchards. Also, while species richness of herbivores was significantly higher in organic orchards as compared to IPM orchards, species abundance was not significantly different between the two.

Table 9a. Species Richness for all Coleoptera over entire season.

	IPM			Organic	
Orchard	Edge	Forest	Forest	Edge	Orchard
3.3(1.6)	3.9(1.9)	8.7(2.8)	12.8(3.0)	14.3(3.2)	14.3(2.1)

Bars join treatments which are not significantly different using Tukey-Kramer HSD.
Numbers in parentheses are standard deviations.

Table 9b. Species Richness for Phytophagous Coleoptera over entire season.

	IPM			Organic	
Orchard	Edge	Forest	Forest	Edge	Orchard
1.0(1.1)	1.2(0.9)	2.2(1.4)	3.1(1.7)	3.2(1.4)	2.5(1.3)

Bars join treatments which are not significantly different using Tukey-Kramer HSD.
Numbers in parentheses are standard deviations.

Table 9c. Species Richness for Predaceous Coleoptera over entire season.

	IPM			Organic	
Orchard	Edge	Forest	Forest	Edge	Orchard
0.3(0.7)	0.7(1.0)	3.3(1.9)	4.5(2.1)	6.0(1.9)	7.0(1.6)

Bars join treatments which are not significantly different using Tukey-Kramer HSD.
Numbers in parentheses are standard deviations.

Table 10a. Species Abundance for all Coleoptera over entire season.

		IPM		Organic	
Orchard	Edge	Forest	Forest	Edge	Orchard
7.8(6.4)	9.2(7.2)	29.9(17.3)	124.3(50.8)	110.2(26.9)	96.6(17.9)

Bars join treatments which are not significantly different using Tukey-Kramer HSD.
 Numbers in parentheses are standard deviations.

Table 10b. Species Abundance for Phytophagous Coleoptera over entire season.

		IPM		Organic	
Orchard	Edge	Forest	Forest	Edge	Orchard
2.9(3.7)	2.7(3.4)	6.9(5.6)	9.8(13.0)	6.6(4.1)	4.6(2.5)

Bars join treatments which are not significantly different using Tukey-Kramer HSD.
 Numbers in parentheses are standard deviations.

Table 10c. Species Abundance for Predaceous Coleoptera over entire season.

		IPM		Organic	
Orchard	Edge	Forest	Forest	Edge	Orchard
0.3(0.7)	0.8(1.1)	8.7(8.7)	10.4(5.9)	27.5(19.2)	32.3(11.0)

Bars join treatments which are not significantly different using Tukey-Kramer HSD.
 Numbers in parentheses are standard deviations.

Table 11a. Species Richness for all Coleoptera over early season.

Orchard	IPM		Organic		Orchard
	Edge	Forest	Forest	Edge	
2.9(1.5)	3.5(1.9)	6.9(2.5)	9.2(3.0)	11.3(2.7)	11.7(2.7)

Bars join treatments which are not significantly different using Tukey-Kramer HSD.
 Numbers in parentheses are standard deviations.

Table 11b. Species Richness for Phytophagous Coleoptera over early season.

Orchard	IPM		Organic		Orchard
	Edge	Forest	Forest	Edge	
1.0(1.2)	1.2(0.9)	1.9(1.3)	2.3(1.5)	2.4(1.1)	2.2(1.2)

Bars join treatments which are not significantly different using Tukey-Kramer HSD.
 Numbers in parentheses are standard deviations.

Table 11c. Species Richness for Predaceous Coleoptera over early season.

Orchard	IPM		Organic		Orchard
	Edge	Forest	Forest	Edge	
0.2(0.6)	0.6(0.9)	2.6(1.6)	3.2(1.7)	4.5(1.6)	5.3(1.8)

Bars join treatments which are not significantly different using Tukey-Kramer HSD.
 Numbers in parentheses are standard deviations.

Table 12a. Species Abundance for all Coleoptera over early season.

Orchard	IPM			Organic	
	Edge	Forest	Forest	Edge	Orchard
6.4(5.5)	6.7(5.7)	20.6(12.7)	29.3(19.3)	66.7(26.5)	50.8(18.2)

Bars join treatments which are not significantly different using Tukey-Kramer HSD.
 Numbers in parentheses are standard deviations.

Table 12b. Species Abundance for Phytophagous Coleoptera over early season.

Orchard	IPM			Organic	
	Edge	Forest	Forest	Edge	Orchard
3.0(3.9)	2.6(3.4)	4.0(4.1)	6.8(11.8)	5.4(3.6)	4.2(2.7)

Bars join treatments which are not significantly different using Tukey-Kramer HSD.
 Numbers in parentheses are standard deviations.

Table 12c. Species Abundance for Predaceous Coleoptera over early season.

Orchard	IPM			Organic	
	Edge	Forest	Forest	Edge	Orchard
0.3(0.7)	0.7(1.0)	7.6(8.2)	5.7(3.4)	16.3(11.6)	19.7(7.9)

Bars join treatments which are not significantly different using Tukey-Kramer HSD.
 Numbers in parentheses are standard deviations.

Table 13a. Species Richness for all Coleoptera over late season.

IPM				Organic	
Orchard	Edge	Forest	Forest	Edge	Orchard
0.9(0.9)	1.2(1.2)	3.5(1.8)	6.7(2.1)	8.5(2.3)	8.2(1.3)

Bars join treatments which are not significantly different using Tukey-Kramer HSD.
 Numbers in parentheses are standard deviations.

Table 13b. Species Richness for Phytophagous Coleoptera over late season.

IPM				Organic	
Orchard	Edge	Forest	Forest	Edge	Orchard
0.0(0.0)	0.1(0.3)	0.6(0.6)	1.1(0.8)	1.0(0.8)	0.3(0.6)

Bars join treatments which are not significantly different using Tukey-Kramer HSD.
 Numbers in parentheses are standard deviations.

Table 13c. Species Richness for Predaceous Coleoptera over late season.

IPM				Organic	
Orchard	Edge	Forest	Forest	Edge	Orchard
0.1(0.3)	0.1(0.4)	1.0(1.0)	2.2(1.6)	3.9(1.5)	4.5(1.0)

Bars join treatments which are not significantly different using Tukey-Kramer HSD.
 Numbers in parentheses are standard deviations.

Table 14a. Species Abundance for all Coleoptera over late season.

IPM				Organic	
Orchard	Edge	Forest	Forest	Edge	Orchard
1.5(1.8)	2.5(3.0)	9.3(6.9)	95.0(45.1)	41.8(20.4)	45.8(12.3)

Bars join treatments which are not significantly different using Tukey-Kramer HSD.
 Numbers in parentheses are standard deviations.

Table 14b. Species Abundance for Phytophagous Coleoptera over late season.

IPM				Organic	
Orchard	Edge	Forest	Forest	Edge	Orchard
0.0(0.0)	0.1(0.3)	3.0(4.2)	3.1(3.5)	1.1(1.0)	0.4(0.7)

Bars join treatments which are not significantly different using Tukey-Kramer HSD.
 Numbers in parentheses are standard deviations.

Table 14c. Species Abundance for Predaceous Coleoptera over late season.

IPM				Organic	
Orchard	Edge	Forest	Forest	Edge	Orchard
0.1(0.3)	0.1(0.4)	1.1(1.3)	4.8(3.9)	10.6(9.3)	12.7(5.1)

Bars join treatments which are not significantly different using Tukey-Kramer HSD.
 Numbers in parentheses are standard deviations.

Objective 4. To use ordination techniques to determine where peak abundance of individual taxa occur.

Ordinations provide a visual way of describing the distances between points in species space. In other words, sample units close to one another in species space have a more similar composition and relative abundance than do points farther away. The term ‘important’ refers to the Tau value that represents the weight given to that species when determining the ordination axes. In all ordinations in this study, the forest sample units were separate from the edge and the orchard. Although there was considerable overlap in species composition, the community structure was more similar between the edge and the orchard than between the forest and the orchard or the forest and the edge.

Bush farm (IPM): The relative abundance of predators and herbivores decreased along the FEO gradient in both early and late seasons. In early season, predators were important in the forest and herbivores were important in the orchard. By late season, predators and herbivores were both important in the forest (Figures 3 and 4).

In particular, the predators, *Mulsantina picta* (Figure 5) and *Malthodes* sp. (Figure 6) were only found in the forest. *Cycloneda polita* (Figure 7) and *Dasyrhodus impressicollis* (Figure 8) both had peak abundances in the forest and on the edge in the early season. By late season they were both restricted to the forest. Finally, *Throscus sericeus* (Figure 9) was found in all three treatments early but was also restricted to the forest by late season.

Of the herbivores, *Sciopithes obscurus* (Figure 10) was only found in the forest. *Syneta albida* (Figure 11) had its peak abundance in the orchard in the early season, but

disappeared altogether by late season. *Thricolepsis inornata* (Figure 12) had its peak abundance in the orchard, but was restricted to the edge by late season.

Figure 3. NMS ordination of sample units in Functional space with Predator overlay.

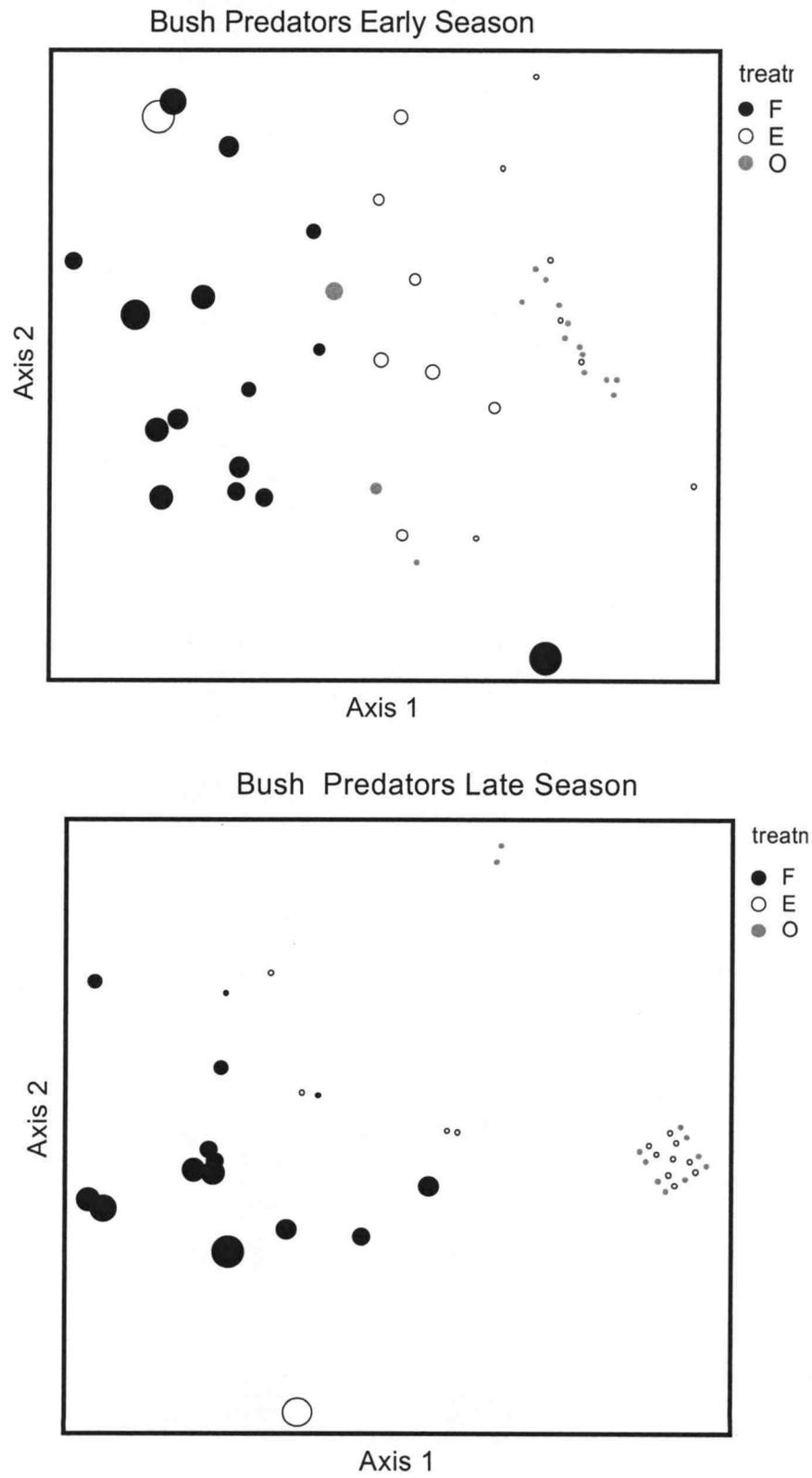


Figure 4. NMS ordination of sample units in Functional space with Herbivore overlay.

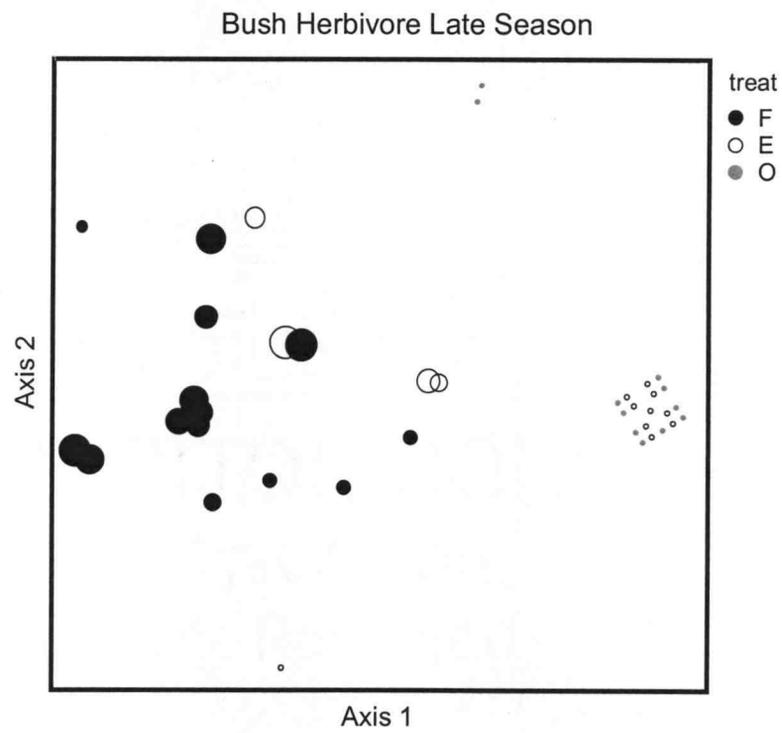
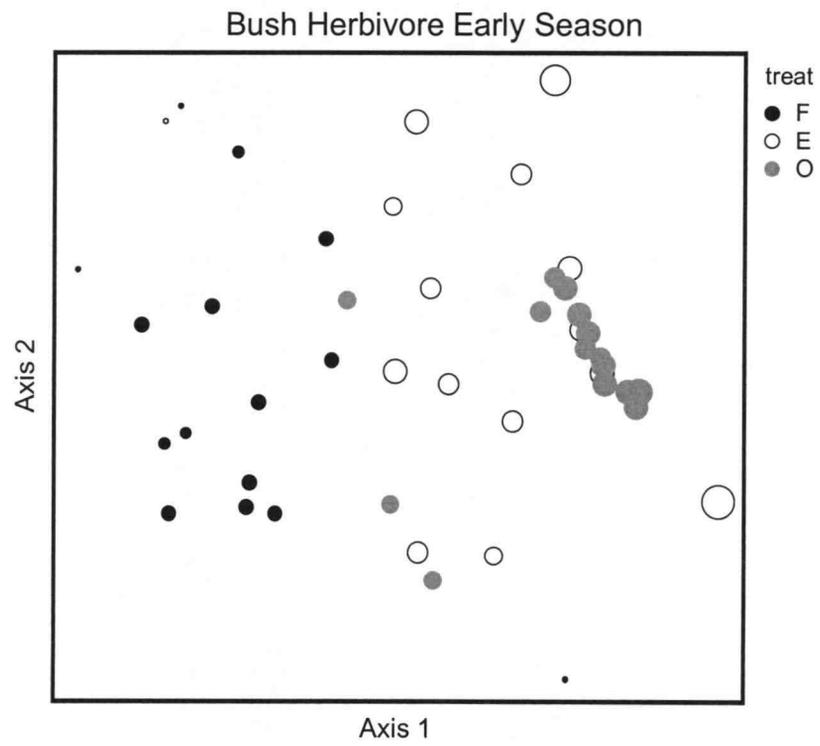


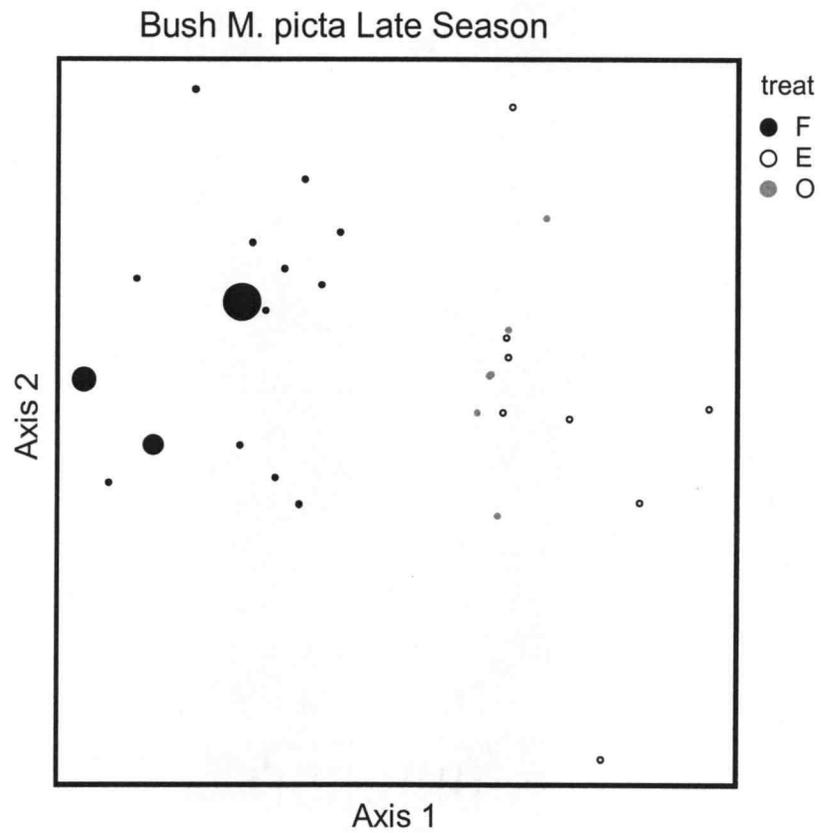
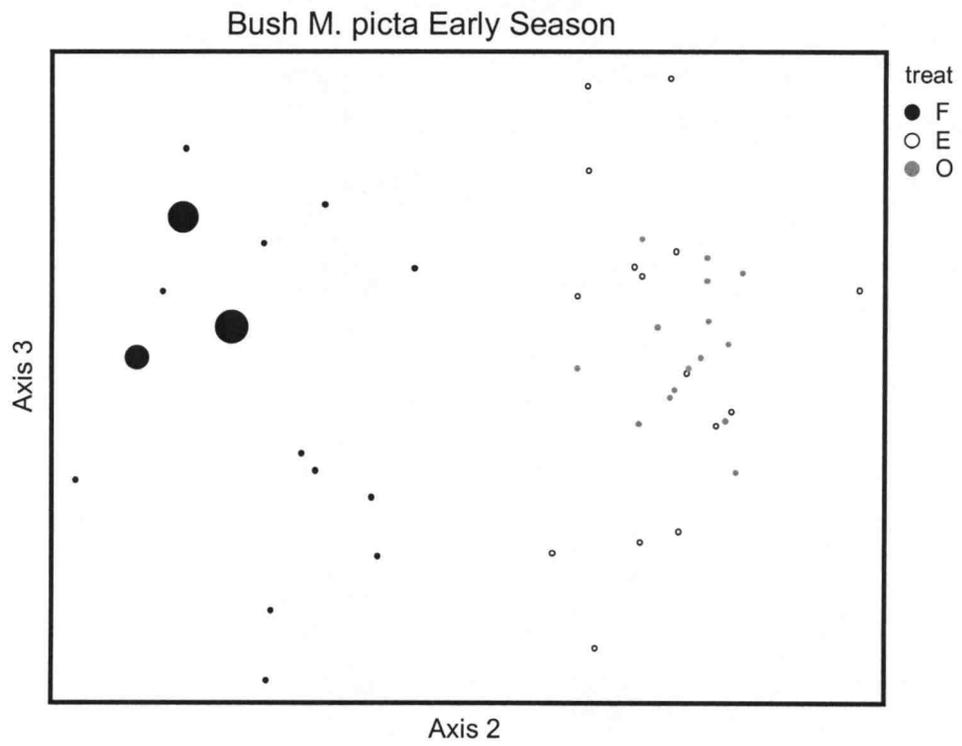
Figure 5. NMS ordination of sample units in Species space with *M. picta* overlay.

Figure 6. NMS ordination of sample units in Species space with Malthodes overlay.

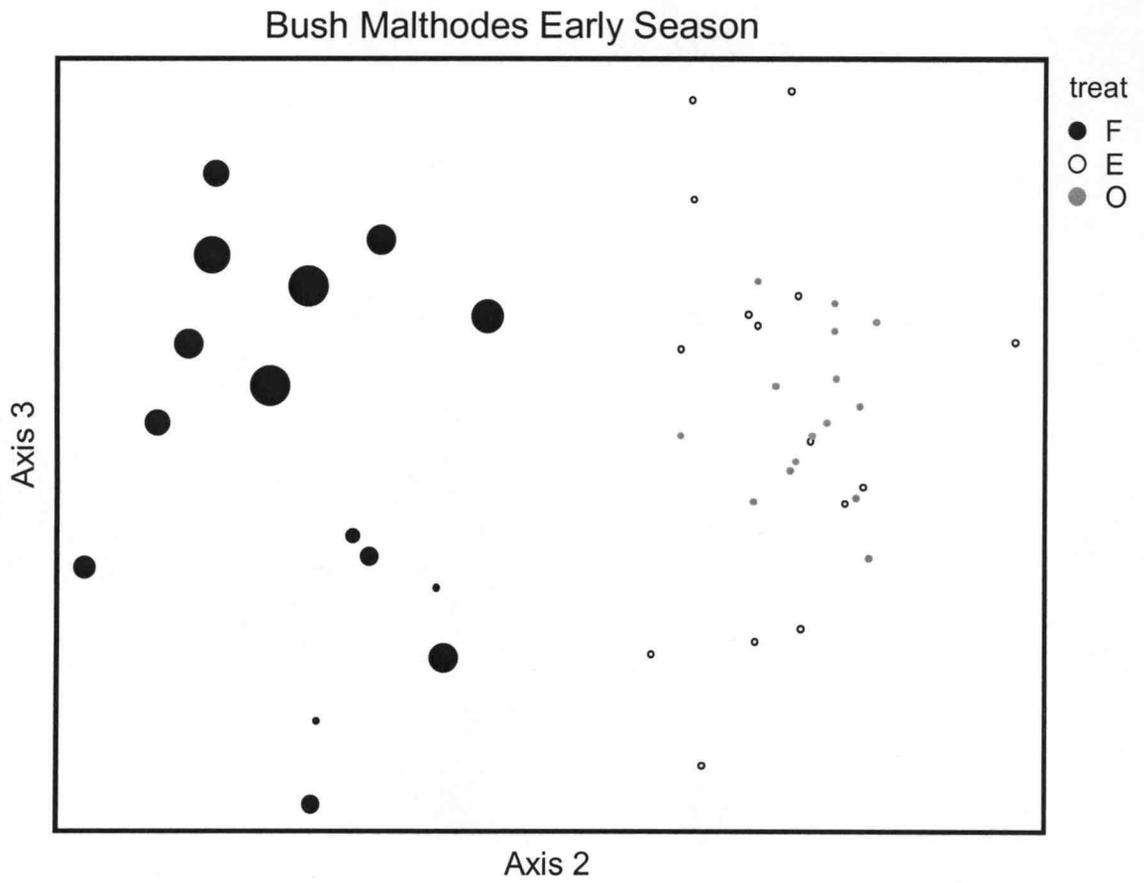


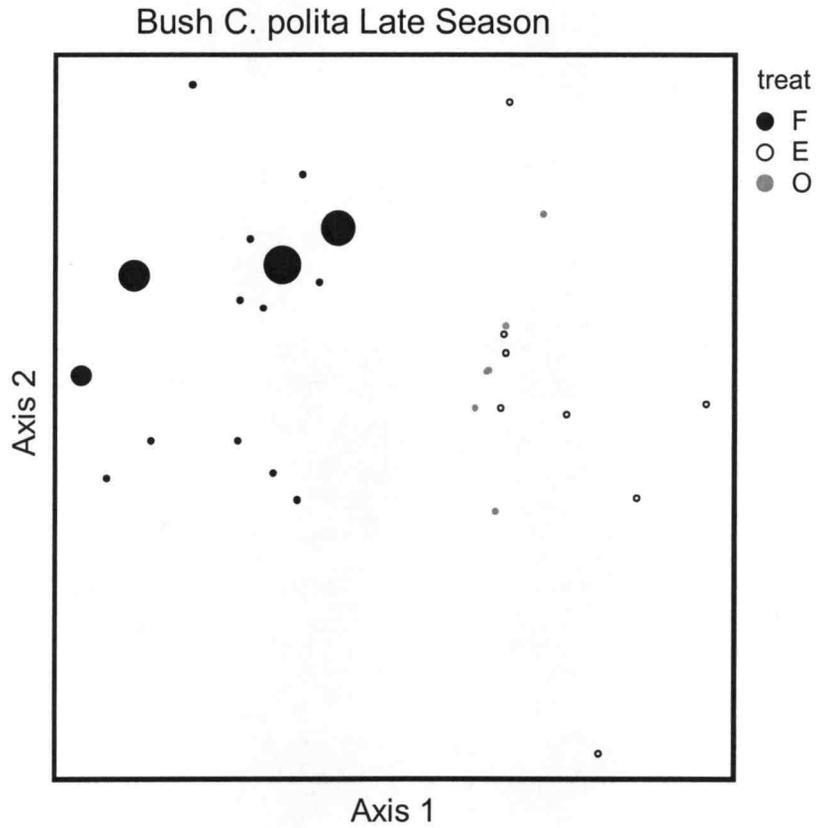
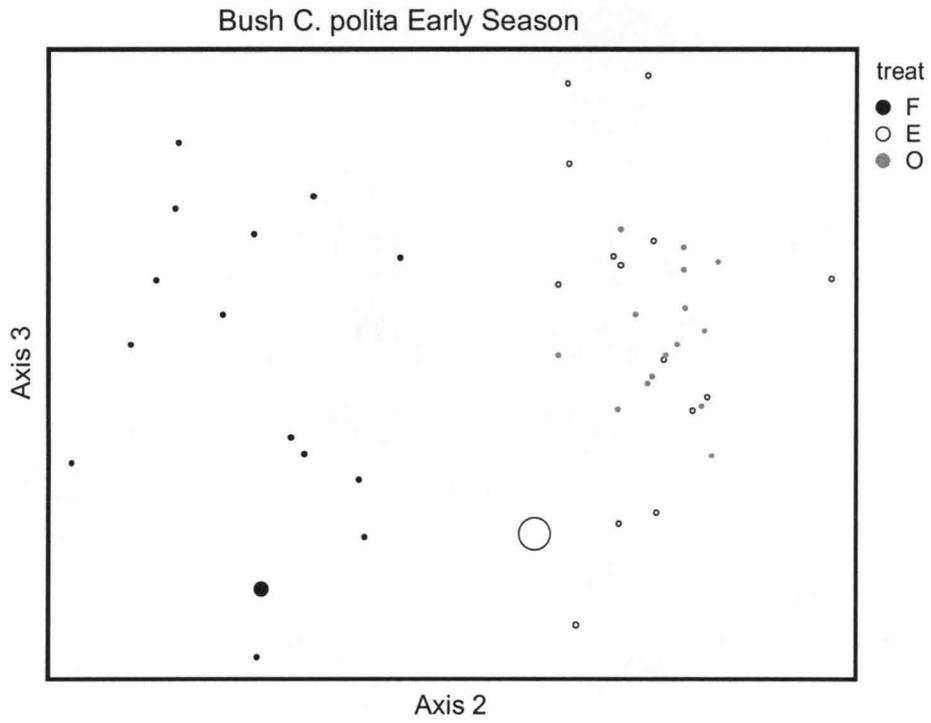
Figure 7. NMS ordination of sample units in Species space with *C. polita* overlay.

Figure 8. NMS ordination of sample units in Species space with *D. impressicollis* overlay.

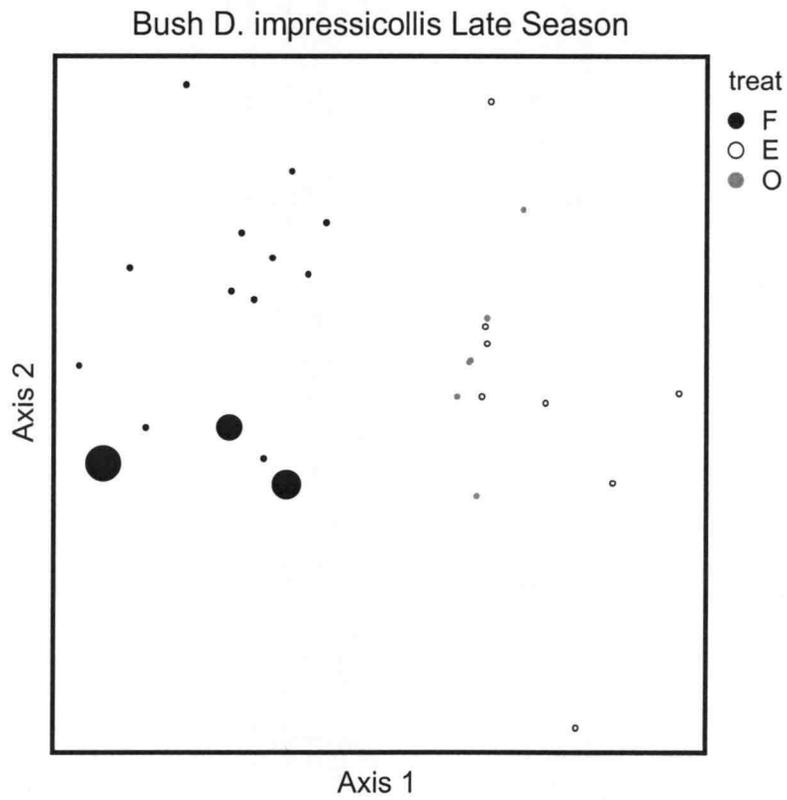
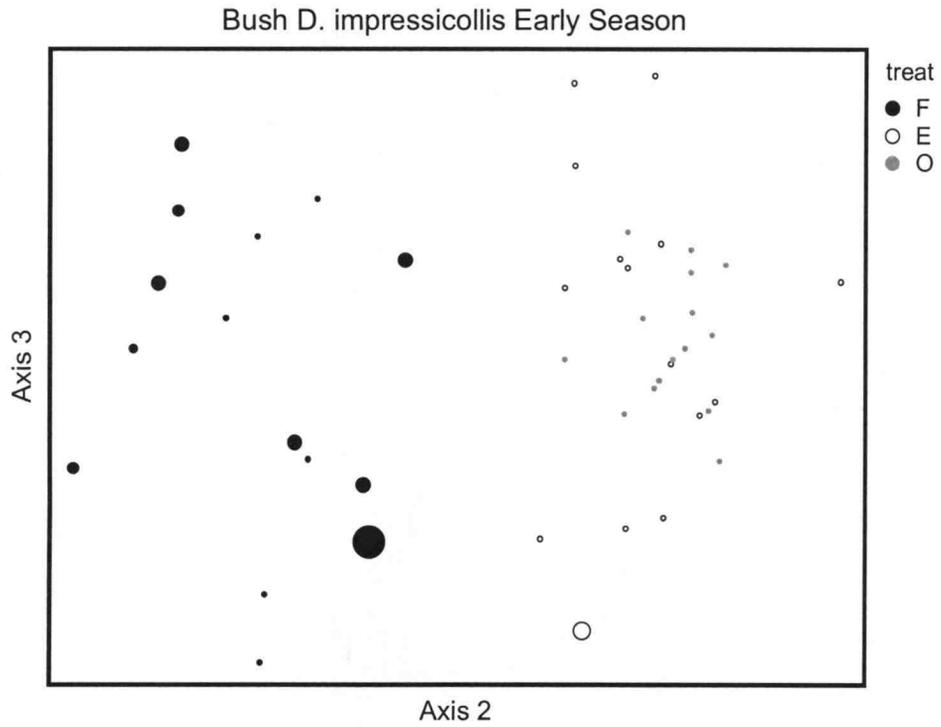


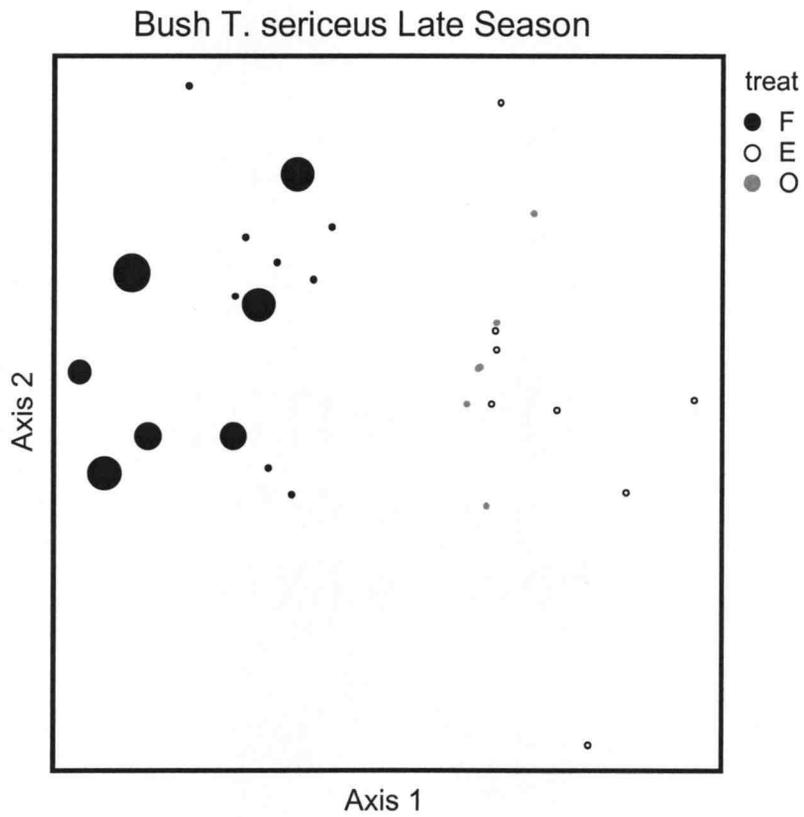
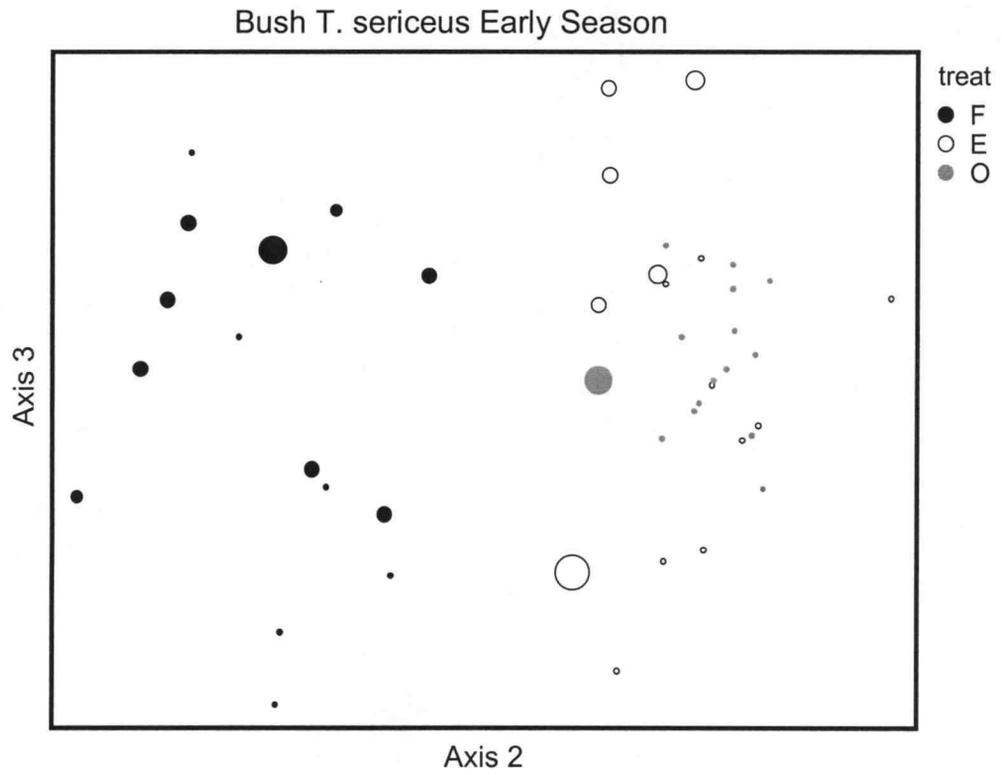
Figure 9. NMS ordination of sample units in Species space with *T. sericeus* overlay.

Figure 10. NMS ordination of sample units in Species space with *S. obscurus* overlay.

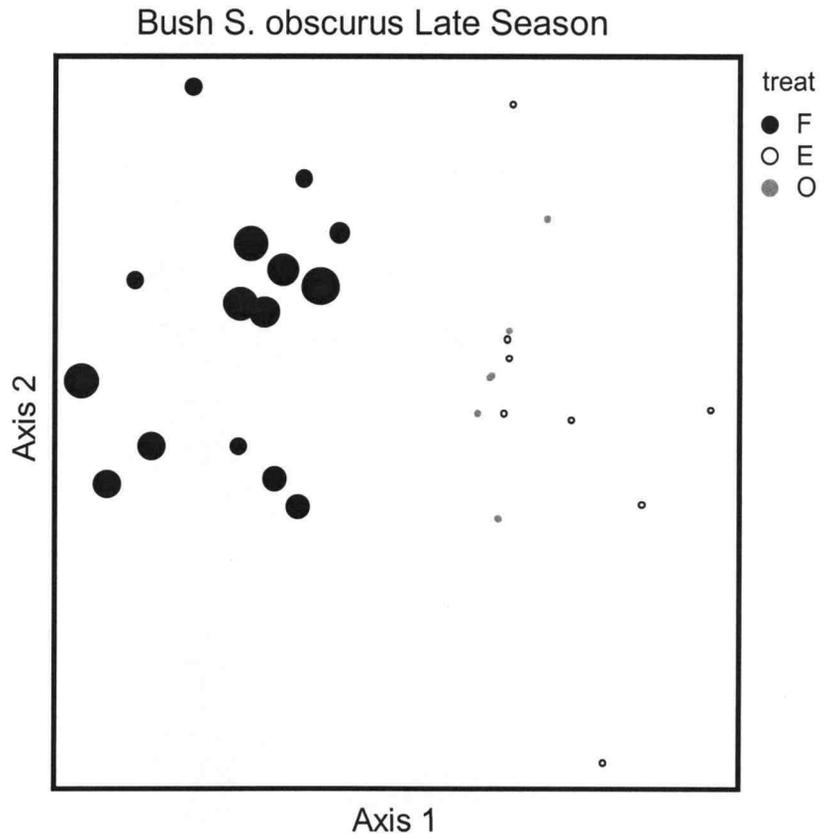
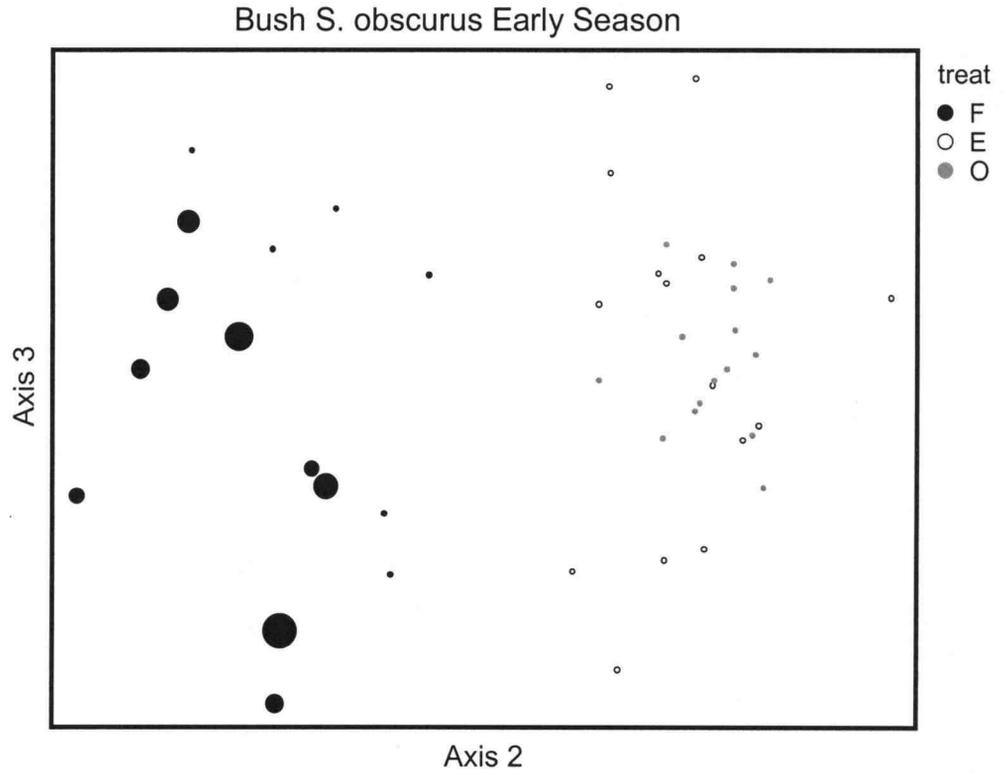


Figure 11. NMS ordination of sample units in Species space with *S. albida* overlay.

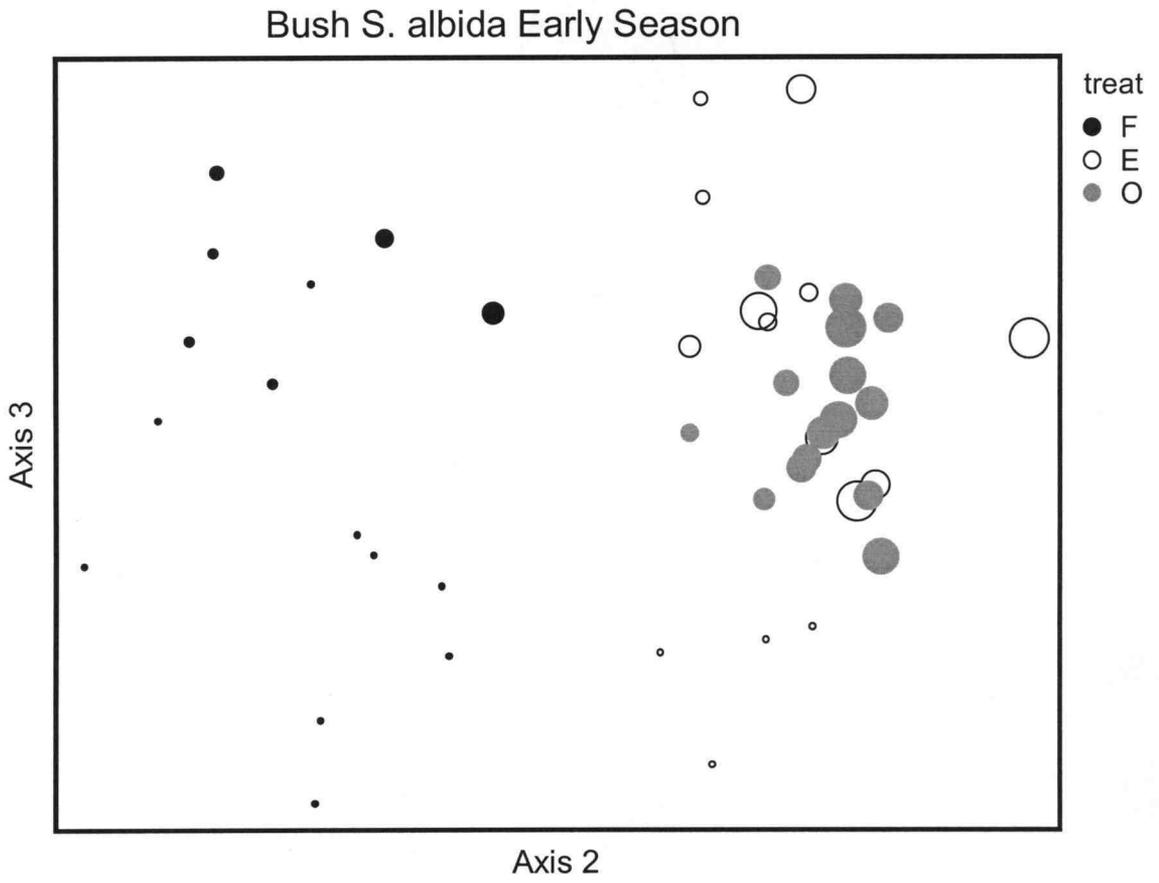
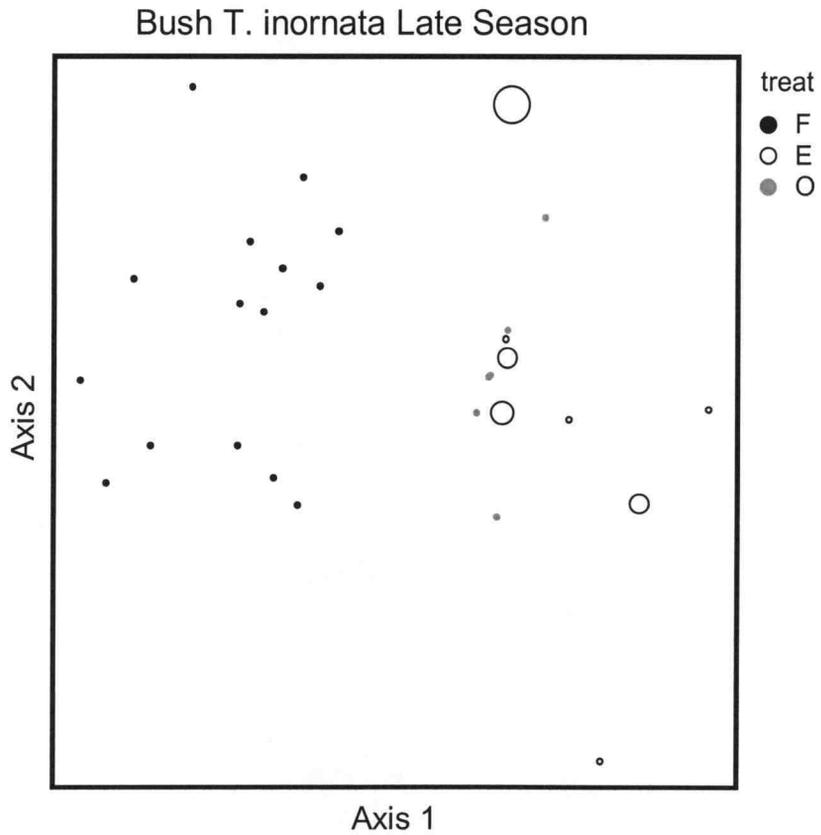
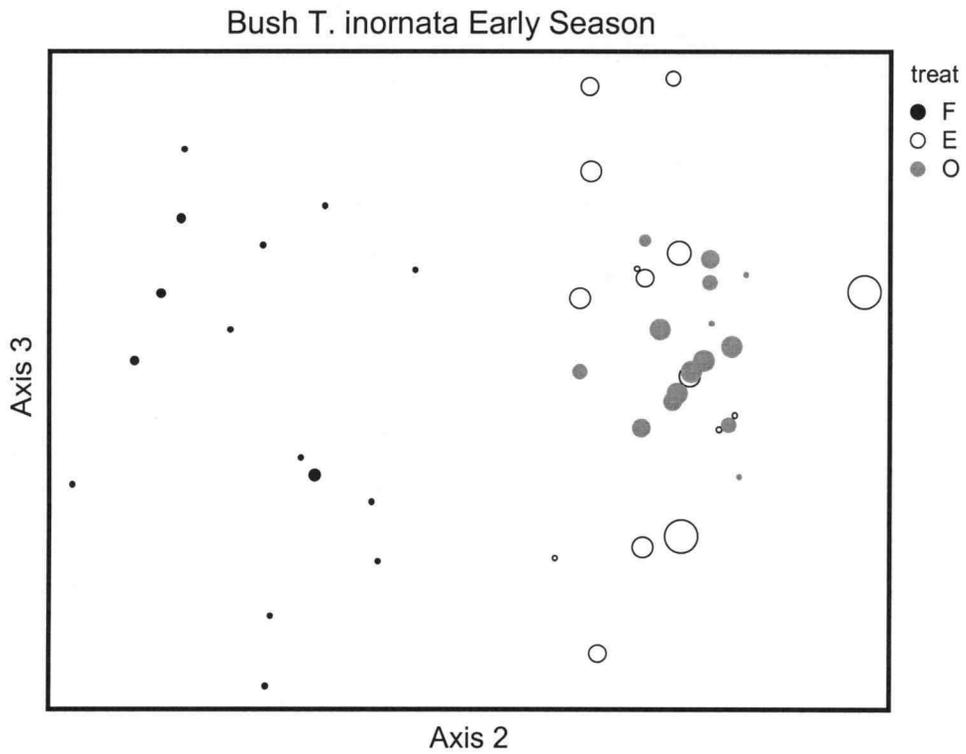


Figure 12. NMS ordination of sample units in Species space with *T. inornata* overlay.

Dorris farm (IPM): In early season, herbivores had peak abundance on the edge but were found in the forest. By late season, they were restricted to the forest (Figure 13). In particular, four species of curculionid, *Lepesoma lecontei* (Casey) (Figure 14), *Nemocestes horni* VanDyke (Figure 15), *Sciopithes obscurus* Horn (Figure 16), and *Sthereus horridus* (Mannerheim) (Figure 17), were only found in the forest. *Syneta albida* (Figure 18) had its peak in the forest but was also found on the edge of the orchard in the early season.

Predators were evenly distributed in the early season, but by late season, they were almost entirely restricted to the forest (Figure 19). In particular, *Scymnus* sp. (Figure 20) and *Throscus sericeus* LeConte (Figure 21) were entirely restricted to the forest. The peak abundances of *Mulstantina picta* (Randall) (Figure 22) and *Scymnus nebulosus* LeConte (Figure 23) were in the orchard early in the season, but these species occurred only in the forest by late season. Finally, *Cycloneda polita* Casey (Figure 24) and *Podabrus piniphilus* (Eschscholtz) (Figure 25) were found on the edge and in the forest in the early season, but disappeared altogether by late season.

Figure 13. NMS ordination of sample units in Functional space with Herbivore overlay.

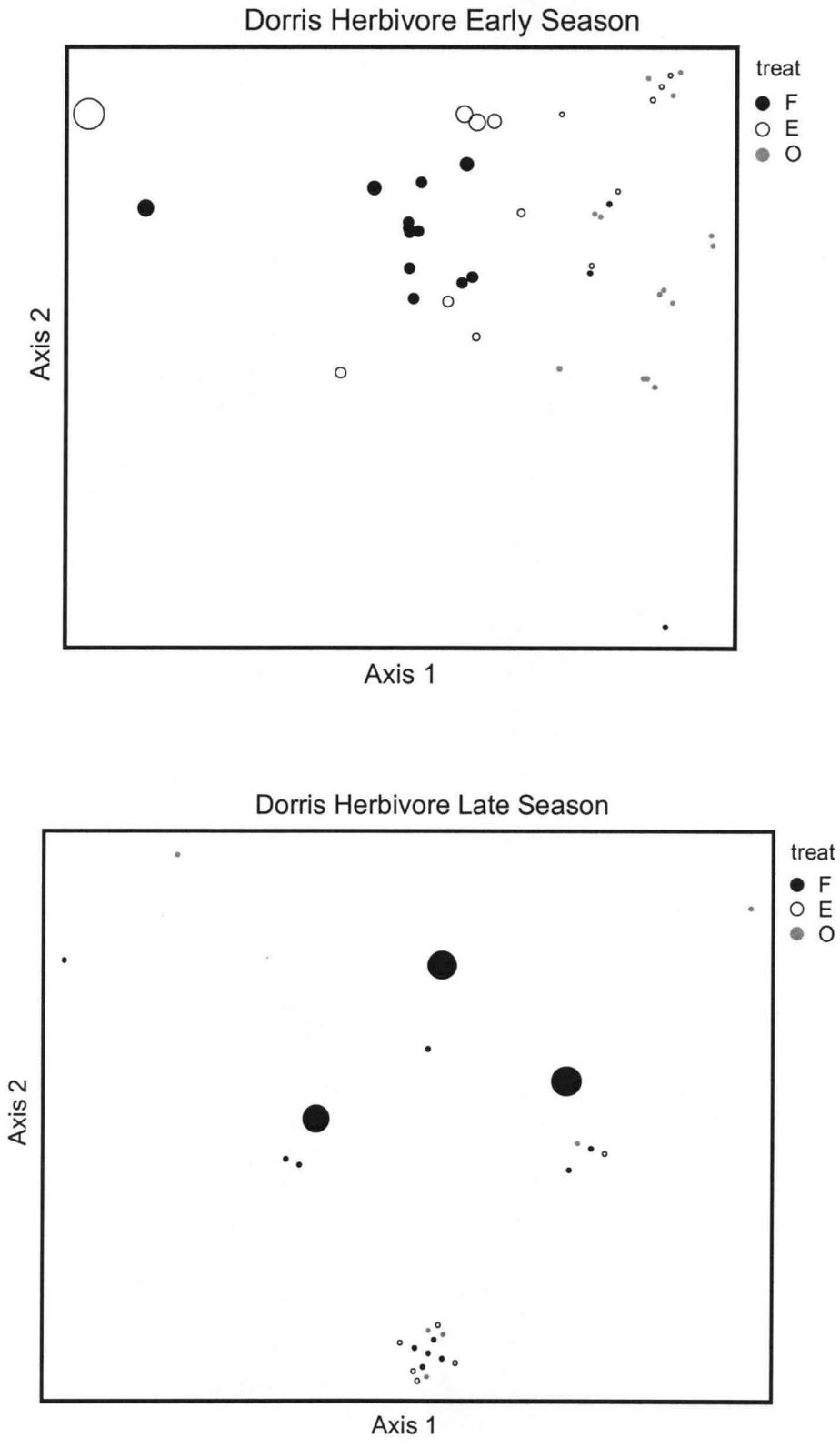


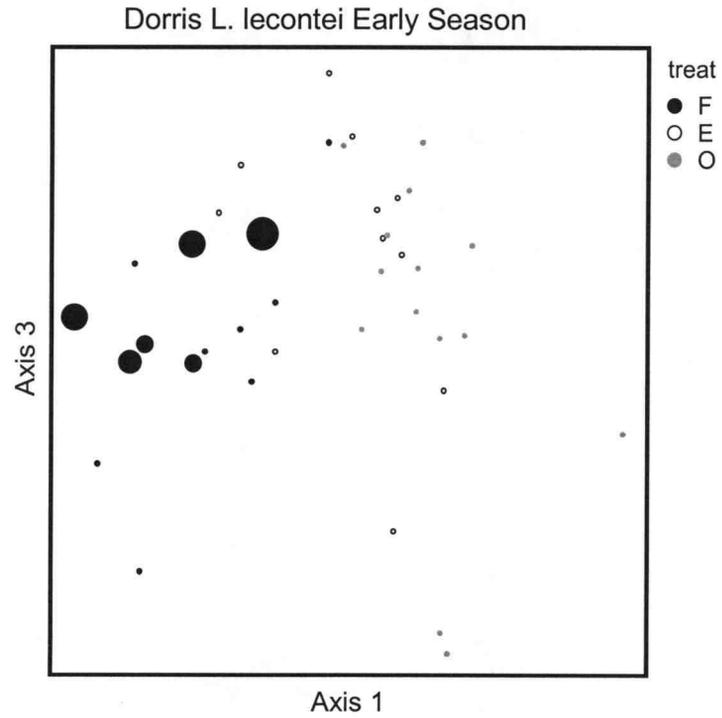
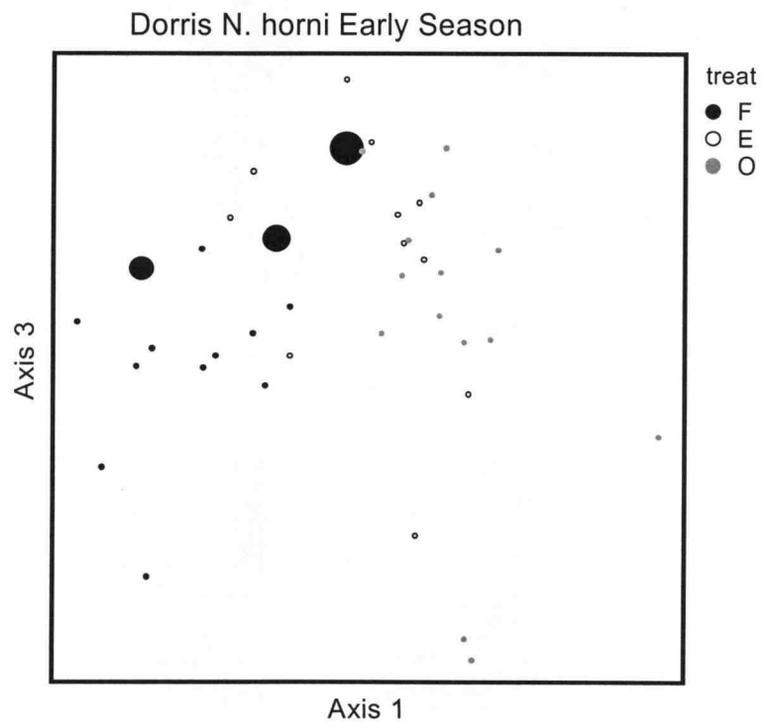
Figure 14. NMS ordination of sample units in Species space with *L. lecontei* overlay.Figure 15. NMS ordination of sample units in Species space with *N. horni* overlay.

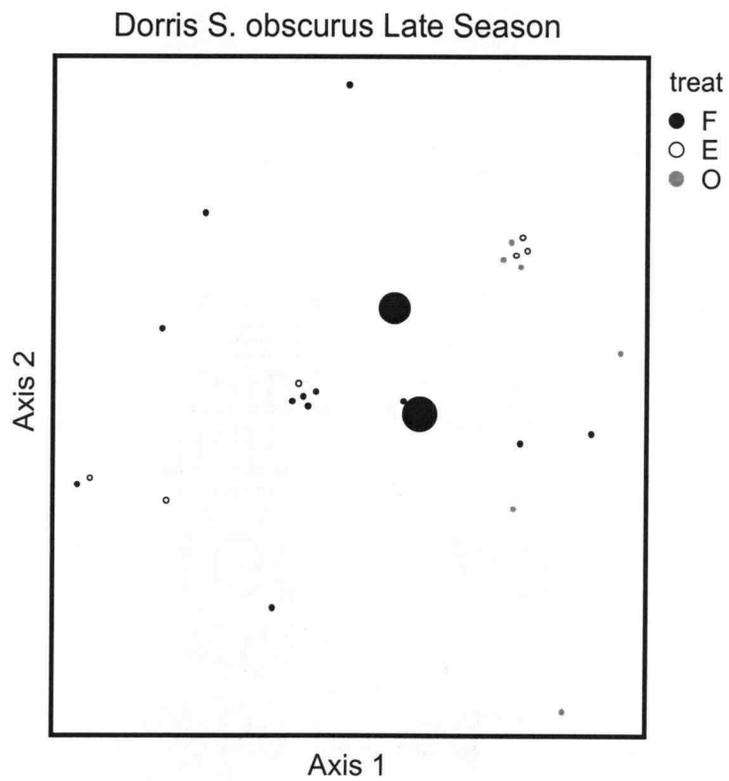
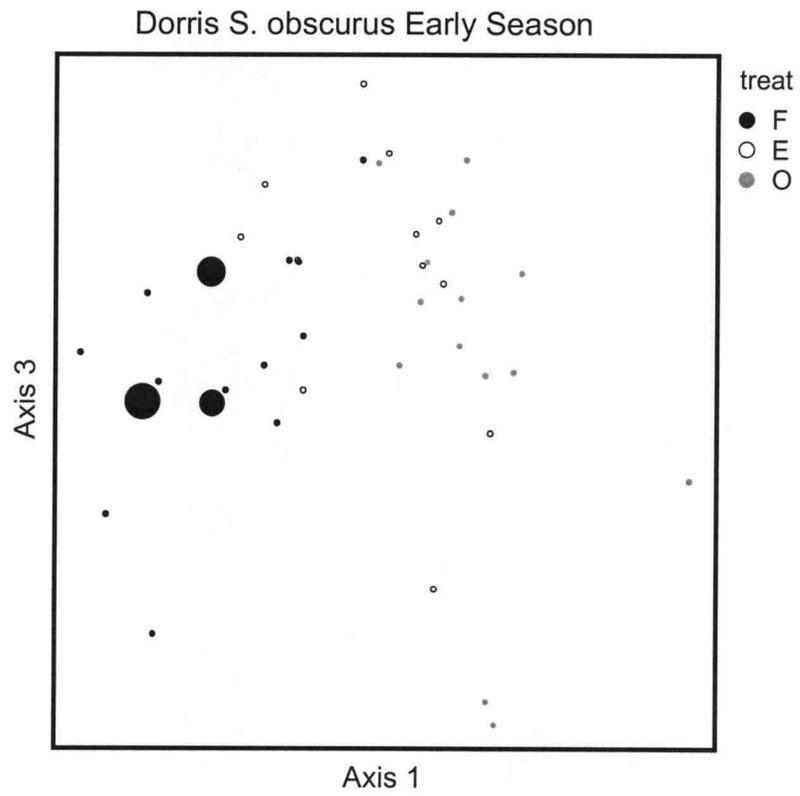
Figure 16. NMS ordination of sample units in Species space with *S. obscurus* overlay.

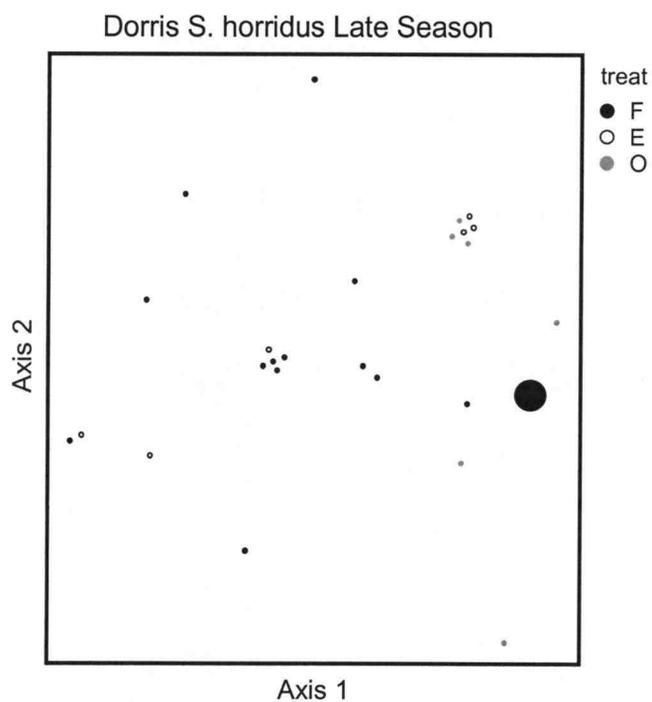
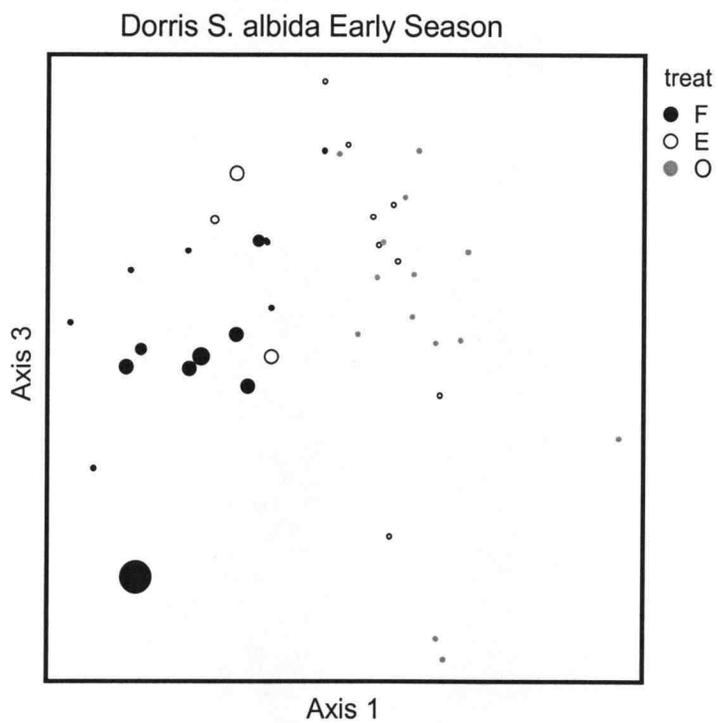
Figure 17. NMS ordination of sample units in Species space with *S. horridus* overlay.Figure 18. NMS ordination of sample units in Species space with *S. albida* overlay.

Figure 19. NMS ordination of sample units in Functional space with Predator overlay.

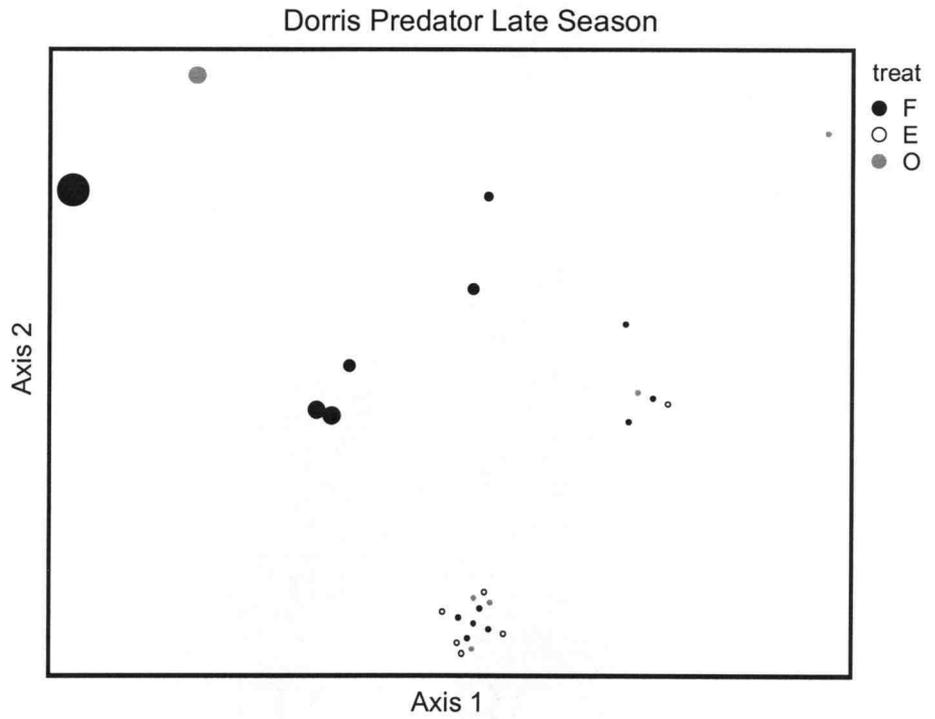
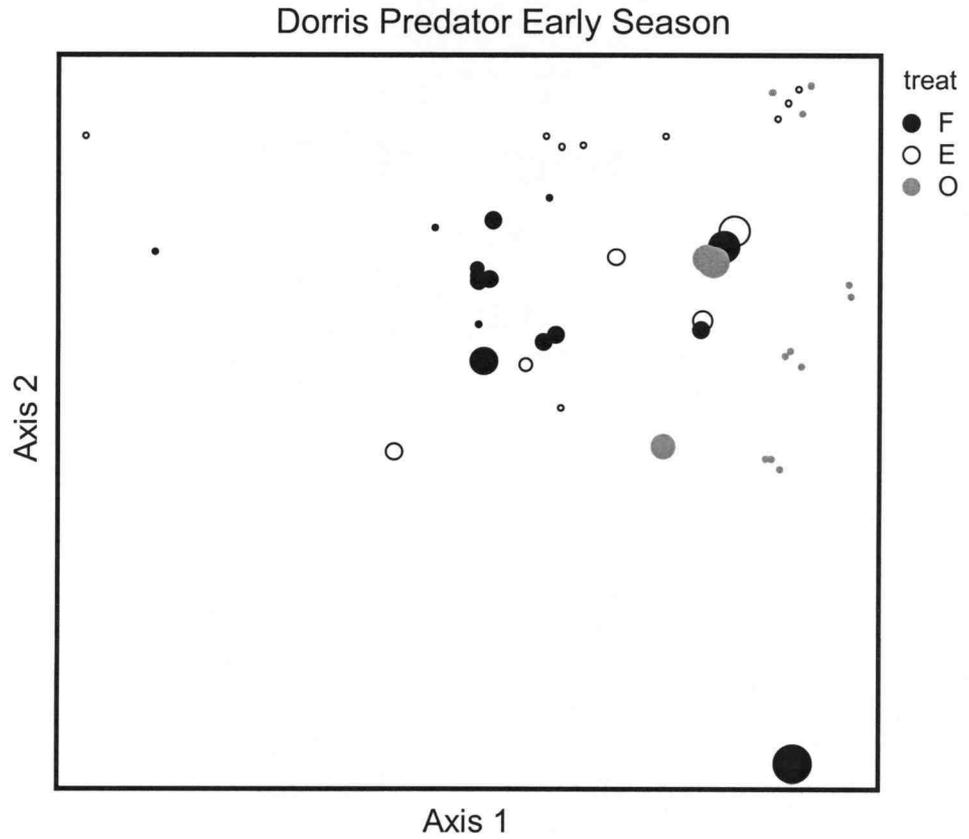


Figure 20. NMS ordination of sample units in Species space with Scymnus overlay.

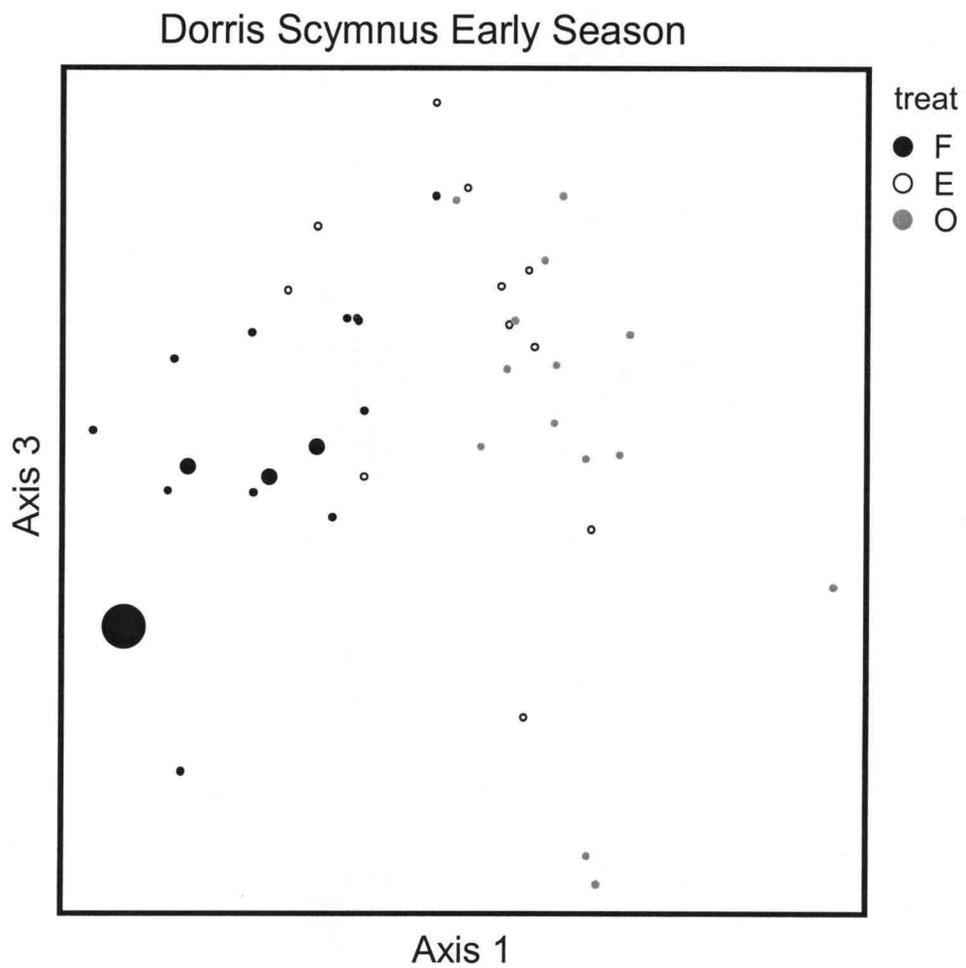


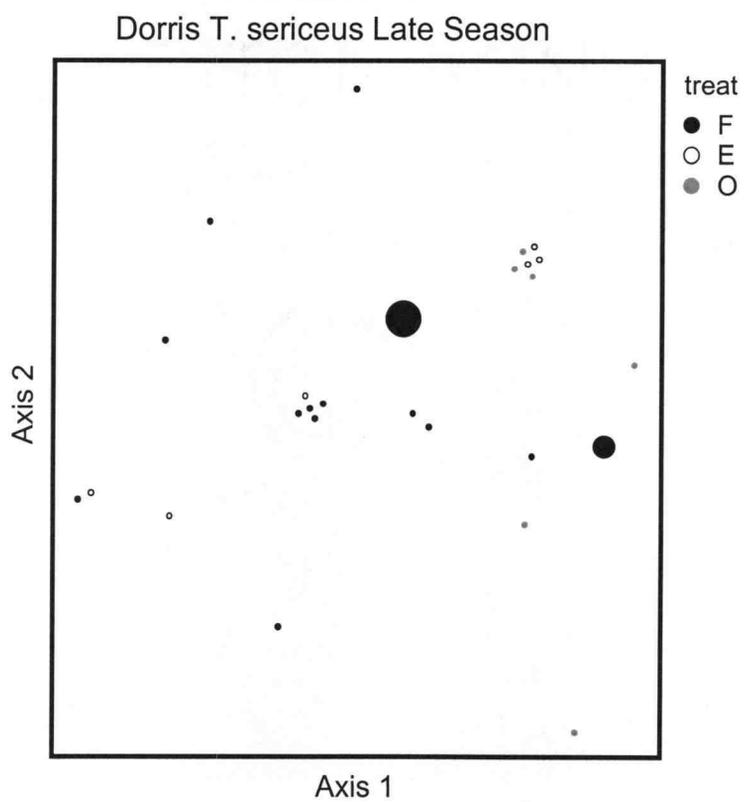
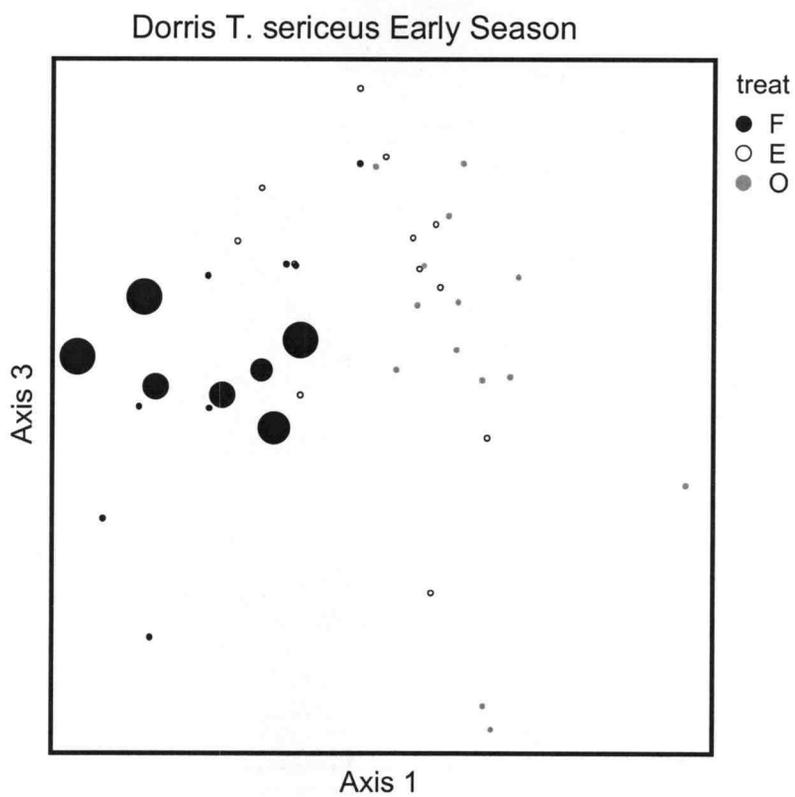
Figure 21. NMS ordination of sample units in Species space with *T. sericeus* overlay.

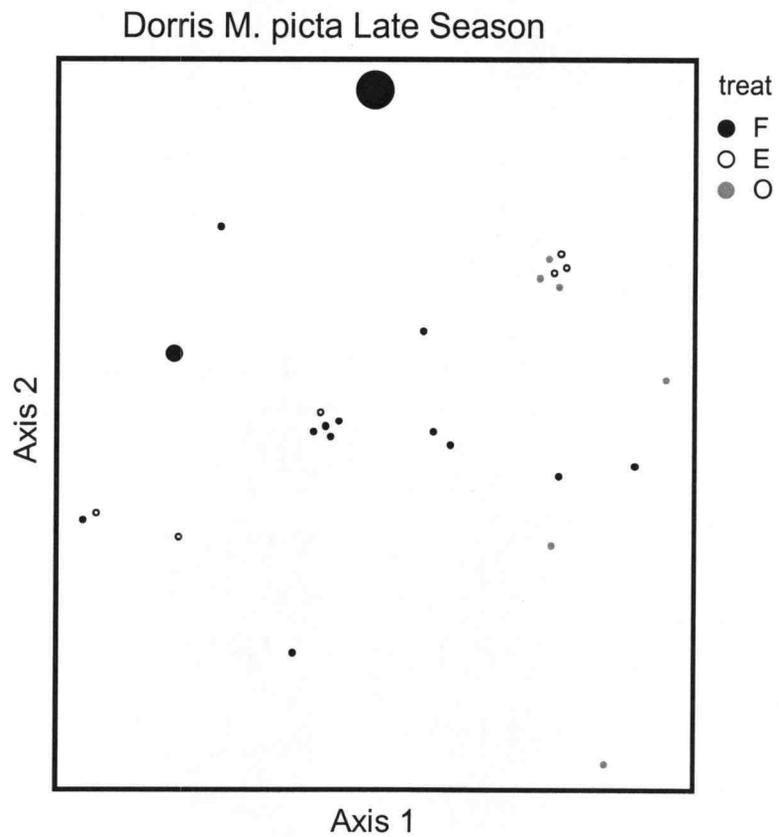
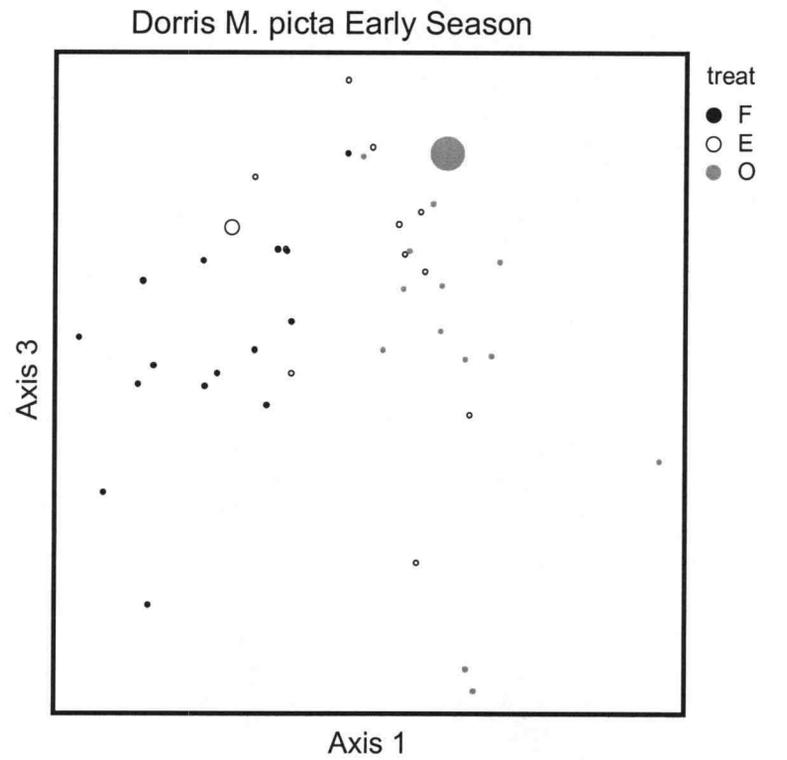
Figure 22. NMS ordination of sample units in Species space with *M. picta* overlay.

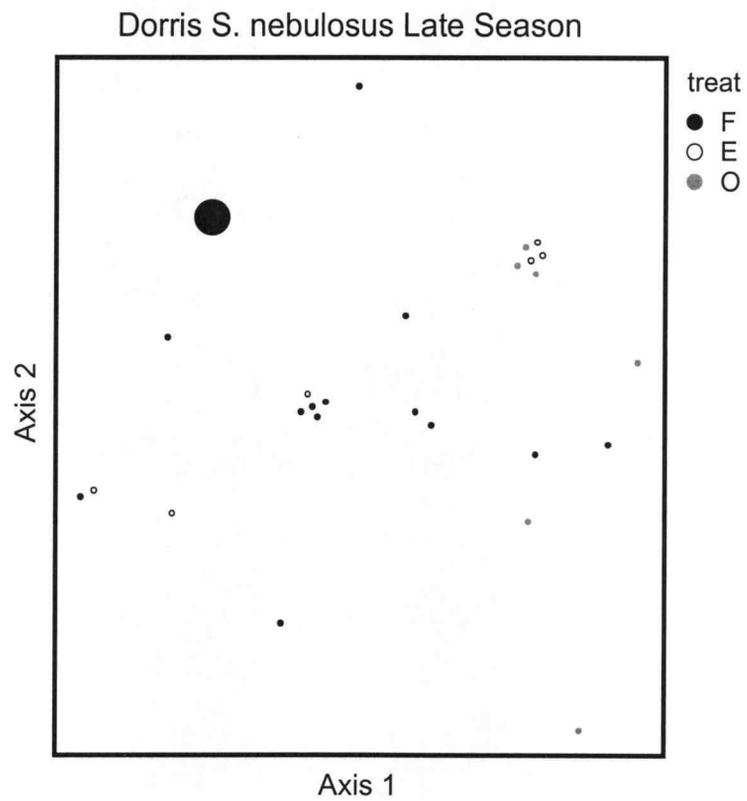
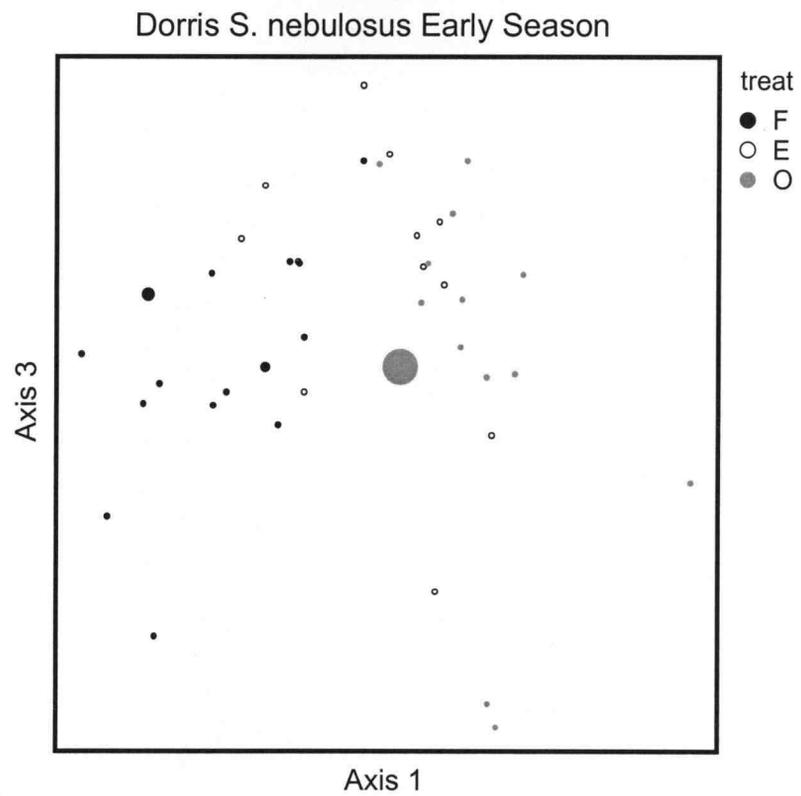
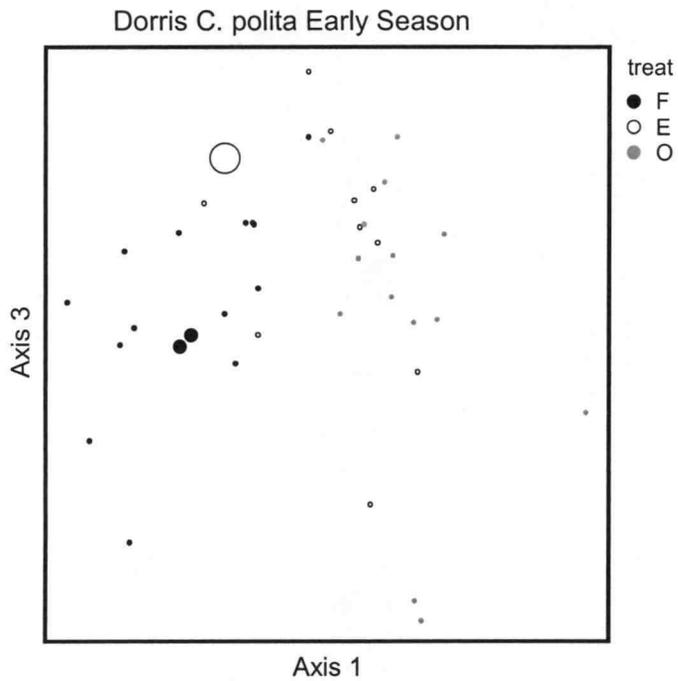
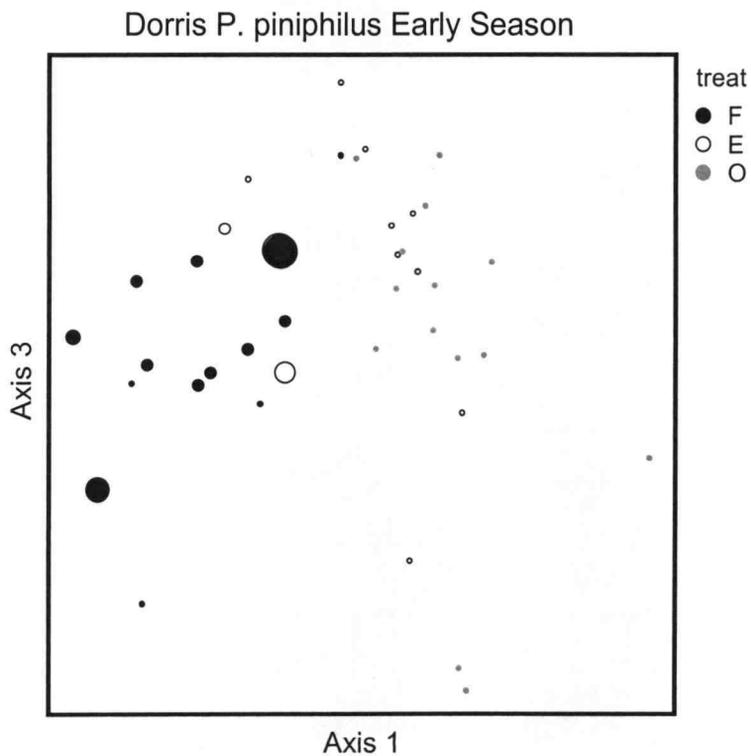
Figure 23. NMS ordination of sample units in Species space with *S. nebulosus* overlay.

Figure 24. NMS ordination of sample units in Species space with *C. polita* overlay.Figure 25. NMS ordination of sample units in Species space with *P. piniphilus* overlay.

Wiebe farm (Organic): In contrast to the previous farms, predators were found in all three treatments in both the early and late season (Figure 26). Herbivores were also found everywhere in the early season, but the peaks shifted to the forest and the edge by late season (Figure 27).

Of the predators, *Ischyropalpus nitidulus* (LeConte) (Figure 28) and *Scymnus* sp. (Figure 29) were evenly distributed early in the season, but the peak abundances shifted to the center of the orchard and the edge in the late season. *Harmonia axyridus* (Pallas) (Figure 30) peaked in the center of the orchard in the early season, but spread out to all three treatments by late season. *Cycloneda polita* (Figure 31) and *Coccinella septempunctata* (Linnaeus) (Figure 32) had peak abundances in the orchard in the early season. However, their distribution in the orchard was uneven. By late season, the peaks remained in the orchard, but they were more evenly distributed. *Throscus sericeus* (Figure 33) and *Scymnus nebulosus* (Figure 34) were evenly distributed in the early season, but the peaks shifted into the forest by late season.

The only herbivore that made up at least one per cent of the total abundance was *Diachus auratus* (Fabricius) (Figure 35). It was evenly distributed across the FEO gradient early in the season, but only occurred in the forest in the late season and was rare.

Figure 26. NMS ordination of sample units in Functional space with Predator overlay.

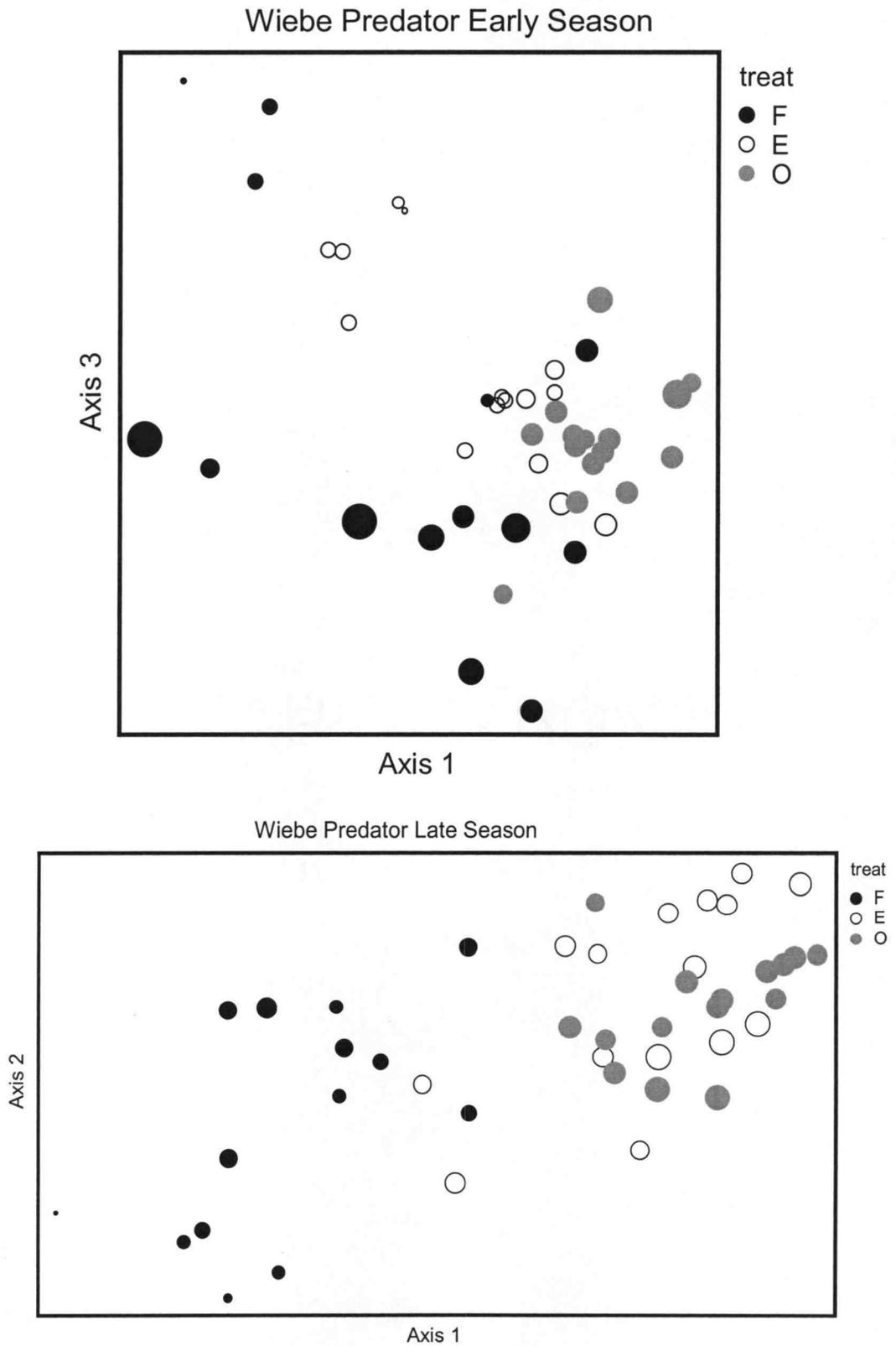


Figure 27. NMS ordination of sample units in Functional space with Herbivore overlay.

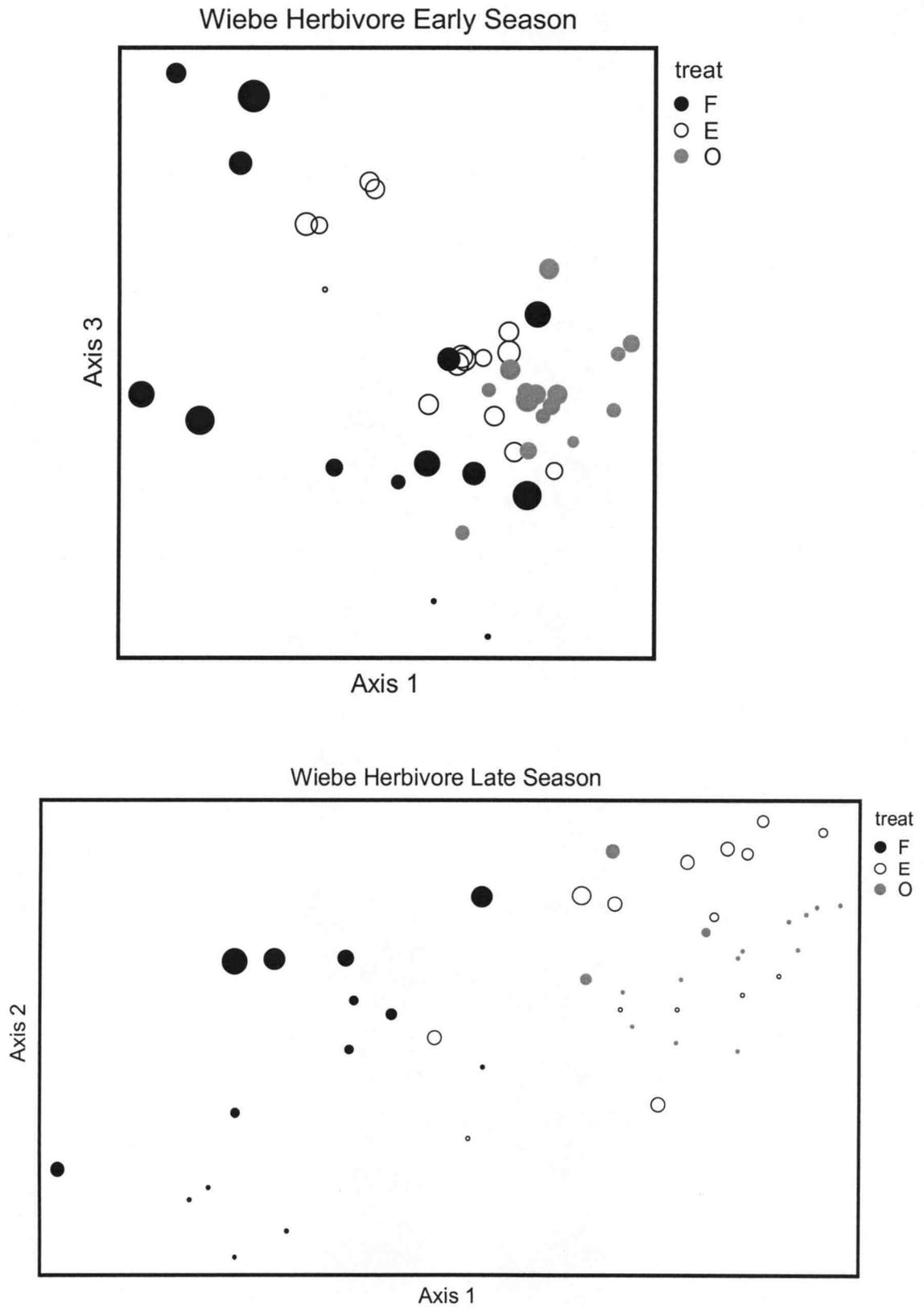


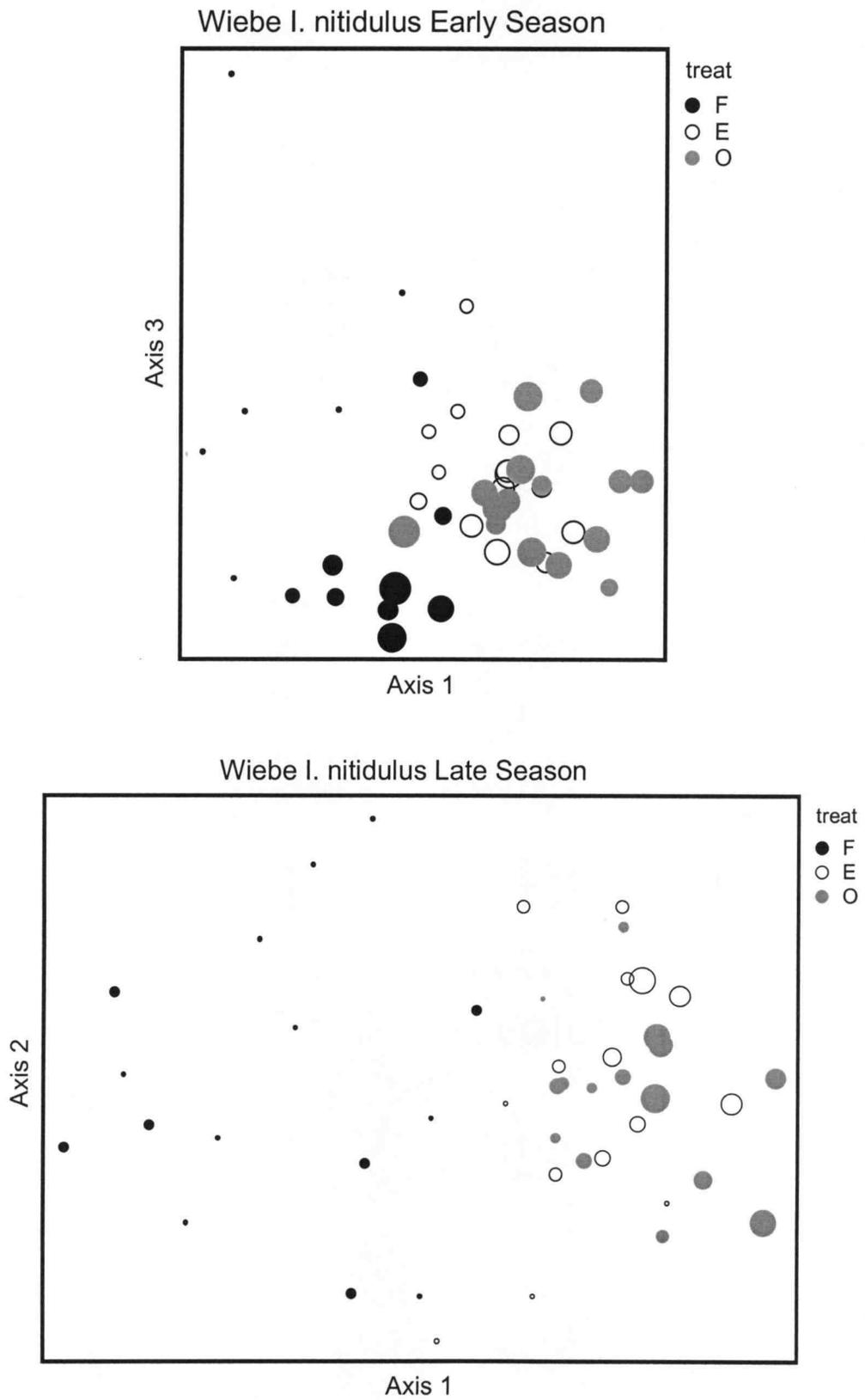
Figure 28. NMS ordination of sample units in Species space with *I. nitidulus* overlay.

Figure 29. NMS ordination of sample units in Species space with Scymnus overlay.

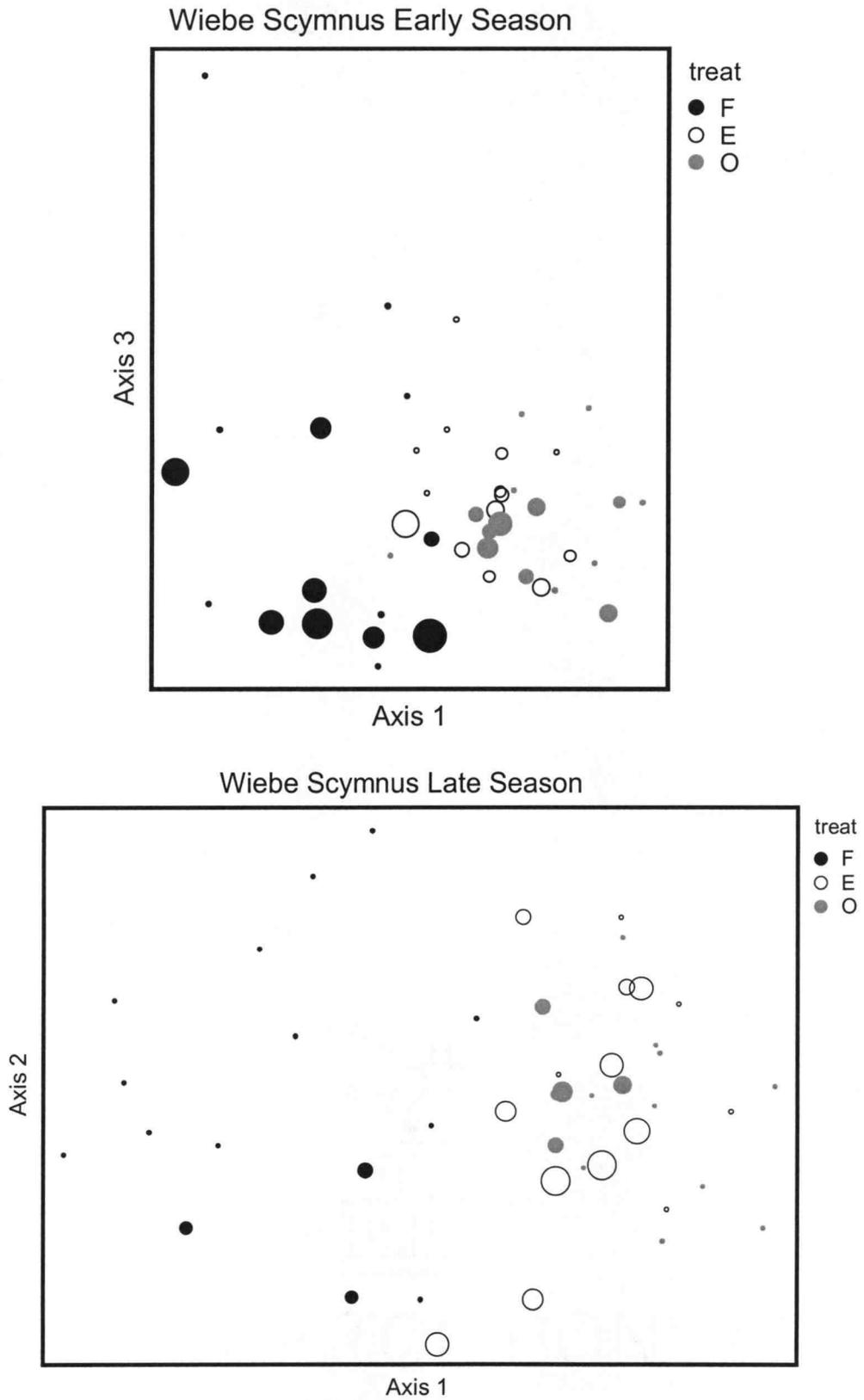


Figure 30. NMS ordination of sample units in Species space with *H. axyridis* overlay.

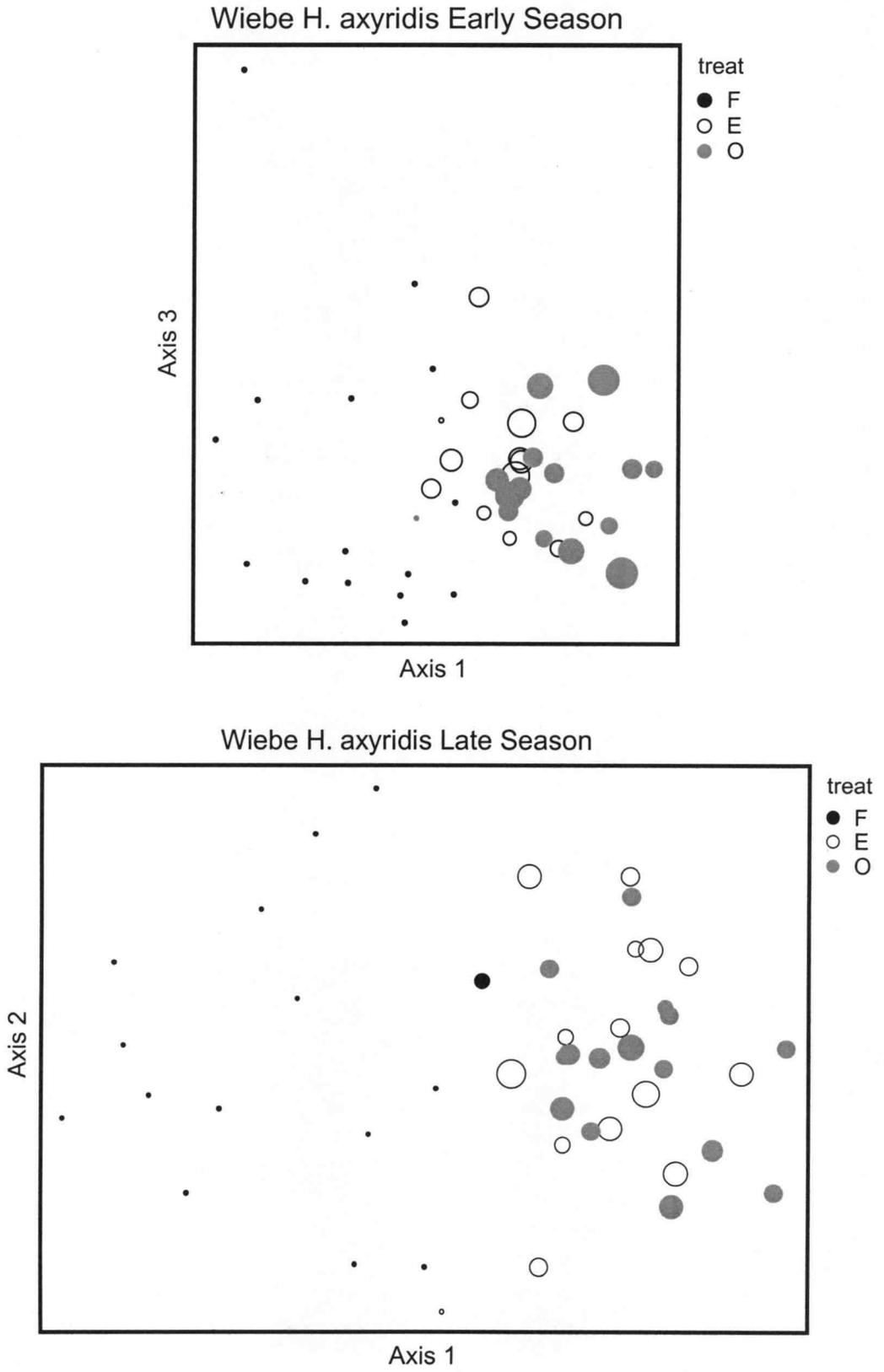


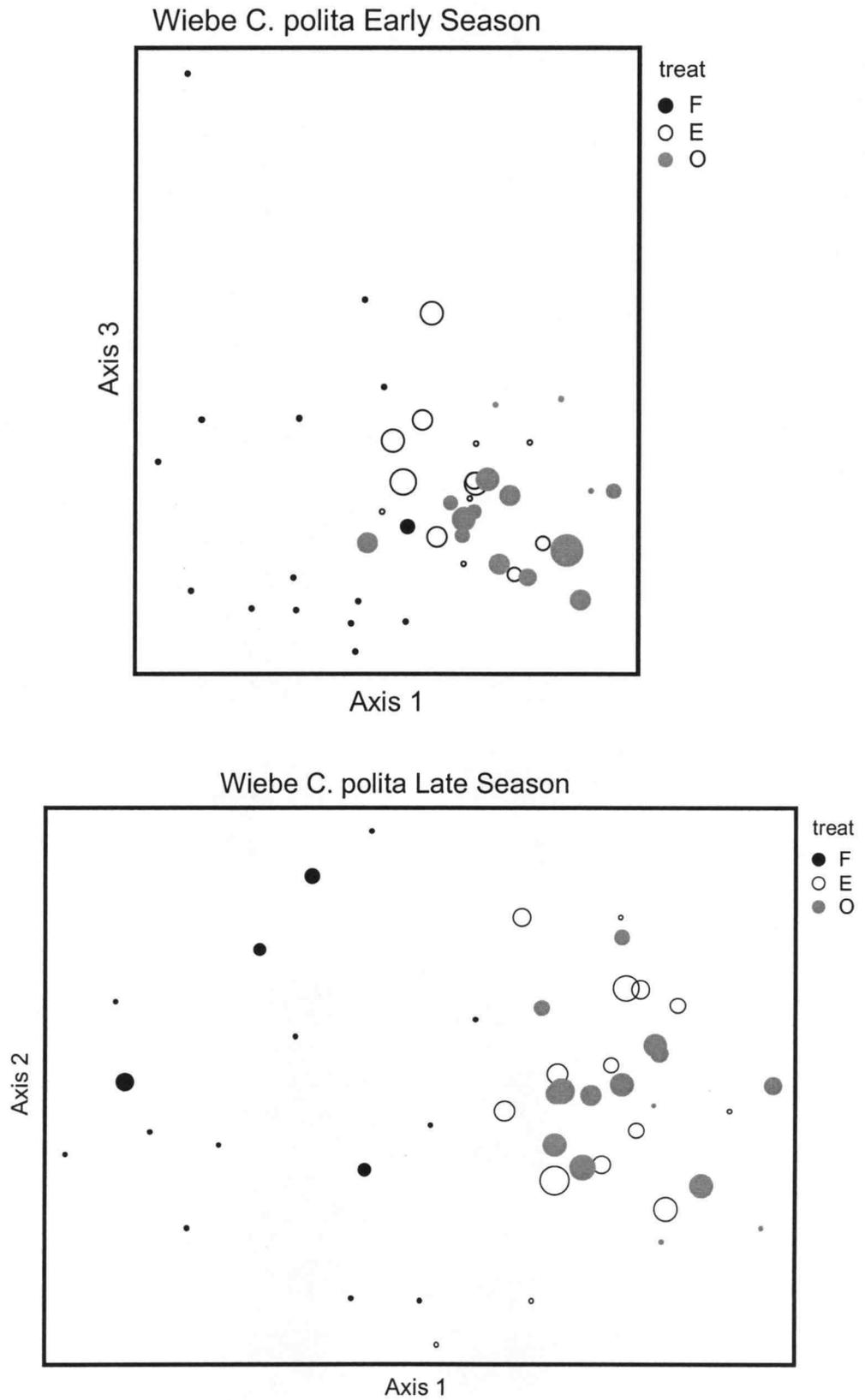
Figure 31. NMS ordination of sample units in Species space with *C. polita* overlay.

Figure 32. NMS ordination of sample units in Species space with *C. septempunctata* overlay.

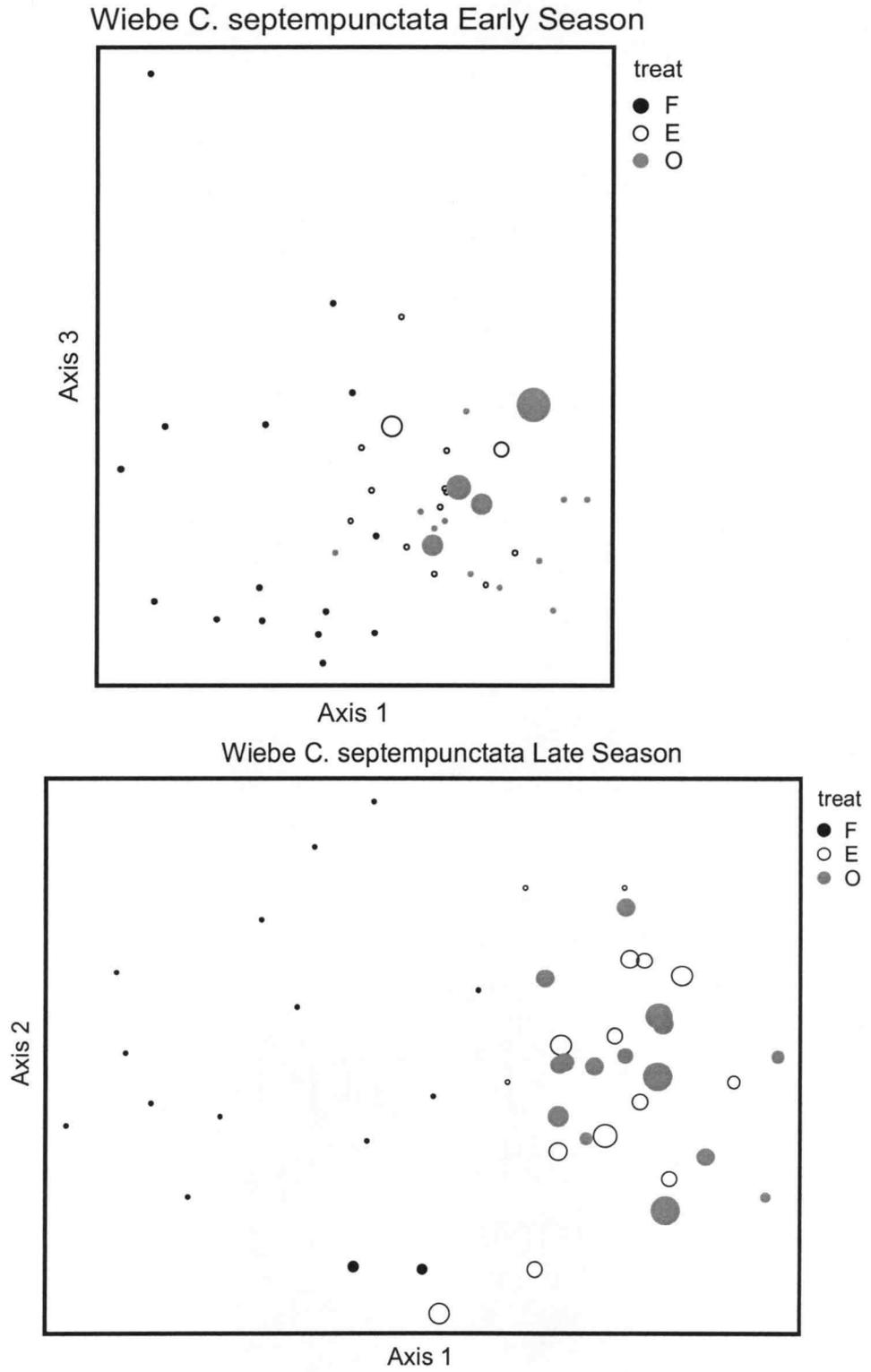


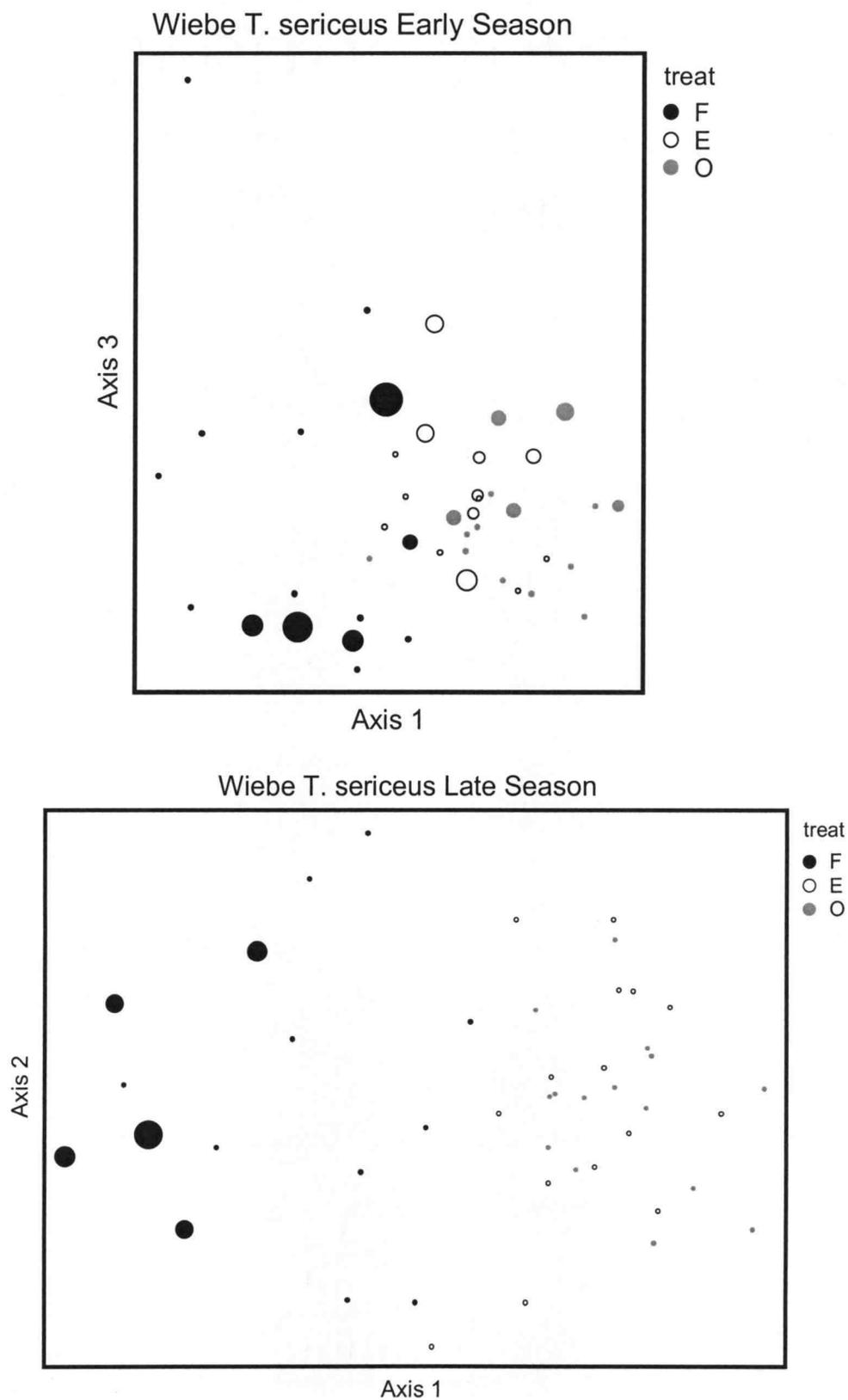
Figure 33. NMS ordination of sample units in Species space with *T. sericeus* overlay.

Figure 34. NMS ordination of sample units in Species space with *S. nebulosus* overlay.

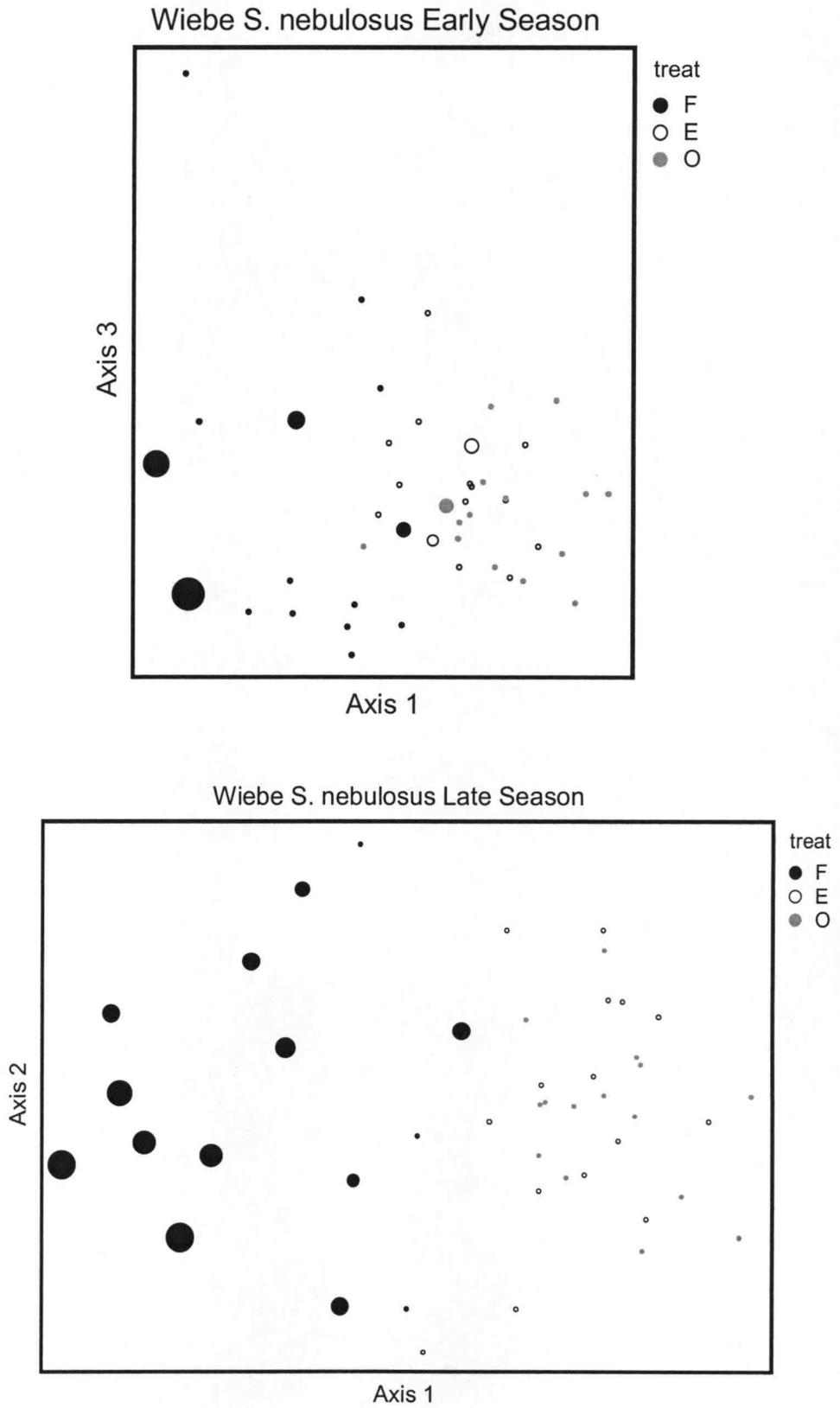
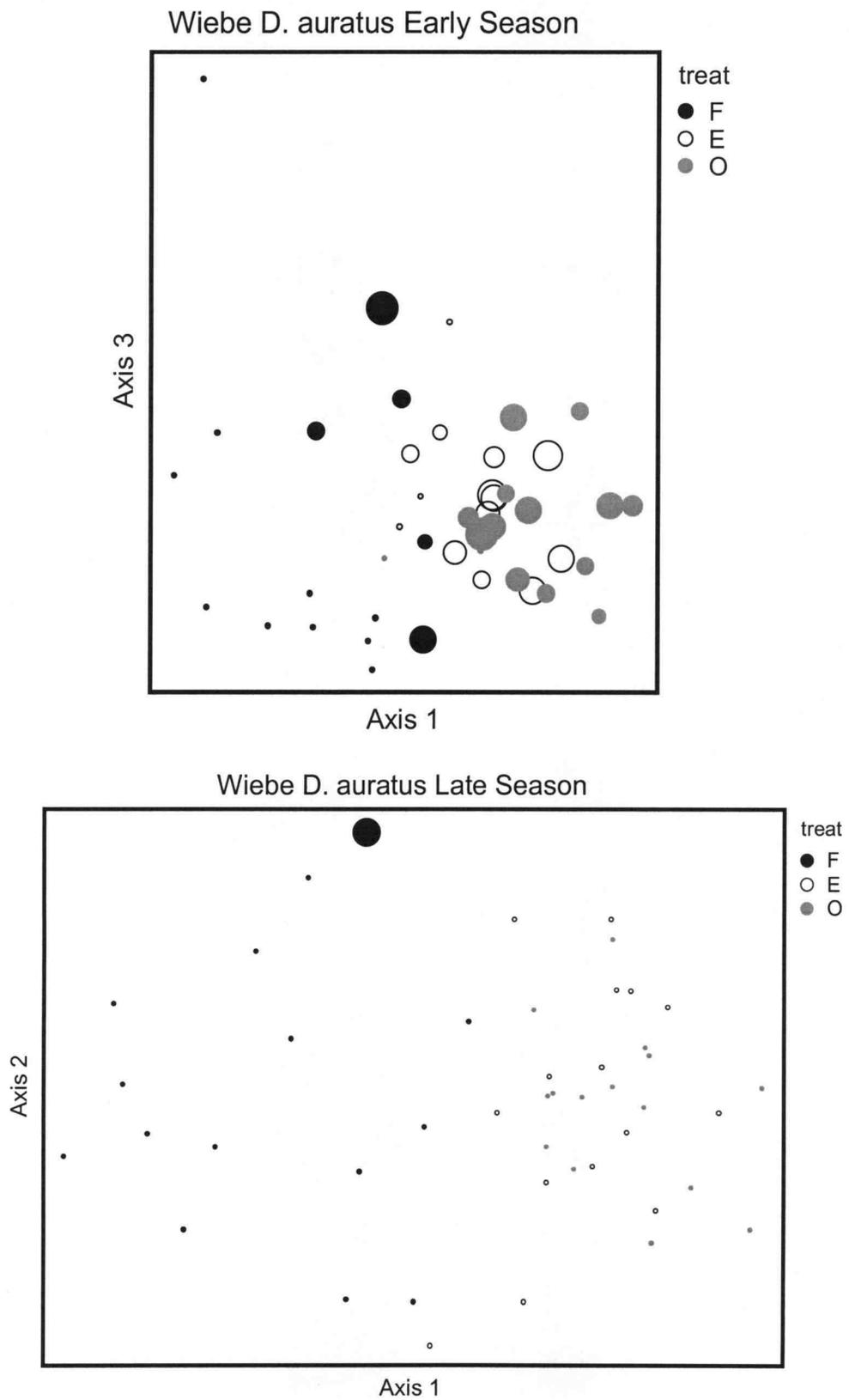


Figure 35. NMS ordination of sample units in Species space with *D. auratus* overlay.

Corricello farm (Organic): Herbivores peaked in the forest in both early and late season (Figure 36). Predators were important in the orchard in both early and late season (Figure 37). All predators occurred in the orchard. *Malthodes* sp. (Figure 38), *Throscus sericeus* (Figure 39), *Harmonia axyridus* (Figure 40) and *Calvia quatuordecimguttata* (Linnaeus) (Figure 41) were all present in the orchard in the early season. *Scymnus* sp. (Figure 42) was present in the late season when its peak shifted from the forest into the orchard. *Cycloneda polita* (Figure 43) peaked in the orchard throughout the season.

Three species of curculionid (*Sciopithes obscures* (Figure 44), *Thricolepsis inornata* Horn (Figure 45) and *Apion fuscirostre* Fabricius (Figure 46)) were predominantly restricted to the forest. Two elaterids, *Agriotes sparsus* LeConte (Figure 47) and *Limonium nitidulus* Horn (Figure 48), peaked in the orchard in the early season, but were absent from samples in the late season. *Syneta albida* (Figure 49) peaked on the edge of the orchard and also disappeared by late season. *Diachus auratus* (Figure 50) peaked in the orchard in the early season, but became very rare in the late season.

Figure 36. NMS ordination of sample units in Functional space with Herbivore overlay.

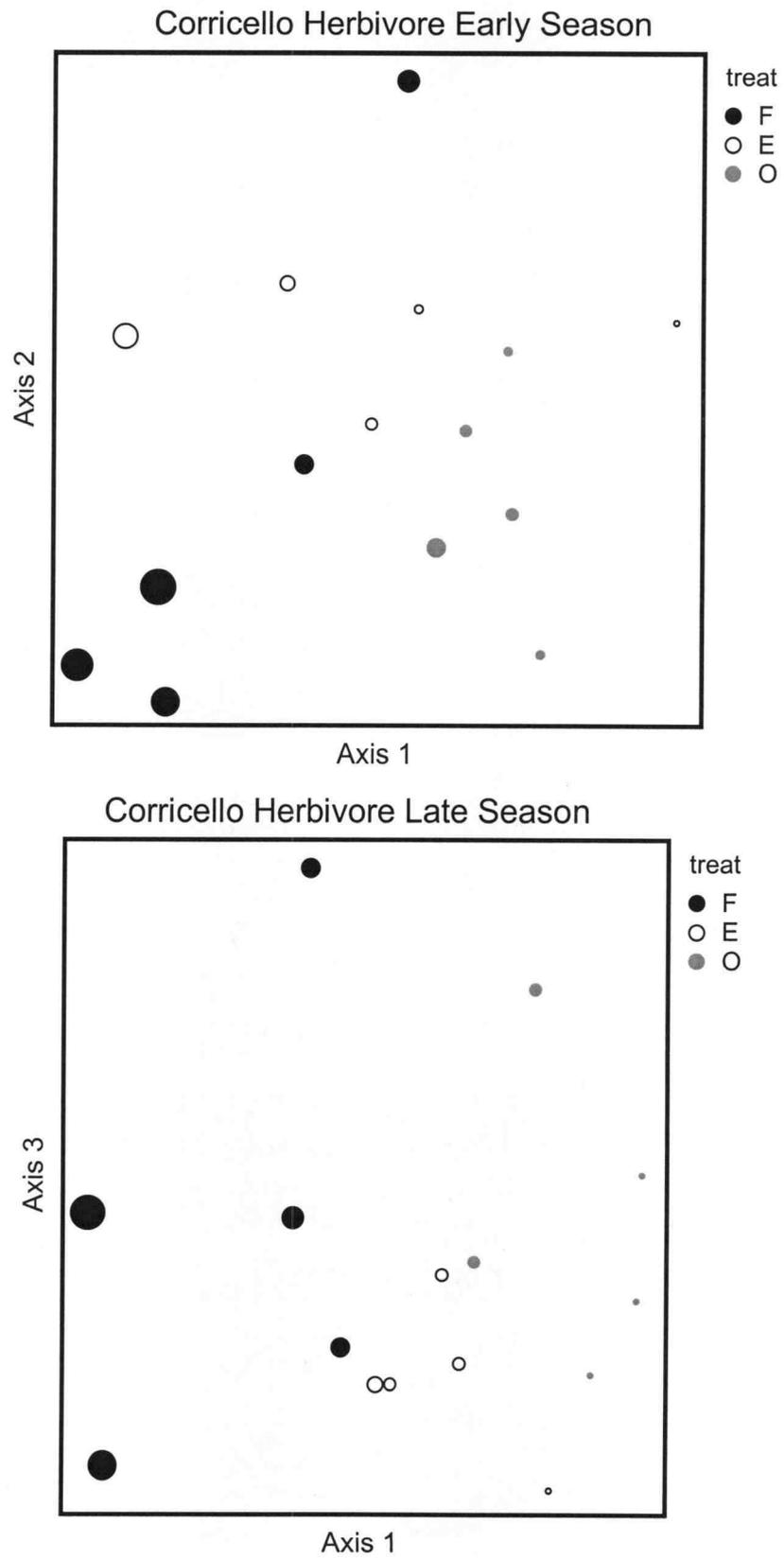


Figure 37. NMS ordination of sample units in Functional space with Predator overlay.

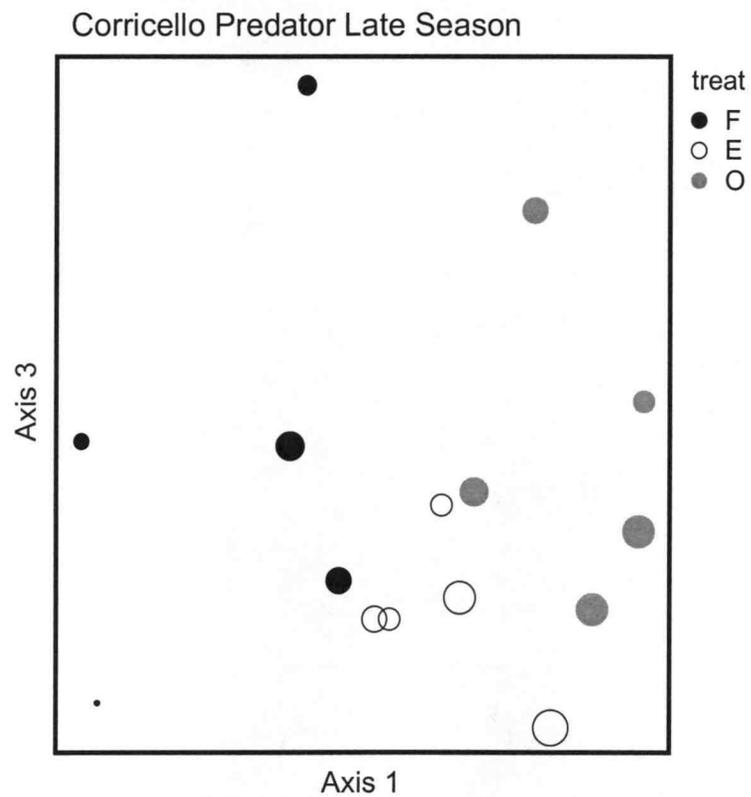
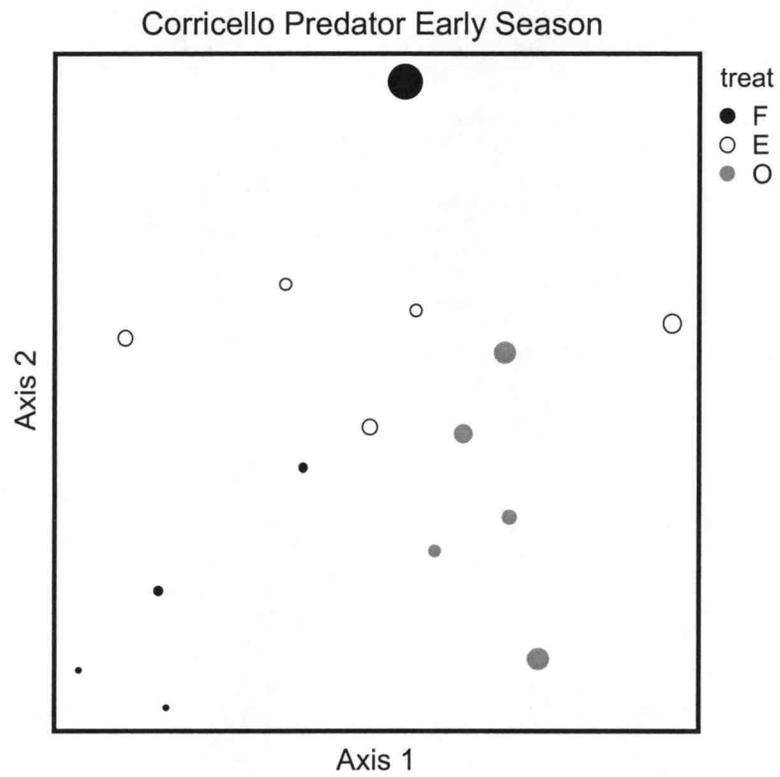


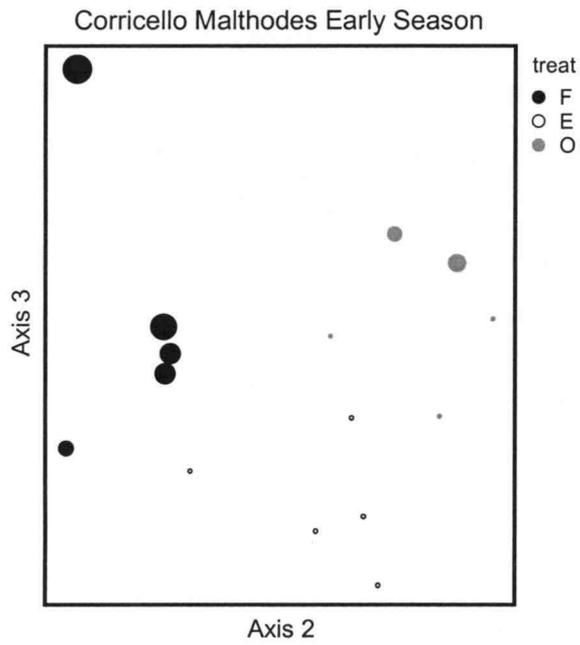
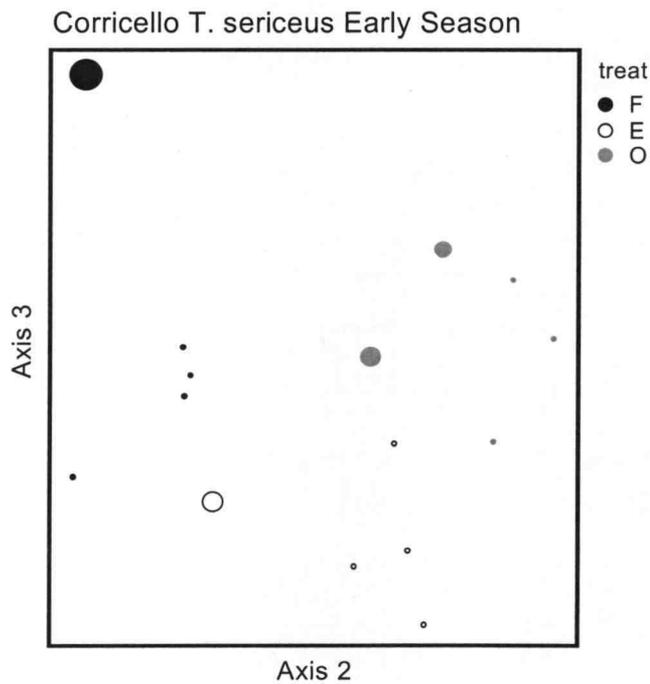
Figure 38. NMS ordination of sample units in Species space with *Malthodes* overlay.Figure 39. NMS ordination of sample units in Species space with *T. sericeus* overlay.

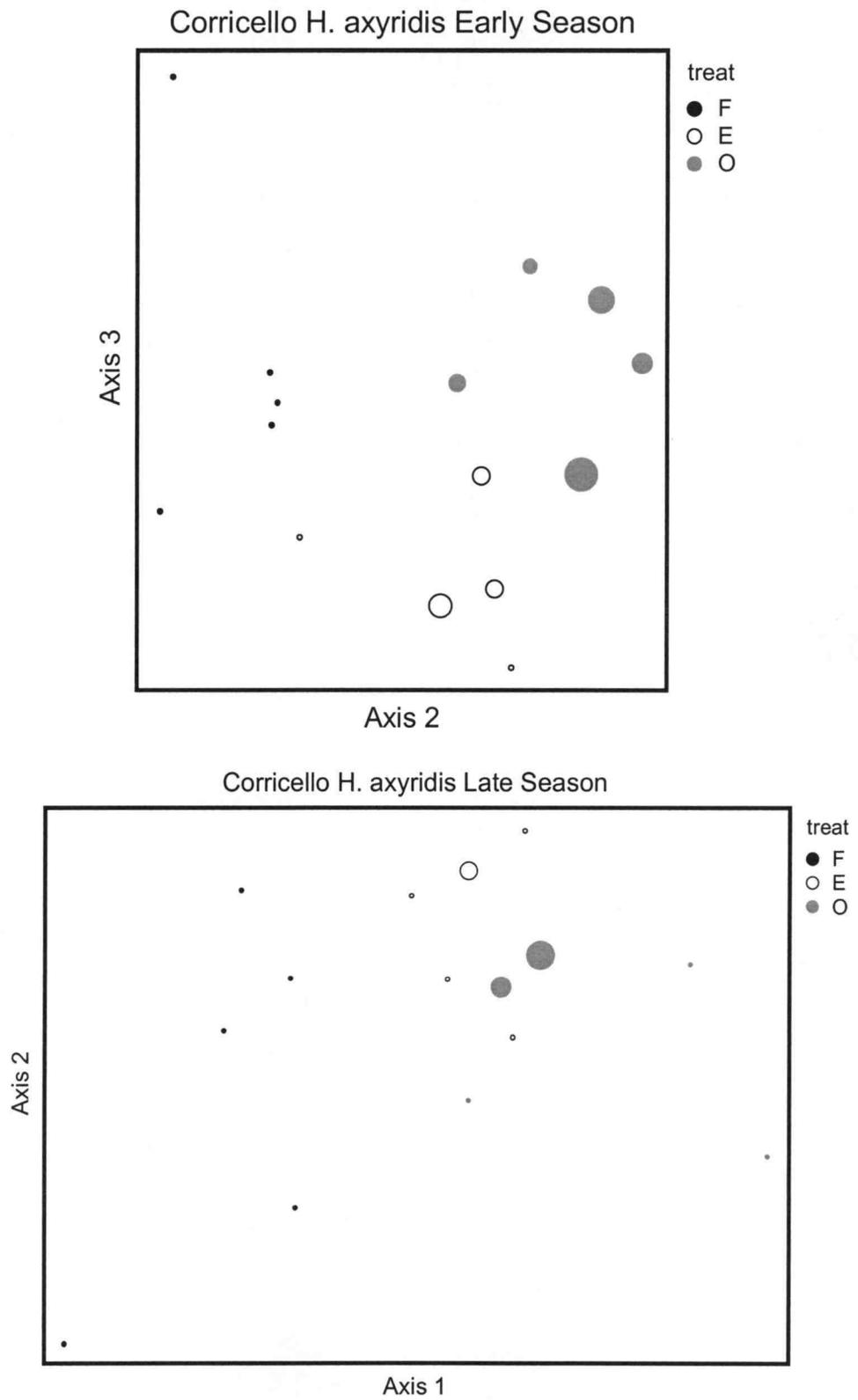
Figure 40. NMS ordination of sample units in Species space with *H. axyridis* overlay.

Figure 41. NMS ordination of sample units in Species space with *C. quatuordecimguttata* overlay.

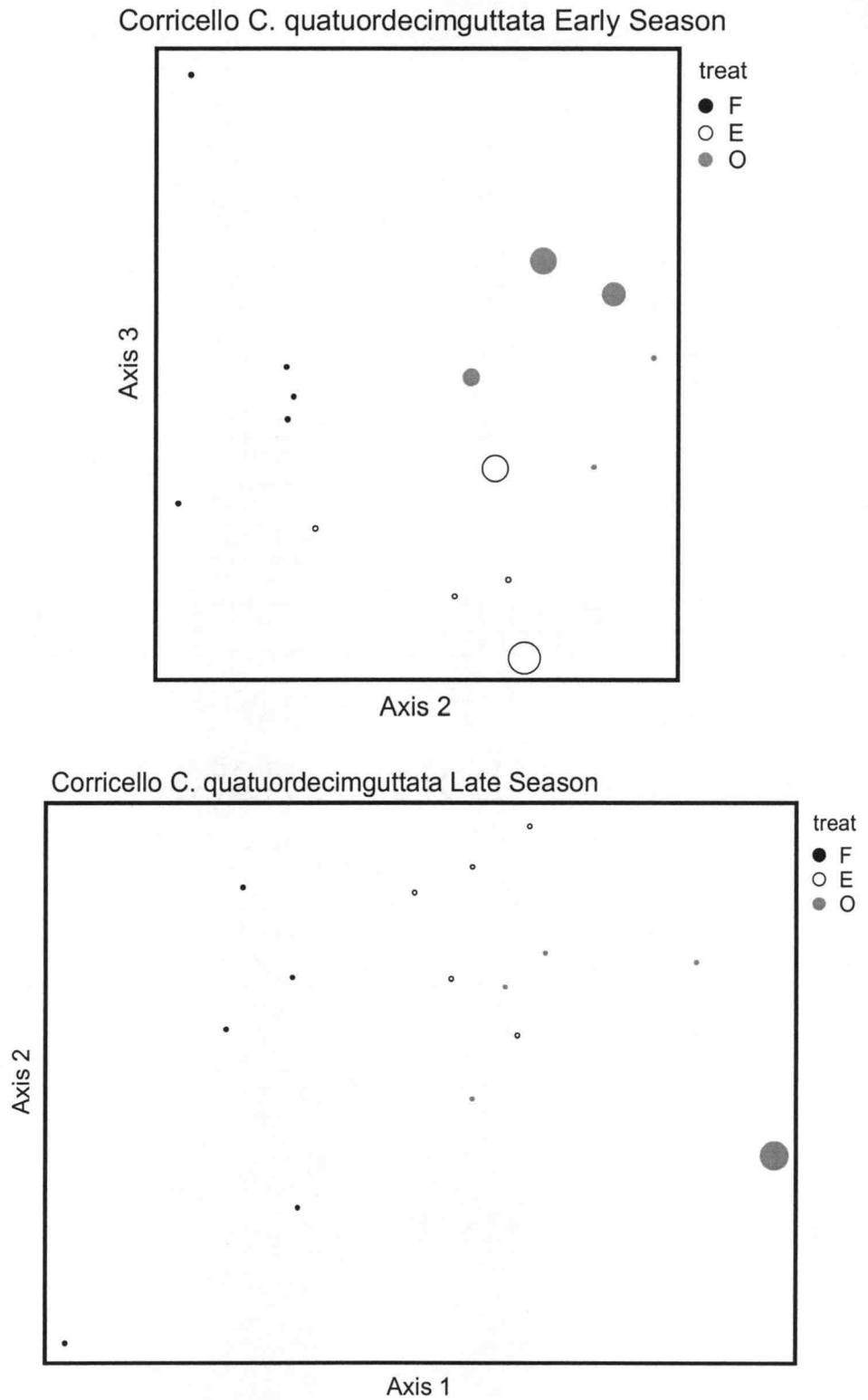


Figure 42. NMS ordination of sample units in Species space with Scymnus overlay.

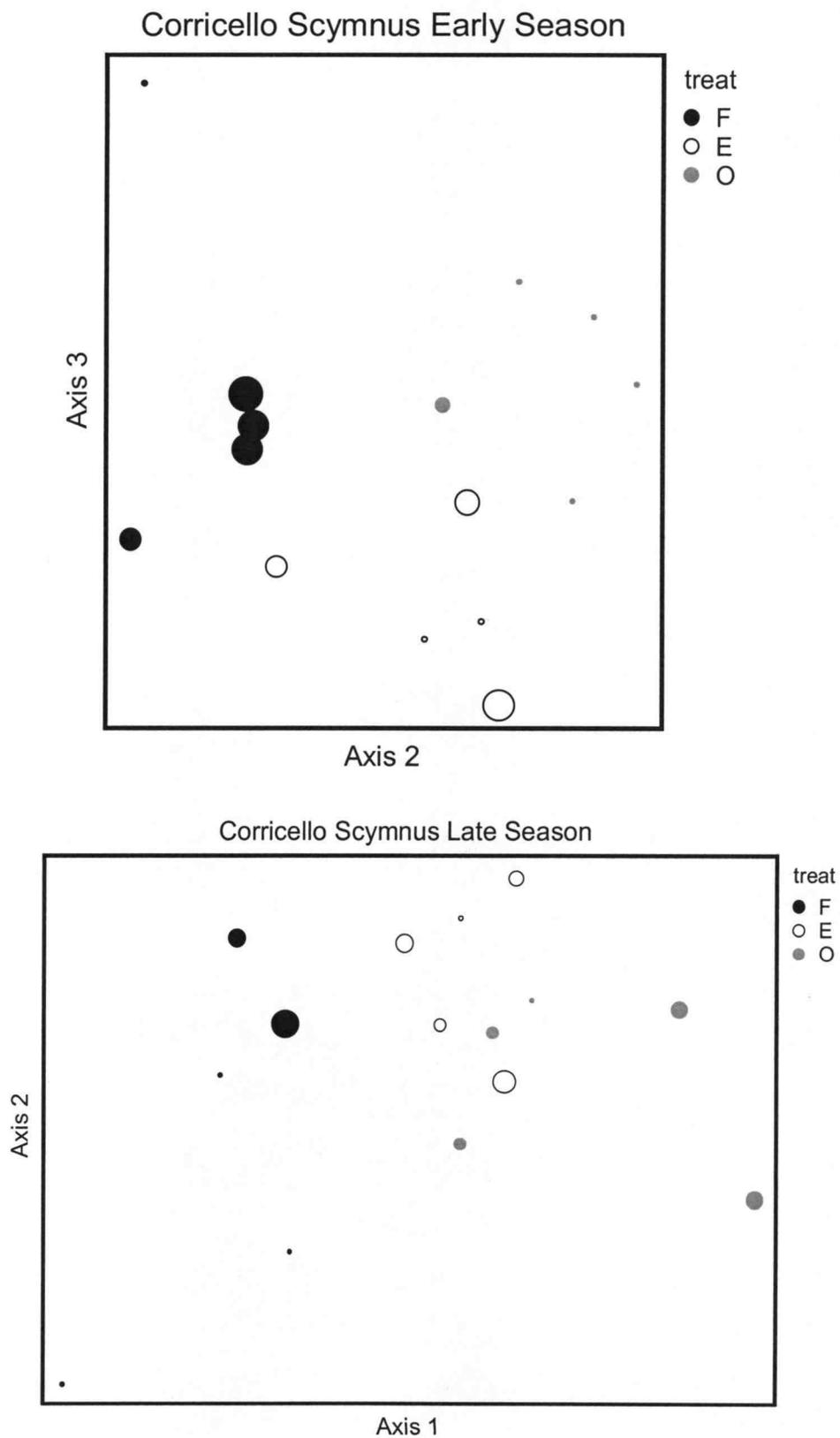


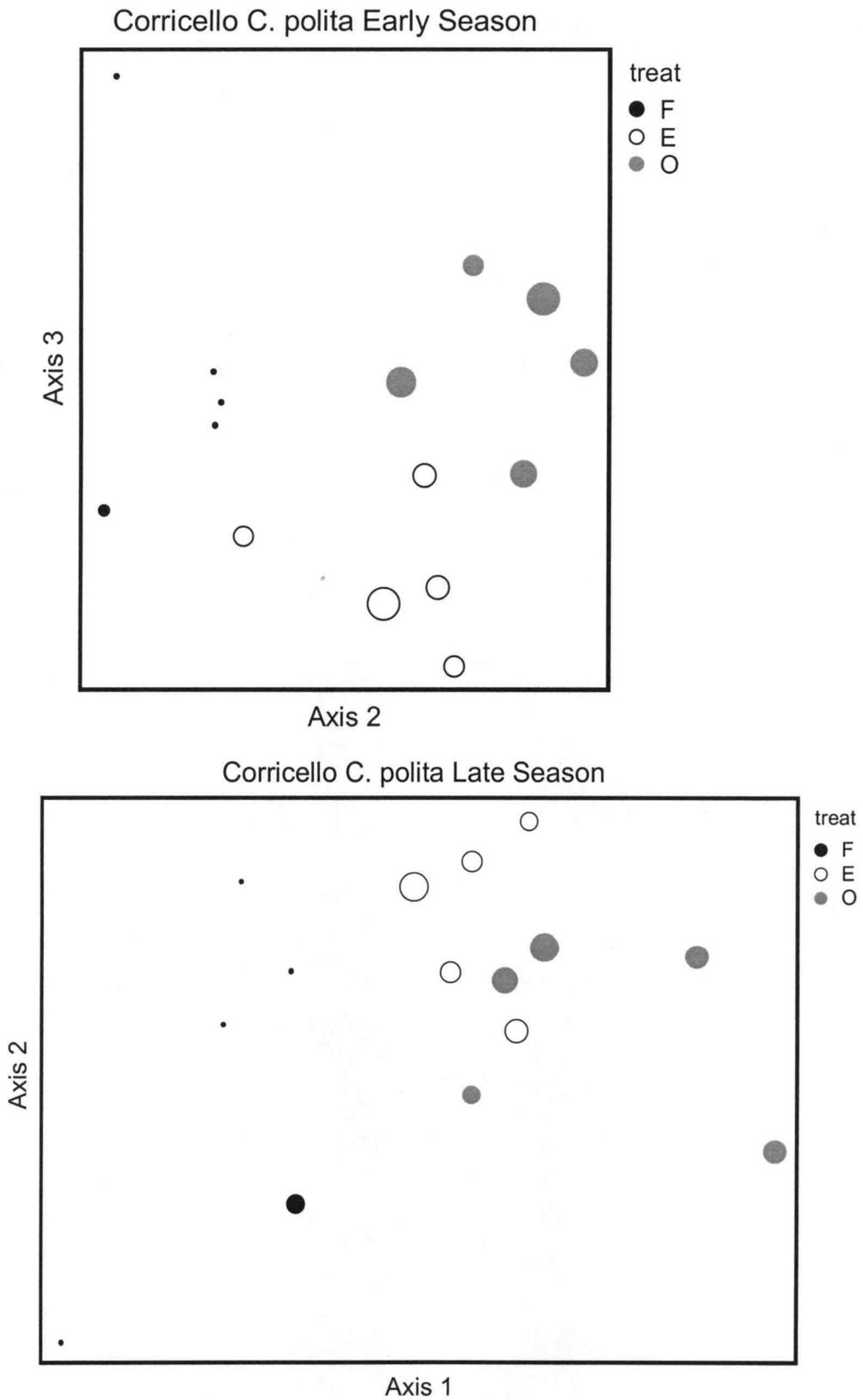
Figure 43. NMS ordination of sample units in Species space with *C. polita* overlay.

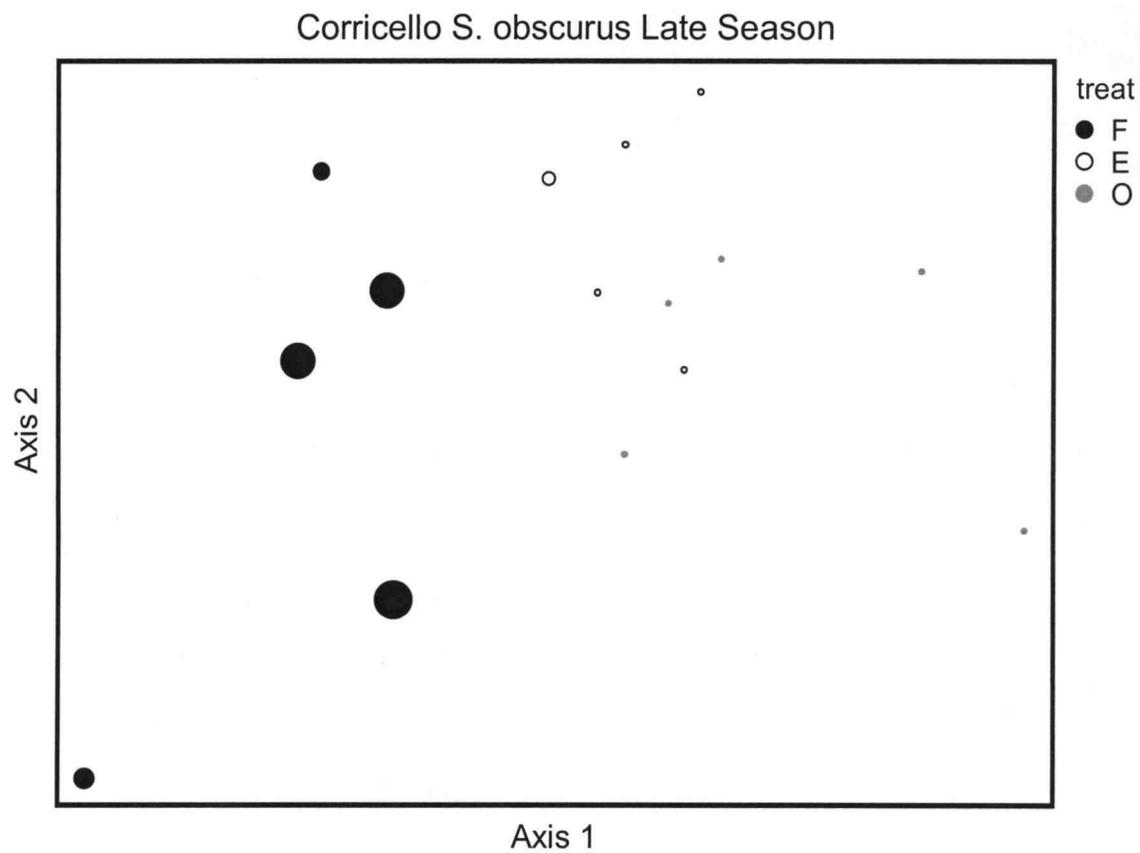
Figure 44. NMS ordination of sample units in Species space with *S. obscurus* overlay.

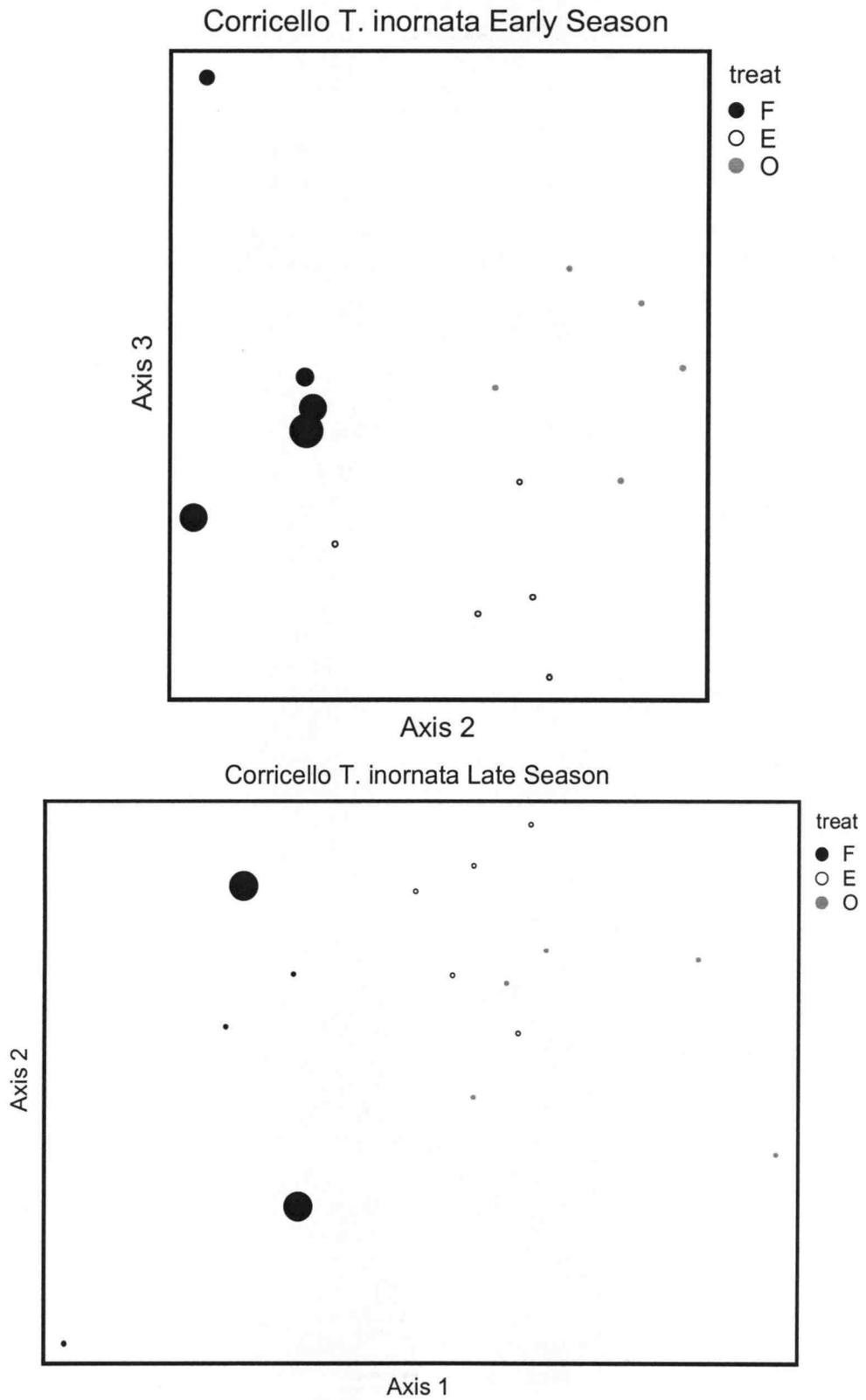
Figure 45. NMS ordination of sample units in Species space with *T. inornata* overlay.

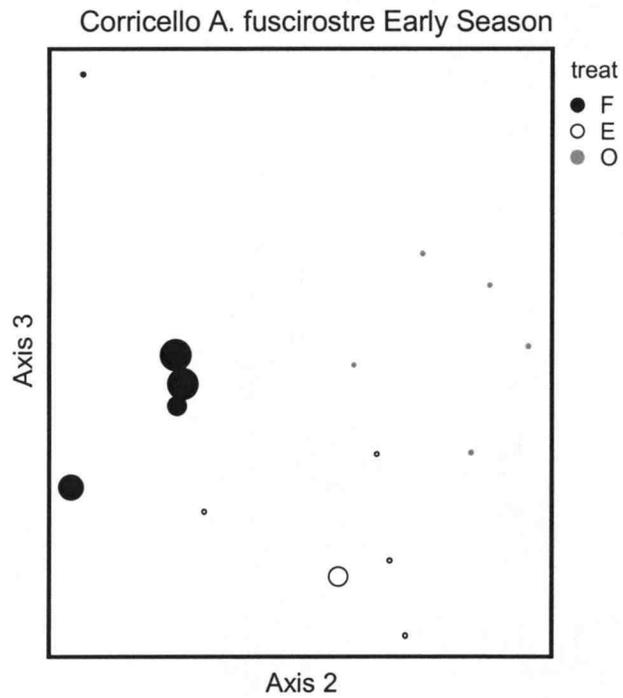
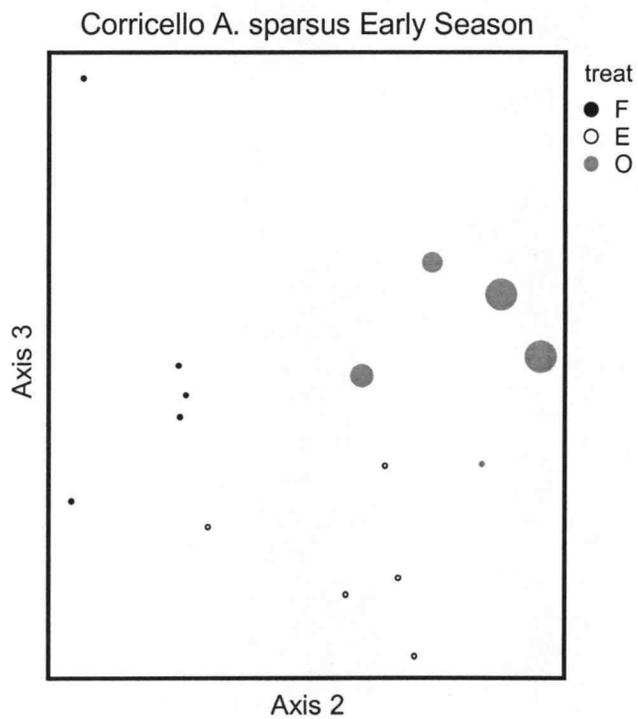
Figure 46. NMS ordination of sample units in Species space with *A. fuscirostre* overlay.Figure 47. NMS ordination of sample units in Species space with *A. sparsus* overlay.

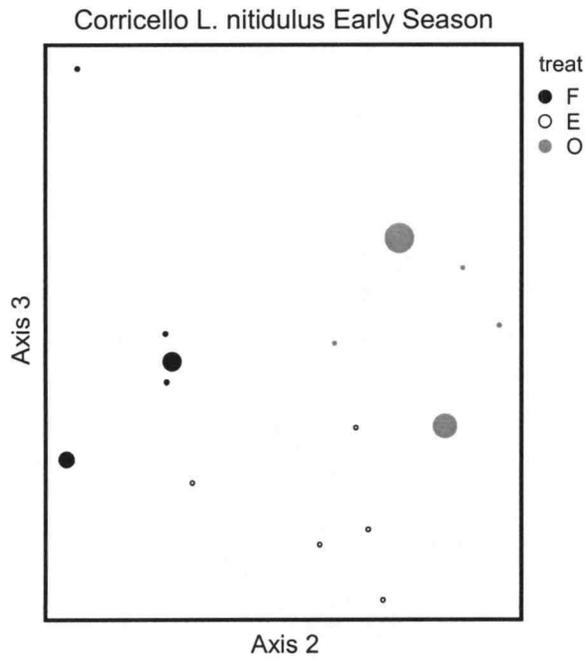
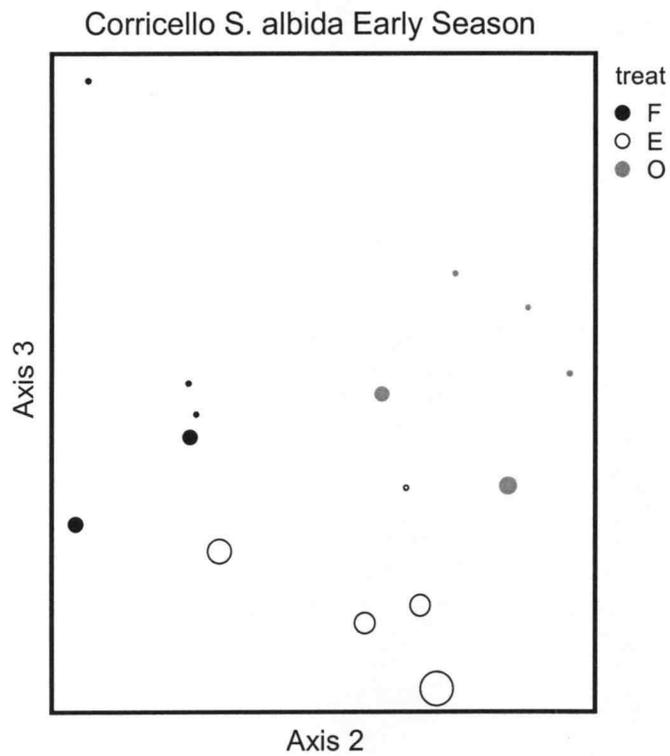
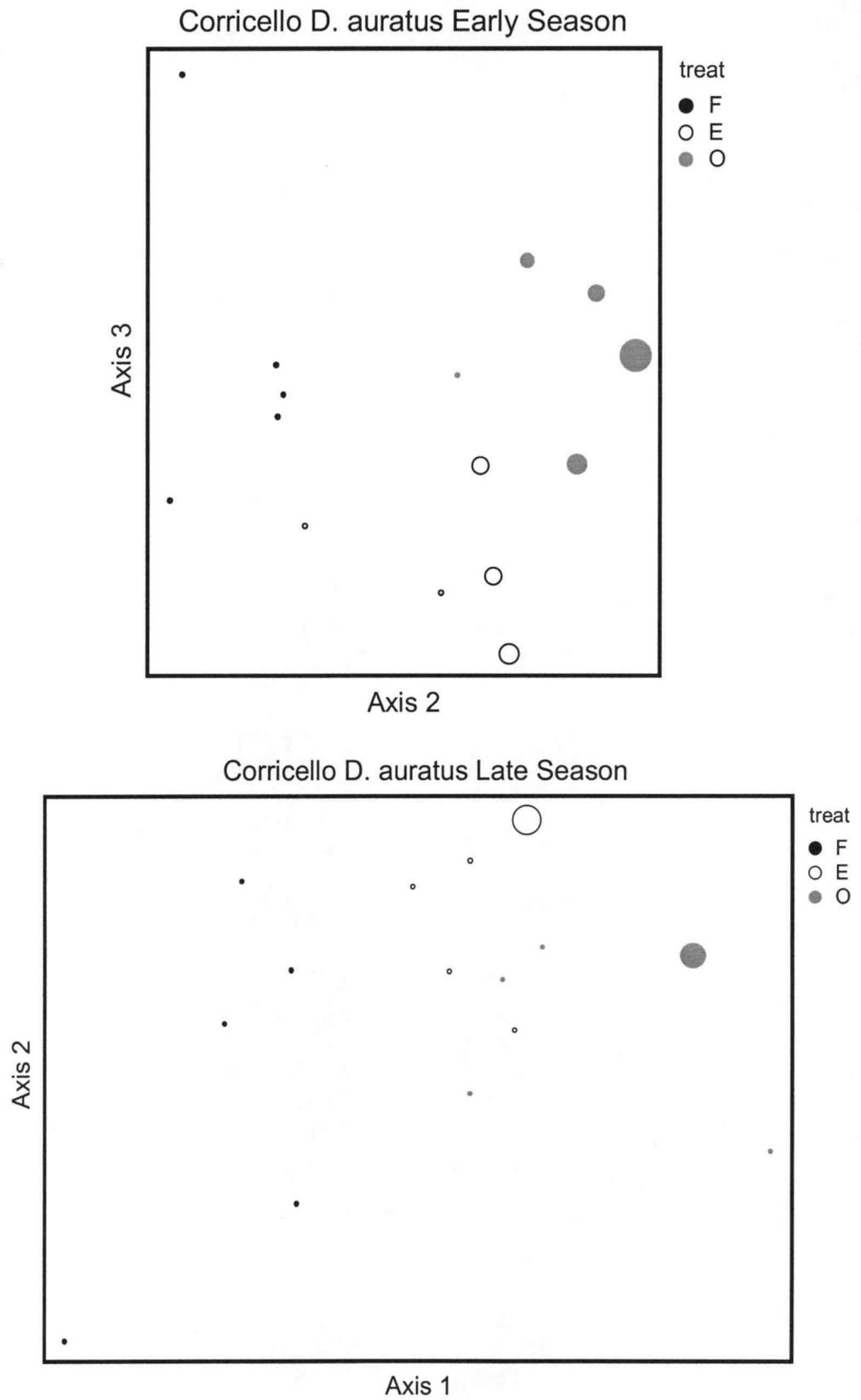
Figure 48. NMS ordination of sample units in Species space with *L. nitidulus* overlay.Figure 49. NMS ordination of sample units in Species space with *S. albida* overlay.

Figure 50. NMS ordination of sample units in Species space with *D. auratus* overlay.

Heteroptera Results:

Functional Groups:

Of the IPM orchards 95% of the individuals were predators, 3% were herbivores and 2% were seed feeders. Of the organic orchards, 94% were predators, 5% herbivores and 1% seed feeders. Since there were only three functional groups of Heteroptera, no ordinations were run on these data.

MRPP:

Significant differences were found across treatments in all four farms. (Table 15).

Table 15. Multi-Response Permutation Procedure. Heteroptera data

Farm	A-value	p-value
Bush	0.115	$<10^{-8}$
Dorris	0.095	$<10^{-7}$
Wiebe	0.110	$<10^{-8}$
Corricello	0.175	$<10^{-4}$

The p-value is the probability of Type I error for the hypothesis of no difference between treatments.
The A-value is the chance-corrected within group agreement.

Objective 1. To compile a complete list of Coleoptera and Heteroptera fauna of *C. avellana* and *C. cornuta*.

Of the Heteroptera, 12 families, 41 genera and 49 species were identified. Fifteen bug species are non-native (Table 16). *Malacocoris chlorizans* (Panzer) (Heteroptera:

Miridae) *E. rubromaculatus*, and *E. vagabundus*, and *Empicoris pilosus* (Fieber) (Heteroptera: Reduviidae) are all new species to Oregon and *Metopoplax ditomoides* (Costa) (Heteroptera: Lygaeidae) is a new species to the U.S. Many of the organisms in this study may well be incidental to hazelnut foliage, especially those taken from the native hazelnut in the forest, as the hazelnuts are surrounded by alternate hosts. Species that are likely tourists are labeled 'T' in Table 17.

Table 16: Adult Heteroptera identified from beating samples of *Corylus* spp.

ANTHOCORIDAE

Anthocoris antevolans White [s,v]**Orius minutus* (Linnaeus) [a,b]*Orius tristicolor* (White) [a,b]

BERYTIDAE

Neoreides muticus (Say) [u,b]

LARGIDAE

Largus cinctus Herrich-Schaeff. [u,v]

LYGAEIDAE

Blissus sp. [s,c]*Kleidocerys franciscanus* (Stal) [u,v]**Megalonotus sabudicola* (Thomson) [u,b]**Metopoplax ditomoides* (Costa) [u,v]*Peritrechus tristis* VanDuzee [u,b]**Plinthisus brevipennis* (Latreille) [u,b]

MIRIDAE

Blepharidopterus angulatus* (Fallen) [u,b]*Blepharidopterus provancheri* (Burque) [u,b]Campyloneura virgula* (Herrich-Schaeff.) [a,b]*Ceratocapsus* sp. [u,c]**Compsidolon salicellum* (Herrich-Schaeff.) [a,b]*Deraeocoris brevis* (Uhler) [u,b]*Deraeocoris validus* (Reuter) [s,c]*Dicyphus discrepans* Knight [u,c]*Dicyphus hesperus* Knight [u,b]*Eurychiloptera pacifica* Stonedahl [u,b]**Heterotoma merioptera* (Scopoli) [u,b]*Hyaliodes harti* Knight [u,c]**Lepidargyrus anicorifer* (Fieber) [s,c]*Lepidopsallus rubidus* (Uhler) [u,c]*Lygus* sp. [u,b]**Malacocoris chlorizan* (Panzer) [a,b]*Paraproba nigrinervis* VanDuzee [a,b]*Phytocoris* spp. [u,b]**Phytocoris tiliae* (Fabricius) [u,b]*Tropidosteptes pacificus* (VanDuzee) [u,c]

NABIDAE

Nabis alternatus Parshley [u,b]*Nabis americanoferus* Carayon [u,v]*Nabis rufuscolus* Reuter [u,b]

PENTATOMIDAE

Cosmopepla integressus (Uhler) [s,c]*Euschistus tristigmus* (Say) [u,b]*Euschistus variolarius* (P. de Bois) [s,v]*Holcostethus abbreviatus* Uhler [u,v]*Neottiglossa tumidifrons* Downes [u,v]*Neottiglossa undata* (Say) [u,v]*Podisus maculiventrus* (Say) [s,v]

PIESMATIDAE

Piesma cineraeum (Say) [s,v]

REDUVIIDAE

Barce fraterna (Say) [u,c]**Empicoris culiciformis* (DeGeer) [u,c]*Empicoris errabundus* (Say) [u,b]**Empicoris pilosus* (Fieber) [u,c]**Empicoris rubromaculatus* (Blackburn) [u,c]**Empicoris vagabundus* (Linnaeus) [u,c]

RHOPALIDAE

Boisea rubrolineata Barber [a,b]

THYREOCORIDAE

Corimelaena pulicaria (Germar) [u,c]

TINGIDAE

Acalypta mera Drake [u,b]*Corythuca salicata* Gibson [u,b]*Physatocheila pexa* (Say) [s,c]

*NON-NATIVE

s = singleton (only one individual)

u = uncommon (<50 individuals)

a = abundant (>50 individuals)

c = *C. cornuta*v = *C. avellana*

b = both

Table 17. Functional Groups of Heteroptera.

	H	Pr	Sd	T	Exot	References
Aantevolans	0	1	0	0	0	Messing & AliNiazee 1985; Lattin 1999a; Anderson 1962
Orius	0	1	0	0	1*	Lattin 1999a; Anderson 1962; Southwood & Leston 1959
Nmuticus	1	0	0	0	0	Parsons et al. 1991; Southwood & Leston 1959
Lcinctus	1	0	0	1	0	Schuh & Slater 1995
Blissus	1	0	0	1	0*	Schuh & Slater 1995
Kfranciscanus	0	0	1	1	0	Schuh & Slater 1995; Parsons et al. 1991
Msabudicola	0	0	1	1	1	Sweet 1963; Parsons et al. 1991
Mditomoides	0	0	1	1	1	Lattin & Wetherill b; Southwood & Leston 1959
Ptristis	0	0	1	1	0	Sweet 1963
Pbrevipennis	0	0	1	1	1	Sweet 1963
Bangulatus	0	1	0	0	1	Wheeler & Henry 1992; Southwood & Leston 1959
Bprovancheri	0	1	0	0	0	Messing & AliNiazee 1985; Kelton 1980
Cvirgula	0	1	0	0	1	Messing & AliNiazee 1985; Viggiani 1994; Wheeler & Henry 1992
Ceratocapsus	0	1	0	1	0*	Parsons et al. 1991
Csalicellum	0	1	0	0	1	Messing & AliNiazee 1985; Viggiani 1994; Wheeler & Henry 1992
Deraeocoris	0	1	0	0	0*	Messing & AliNiazee 1985; Viggiani 1994; Westigard 1973; Kelton 1980
Dbrevis	0	1	0	0	0	Messing & AliNiazee 1985; Viggiani 1994; Westigard 1973; Kelton 1980
Dvalidus	0	1	0	0	0	Messing & AliNiazee 1985; Viggiani 1994; Westigard 1973; Kelton 1980
Dicyphus	0	1	0	0	0*	Parsons et al. 1991; Kelton 1980
Ddiscrepans	0	1	0	0	0	Parsons et al. 1991; Kelton 1980
Dhesperus	0	1	0	0	0	Parsons et al. 1991
Epacifica	0	1	0	0	0	Parsons et al. 1991
Hmerioptera	0	1	0	0	1	Messing & AliNiazee 1985; Southwood & Leston 1959
Hharti	0	1	0	0	0	Kelton 1980
Lancorifer	1	0	0	0	1	Wheeler & Henry 1992
Lrubidus	0	1	0	0	0	MacPhee & Sanford 1954; Kelton 1980
Lygus	1	0	0	1	0*	Parsons et al. 1991
Mchlorizan	0	1	0	0	1	Southwood & Leston 1959
Mnigrinervis	0	1	0	0	0	Messing & AliNiazee 1985; Viggiani 1994; Parsons et al. 1991
Phytocoris	0	1	0	0	0*	Messing & AliNiazee 1985; Parsons et al. 1991
Ptiliae	0	1	0	0	1	Messing & AliNiazee 1985; Wheeler & Henry 1992
Tpacificus	1	0	0	1	0	Lattin 1999b
Nalternatus	0	1	0	1	0	Messing & AliNiazee 1985; Parsons et al. 1991
Namericoferus	0	1	0	1	0	Parsons et al. 1991
Nrufuscolus	0	1	0	1	0	Parsons et al. 1991
Cintegressus	1	0	0	1	0	Parsons et al. 1991
Etristigmus	1	0	0	0	0	McPherson 1982
Evariolarus	1	0	0	0	0	McPherson 1982
Habbreviatus	1	0	0	1	0	McPherson 1982
Ntumidifrons	1	0	0	1	0	McPherson 1982
Nundata	1	0	0	1	0	McPherson 1982
Pmaculiventrus	0	1	0	0	0	McPherson 1982
Pcineræum	1	0	0	1	0	Southwood & Leston 1959
Bfraterna	0	1	0	1	0	Parsons et al. 1991; Wygodzinsky 1966
Empicoris	0	1	0	0	1*	Butler 1923; Southwood & Leston 1959; Wygodzinsky 1966
Eculiciformis	0	1	0	0	1	Butler 1923; Southwood & Leston 1959
Eerrabundus	0	1	0	0	0	Wygodzinsky 1966
Epilosus	0	1	0	0	1	Wygodzinsky 1966
Erubromaculat	0	1	0	0	1	Wygodzinsky 1966
Evagabundus	0	1	0	0	1	Butler 1923; Southwood & Leston 1959; Wygodzinsky 1966
Brubrolineata	1	0	0	1	0	Schuh & Slater 1995
Cpularia	1	0	0	1	0	Parsons et al. 1991
Amera	1	0	0	1	0	Drake & Ruhoff 1965
Csalicata	1	0	0	0	0	Thomson & Wong 1933; Drake & Ruhoff 1965
Ppexa	1	0	0	1	0	Drake & Ruhoff 1965

H = herbivore

Pr = predator

Sd = seed feeder

T = likely tourist

Exot = non-native

* some species within genus

M. chlorizans is a European species that has been recorded from British Columbia on *Corylus* since the 1950's and was reported in Seattle, Washington in 1986 (Schwartz and Scudder 1998). *M. chlorizans* was the most abundant Heteroptera on hazelnuts in this study. It is very similar to *Blepharidopterus provancheri* (Burque) and some of the individuals identified as *M. chlorizans* may actually be *B. provancheri*, but most are correctly identified. *M. chlorizans* is a mirid predator of soft bodied arthropods. It forages mainly on trees and shrubs and is similar to other mirids already established on hazelnut foliage.

Five species of *Empicoris* were identified. Of those, only *E. errabundus* (Say) is native. They are all predators of soft-bodied arthropods. *E. pilosus*, *E. rubromaculatus*, and *E. vagabundus* have not previously been recorded from Oregon (Lattin and Wetherill b). *E. pilosus* has been recorded on Hazelnut foliage in the United Kingdom (Butler, 1923).

M. ditomoides is native to Europe, and is a pest of cotton and other crops in its native range. *M. ditomoides* is probably incidental to hazelnut foliage (Lattin and Wetherill a).

Objective 2. To determine the amount of overlap across host plants.

Of the 53 taxonomic groups, 26 were found on both host plants (Table 18). Eleven were found only on *C. avellana*. Of those, four were singletons. Sixteen groups were found only on *C. cornuta*, of those, five were singletons. Most of the difference in host plants was due to rare species and may be in part due to sampling error.

Table 18. Total numbers of individuals and species for Heteroptera data.

	Forest	Edge	Orchard
Bush (IPM)			
Total individuals	152	155	178
Total species	26	10	10
Unique	18	1	2
Dorris (IPM)			
Total individuals	143	144	79
Total species	25	11	6
Unique	17	1	0
Weibe (organic)			
Total individuals	283	916	1120
Total species	32	24	25
Unique	15	4	5
Corricello* (organic)			
Total individuals	26	211	375
Total species	12	12	15
Unique	5	2	3

* Corricello farm has only one transect (15 sample units rather than 45).

Objective 3. To measure arthropod abundance and diversity across a forest-edge-orchard gradient on organic and IPM orchards.

IPM orchards: Species richness and abundance of phytophagous Heteroptera was not significantly different over the FEO gradient. Although species richness of predaceous Heteroptera significantly decreased over the FEO gradient, species abundance of predaceous Heteroptera was not significantly different over the FEO gradient.

Organic orchards: Species richness and abundance of phytophagous Heteroptera were not significantly different over the FEO gradient. Although species richness of predaceous Heteroptera was not significantly different across the FEO gradient, species

abundance of predaceous Heteroptera was significantly higher in the orchard than in the adjacent forest.

Species richness and abundance of predaceous and phytophagous Heteroptera were significantly higher in the organic orchards than in the IPM orchards. Species richness and abundance of predaceous Heteroptera was not significantly different between the forests adjacent to both IPM and organic orchards. However, species abundance of phytophagous Heteroptera was significantly lower in the forest adjacent to IPM orchards as compared to the forest adjacent to organic orchards (Tables 19 and 20).

Table 19a. Species Richness for all Heteroptera.

IPM			Organic		
Orchard	Edge	Forest	Forest	Edge	Orchard
2.6(1.2)	3.6(1.4)	5.1(2.2)	6.4(3.2)	8.1(1.3)	7.9(1.5)

Bars join treatments that are not significantly different.
Numbers in parentheses are standard deviations.

Table 19b. Species Richness for Phytophagous Heteroptera.

IPM			Organic		
Orchard	Edge	Forest	Forest	Edge	Orchard
0.0(0.0)	0.1(0.3)	0.5(0.8)	1.0(1.1)	1.8(0.9)	1.1(0.6)

Bars join treatments that are not significantly different.
Numbers in parentheses are standard deviations.

Table 19c. Species Richness for Predaceous Heteroptera.

IPM			Organic		
Orchard	Edge	Forest	Forest	Edge	Orchard
2.6(1.2)	3.4(1.3)	4.4(1.8)	5.2(2.7)	6.0(1.1)	6.4(1.2)

Bars join treatments that are not significantly different.
Numbers in parentheses are standard deviations.

Table 20a. Species Abundance for all Heteroptera.

IPM			Organic		
Orchard	Edge	Forest	Forest	Edge	Orchard
8.6(6.9)	10.0(6.2)	9.8(5.1)	15.5(10.4)	56.3(20.5)	74.8(17.0)
-----	-----	-----	-----	-----	-----
-----	-----	-----	-----	-----	-----
-----	-----	-----	-----	-----	-----

Bars join treatments that are not significantly different.
 Numbers in parentheses are standard deviations.

Table 20b. Species Abundance for Phytophagous Heteroptera.

IPM			Organic		
Orchard	Edge	Forest	Forest	Edge	Orchard
0.0(0.0)	0.1(0.3)	0.6(1.1)	2.5(3.9)	3.3(2.1)	2.0(1.5)
-----	-----	-----	-----	-----	-----
-----	-----	-----	-----	-----	-----
-----	-----	-----	-----	-----	-----

Bars join treatments that are not significantly different.
 Numbers in parentheses are standard deviations.

Table 20c. Species Abundance for Predaceous Heteroptera.

IPM			Organic		
Orchard	Edge	Forest	Forest	Edge	Orchard
8.5(6.9)	9.7(6.3)	8.9(4.4)	12.8(9.5)	52.8(20.6)	72.5(16.7)
-----	-----	-----	-----	-----	-----
-----	-----	-----	-----	-----	-----
-----	-----	-----	-----	-----	-----

Bars join treatments that are not significantly different.
 Numbers in parentheses are standard deviations.

Objective 4. To use ordination techniques to determine where peak abundance of individual taxa occur.

Mirid predators appeared to be the most abundant Heteroptera predators within the orchards, especially the IPM orchards. The most common true bug in the hazelnut system was a recently introduced mirid predator, *Malacocoris chlorizans* (Panzer). Its peak abundance was in the orchard, but it was very common on the edge and in the forest of both IPM and organic orchards (Figure 51). *Paraproba nigrinervis* VanDuzee (Figure 52) and *Compsidolon salicellum* (Herrich-Schaeffer) (Figure 53) had similar distributions. All appeared to be unaffected by the insecticide treatments. *Campyloneura virgula* (Herrich-Schaeffer) (Figure 54) had its peak abundance in the forest, but also occurred in both IPM and organic orchards, also suggesting resistance to insecticides. *Blepharidopterus angulatus* (Fallen) (Figure 55) and *Eurychilopterella pacifica* Stonedahl (Figure 56) were found in high numbers only in IPM orchards. Neither was common in organic orchards or forested areas.

Two species of anthocorid predators, *Orius tristicolor* (White) and *Orius minutus* (Linnaeus) were not separated in the analysis. They were very common in the organic orchards as well as the surrounding forest. But, they only occurred in the forest and on the edge of the IPM orchards, suggesting sensitivity to insecticides (Figure 57). *Deraeocoris brevis* (Uhler) a mirid predator, was only found in organic orchards and was not found in high numbers in the forests of either the organic or IPM farms (Figure 58).

B. provancheri, a mirid predator, was found mostly on the edge of the IPM orchards with relatively few found in the center of the orchard or in the forest (Figure 59).

Dicyphus hesperus Knight (Figure 60), *Heterotoma merioptera* (Scopoli) (Figure 61), *Lepidopsallus rubidus* (Uhler) (Figure 62) and *Hylisodes harti* Knight (Figure 63), all mirid predators, had peak abundances in the forests of IPM and organic farms with relatively few individuals found on the edge or in the center of the orchard.

Corythuca salicata Gibson, the western willow tingid, was the only herbivore that made up at least 1% of the total Heteroptera assemblage. It was found only on the edge and in the forest adjacent to organic orchards (Figure 64). It has been considered a pest of apple and hazelnut orchards (Thompson and Wong 1933), but problems with this species occurred before the advent of organophosphates. This species should be monitored as organic orchards become more prevalent.

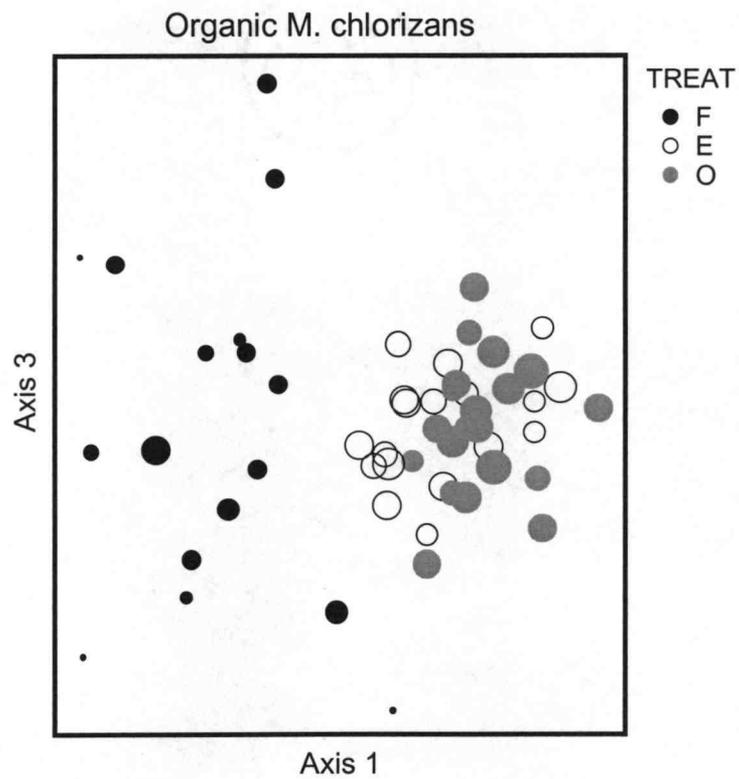
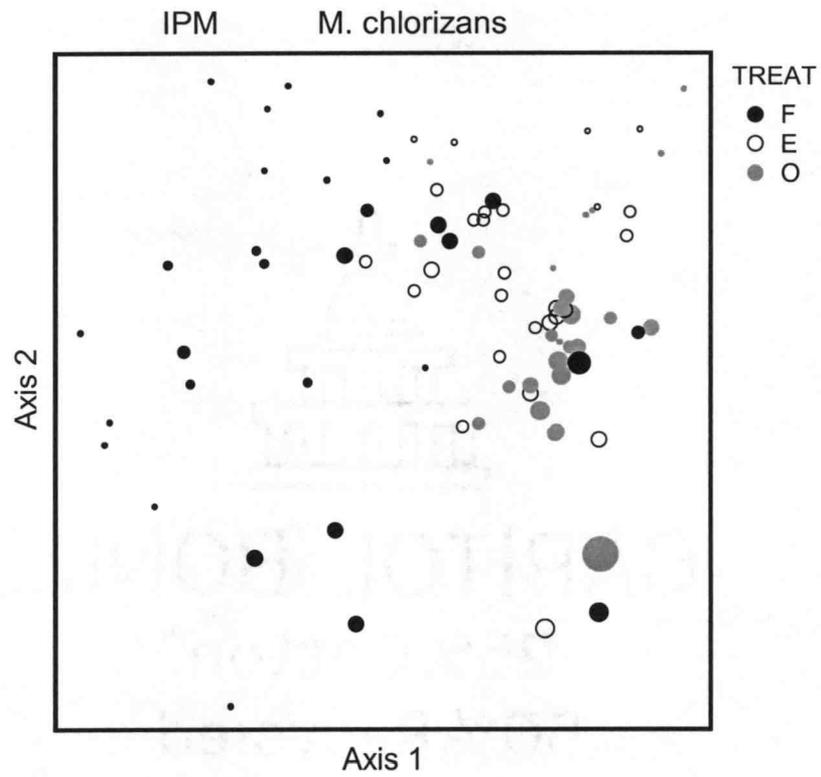
Figure 51. NMS ordination of sample units in Species space with *M. chlorizans* overlay.

Figure 52. NMS ordination of sample units in Species space with *P. nigrinervis* overlay.

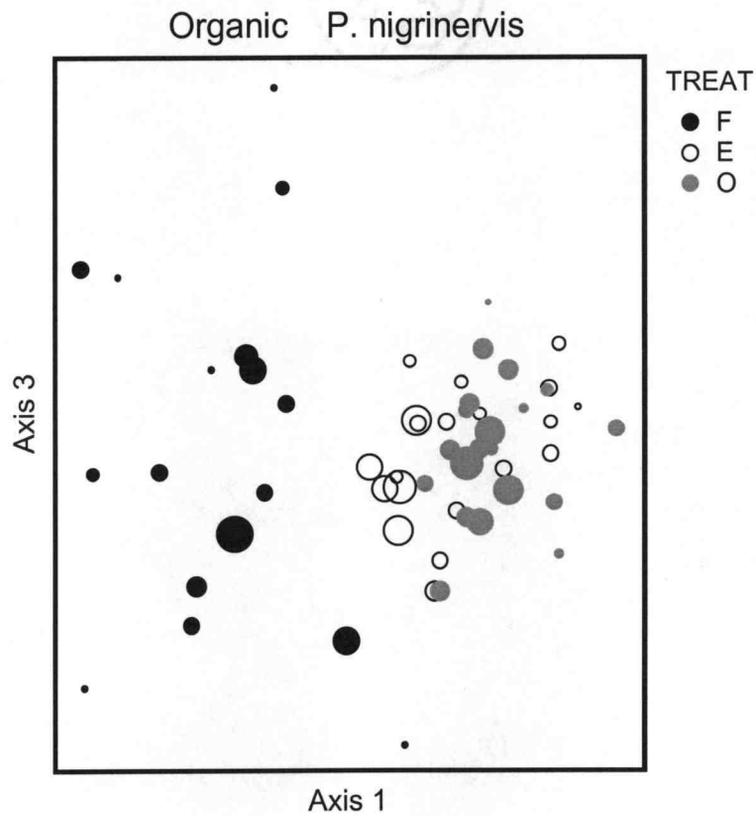
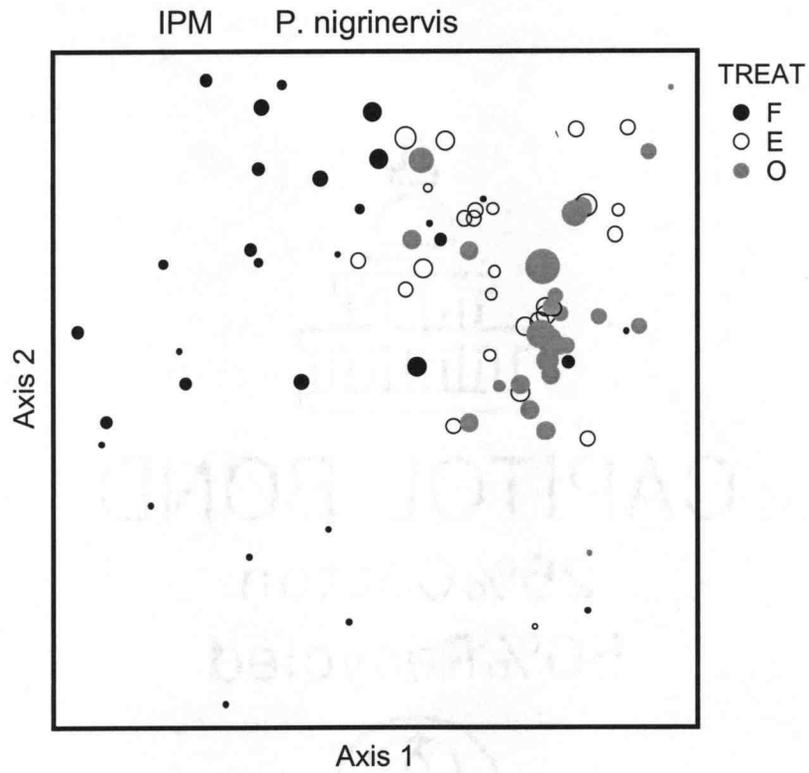


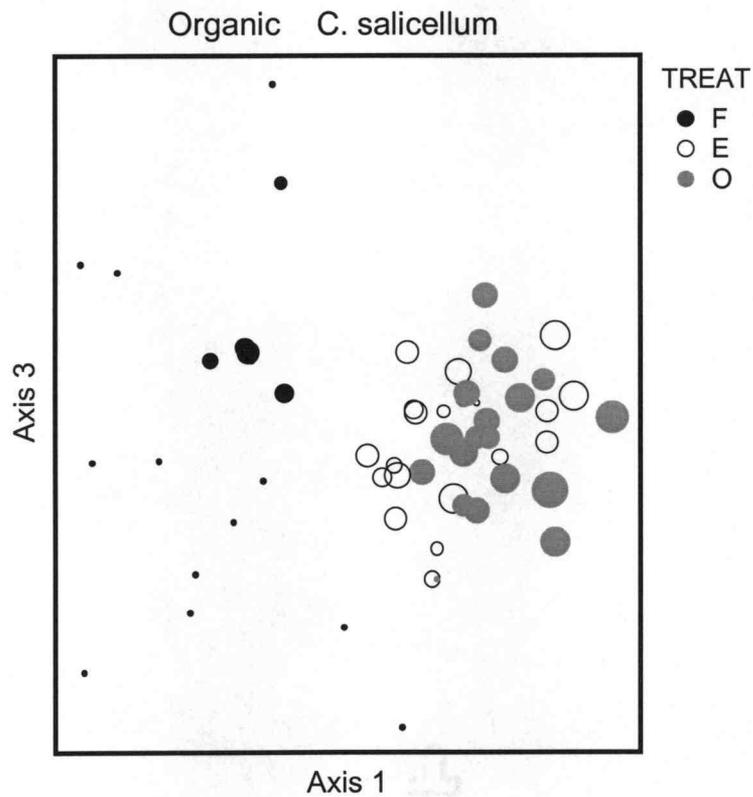
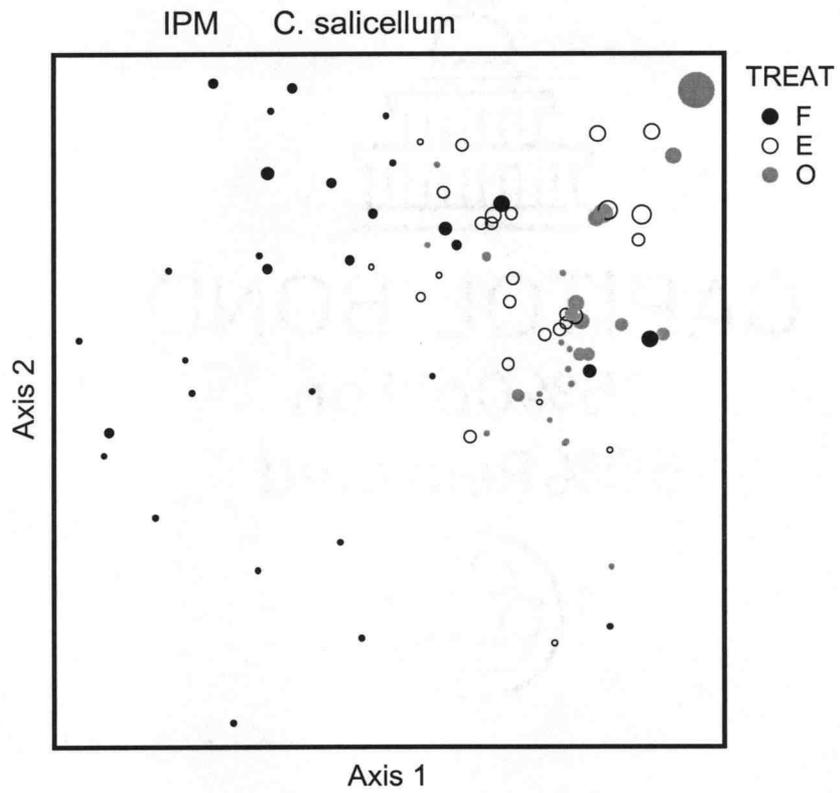
Figure 53. NMS ordination of sample units in Species space with *C. salicellum* overlay.

Figure 54. NMS ordination of sample units in Species space with *C. virgula* overlay.

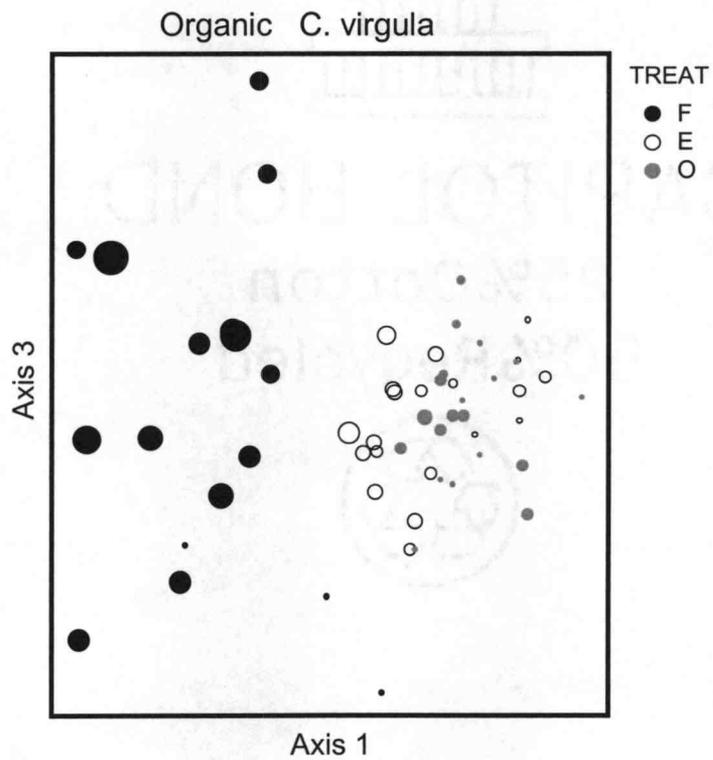
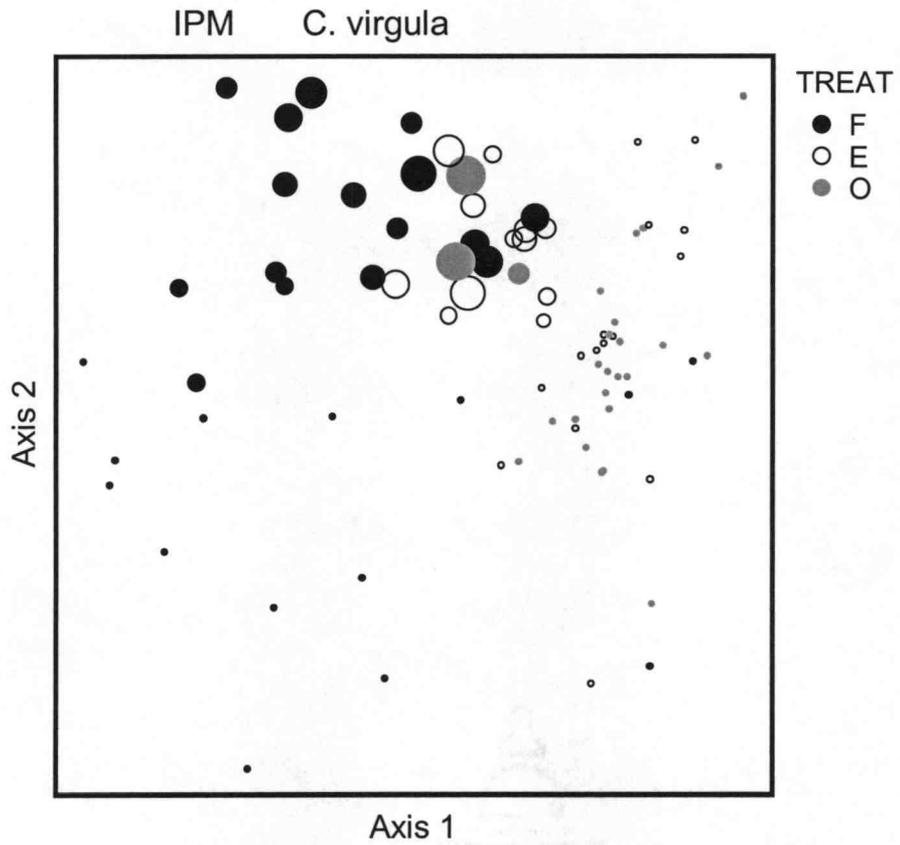


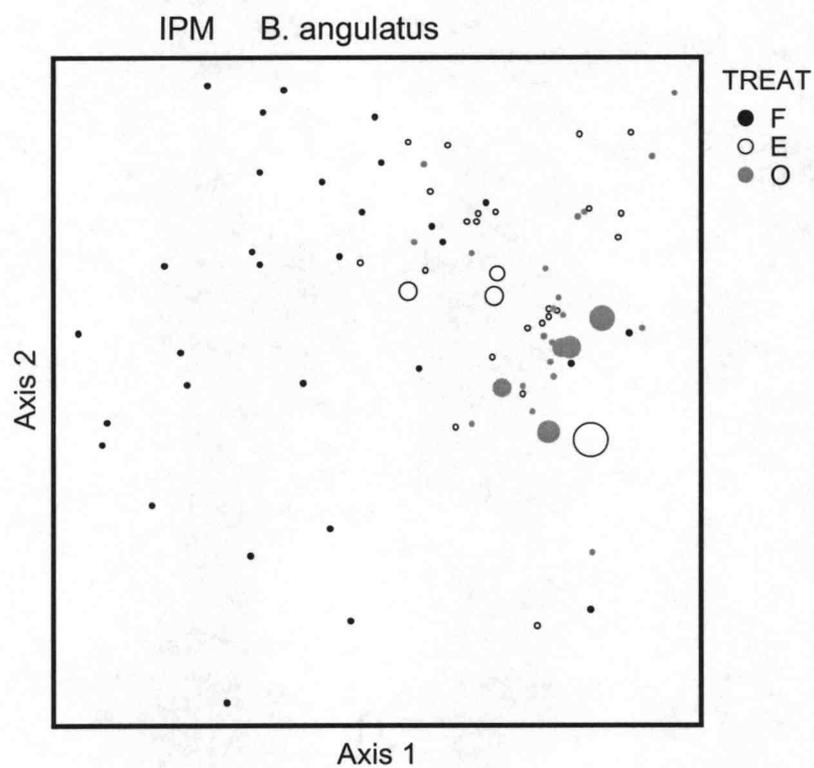
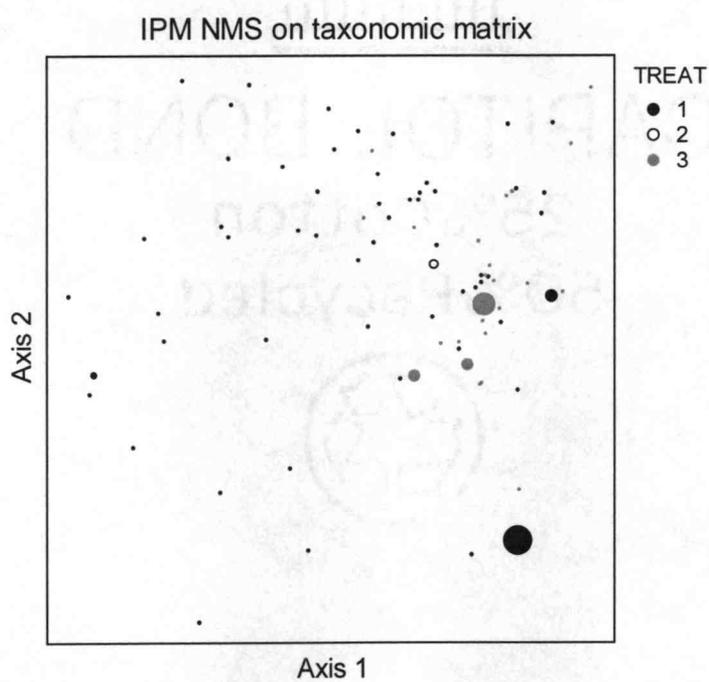
Figure 55. NMS ordination of sample units in Species space with *B. angulatus* overlay.Figure 56. NMS ordination of sample units in Species space with *E. pacifica* overlay.

Figure 57. NMS ordination of sample units in Species space with Orius spp. overlay.

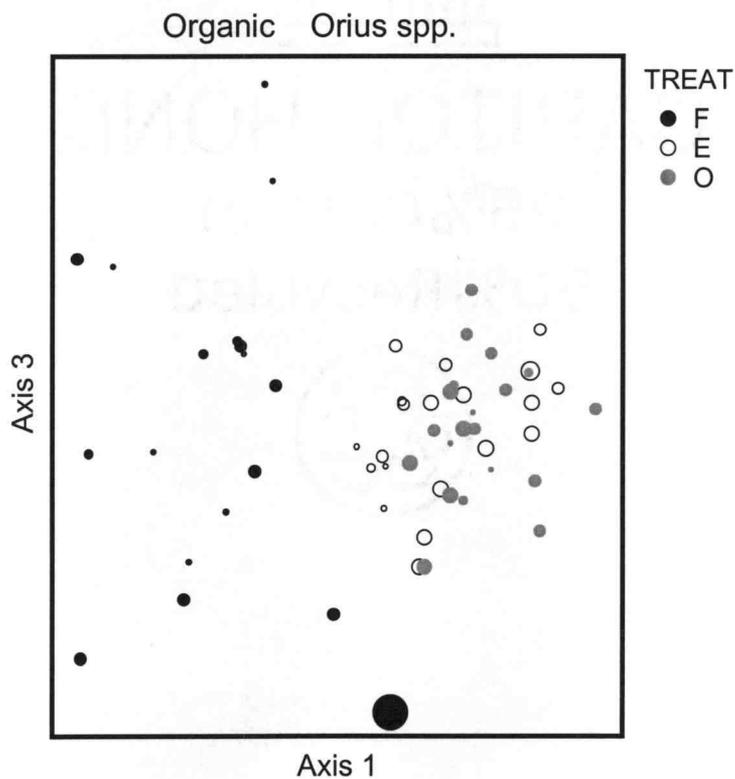
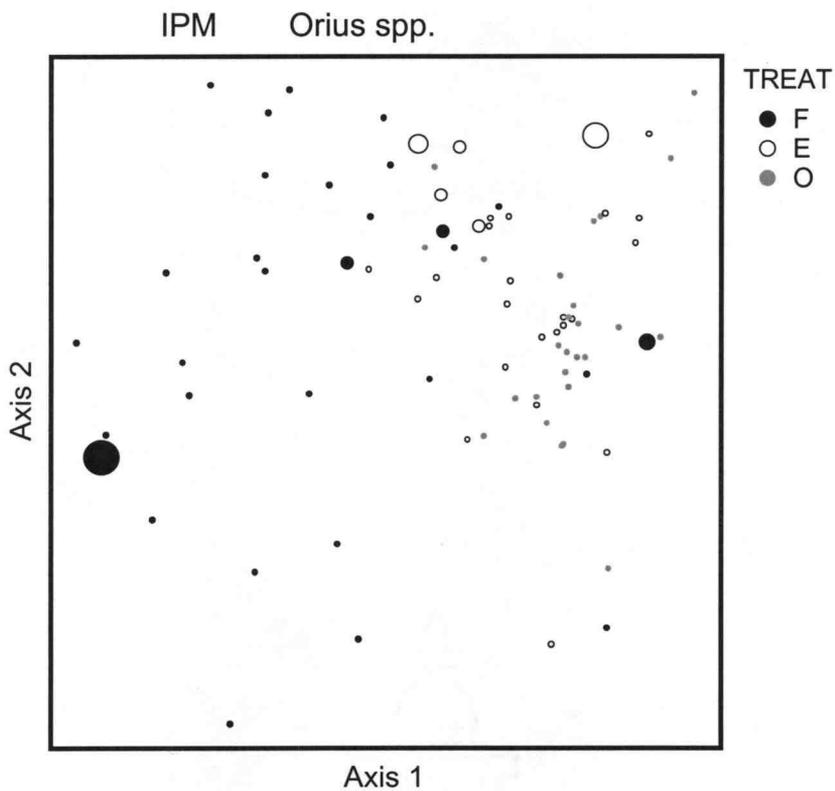


Figure 58. NMS ordination of sample units in Species space with *D. brevis* overlay.

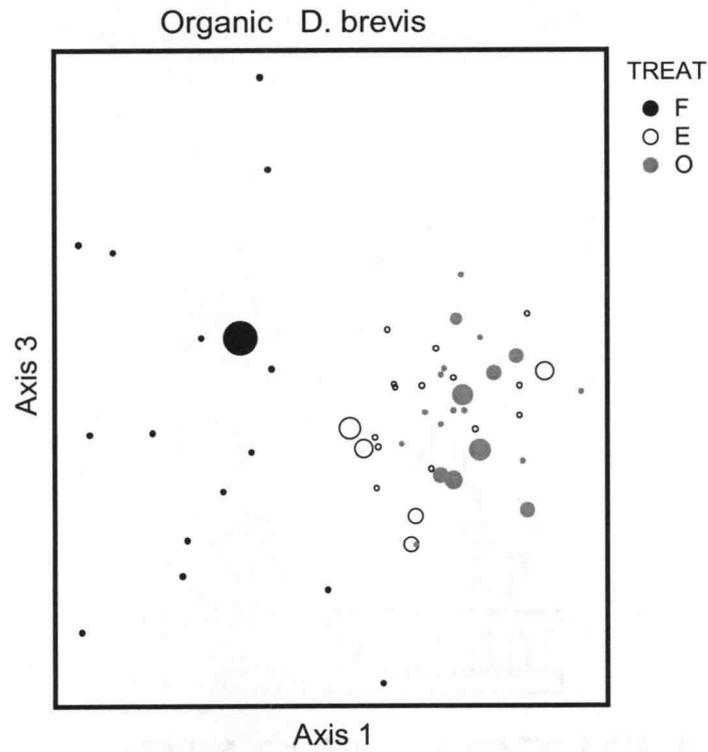


Figure 59. NMS ordination of sample units in Species space with *B. provancheri* overlay.

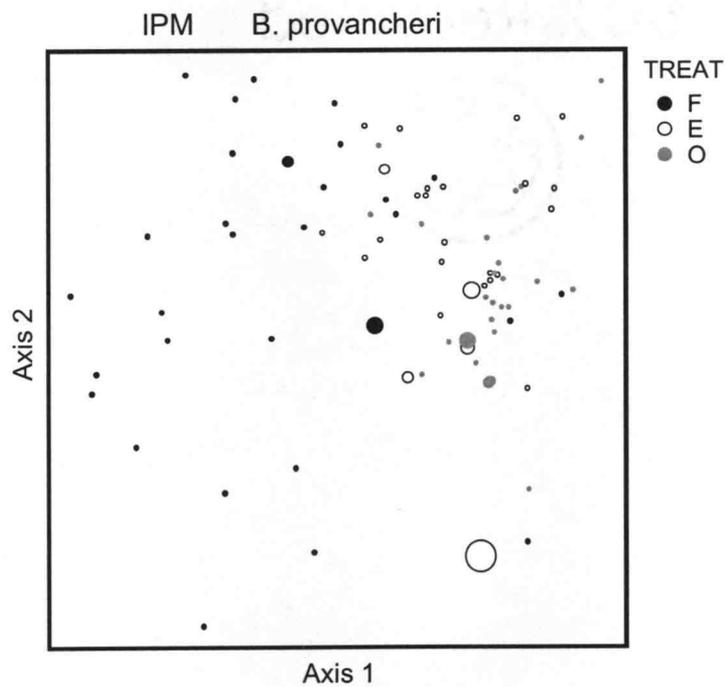


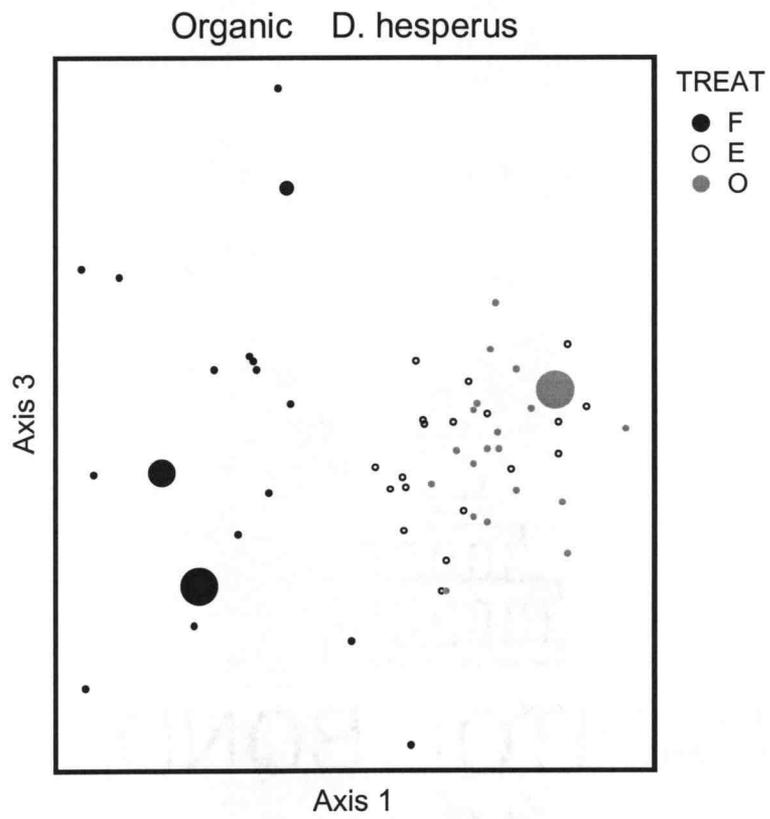
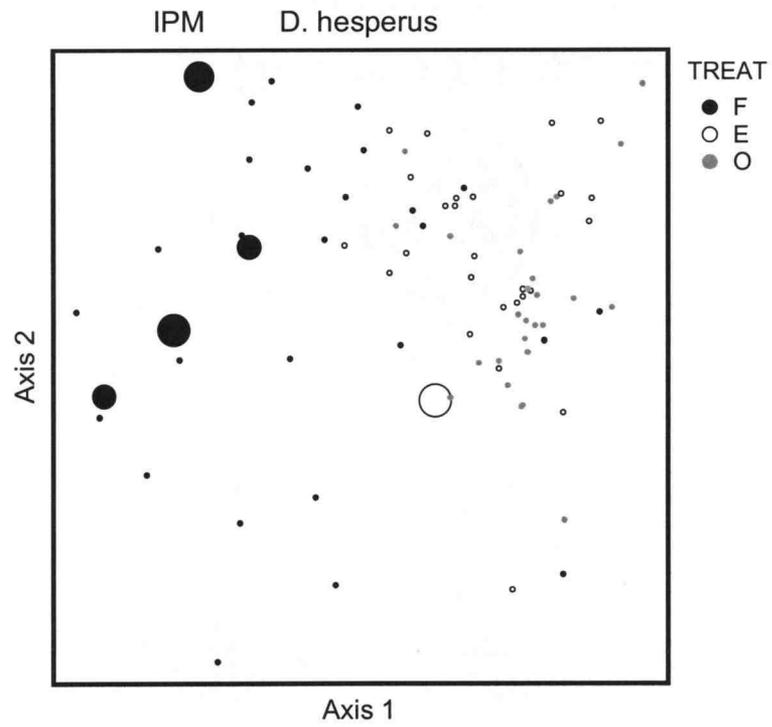
Figure 60. NMS ordination of sample units in Species space with *D. hesperus* overlay.

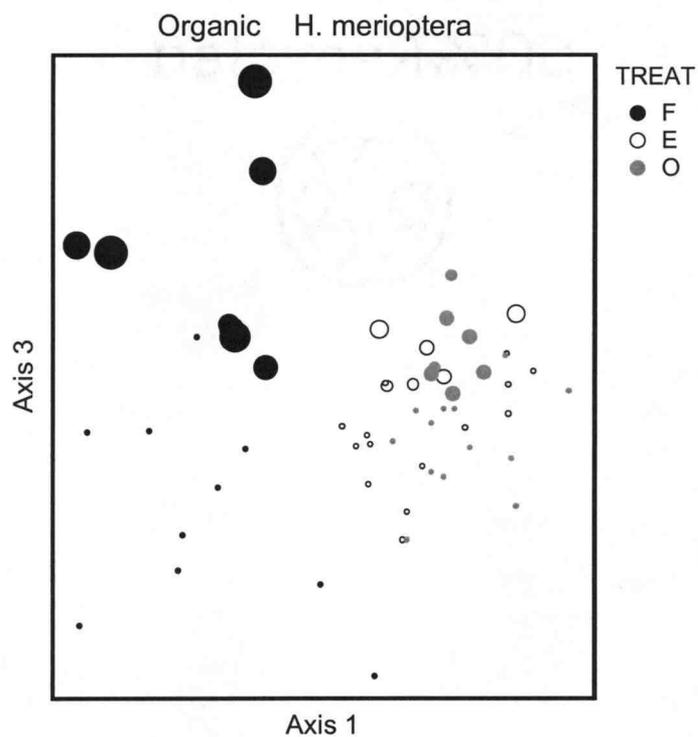
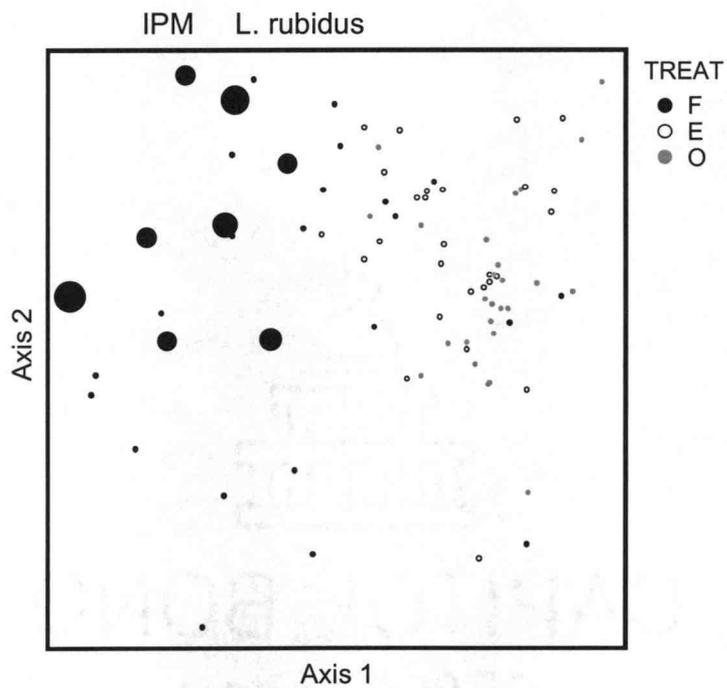
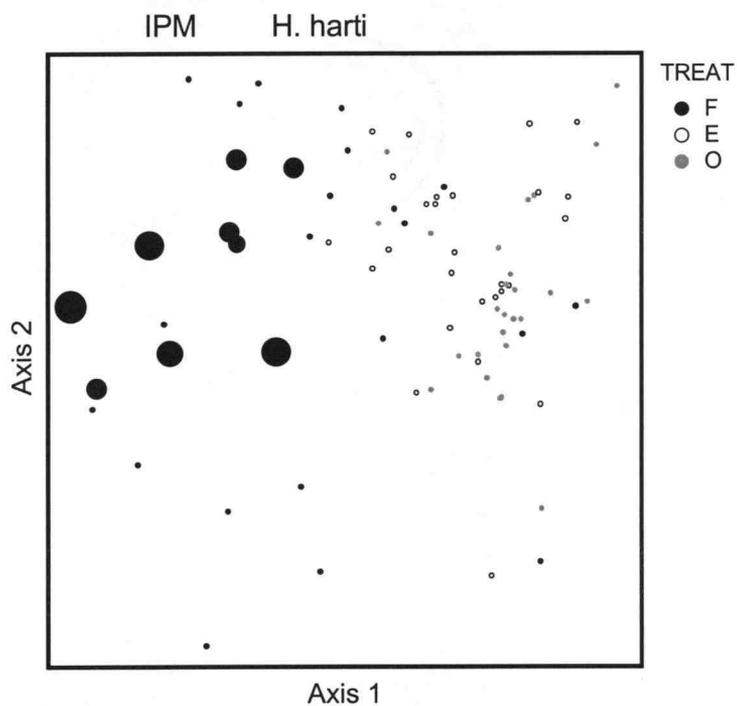
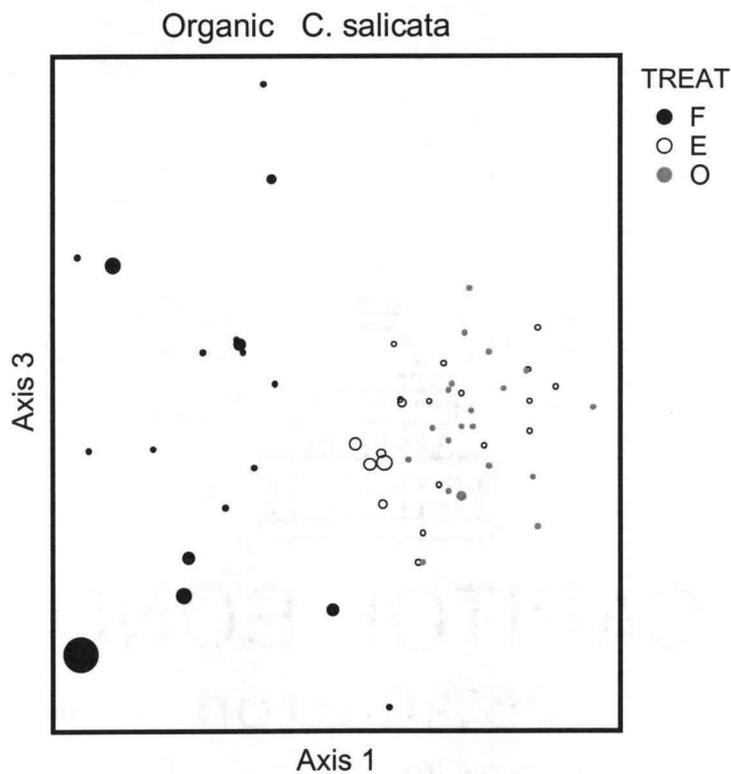
Figure 61. NMS ordination of sample units in Species space with *H. merioptera* overlay.Figure 62. NMS ordination of sample units in Species space with *L. rubidus* overlay.

Figure 63. NMS ordination of sample units in Species space with *H. harti* overlay.Figure 64. NMS ordination of sample units in Species space with *C. salicata* overlay.

DISCUSSION

Integrated Pest Management:

The Integrated Pest Management (IPM) program used in hazelnut orchards has made great progress in the past twenty years. Insecticide sprays have decreased from up to five sprays in the 1980's to one or two sprays in the late 1990's (Progar and AliNiazee 1999). Prior to the development of the IPM program in hazelnuts, repeated spraying of the orchards for control of the filbert aphid, *Myzocallis coryli* (Goeze), and the filbert worm, *Cydia latiferreana* Walsingham, led to resistance in the filbert aphid and to secondary pest outbreaks due to release from predators (AliNiazee and Messing 1995). The release of a classical biological control agent (*Trioxys pallidus*) for the filbert aphid and increased monitoring for the filbert worm have reduced the need for insecticide sprays (AliNiazee 1998). However, this study strongly suggests that the continued use of even one application of esfenvalerate per year is highly disruptive to the Coleoptera and Heteroptera assemblages, many of which are beneficial. In addition, although the IPM farms have a lower species richness of phytophagous Coleoptera and Heteroptera, the abundance of those herbivores is not significantly different from that of the organic orchards. Most of the abundance of phytophagous Coleoptera in the IPM orchards is due to *Syneta albida*. High numbers of aphids were found (several hundred per leaf) at one of the IPM orchards while low numbers were found throughout the season in both organic orchards (10-20 per leaf) (personal observation). Pimentel (1961) states that animal outbreaks occur most frequently in cultivated areas of monocultures and secondary pest outbreaks are often attributed to the use of pesticides.

Hazelnut orchards are known for their high diversity of beneficial organisms (AliNiazee and Messing 1995, AliNiazee 1998). This study has added to the list of Coleoptera and Heteroptera beneficials. Most of these are specialist predators of soft-bodied arthropods. Messing (1982) found that insecticide sprays of Diazinon, Zolone, Metasystox-R, Systox, Thiodan, and Sevin all destroyed the predator complex on hazelnuts in the field. No studies of the effects of esfenvalerate on beneficial species could be found in the literature. However, this study illustrates that only one application of esfenvalerate per year all but eliminates the suite of beneficials in hazelnuts.

A set of "soft" pesticides is now being tested for effective control of the filbert worm. Effective control of the filbert worm is essential because of the extremely low tolerance of infestation (<1% of nuts) for commercial production. In addition to tests on effective control of the filbert worm, tests on the toxicity to beneficial species should also be performed.

Natural Biological Control:

In the organic farms, the species richness and abundance of predaceous Coleoptera was significantly higher in the orchard than in the adjacent forest over the entire season. The species richness and abundance of phytophagous Coleoptera in the orchard was not significantly different from the forest in the early season, but by late season the species richness and abundance of phytophagous Coleoptera was significantly lower in the orchard than in the forest. A similar decline of phytophagous Coleoptera is achieved in both IPM and organic orchards however, predaceous Coleoptera are not found in the IPM orchards.

The shifts in peak abundances of individual species show that the IPM orchards are a sink for both predaceous and phytophagous Coleoptera and Heteroptera. Most species either disappear or are limited to the forest in late season. *Syneta albida* (Coleoptera: Chrysomelidae) and four species of mirid predators do retain high numbers within the IPM orchards.

Malacocoris chlorizans, *Compsidolon salicellum*, *Campyloneura virgula*, and *Paraproba nigrinervis* (Heteroptera: Miridae) all exist in the IPM orchards even after treatment with esfenvalerate (ASANA), the most commonly used chemical in hazelnut systems. The first three species are non-native to North America. This study is the first record of *M. chlorizans* in Oregon and it is the most abundant true bug in the hazelnut orchards examined. Further studies could determine the effect that this newly introduced predator will have on the existing predator complex. Elliot et al. (1996) noted that the Coccinellidae assemblages of field crops changed significantly after the introduction of *C. septempunctata*. Two species of native ladybirds decreased significantly, although the total abundance of coccinellids did not change significantly after the introduction. Therefore, the introduction of a new predator does not always increase the amount of natural biological control in a system. In fact, introductions may negatively affect the predator complex by competitive suppression.

In the organic orchards, peak abundances of predators shift from early to late season. Some species shift from the forest to the orchard, while others shift from the orchard to the forest. However, species richness and abundance remain high over the entire season in organic orchards. Predators such as *C. quatuordecimguttata*, *I. nitidulus*, *H. axyridis*, *Malthodes* spp. and *T. sericeus* are all important in the orchard in the early

season. In the late season *T. sericeus* moves into the forest, but *C. septempunctata* and *C. polita* increase within the orchard. *I. nitidulus* and *H. axyridis* remain strong in the orchard all season. Also, *Scymnus* spp. moves from the forest onto the edge of the orchard in late season.

This suite of biological control agents lends stability to the agro-ecosystem. Magurran (1988) states that diversity measures are practical for conservation and ecological monitoring. It seems reasonable to suggest that diversity of predator complexes in agro-ecosystems is beneficial. Pimentel (1961) cites many instances in which diversity and complexity of predators assemblages are responsible for stability.

Predator diversity would increase control of pests if the predator species forage in different locations, different seasons, on different life stages (Chang 1996) or at different temperatures (Obrycki and Tauber 1981). Intraguild predation and competition for prey would be two reasons why diversity would not be beneficial (Polis and Holt 1992). If intraguild predation or competition played a large part in hazelnut systems, we would not see such a diverse assemblage that overlaps across the season. Or, if either intraguild predation or competition is reducing some of the predators in the system, there are still several species of predators that do coexist within the crop ecosystem.

Refugia:

Forested areas adjacent to orchards may provide refuge for those species that do not compete well within the orchard and may also provide overwintering areas for those which cannot complete their lifecycle within the orchard. These refuges are what Polis and Holt (1992) call niche shifts where one intraguild predator maintains its population

on a less favorable resource during the time frame when that predator is in competition with or threatened by predation from another intraguild predator.

The forest as a refuge is a low input management strategy that provides year round shelter and food for predators in a heavily managed orchard system. Dennis and Fry (1992) concluded that maintenance of native vegetation adjacent to crops is economically justified by the enhanced predators within the crop. Many beneficial arthropods that forage in the canopy spend some part of their lifecycle on or below ground. The ground of hazelnut orchards is generally managed very rigorously. A healthy forest floor provides what an orchard floor cannot and therefore acts as a refuge.

The forested areas are structurally and taxonomically more diverse with respect to the flora. Diversity of arthropods has been linked with plant diversity in experimental studies (Pimentel 1961, Siemann et al. 1998). Their results also indicate that herbivore diversity is a function of plant diversity and the diversity of predators and parasites. Although sampling was only conducted on *C. cornuta*, the herbivore community of the forest should be more diverse than the orchard and this should be reflected in the samples from *C. cornuta*. In the organic orchards, the herbivorous Coleoptera were more diverse in the forest in the late season, but were not significantly different in the early season. The species richness of phytophagous Heteroptera of the organic orchards was equal in the forest and orchard, but significantly higher on the edge.

The diversity of predators should be a function of the diversity of the prey (soft-bodied arthropods) (Pimentel 1961) and the structural diversity of the substrate. The diversity of predaceous Coleoptera was higher in the orchards than in the forests of the organic sites, which is not as expected. Earlier observations indicate that there are fewer

filbert aphids per leaf in the organic orchards as compared to the IPM orchards. The next question to be asked is; What are these predators feeding on in the organic orchards? Is there an alternative prey such as Collembola or Psocoptera? Or is there a large amount of intraguild predation?

Edge Effects:

In all comparisons in the IPM orchards, the edge was intermediate in species richness between the forest and the orchard. The orchard acts as a sink for diversity and the forest as a source. Jepson & Thacker (1990) suggested that invasion-mediated recovery of sprayed areas is a function of dispersal rate, resource availability, host range, number of generations per year and overwintering sites of the colonizing organisms. In the organic orchards, the species richness of phytophagous Heteroptera was significantly higher on the edge. Bedford & Usher (1994) found a significantly higher species richness of Carabidae and Araneae on a woodland edge adjacent to arable fields. However, the woodland and the field supported distinct assemblages. In the hazelnut agro-ecosystem, the forest and orchard assemblages overlap more than they are different and the differences are mostly attributable to rare species. Therefore, strong edge effects would not be expected.

In the literature, there is some confusion as to whether edge effects are responses of individual taxa to a steep resource gradient or whether edge effects are responses of species richness across a border separating two distinct ecosystems. In any case, edges are a sharp boundary between two sets of resources. For organisms that require resources from both sides of the border, higher abundance on the edge would be expected. For

organisms that find all of the necessities of life within one set of resources, lower abundance on the edge would be expected. In the organic orchards, most of the organisms in this study were found both in the forest, on the edge and in the center of the orchard. Detailed studies of whether beneficial organisms can successfully complete their lifecycle within the orchard system is necessary before we can predict which type of response each organism should have at the edge. Also, measurement of immigration and emigration from the forest would further our understanding of the effects of natural forested land adjacent to hazelnut orchards.

Diversity Studies:

Diversity studies are becoming more common as the importance of individual species is acknowledged. Many mechanisms are involved in determining the species richness of a certain area and there are many avenues of investigation open for biological diversity studies. Kitching et al. (1997) suggest that the mechanisms controlling species richness are historical, ecological, and geographical. This study is located in one geographical region, the Willamette Valley of Oregon. However the historical mechanisms are two-fold. In ecological time, the IPM orchards and the organic orchard have separate histories of management. And in geological time, the two species of host plants, *C. cornuta* and *C. avellana* have distinct evolutionary histories. The former is restricted to the new world and the latter originates in the old world. These separate histories affect the plant and its arthropod assemblage. The historical differences lead to ecological differences. The physical structure of each tree is a function of its species, its location and alterations by man. The leaves and the hairs on the leaves are much denser

on *C. avellana*. The nutshell of *C. cornuta* is thicker and the husk surrounds the shell completely.

The arthropod fauna is also affected by the location of the tree. Trees under a dense canopy are more shrub-like with long branches and sparser foliage. Also, the arthropod community within the forest is affected by the surrounding vegetation. Schowalter (1996) stated that diverse vegetation limits herbivore population growth by making the hosts more distant and less apparent to the herbivores and by non-hosts acting as barriers to population spread.

On a larger scale, diversity has been linked with landscape heterogeneity (Colunga-Garcia et al. 1997). Finally, alterations by man include pruning, spraying with chemicals, domestication, and harvesting the nuts. All of the factors listed here and more affect the local diversity of the insects on a host plant.

Kitching et al. (1997) also listed seven emergent factors of biological diversity studies. 1) Ordinal, familial and species profiles. In this study, most organisms were identified to species. Ordinations were run on the specific, the generic and the familial level (results not shown). The specific and generic levels lead to very similar results because most of the genera contain only one species. However, on the familial level, some of the relationships (distances in species space from sample units in the forest to the edge and orchard) break down. As species are the primary unit of biological diversity, it is very important that diversity studies are performed on this level when possible.

2) Size/abundance relationships. The relative abundance of species in an ecosystem does not contribute much knowledge if the relative impact of each species is skewed. Size of an organism is often used as a gross estimate of impact. In this study,

size class was not considered. Since the relative impact of each species was unknown, the relativization by species maximum to equate abundant and rare species did not lose very much information. In most biodiversity studies, it is assumed that abundance equals impact. True impact would be estimated more precisely by the amount and type of food ingested by each individual in its life time or life stage. Unfortunately, this information is rarely known. It would be interesting to look at this relationship between well documented organisms such as Coccinellidae. Since many species are well known and size varies between species, the number of aphids ingested per lifetime could be compared to the size or mass of the species of lady beetle.

3) Guild structure. There is much confusion in the literature about the true meaning of "guild" (Hawkins and MacMahon 1989, Simberloff and Dayan 1991). The guild concept ignores all taxonomic boundaries and is therefore inappropriate in taxonomically limited surveys. I have used the term functional group rather than guild because this term does not assume an all-inclusive group. However, the idea of dividing organisms into feeding groups is useful when looking at differences in arthropod assemblages and in IPM decision making practices. In this study, I have also looked at species richness within functional feeding groups to look at the differences in diversity of feeding habits within a taxonomic unit.

4) Dominance, evenness and richness measures. Many diversity indices are available today. Magurran (1988) and more recently Hayak and Buzas (1997) have written books for analyzing natural populations. The traditional diversity indices, Richness (S), Shannon's (H), and Simpson's (D) differ only in the weighting of rare species (Hill 1973). The worker is left to decide which is most appropriate. Species

richness, a strict count of the number of species, is generally more intuitive and receptive to statistical analysis because the underlying distribution can be found. The distribution of the other two indices is unknown. Therefore, statistical comparisons are unjustified. In this study, I have reported three diversity indices, but have made comparisons of only species richness and abundance separately, not combined within an index. Species abundance models give more information than the diversity indices with respect to abundance. Use of these models in diversity studies will likely increase as workers learn to use and interpret these models.

5) Levels of endemism. In this study, I did not look directly at endemism. However, non-native species are discussed. Fourteen percent and 31% of Coleoptera and Heteroptera species, respectively, are non-native.

6) Food web properties. As mentioned earlier the feeding habits of the organisms in this study were taken from the literature and no field observations of feeding were conducted. Increased knowledge of the prey species and the relative abundance of prey species compared to the relative amount of each species consumed would be very useful.

7) Seasonality. In this study the Coleoptera assemblage was analyzed on three levels, the entire season, the early season and the late season. Heteroptera were only analyzed over the entire season. Shifts in peak abundances of individual taxa from early to late season show that the arthropod distributions change over time. The added dimensionality of time complicates the experimental design. In this study, dates were ordinated in species space to determine the cut-off point between early and late season. This method is very useful in determining non-arbitrary shifts in species assemblages over time.

Woolhouse & Harmsen (1987) suggest that agro-ecosystems tend to be less diverse because many agricultural systems are monocultures of exotic plants. However, the hazelnut agro-ecosystem is incredibly diverse, especially in predators.

In conclusion, this study shows that the management techniques in IPM orchards severely limit the potential natural biological control. Thus, further study and adoption of 'soft' pesticides and/or target-specific pesticides is in order.

BIBLIOGRAPHY

- AliNiazee, M.T. 1980. Filbert insect and mite pests. Oregon State University, Corvallis, OR. Agricultural Experiment Station Bulletin 643.
- AliNiazee, M.T. 1994. Insect pest management in hazelnut orchards of North America. *Acta Horticulturae* 351:543-550.
- AliNiazee, M.T. 1998. Ecology and management of hazelnut pests. *Annual Review of Entomology* 43:395-419.
- AliNiazee, M.T., and R.H. Messing. 1995. Filbert Aphid. In: *Biological Control in the Western United States*. University of California Press.
- Anderson, N.H. 1962. Anthocoridae of the Pacific Northwest with notes on distribution, life histories, and habits (Heteroptera). *Canadian Entomologist* 94:1325-1334.
- Arnett, R.H. 1968. *The Beetles of the United States*. American Entomological Institute, Ann Arbor, MI
- Arnett, R.H. 1985. *American Insects: A handbook of the insects of America North of Mexico*. Van Nostrand Reinhold Co., New York.
- Bedford, S.E., and M.B. Usher. 1994. Distribution of arthropod species across the margins of farm woodlands. *Agriculture, Ecosystems & Environment* 48:295-305.
- Beirne, B.P. 1971. Pest insects of annual crop plants in Canada. *Memoirs of the Entomological Society of Canada* 78:1-123.
- Beller, S., and M.H. Hatch. 1932. Coleoptera of Washington: Chrysomelidae. *University of Washington Publications in Biology* 1(2):65-144.
- Berdegue, M., J.T. Trumble, J.D. Hare, and R.A. Redad. 1996. Is it enemy free space? The evidence for terrestrial insects and freshwater arthropods. *Ecological Entomology*. 21:203-217.

- Booth, R.G., M.L. Cox, and R.B. Madge. 1990. IIE guides to insects important to man. International Institute of Entomology, London.
- Borror, D.J., C.A. Triplehorn, and N.F. Johnson. 1989. An Introduction to the study of Insects. Harcourt Brace College Publishing, New York, NY.
- Butler, E.A. 1923. A biology of the British Hemiptera-Heteroptera. H. F. & G. Witherby, London.
- Chang, G.C. 1996. Comparison of single versus multiple species of generalist predators for biological control. *Environmental Entomology* 25(1):207-212.
- Chapin, J.B. 1985. Revision of the genus *Mulsantina* Weise (Coleoptera: Coccinellidae). *Annals of the Entomological Society of America* 78:348-368.
- Colunga-Garcia, M., S.H. Gage, and D.A. Landis. 1997. Response of an assemblage of Coccinellidae (Coleoptera) to a diverse agricultural landscape. *Environmental Entomology* 26(4):797-804.
- Dennis, P., and G.L.A. Fry. 1992. Field margins: Can they enhance natural enemy population densities and general arthropod diversity on farmland? *Agriculture, Ecosystems & Environment* 40:95-115.
- Drake, C.J., and F.A. Ruhoff. 1965. Lacebugs of the world: A catalog (Hemiptera: Tingidae). Smithsonian Institution, Washington DC.
- Ecevit, O., C. Tuncer, S.K. Ozman, S. Mannan, and I. Akca. 1996. Natural enemies found in Black Sea hazelnut orchards and their potential in biological control, pp. 134-145. *In: Proceeding of The Symposium on Hazelnut and other nut crops of Turkey*. 11-12 January, Ondokuzmayis Universitesi, Turkey.
- Elliot, N., R. Kieckhefer, and W. Kauffman. 1996. Effects of an invading coccinellid on native coccinellids in an agricultural landscape. *Oecologia* 105:537-544.
- Essig, E.O. 1958. Insect and mites of Western North America. The MacMillan Company, New York, NY.

- Geier, P.W., and L.R. Clark. 1978. The nature and future of pest control: production process or applied ecology? *Protection Ecology* 1:79-101.
- Hawkins, C.P., and J.A. MacMahon. 1989. Guilds: The multiple meanings of a concept. *Annual Review of Entomology* 34:423-454.
- Hayak, L.C., and M.A. Buzas. 1997. *Surveying Natural Populations*. Columbia University Press, New York, NY.
- Haynes, D.L., R.L. Tummala, and T.L. Ellis. 1980. Ecosystem Management for Pest Control. *Bioscience* 30(10):690-695.
- Hill, M.O. 1973. Diversity and evenness: A unifying notation and its consequences. *Ecology* 54:427-432.
- Jaques, H.E. 1951. *How to Know the Beetles*. W.M.C. Brown Company, Dubuque, Iowa.
- Jepson, P.C., and J.R.M. Thacker. 1990. Analysis of the spatial component of pesticide side-effects on non-target invertebrate populations and its relevance to hazard analysis. *Functional Ecology* 4:349-355.
- Johnson, P. 1999. Personal Communication, Aug. 19, 1999. SD Natural History Collections and Biological Survey. Box 2207A, South Dakota State University, Brookings, SD 57007. (605) 688-4438.
- Jolivet, P.H.A., and M.L. Cox. 1996. *Chrysomelidae Biology*. SPB Academic Publishing, New York.
- Jones, D. 1984. Use, misuse, and role of multiple-comparison procedures in ecological and agricultural entomology. *Environmental Entomology* 13(3):635-649.
- Kelton, L.A. 1980. The plant bugs of the prairie provinces of Canada: Heteroptera: Miridae. The insects and arachnids of Canada. Ministry of Supply and Services, Canada.

- Kitching, R.L., H. Mitchell, G. Morse, and C. Thebaud. 1997. Determinants of species richness in assemblages of canopy arthropods in rainforests. In *Canopy Arthropods*, ed. N.E. Stork, J. Adis, and R.K. Didham. Chapman and Hall, New York, NY.
- Kogan, M. 1998. Integrated pest management: Historical perspectives and contemporary developments. *Annual Review of Entomology* 43:243-270.
- Lattin, J.D. 1999a. Bionomics of the Anthocoridae. *Annual Review of Entomology* 44:207-231.
- Lattin, J.D. 1999b. Personal Communication. Department of Entomology, Oregon State University, Corvallis, OR 97331. (541) 737-5505.
- Lattin, J.D., and K.R. Wetherill. a. Five species of *Empicoris* Wolff from *Corylus cornuta* and *Corylus avellana* in Oregon (Hemiptera: Heteroptera: Reduviidae). (Submitted)
- Lattin, J.D., and K.R. Wetherill. b. *Metopoplax ditomoides* (Costa), a species of Lygaeidae new to North America (Hemiptera: Heteroptera), found on filbert. (Submitted)
- MacPhee, A.W., and K.H. Sanford. 1954. The influence of spray programs on the fauna of apple orchards in Nova Scotia. VII. Effects on some beneficial arthropods. *Canadian Entomologist* 86:128-135.
- Magurran, A.E. 1988. *Ecological Diversity and Its Measurement*. Princeton University Press, Princeton, NJ.
- McCune, B., and M.J. Mefford. 1999. *Multivariate analysis of ecological data*. 4.0 ed. MjM Software, Gleneden Beach, OR.
- McPherson, J.E. 1982. *The Pentatomidae (Hemiptera) of Northeastern North America*. Southern Illinois University Press, Carbondale, IL.

- Mehlenbacher, S.A. 1991. Hazelnuts (*Corylus*). 290 pp. In: *Genetic resources of temperate fruit and nut crops*. eds. J.N. Moore, and J.R. Ballington, Jr. International Society for Horticultural Science, Wageningen, Netherlands.
- Merritt, R.W., and K.W. Cummins. 1984. An introduction to the aquatic insects of North America. Kendall/Hunt Publishing, Dubuque, IA.
- Messing, R.H. 1982. *The biology of the predator complex of the filbert aphid, Myzocallis coryli* Goetze, in Western Oregon. Master of Science. Oregon State University
- Messing, R.H., and M.T. AliNiasee. 1985. Natural enemies of *Myzocalis coryli* (HOM.: Aphididae) in Oregon hazelnut orchards. *Journal of the Entomological Society of British Columbia* 82:14-18.
- Obrycki, J.J., and M.J. Tauber. 1981. Phenology of three coccinellid species: Thermal requirements for development. *Annals of the Entomological Society of America* 74:31-36.
- Ozanne, C.M.P., C. Hambler, A. Foggo, and M.R. Speight. 1997. The significance of edge effects in the management of forests for invertebrate biodiversity. In *Canopy Arthropods*, ed. N.E. Stork, J. Adis, and R.K. Didham. Chapman and Hall, New York, NY.
- Parsons, G.L., G. Cassis, A.R. Moldenke, J.D. Lattin, N.H. Anderson, J.C. Miller, P. Hammond, and T.D. Schowalter. 1991. Invertebrates of the H.J. Andrews Experimental Forest, Western Cascade Range, Oregon. V: An annotated List of Insects and Other Arthropods. USDA Forest Service, Portland, OR.
- Parsons, G.L., J.C. Miller, and J.R. LaBonte. In Prep. Oregon Beetles: A natural history and checklist. Oregon State University, Corvallis, OR 97331. (541) 737-4733.
- Pimentel, D. 1961. Species diversity and insect population outbreaks. *Annals of the Entomological Society of America* 54:76-86.
- Polis, G.A., and R.D. Holt. 1992. Intraguild predation: the dynamics of complex trophic interactions. *Trends in Ecology and Evolution* 7(5):151-154.

- Powell, J.A., and C.L. Hogue. 1979. *California Insects*. University of California Press, Berkley, CA.
- Progar, R., and M.T. AliNiasee. 1999. The economic and environmental impact of an IPM program and a classical biological control program on hazelnuts in Oregon. Department of Entomology, Oregon State University, Corvallis, OR 97331. (541) 737-5493.
- Rees, N.E., P.C. Quimby, Jr., G.L. Piper, E.M. Coombs, C.E. Turner, N.R. Spencer, and L.V. Knutson. 1996. *Biological Control of Weeds in the West*. Western Society of Weed Science, Bozeman, MT.
- Rosenthal, J.P., and R. Dirzo. 1997. Effects of life history, domestication and agronomic selection on plant defense against insects: Evidence from maizes and wild relatives. *Evolutionary Ecology* 11:337-355.
- Schowalter, T.D. 1996. Stand and landscape diversity as a mechanism of forest resistance to insects. In *Dynamics of forest herbivory: quest for pattern and principle*. eds. W.J. Mattson, P. Niemela, and M. Rousi. USDA Forest Service, St. Paul, MN.
- Schuh, R.T., and J.A. Slater. 1995. *True Bugs of the World (Hemiptera: Heteroptera)*. Cornell University Press, New York, NY.
- Schwartz, M.D., and G.G.E. Scudder. 1998. Newly recognized holarctic and introduced plant bugs in North America (Heteroptera: Miridae). *Canadian Entomologist* 130:267-283.
- Semjanov, V.P. 1982. Biology of the ladybird beetle *Calvia quatuordecimguttata* L. (Coleoptera, Coccinellidae). *Entomological Review* 59(4): 47-53.
- Siemann, E., D. Tilman, J. Haarstad, and M. Ritchie. 1998. Experimental tests of the dependence of arthropod diversity on plant diversity. *American Naturalist* 152(5):738-750.
- Simberloff, D., and T. Dayan. 1991. The guild concept and the structure of ecological communities. *Annual Review of Ecology and Systematics* 22:115-143.

- Southwood, T.R.E. 1978. *Ecological Methods*. Second Edition. Chapman and Hill, New York, NY.
- Southwood, T.R.E., and D. Leston. 1959. *Land and water bugs of the British Isles*. Warne & Co. LTD, London.
- Strong, D.R., J.H. Lawton, and T.R.E. Southwood. 1984. *Insects on Plants*. Blackwell Scientific Publications, Oxford.
- Sweet, M.H. 1963. The biology and ecology of the Rhyparochrominae of New England (Heteroptera: Lygaeidae). *Entomologica Americana* 154:1-201.
- Thompson, B.G., and K.L. Wong. 1933. Western Willow Tingid, *Corythuca salicata* Gibson, in Oregon. *Journal of Economic Entomology* 26:1090-1095.
- Thompson, M.M., H.B. Lagerstedt, and S.A. Mehlenbacher. 1996. Hazelnuts. In *Fruit Breeding*, eds. J. Janick, and J. Moore, vol. 3, pp. 125-184. John Wiley and Sons, Inc.
- Ural, I., M. Isik, and A. Kurt. 1973. A study of the insect species found on hazelnut plantation in Eastern Black Sea coast. *Bitki Koruma Bulteni Cilt* 13(2):55-65.
- Viggiani, G. 1994. Predatoi e parassitoidi utili nell'agroecosistema nocciolo. *Acta Horticulturae* 351:583-589.
- Westigard, P.H. 1973. The biology and effect of pesticides on *Deraeocoris brevis piceatus* (Heteroptera: Miridae). *Canadian Entomologist* 105:1105-1111.
- Wheeler, A.G., Jr., and T.J. Henry. 1992. A synthesis of the Holarctic Miridae (Heteroptera): Distribution, biology, and origin, with emphasis on North America. Entomological Society of America, Lanham, MD.
- Winkler, J.R. 1964. *A Book of Beetles*. Spring Books, London.

- Wood, S.L. 1982. The bark and ambrosia beetles of North and Central America (Coleoptera: Scolytidae), a taxonomic monograph. *Great Basin Naturalist Memoirs* 6:1-1359.
- Woolhouse, M.E.J., and R. Harmsen. 1987. Just how unstable are agroecosystems. *Canadian Journal of Zoology* 65:1577-1580.
- Wygodzinsky, P.W. 1966. A monograph of the Emesinae (Reduviidae, Hemiptera). *Bulletin of the American Museum of Natural History* 133:1-614.