Insect Communities Associated with Beneficial Insect Habitat Plants in North Carolina

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Environ. Entomol. 35(6): 1541–1549 (2006)

ABSTRACT This study recorded the arthropod communities present in three commercially available beneficial insect habitat seed mixes (Peaceful Valley's Good Bug Blend, Clyde Robin's Border Patrol, and Heirloom Seed's Beneficial Insect Mix) and three commonly grown cut flower/herb plantings (*Zinnia*, *Celosia*, and fennel). Communities were sampled three ways: (1) foliar and floral collections were made using a D-Vac and aerial nets, and insects were identified to family and assigned to feeding groups; (2) pitfall traps were used to collect ground beetle and ground-dwelling spider populations; and (3) evening observations recorded visits by noctuid (Lepidoptera: Noctuidae) and hawk moths (Lepidoptera: Sphingidae) to flowers. Overall, Good Bug Blend had the highest abundance and diversity of beneficial parasitoids, predators, and ground beetles. However, along with Border Patrol, it also harbored the highest diversity and abundance of crop-feeding herbivores. The Border Patrol plantings had the highest diversity and abundance of insect herbivore crop pests and the highest number of feeding visits by pest moth species during evening observations. The moth visits were most likely caused by the presence of evening primrose in this mix that blooms at dusk when moths are most active. *Celosia* harbored the greatest diversity and abundance of predators and parasitoids in the cut flower/herb plots. Fennel had the lowest overall abundance and diversity of all the plantings, but this may have been caused by late summer flowering.

KEY WORDS beneficial insects, beneficial insect habitat, cut flowers, commercial insect habitat

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Many organic farmers and researchers alike believe that an increase in plant diversity around agricultural crops will improve biological control of insect pests (Landis et al. 2000). This idea was predicted by the "enemies hypothesis" (Root 1973), and is supported by a review by Andow (1991). Taking these concepts and translating them into effective pest management tools has been a difficult task.

Research in conservation biological control has focused on developing an understanding of the ecological processes that affect natural enemies at spatial scales ranging from individual fields to entire landscapes (see reviews in Barbosa and Benrey 1998, Pickett and Bugg 1998, Gurr et al. 2004, Wäckers et al. 2005). A number of practices such as provisioning of ground cover, alternate hosts, and crop diversity can significantly increase natural enemy diversity in a cropping system (van Emden 1990). However, these practices are rarely implemented because of operational and economic considerations, and they highlight a gap between research and implementation (Ehler 1998). As a result, organic growers in particular have little or no scientific guidance on the use of beneficial insect habitat and base their decisions regarding habitat on mainly anecdotal information.

Several companies produce and/ or distribute beneficial insect habitat, usually in the form of specific seed mixtures (Dufour 2000). For beneficial insect habitats to be considered in a pest management strategy, there must be a net gain in beneficial and a net reduction in pest insect species—a relationship that is often difficult to determine (Landis et al. 2000). Suppliers of these mixtures claim that planting their flowering plant mix will contribute significantly to pest management, but little research exists evaluating the effectiveness of these seed mixes as pest management tools under field conditions.

Presently, only two studies evaluating a flowering mixture for pest suppression could be found. Al-Doghairi and Cranshaw (2004) compared four flowers and one commercial seed mixture for parasitism rates and pest densities in cabbage plants. No significant differences were seen between interplanted treatments and controls. Braman et al. (2002) evaluated two commercially available wildflower mixtures for pest suppression in turfgrass. The abundance of some beneficial arthropods was increased in wildflower plots for 1 yr of the study, but the increased abundance was only occasionally observed in adjacent turfgrass plots. Predation of two key pests, fall armyworm and Japanese beetles, was not influenced by the presence of the wildflower mixes. The presence of beneficial

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Table 1. Plant species present in three commercial beneficial insect habitat seed mixes studied in Goldsboro, NC, 2003

Product name	Common name	Scientific name
Border Patrol	Evening Primrose	*Oenotheria argillicola* Mackenzie
	Buckwheat	*Fagopyrum convolvulis* Moench.
	Baby Blue Eyes	*Nemophilia menziesii* Hook. and Arn.
	Bishop's Flower	*Ammi majus* L.
	Blackeyed Susan	*Rudbeckia hirta* L.
	Strawflower	*Helichrysum* ssp. P. Mill.
	Nasturtium	*Tropaeolum majus* L.
	Angelica	*Angelica atropurpurea* L.
	Yarrow	*Achillea millefolium* L.
	Dame's Rocket[a]	*Hesperis matronalis* L.
	Siberian Wallflower[a]	*Erysimum hieraciifolium* L.
Beneficial Insect Mix	Sweet Alyssum	*Lobularia maritime* (L.) Desv.
	Baby Blue Eyes	*Nemophila menziesii* Hook. and Arn.
	Bishop's Flower	*Ammi majus* L.
	Blackeyed Susan	*Rudbeckia hirta* L.
	Candytuft	*Iberis sempervirens* L.
	Coriander	*Coriandrum sativum* L.
	Purple Prairie Clover	*Dalea purpurea* Vent.
	Lance-Leaved Coreopsis	*Coreopsis lanceolata* L.
	Shasta Daisy	*Leucanthemum x superbum* (J.W. Ingram) Berg. ex Kent.
	Forget-me-not	*Myosotis sylvatica* Ehrh. ex Hoffmann
	Blanket Flower	*Gaillardia* spp. Foug.
	Gayfeather	*Liatris* spp. Gaertn. ex Schreb.
	California Poppy	*Eschscholzia californica* Cham.
	Dill	*Anethum graveolens* L.
	Siberian Wallflower	*Erysimum hieraciifolium* L.
Good Bug Blend	Alyssum	*Lobularia maritime* (L.) Desv.
	Caraway	*Carum carvi* L.
	Carrot	*Apiaceae*
	Celery	*Apium graveolens* L.
	Chervil	*Anthriscus cerefolium* (L.) Hoffmann
	Clovers and Alfalfa	*Trifolium* spp. L. and *Medicago sativa* L.
	Coriander	*Coriandrum sativum* L.
	Daikon/Radish	*Raphanus sativus* L.
	Dill	*Anethum graveolens* L.
	Fennel	*Foeniculum foeniculum* (L.) Karst.
	Gypsophila	*Gypsophila* spp. L.
	Nasturtium	*Tropaeolum majus* L.
	Yarrow	*Achillea* spp. L.

[a] Species not advertised as component of seed mixture.

insects in the wildflower mixes suggested they could act as refugia in cases where adjacent turfgrass required insecticide treatment.

The purpose of this study was to evaluate not only beneficial insects but all insect feeding groups associated with several commercially available beneficial insect habitats and several commonly grown cut flowers and herbs. The commercial habitat seed mixes were selected to be representative of the variety of habitats on the market. The cut flower and herb varieties selected are already regularly grown on organic farms in North Carolina. This study will establish basic information about insect communities harbored by these plants and allow us to begin developing recommendations to organic growers about commercial beneficial insect habitats.

Materials and Methods

Seed Sources. All seeds were purchased in February 2003. The three commercial habitat sources were: Border Patrol (Clyde Robin's Seed Co., Castro Valley, CA), Beneficial Insect Mix (Heirloom Seeds, W. Elizabeth, PA), and Good Bug Blend (Peaceful Valley, Grass Valley, CA). The cut flower/ herb seed sources were *Foeniculum vulgare* variety bronze fennel (Family: Apiaceae), *Zinnia elegans* variety pastel dreams (Family: Asteraceae), and *Celosia cristata* variety cockscomb amaranth (Family: Amaranthaceae). Seed composition of each of the commercial blends is presented in Table 1.

Plants. For each of the commercial habitat mixes, seeds were separated from one another using an air column seed separator (model 757; SD Seed Blower, Seedburo Equipment Co., Chicago, IL), various sized sieves (Precision Eforming, Cortland, NY), and hand separation (Forehand 2005). The relative numerical abundance of each seed species was estimated for planting in the greenhouse and transplanting into the field. Transplants were started late March in greenhouses at North Carolina State University, and each species was planted separately, with the exception of the clover and alfalfa from Good Bug Blend, which were planted in a mixture. When plants reached 10 cm tall, they were transplanted into field plots.

Experimental Design. This study was conducted in 2003 at the Center for Environmental Farming Systems (CEFS), Goldsboro, NC. All plot areas and sur-

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rounding crop fields were pesticide free for at least 3 yr before this study and were transitioning toward organic certification.

To maximize distance between flowering habitats, this study was set up using a complete block design with selective placement of treatments. Three blocks were planted with the same order of treatment plots as follows: *Celosia,* fennel, Border Patrol, Good Bug Blend, *Zinnia,* and Beneficial Insect Mix. The first block bordered various solanaceous crops; the second block was 58.4 m to the south, bordering a mix of brassica crops; and the third was 38 m to the southeast and planted beside corn and clovers. Plots within each block were surrounded and separated by a 1.5-m buffer that was planted with brown-top millet (Wyatt Quarles, Garner, NC) and mulched. Each plot with *Celosia,* fennel, or *Zinnia* was 6.1 by 2.1 m and planted in three rows 76 cm apart, with 30.5 cm between each transplant. While there was likely to be some movement of insects between plots, this study was conducted to estimate the relative attractiveness of each habitat to insects and the insect communities harbored by each. Therefore, insect movement should not have affected our relative results.

Transplanting design for the commercial habitat seed mixes was based on the numerical abundance of each species present in each mix (Forehand 2005). Plywood templates with a pair of 10.2-cm holes cut every 0.09 m^2 was used as a guide to ensure uniformly spaced plants (Forehand 2005). For Border Patrol, a 1.5 by 0.6-m template was used 12 times per plot—4 times lengthwise and 3 times across—so that each plot measured 6.0 by 1.8 m. Transplanting locations for angelica and strawflower were left empty because seeds did not germinate. For Beneficial Insect Mix, a 1.5 by 0.9-m template was used eight times per plot—four times lengthwise and two times across—so each plot measured 6.0 by 1.8 m. The planting template for Good Bug Blend used a 1.2 by 3.0-m template to accommodate the high variability in abundance of the 14 plant species (Forehand 2005). The template was used 2.5 times and plots measured 6.0 by 1.2 m.

Plot Management. In April 2003, soybean meal (Wyatt Quarles) that had not been treated with pesticides was applied to each plot at a rate of 78.5 kg/ha and incorporated with rakes. All plants were transplanted 15–18 May 2003 using the templates as a guide and hand trowels and bulb diggers for planting. All plots were mulched with organic wheat straw. For 2 wk after transplanting, any dead plants were replaced. Plants were watered as needed, and weed management consisted of hand-weeding within plot and mechanical control around and between plots.

Foliar and Floral Sampling. On eight dates in 2003 (19 June, 25 June, 3 July, 9 July, 16 July, 23 July, 30 July, 6 August), insect samples were collected from each plot using a D-Vac (D-Vac, Ventura, CA) vacuum sampler for 1 min per plot and two 30.5-cm aerial nets (Bioquip, Dominguez, CA) for 1 min before and during sampling with D-vac. Sampling was conducted between 1100 and 1400 hours, when insect numbers were expected to be greatest (Jervis and Kidd 1996). Samples were collected from one of the outside rows of *Celosia,* fennel, and *Zinnia* and down one side of the three habitat mixes. To allow insect communities and plants to recover, the sides of plots sampled each week was alternated so that no side was sampled more often than every 2 wk. Family level identification was performed on all insects >3 mm. For insects <3 mm, identifications were done for specimens from three 5.5% subsamples from each plot. Numbers from the combined subsamples were scaled up to provide a single estimate of the number of smaller specimens from each family in each plot.

Moth Sampling. Observations of flower visits by adult Lepidoptera were made on four dates in 2003: 24 July, 30 July, 6 August, and 13 August. Observations began at dusk (≈1830 hours) and continued until total darkness, ≈1 h later. Each plot was observed three times during the hour for 1 min using flashlights covered with red cellophane. The red light produced allowed us to take advantage of insects general lack of sensitivity of longer light wavelengths (Atkins 1978), so we could clearly see the moths but not attract them to our light source. The total number of noctuid moths (Lepidoptera: Noctuidae) and hawk moths (Lepidoptera: Sphingidae) visiting each plot was recorded. Samples of these moths collected. The noctuids included both tobacco budworm [*Heliothis virescens* (F.)] and tomato fruitworm, *Helicoverpa zea* (Boddie). Sphingids were primarily tobacco hornworm, *Manduca sexta* L., with some white-lined sphinx moths, *Hyles lineata* (F.). All of these species are considered pests of crop plants grown on the CEFS Farm. If a moth moved between plants in the same plot without leaving the plot, it was counted only one time. If a moth left the plot and returned, it was counted as a second visit. Moths were collected on 24 July using aerial nets for identification.

Pitfall Traps. To sample ground beetles (Coleoptera: Carabidae) and spiders (Araneae), one pitfall trap was placed into each of the three plots for each of the different plant communities on seven dates in 2003: 26 June, 10 July, 17 July, 25 July, 31 July, 7 August, and 14 August. Pitfall traps were constructed using two 473-ml plastic cups (Solo Cup Co., Highland Park, IL) set inside of each other. The outer cup had drainage holes cut in the bottom, and the inner cup had holes on the sides, ≈6 cm from the top. Pitfall traps were randomly placed in the ground so that the upper lip of the cup was even with the soil surface and filled with ≈2.5 cm of 50% antifreeze (Honeywell International, Morristown, NJ). Traps were set at ≈1000 hours, and samples were collected 24 h later.

Insect Identification. Insects were identified using the following sources: Mitchell 1960a, b, Borror and White 1970, Bland and Jaques 1978, McAlpine et al. 1981, 1987, White 1983, Stehr 1987, 1991, Borror et al. 1989, Grissell and Schauff 1990, Gibson et al. 1997, Flint and Dreistadt 1998, Mullen and Durden 2002. After identification, insects were grouped into feeding groups (Table 2) based on consensus information obtained from Borror and White (1970), Borror et al. (1989), and Flint and Dreistadt (1998). The "parasi-

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Table 2. List of insect families by feeding group

Decomposer/fungus feeder		
Lathridiidae	Lauxaniidae	Lonchopteridae
Mordellidae	Mycetophilidae	Nitidulidae
Phalacridae	Phoridae	Psocoptera[a]
Scatopsidae	Sciaridae	Sepsidae
Stratiomyidae	Sarcophagidae	
Herbivore–crop pest		
Aphidae	Arctiidae	Chrysomelidae
Cicadellidae	Coreidae	Curculionidae
Elateridae	Languriidae	Lygaeidae
Membracidae	Miridae	Noctuidae
Papillionidae	Pentatomidae	Pieridae
Rhopalidae	Scarabaeidae	Sphingidae
Tephritidae	Thysanoptera[a]	
Herbivore–noncrop feeder		
Acrididae	Anthicidae	Berytidae
Cecidomyiidae	Cercopidae	Chloropidae
Cydnidae	Delphacidae	Drosophilidae
Geometridae	Gryllidae	Hesperiidae
Nymphalidae	Otitidae	Tettigoniidae
Thyreocoridae	Tipulidae	
Pollinators		
Anthophoridae	Apidae	Halictidae
Parasitoid–beneficial		
Bethylidae	Braconidae	Dryinidae
Encyrtidae	Eulophidae	Ichneumonidae
Mymaridae	Proctotrupidae Trichogrammatidae	Scelionidae
Parasitoid–mixed		
Ceraphronidae	Diapriidae	Pteromalidae
Parasitoid–noncrop		
Eucoilidae	Meloidae	Platygasteridae
Scoliidae	Tiphiidae	
Predator–beneficial		
Anthocoridae	Carabidae	Chrysopidae
Coccinellidae	Dolichipodidae	Formicidae
Lygaeidae	Nabidae	Pentatomidae
Reduviidae	Araneidae	Staphylinidae
Syrphidae	Tachinidae	Vespidae
Predator–inconsequential		
Cantharidae	Cucujidae	Empididae
Lampyridae	Libellulidae	Sphecidae

[a] Order level identification.

toid–mixed" feeding group consisted of families with very diverse life histories that could not be overall categorized as beneficial or detrimental. The "parasitoid–noncrop" feeding group consisted of families that were less likely to contribute to the suppression of important agricultural crop pests (e.g., Scoliidae and Tiphiidae are scarab beetle larval parasitoids). "Inconsequential predators" were categorized because of their varied life histories. For example, Cucujidae and Lampyridae seldom occur in numbers that would impact pest populations, whereas Sphecidae usually feed on a single type of insect or spider.

Reference collections were assembled and later verified by one of the following: David Stephan, Robert Blinn, Dr. Brian Wiegmann of North Carolina State University or Dr. Ken Ahlstrom, North Carolina Department of Agriculture and Consumer Services–Plant Protection Section.

Data Analysis. For each feeding group, six diversity indices were calculated: Simpson's Index; Shannon-Wiener's Index (often called Shannon's Index); Hill's N1 and N2 diversity numbers; species evenness [exp (Shannon)/species richness]; and species richness (Hill 1973). Because the diversity index literature does not present a clear favorite index and because different indices perform better under varying circumstances, we chose to calculate and present these six commonly used indices (Hill 1973, Peet 1974, Mouillot and Leprêtre 1999). Diversity measures were analyzed using a split plot analysis of variance (ANOVA) with habitat as a whole plot factor and date as a subplot factor, with whole plots in blocks (PROC GLM; SAS Institute 2002). Habitat was tested against block × habitat (with 10 denominator df), and date and habitat × date were tested against subplot error (with 79 denominator df). Means were separated using LS means (SAS Institute 2002).

Results

Habitat type had a significant impact on the total abundance and diversity of insects found in sample plots for each of the calculated indices (see Table 3 for statistics). Of all the potential habitats studied, Border Patrol generally had the highest overall diversity for the index values calculated (Table 3). Of the cut flower/herb plantings, *Celosia* had the highest overall diversity and abundance for Simpson's Index, Shannon's Index, and Hill's N1 and N2 diversity numbers (Table 3). With the exception of species evenness,

Table 3. Diversity/abundance index values (mean ± SD) for the entire community of insects collected from six potential beneficial insect habitats, Goldsboro, NC, 2003

Habitat	Simpson	Shannon	N1	N2	Evenness	Richness	Total no. insects/m^2
BP	0.11 ± 0.07c	2.78 ± 0.38a	17.02 ± 5.17a	11.44 ± 4.32a	0.41 ± 0.08a	41.8 ± 12.4a	852.68 ± 450.20
GBB	0.12 ± 0.06bc	2.61 ± 0.34b	14.36 ± 4.41b	9.17 ± 3.39c	0.36 ± 0.06b	40.7 ± 11.4a	1039.14 ± 572.38
BIM	0.15 ± 0.06b	2.50 ± 0.31c	12.67 ± 3.70c	7.38 ± 2.61d	0.34 ± 0.07b	38.2 ± 9.9a	883.75 ± 392.26
Celosia	0.10 ± 0.03c	2.65 ± 0.22b	14.54 ± 3.15b	10.28 ± 2.44b	0.46 ± 0.11a	32.8 ± 9.8b	446.64 ± 291.89
Zinnia	0.15 ± 0.06b	2.48 ± 0.30c	12.41 ± 3.43c	7.67 ± 2.44d	0.42 ± 0.14a	32.0 ± 10.2b	416.97 ± 269.77
Fennel	0.32 ± 0.15a	1.72 ± 0.43d	6.12 ± 2.59d	3.84 ± 1.82e	0.31 ± 0.11b	20.6 ± 7.1c	419.76 ± 257.62
LSD	0.03	0.08	0.89	0.93	0.05	4.37	
F (habitat)	90.92	219.84	169.90	82.34	11.63	31.88	
df (habitat, block × habitat)	5,10	5,10	5,10	5,10	5,10	5,10	
P (habitat)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	

Means within the same column followed by the same letter are not significantly different (PROC Mixed; SAS Institute 2002).
BP, Border Patrol; BIM, Beneficial Insect Mix; GBB, Good Bug Blend.

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Table 4. Diversity/abundance index values for feeding groups of insects collected from six potential beneficial insect habitats, Goldsboro, NC, 2003

Habitat	Simpson	Shannon	N1	N2	Evenness	Richness	Total no. insects/m^2
Parasitoids–beneficial							
BP	0.42 ± 0.14c	1.09 ± 0.30	3.08 ± 0.82ab	2.58 ± 0.70ab	0.69 ± 0.11d	4.33 ± 1.55ab	93.48 ± 53.70
GBB	0.40 ± 0.19c	1.15 ± 0.41	3.38 ± 1.12a	2.93 ± 0.98a	0.77 ± 0.13bc	4.58 ± 1.77a	86.31 ± 50.26
BIM	0.43 ± 0.10c	0.97 ± 0.31	2.75 ± 0.72bc	2.45 ± 0.55b	0.76 ± 0.15c	3.83 ± 1.40bc	91.16 ± 79.84
Celosia	0.45 ± 0.18bc	0.94 ± 0.35	2.67 ± 0.73bc	2.47 ± 0.65b	0.82 ± 0.13b	3.42 ± 1.25cd	57.47 ± 47.91
Zinnia	0.51 ± 0.21b	0.81 ± 0.39	2.41 ± 0.83cd	2.22 ± 0.73bc	0.80 ± 0.13bc	3.13 ± 1.26d	47.15 ± 36.09
Fennel	0.60 ± 0.25a	0.62 ± 0.41	2.01 ± 0.73d	1.94 ± 0.69c	0.91 ± 0.12a	1.92 ± 1.25e	15.48 ± 11.39
LSD	0.08	0.16	0.48	0.42	0.06	0.70	
F (habitat)	8.12	12.93	9.66	6.25	12.37	18.79	
df (habitat, block × habitat)	5,10	5,10	5,10	5,10	5,10	5,10	
P (habitat)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	
Predators–beneficial							
BP	0.35 ± 0.13a	1.29 ± 0.30a	3.79 ± 1.04ab	2.98 ± 0.84ab	0.51 ± 0.17c	8.04 ± 2.65ab	121.91 ± 98.13
GBB	0.30 ± 0.10a	1.48 ± 0.27a	4.55 ± 1.24a	3.76 ± 1.50a	0.58 ± 0.17abc	8.17 ± 2.01a	69.99 ± 47.93
BIM	0.37 ± 0.10a	1.25 ± 0.33ab	3.66 ± 1.11b	3.00 ± 0.97ab	0.54 ± 0.15bc	7.17 ± 2.10bc	136.28 ± 100.43
Celosia	0.29 ± 0.13a	1.36 ± 0.30a	4.02 ± 0.97ab	3.54 ± 0.80a	0.63 ± 0.14a	6.71 ± 2.11c	47.07 ± 40.24
Zinnia	0.36 ± 0.19a	1.28 ± 0.42a	3.88 ± 1.34ab	3.31 ± 1.28a	0.63 ± 0.15ab	6.42 ± 2.12c	98.17 ± 82.79
Fennel	0.49 ± 0.19a	0.96 ± 0.37 b	2.76 ± 0.95c	2.31 ± 0.82b	0.63 ± 0.15a	4.54 ± 1.67d	92.08 ± 67.23
LSD	0.16	0.29	0.85	0.86	1.11	0.88	
F (habitat)	1.94	3.48	4.65	3.37	2.52	22.37	
df (habitat, block × habitat)	5,10	5,10	5,10	5,10	5,10	5,10	
P (habitat)	0.17	0.04	0.02	0.05	0.10	<0.01	
Herbivores–crop pest							
BP	0.37 ± 0.15c	1.33 ± 0.40a	4.04 ± 1.44a	3.16 ± 1.18a	0.48 ± 0.11a	8.92 ± 3.37a	247.61 ± 134.60
GBB	0.38 ± 0.14c	1.26 ± 0.34a	3.70 ± 1.05a	2.85 ± 0.76a	0.44 ± 0.08ab	8.67 ± 2.78a	210.36 ± 186.77
BIM	0.49 ± 0.15b	1.03 ± 0.31b	2.93 ± 0.89b	2.21 ± 0.67b	0.40 ± 0.15bc	8.08 ± 2.73ab	189.00 ± 106.71
Celosia	0.50 ± 0.15b	1.00 ± 0.31b	2.84 ± 0.81b	2.15 ± 0.59b	0.43 ± 0.15ab	7.33 ± 2.81b	188.08 ± 109.21
Zinnia	0.63 ± 0.14a	0.74 ± 0.24c	2.15 ± 0.49c	1.65 ± 0.37c	0.34 ± 0.21c	7.46 ± 2.78b	171.05 ± 150.23
Fennel	0.69 ± 0.15a	0.56 ± 0.24d	1.80 ± 0.43c	1.51 ± 0.36c	0.43 ± 0.19ab	4.54 ± 1.53c	288.31 ± 206.14
LSD	0.08	0.16	0.45	0.34	0.08	0.83	
F (habitat)	26.42	35.57	36.52	35.51	3.80	36.14	
df (habitat, block × habitat)	5,10	5,10	5,10	5,10	5,10	5,10	
P (habitat)	<0.01	<0.01	<0.01	<0.01	0.03	<0.01	
Parasitoids–mixed[a]							
BP	0.75 ± 0.26a	0.36 ± 0.36a	1.52 ± 0.54a	1.51 ± 0.54a	0.95 ± 0.08a	1.29 ± 0.91a	10.83 ± 10.21
GBB	0.81 ± 0.23a	0.24 ± 0.31a	1.34 ± 0.44a	1.37 ± 0.47a	0.95 ± 0.10a	1.25 ± 0.68a	8.72 ± 8.51
BIM	0.78 ± 0.26a	0.25 ± 0.33a	1.36 ± 0.47a	1.44 ± 0.54a	0.99 ± 0.04a	1.04 ± 0.75a	7.64 ± 7.74
Celosia	0.70 ± 0.27a	0.38 ± 0.38a	1.57 ± 0.59a	1.65 ± 0.63a	0.99 ± 0.03a	1.00 ± 0.93a	7.03 ± 7.35
Zinnia	0.81 ± 0.23a	0.26 ± 0.30a	1.36 ± 0.43a	1.37 ± 0.50a	0.93 ± 0.13a	0.88 ± 0.85a	6.71 ± 9.70
Fennel	0.94 ± 0.18a	0.07 ± 0.24a	1.11 ± 0.37a	1.36 ± 0.38a	0.98 ± 0.08a	0.54 ± 0.72a	1.87 ± 3.27
LSD	0.29	0.38	0.56	0.62	0.07	0.67	
F (habitat)	0.27	0.18	0.16	0.26	0.32	1.66	
df (habitat, block × habitat)	5,10	5,10	5,10	5,10	5,10	5,10	
P (habitat)	0.92	0.96	0.97	0.93	0.89	0.23	
Parasitoids–noncrop							
BP	0.83 ± 0.19a	0.27 ± 0.30a	1.38 ± 0.46a	1.28 ± 0.36a	0.82 ± 0.20a	1.83 ± 1.17ab	20.97 ± 30.01
GBB	0.84 ± 0.20a	0.27 ± 0.33a	1.38 ± 0.51a	1.29 ± 0.43a	0.81 ± 0.20a	1.58 ± 1.14bc	9.13 ± 11.61
BIM	0.73 ± 0.22a	0.43 ± 0.34a	1.63 ± 0.64a	1.54 ± 0.61a	0.76 ± 0.20a	2.13 ± 0.90a	24.01 ± 26.08
Celosia	0.78 ± 0.23a	0.37 ± 0.37a	1.54 ± 0.63a	1.45 ± 0.60a	0.82 ± 0.18a	1.50 ± 1.18c	6.16 ± 10.55
Zinnia	0.73 ± 0.23a	0.39 ± 0.32a	1.55 ± 0.47a	1.51 ± 0.47a	0.81 ± 0.20a	1.38 ± 1.01c	20.14 ± 19.09
Fennel	0.89 ± 0.21a	0.15 ± 0.28a	1.71 ± 0.39a	1.22 ± 0.44 a	0.96 ± 0.10a	0.38 ± 0.65d	20.65 ± 21.95
LSD	0.15	0.23	0.41	0.40	0.10	0.32	
F (habitat)	1.48	1.36	1.11	1.26	2.49	34.42	
df (habitat, block × habitat)	5,10	5,10	5,10	5,10	5,10	5,10	
P (habitat)	0.28	0.32	0.41	0.35	0.10	<0.01	
Predators–inconsequential							
BP	0.81 ± 0.30a	0.20 ± 0.31a	1.29 ± 0.47a	1.31 ± 0.59bc	0.87 ± 0.20a	1.50 ± 0.98ab	11.83 ± 15.30
GBB	0.76 ± 0.25a	0.33 ± 0.39a	1.51 ± 0.66a	1.52 ± 0.66ab	0.82 ± 0.22a	1.63 ± 1.28a	7.51 ± 11.20
BIM	0.70 ± 0.33a	0.36 ± 0.34a	1.52 ± 0.53a	1.44 ± 0.59ab	0.80 ± 0.22a	1.75 ± 1.22a	8.64 ± 10.61
Celosia	0.67 ± 0.30a	0.39 ± 0.36a	1.57 ± 0.56a	1.62 ± 0.65a	0.86 ± 0.17a	1.54 ± 1.14ab	6.36 ± 11.79
Zinnia	0.83 ± 0.29a	0.18 ± 0.29a	1.25 ± 0.41a	1.21 ± 0.38c	0.95 ± 0.11a	1.08 ± 0.78b	6.86 ± 9.37
Fennel	0.90 ± 0.20a	0.07 ± 0.21a	1.10 ± 0.28a	1.17 ± 0.34c	0.99 ± 0.04a	0.38 ± 0.58c	13.75 ± 22.22
LSD	0.21	0.21	0.32	0.21	0.16	0.52	
F (habitat)	2.90	3.12	3.02	5.86	1.57	9.60	
df (habitat, block × habitat)	5,10	5,10	5,10	5,10	5,10	5,10	
P (habitat)	0.07	0.06	0.06	<0.01	0.26	<0.01	

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Table 4. Continued

Habitat	Simpson	Shannon	N1	N2	Evenness	Richness	Total no. insects/m^2
Herbivores–noncrop pest							
BP	0.47 ± 0.17a	1.01 ± 0.28a	2.84 ± 0.73a	2.21 ± 0.57a	0.39 ± 0.16c	7.83 ± 2.35a	226.59 ± 142.74
GBB	0.46 ± 0.13a	1.02 ± 0.27a	2.87 ± 0.72a	2.29 ± 0.52a	0.37 ± 0.10c	8.33 ± 2.99a	104.97 ± 115.09
BIM	0.45 ± 0.12a	1.06 ± 0.26a	2.99 ± 0.75a	2.38 ± 0.56a	0.42 ± 0.14abc	7.58 ± 2.15a	141.30 ± 89.54
Celosia	0.49 ± 0.13a	0.92 ± 0.24a	2.58 ± 0.56a	2.15 ± 0.46a	0.49 ± 0.18ab	6.00 ± 2.40b	105.40 ± 92.59
Zinnia	0.51 ± 0.16a	0.94 ± 0.30a	2.67 ± 0.77a	2.15 ± 0.63a	0.47 ± 0.13ab	6.04 ± 2.10b	131.48 ± 110.48
Fennel	0.57 ± 0.18a	0.78 ± 0.29a	2.26 ± 0.63a	1.90 ± 0.56a	0.51 ± 0.22a	5.13 ± 2.19b	231.10 ± 182.56
LSD	0.10	0.20	0.49	0.37	0.13	2.20	
F (habitat)	2.06	3.29	3.18	2.22	2.24	4.39	
df (habitat, block × habitat)	5,10	5,10	5,10	5,10	5,10	5,10	
P (habitat)	0.16	0.06	0.06	0.14	0.03	<0.01	
Pollinators							
BP	0.64 ± 0.39a	0.30 ± 0.31a	1.41 ± 0.43a	1.42 ± 0.49a	0.95 ± 0.07a	1.13 ± 0.80a	0.68 ± 0.52
GBB	0.64 ± 0.33a	0.23 ± 0.32a	1.31 ± 0.44a	1.65 ± 0.81a	0.98 ± 0.04a	0.63 ± 0.77b	0.30 ± 0.47
BIM	0.62 ± 0.33a	0.35 ± 0.32a	1.48 ± 0.45a	1.76 ± 0.81a	0.96 ± 0.06a	1.04 ± 0.86a	0.75 ± 0.84
Celosia	0.79 ± 0.40a	0.12 ± 0.27a	1.17 ± 0.38a	1.29 ± 0.76a	0.99 ± 0.17a	0.54 ± 0.66b	0.21 ± 0.25
Zinnia	0.83 ± 0.33a	0.05 ± 0.18a	1.07 ± 0.25a	1.50 ± 1.00a	1.00 ± 0.04a	0.58 ± 0.58b	0.19 ± 0.25
Fennel	1.00 ± 0.00a	0.00 ± 0.00a	1.00 ± 0.00a	1.00 ± 0.00a	1.00 ± 0.00a	0.25 ± 0.44b	0.07 ± 0.13
LSD	0.51	0.32	0.44	1.23	0.05	0.39	
F (habitat)	0.27	1.42	1.42	0.76	0.74	2.65	
df (habitat, block × habitat)	5,10	5,10	5,10	5,10	5,10	5,10	
P (habitat)	0.91	0.37	0.37	0.59	0.29	<0.01	
Decomposers and fungus feeders							
BP	0.34 ± 0.15a	1.31 ± 0.45a	4.07 ± 1.51a	3.48 ± 1.34a	0.62 ± 0.19c	6.92 ± 2.55a	115.09 ± 145.75
GBB	0.47 ± 0.24a	1.03 ± 0.52ab	3.14 ± 1.35a	2.67 ± 1.15a	0.60 ± 0.24c	6.00 ± 2.45ab	87.48 ± 101.90
BIM	0.43 ± 0.19a	1.11 ± 0.44a	3.32 ± 1.43a	2.88 ± 1.36a	0.63 ± 0.19c	5.54 ± 2.19ab	97.96 ± 89.52
Celosia	0.36 ± 0.16a	1.21 ± 0.38a	3.59 ± 1.31a	3.33 ± 1.34a	0.77 ± 0.17ab	4.83 ± 1.81b	59.29 ± 58.85
Zinnia	0.33 ± 0.12a	1.28 ± 0.32a	3.80 ± 1.24a	3.44 ± 1.29a	0.70 ± 0.19bc	5.50 ± 2.27ab	76.92 ± 113.93
Fennel	0.58 ± 0.31a	0.69 ± 0.58b	2.35 ± 1.47a	2.18 ± 1.34a	0.82 ± 0.15a	2.92 ± 2.04c	130.57 ± 185.63
LSD	0.21	0.39	1.10	1.04	0.12	2.23	
F (habitat)	2.16	3.23	2.80	2.32	5.39	8.65	
df (habitat, block × habitat)	5,10	5,10	5,10	5,10	5,10	5,10	
P (habitat)	0.14	0.05	0.08	0.12	<0.01	<0.01	

For each feeding group, means within a column followed by the same letter are not significantly different (PROC TTEST; SAS Institute 2002).

[a] Parasitoids comprised of families with varied life histories that could not be easily classified into beneficial or non-crop feeding groups.

BP, Border Patrol; BIM, Beneficial Insect Mix; GBB, Good Bug Blend.

fennel had significantly lower index values compared with all other plant communities studied (Table 3).

Beneficial parasitoid diversity was significantly affected by habitat type for all of the index values (Table 4). Good Bug Blend and Border Patrol had the highest diversity and richness index values for beneficial parasitoids, but the lowest species evenness values. In general, fennel had the lowest diversity and richness values for beneficial parasitoids but the highest species evenness.

Four of the six abundance and diversity index values for the beneficial predator feeding group were significantly influenced by habitat type (Table 4). *Celosia* and Good Bug Blend had the highest beneficial predator index values for the cut-flower/herb and commercial mixtures, respectively, and fennel had the lowest index values.

Herbivore crop pest diversity indices were all significantly influenced by habitat type (Table 4). For four of the six index values calculated for herbivore crop pests, Border Patrol and Good Bug Blend were significantly higher than all other habitat types, whereas fennel had the lowest index values.

None of the diversity index values were significantly affected by habitat type for the mixed parasitoid feeding group (Table 4). Only species richness was significantly affected by habitat in the noncrop parasitoid feeding group. Only Hill's N2 and species richness index values were significantly affected by habitat for inconsequential predators. Overall, fennel had the lowest Hill's N2 and species richness index values for inconsequential predators. Habitat significantly affected species evenness and richness for noncrop pests. The three commercial mixes had the highest noncrop pests index values, whereas fennel had the lowest index values overall.

The only diversity value for pollinators that was significantly affected by habitat was species richness, in which Border Patrol and Beneficial Insect Mix had the highest index values and fennel had the lowest (Table 4). Three of the abundance and diversity indices for the decomposer/fungal feeder group were significantly altered by habitat type (Table 4). There was no significant difference in the decomposer index values between the three commercially available seed mixes, although Border Patrol generally had the highest values. Fennel had the lowest overall index values of all habitat types for decomposers.

Moth feeding activity varied significantly among the various beneficial insect habitats (Table 5). The high-

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est mean number of noctuid moth flower visits per minute was recorded in Border Patrol, whereas the lowest values were in Good Bug Blend, *Zinnia*, and Beneficial Insect Mix. Border Patrol had significantly higher mean hawk moth visits.

Habitat type significantly altered the mean number of carabid beetles collected in pitfall traps (Table 6). The numerical trend indicated Good Bug Blend and fennel had the highest values, whereas *Celosia* and Beneficial Insect Mix had the lowest. No significant difference was seen in the mean number of spiders collected in pitfall traps placed in the habitats.

Discussion

Border Patrol was chosen for this study because it offered the greatest variety of flower types compared with other commercial seed mixtures. The Border Patrol seed mixture had high diversity and evenness of beneficial parasitoids, but also had the greatest abundance and diversity of crop feeding herbivores, mixed parasitoids, and decomposers/ fungal feeders, and it also attracted the highest number of pest moths of the six habitats tested. Evening primrose, the largest plant in this mixture, has large cup-shaped flowers with long, tubular corollae that open at dusk and are accessible to adult Lepidoptera (Brickell and Zuk 1997). Because Border Patrol harbors comparatively high crop pest populations and comparatively high levels of pest moth feeding were observed in this habitat, planting it near crops may actually increase pest insect populations.

Good Bug Blend was chosen for this study because of the high proportion of plant species with small, easily accessible nectaries within flowers. This type of floral structure is purported to benefit small parasitoids (Leius 1960, Patt et al. 1997, Colley and Luna 2000, Luna and Jepson 2002, Wäckers 2004). In this study, Good Bug Blend harbored high abundance and diversity of beneficial predators, parasitoids, and ground beetles. Because this seed mixture included plants with relatively small, shallow flowers, large pollinators and moths were apparently less able to feed. Along with Border Patrol, Good Bug Blend also harbored the highest abundance and diversity of crop-feeding herbivores.

Table 5. Feeding visits per minute (mean ± SD) by noctuid moths (Lepidoptera: Noctuidae) and hawk moths (Lepidoptera: Sphingidae) in cut flower, herb, and beneficial insect habitat plantings, Goldsboro, NC, 2003

Habitat	Noctuid moths	Hawk moths
BP	2.14 ± 1.86a	1.81 ± 2.29a
GBB	0.78 ± 0.90b	0.06 ± 0.13b
BIM	1.06 ± 0.93b	0.06 ± 0.13b
Celosia	1.56 ± 1.45ab	0b
Zinnia	0.97 ± 0.48b	0b
Fennel	1.44 ± 2.76ab	0b
LSD	0.85	0.46
F (habitat)	3.38	24.80
df (habitat, block × habitat)	5,10	5,10
P (habitat)	0.05	<0.01

Means within a column followed by the same letter are not significantly different (PROC TTEST; SAS Institute 2002).

BP, Border Patrol; BIM, Beneficial Insect Mix; GBB, Good Bug Blend.

Table 6. Mean no. of carabid beetles (Coleoptera: Carabidae) and spiders (Acarina: Araneidae) collected from pitfall traps in six potential beneficial insect habitats, Goldsboro, NC, 2003

Habitat	Carabid beetles	Spiders
BP	0.57 ± 0.68c	0.71 ± 0.72a
GBB	2.14 ± 1.74a	1.09 ± 1.86a
BIM	1.05 ± 1.02bc	0.67 ± 1.02a
Celosia	0.29 ± 0.90c	0.67 ± 1.15a
Zinnia	0.24 ± 0.70c	0.81 ± 1.57a
Fennel	1.71 ± 1.49ab	1.00 ± 0.95a
LSD	0.88	0.45
F (habitat)	7.91	1.65
df (habitat, block × habitat)	5,10	5,10
P (habitat)	<0.01	0.23

Means within a column followed by the same letter are not significantly different (PROC TTEST; SAS Institute 2002).

BP, Border Patrol; BIM, Beneficial Insect Mix; GBB, Good Bug Blend.

Beneficial Insect Mix was chosen for this study because the plant species present in this seed mixture represented "showy" types of flowers typically associated with cut flower production or gardening. Lepidopteran pests were not highly attracted to this habitat. Because of the large number of plant species found in Beneficial Insect Mix, it was expected that a high diversity of insects would also be observed. High abundance and diversity values were only found for noncrop herbivores and noncrop parasitoids, and this mix ranked the lowest of the three commercial seed mixtures for numbers of beneficial parasitoids and predators. It is possible that the relatively large flowers that benefited pollinators were unable to feed microscopic (1–2 mm) Hymenoptera parasitoids. This idea is supported by the work of Patt et al. (1997), who evaluated the influence of floral architecture on two parasitic Hymenoptera.

Celosia was chosen for this study because it is commonly grown in North Carolina as a cut flower crop. Overall, these plants ranked among the highest abundance and diversity values for predators, both beneficial and those of no agronomic consequence, as well as parasitoids that show varied life histories. While *Celosia* was the most effective of the three cut flower/ herb plantings at attracting several different feeding groups of predators and parasitoids, the groups found were for the most part not considered useful in biological control of crop pests. The floral structure of *Celosia* has very tightly clustered flower heads, containing up to thousands of individual flowers (Brickell and Zuk 1997), with relatively shallow, easily accessible pollen (Moore et al. 1998). *Celosia* attracted intermediate numbers of noctuid moths and no hawk moths, probably a reflection of this floral structure.

Zinnia is a commonly grown cut flower in the southeastern United States (Greer 2000). The large, daisy-like flower heads are borne on solitary long stems and bloom throughout the summer months (Brickell and Zuk 1997). *Zinnias,* which are in the same family as

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sunflowers, reportedly attract various kinds of beneficial insects from many different feeding groups (Dufour 2000, Jones and Gillett 2005). This study found these plants had some of the lowest index values of insect abundance and diversity. While well suited for a cut flower cash crop, *Zinnia* does not seem to be effective at attracting beneficial insect populations.

Fennel is often recommended for attracting beneficial organisms in agricultural landscapes (Al-Doghairi and Cranshaw 1999, Dufour 2000), but recommendations for using this plant have not been based on scientific evidence. Several studies have documented feeding by parasitic Hymenoptera on fennel and other umbelliferous plants (Maingay et al. 1991, Poncavage 1991, Hodgson and Lovei 1993, Patt et al. 1997, Baggen and Gurr 1998, Al-Doghairi and Cranshaw 1999, Baggen et al. 2000, Dufour 2000). However, this study found fennel had the lowest species diversity and abundance for all indices and for all feeding groups. One explanation may be that 120-d transplants were used in this study, which did not begin flowering until late summer. Fennel had an intermediate number of noctuid moth visits and no hawk moth visits, probably reflecting the small umbelliferous structure of the flowers. A high mean number of ground beetles were collected from fennel, possibly in response to numerous immature Lepidoptera feeding on foliage.

This study shows that a wide variety of arthropods are attracted to commercially available beneficial insect habitats, not only the intended beneficials. Although beneficial insects were collected from all the plantings in this study, it is unclear whether they were feeding within or benefiting from the particular plant communities. More work is necessary to determine whether these habitat plants provide pollen, nectar, alternate hosts, or other resources to specific natural enemies that attack crop pests and if they benefit field populations of these enemies and assist in pest management. For example, Good Bug Blend had the highest diversity of beneficial parasitoids and predators of the habitat plants tested in this study. However, Forehand (2005) found that parasitism of pest moth eggs and caterpillars was not changed when small organic tomato fields were surrounded by Good Bug Blend. This suggests that high abundance and diversity of beneficial insects in a habitat may not be a predictor of how or whether the habitat functions as a pest management tool under field conditions.

Acknowledgments

We thank D. Stephan, R. Blinn, B. Wiegmann, and K. Ahlstrom for taxonomic assistance, C. Brownie for invaluable stastical assistance and recommendations, B. Perry, T. Matthews, and E. Pitzer for assistance with field plots at the Center for Environmental Farming Systems in Goldsboro, NC, and M. Gibbs, L. Jackson, B. Witting, M. Kroner, S. Kennedy, D. Frank, and M. Perry for tireless effort and support throughout this study.

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Received for publication 22 March 2006; accepted 27 August 2006.

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