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Abundance and diversity of beneficial and pest arthropods in buckwheat on blueberry and vegetable farms in north Florida

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The diversity of plants in agricultural crops can be managed to provide non-crop floral resources that increase the variety and abundance of beneficial arthropods (Root 1973; Gurr et al. 2003). The diversity-driven reduction of herbivore damage has typically been attributed either to an increase in predator and parasite abundance (the "enemies" hypothesis), or to the fact that the crop host is less concentrated in a diverse setting, reducing the likelihood that an herbivore will be able to locate and colonize the non-contiguous crop (the "resource concentration" hypothesis) (Root 1973). Buckwheat, *Fagopyrum esculentum* Moench (Polygonaceae), a common cover crop, has been reported as an excellent source of nectar and habitat for natural enemies, with the added benefit of a short sowing-to-flower time (Bowie et al. 1995). Beneficial hymenopteran species, in particular, benefit from the increased nectar resources available in buckwheat (Ponti et al. 2007; Taki et al. 2009).

Buckwheat has been planted in association with many crops, including blueberry (Walton & Issacs 2011), cabbage (Lee & Heimpel 2005), zucchini squash (as a living mulch) (Frank & Liburd 2005), and apple (Stephens et al. 1998), to increase pollinators, predators, and parasitoids and decrease the damage caused by pests. However, floral resources such as buckwheat can also increase the diversity and abundance of pests, potentially resulting in more crop damage (Baggen & Gurr 1998). Furthermore, intercropping with buckwheat, although affecting pest populations, has not consistently been associated with an increase in marketable yields (Razze et al. 2016). A crucial component of managed diversity is the selective enhancement of beneficial arthropod populations (Landis et al. 2000). Consequently, this study was conducted to quantify the selectivity, measured by the relative abundance of beneficial and pest arthropods, of buckwheat plantings at operational blueberry and vegetable farms in north Florida.

The diversity and abundance of beneficial and pest arthropods were investigated at 2 farms where buckwheat ('Mancan' variety, Hancock Seed and Feed, Dade City, Florida) had been planted as a nectar and habitat resource primarily to increase pollinator and natural enemy populations. Both farms were located in Suwannee County in north Florida. One farm (30.295017°N, 82.844151°W) produced blueberries on 5.8 acres (2.35 ha), whereas the other farm (30.379306°N, 83.074704°W) produced certified organic tomatoes, peppers, and cucumbers. At the blueberry farm site, buckwheat was planted in 3 strips, each 2 m in width and 75 m in length, running north to south along the field borders and in the center drive row. In 2014, the vegetable farm study encompassed a tomato planting 92 m in length, rows being planted 1.5 m apart with buckwheat planted adjacent to the exterior rows and in a single interior row, spanning half the length of the row (46 m). During 2015, the study site was split so that 6 rows produced tomato and 6 rows produced bell pepper. Buckwheat was planted between rows 3 and 4 in both the pepper and tomato plantings. The plantings were made on a plastic lining with drip irrigation in three 15 m sections, each alternating with a 15 m unplanted area.

During the growing season (May to Sep) in 2014 and 2015, the buckwheat at both farms was sampled biweekly using a sweep net, 10 sweeps per sample. Nineteen samples from the blueberry farm and 38 samples from the vegetable farm were taken during both growing seasons. This difference in sample size was due to the perennial nature of the blueberry planting, which limited our ability to modify the site layout, restricting the buckwheat plantings to the edge of the grove and in the center drive row; in contrast, the vegetable farm was conducive to planting buckwheat strips directly in the crop rows, allowing the planting of additional sections of buckwheat for sampling. The study began on 1 May and ended on 30 Sep each year. Samples were taken at 9 AM by sweeping the tops of the buckwheat plants. Collections were sent to the University of Florida Entomology and Nematology Department in Gainesville, Florida, for identification to taxonomic family, with particular taxa identified to species.

We characterized the pest and beneficial arthropod diversity and abundance at both farm sites by 1) conducting a general analysis of arthropod community assemblages and associated sampling thoroughness at the sites and 2) determining the abundance of beneficial and pest arthropods by category and taxonomic order. Descriptors for the arthropod assemblages at both sites, including observed and predicted family richness derived via coverage-based extrapolation of observed richness and the Sorenson index, were calculated using R software (R Team 2016) and the R software package iNEXT (Hsieh et al. 2016). To compare beneficial and pest arthropod abundance between sites, taxonomic families were combined into categories (Table 1). A general category of beneficial families was split into 2 subcategories. The first included Hymenoptera in the suborder Apocrita, excluding Formicidae. Members of this subcategory function as pollinators, parasitoids, or predators. The second subcategory contained the non-hymenopteran predators, including the arachnid order Arenae; coleopteran families

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Table 1. Mean number (± SD) of specimens in sweep samples taken at north Florida blueberry and vegetable farms in spring 2014 and 2015.

	Mean ± SD per sample[a]			
Taxon	Blueberry farm (*N* = 19)	Vegetable farm (*N* = 38)	Deviance	*P*
Beneficial arthropods	9.16 ± 8.51a	4.39 ± 4.40b	7.73	0.0054
Hymenoptera	8.26 ± 8.31a	2.47 ± 2.90b	16.28	<0.0001
Hymenoptera: Apidae	1.00 ± 1.86	0.08 ± 0.36		
Hymenoptera: Braconidae	0	0.05 ± 0.23		
Hymenoptera: Chrysididae	0	0.08 ± 0.27		
Hymenoptera: Crabronidae	0.11 ± 0.32	0.18 ± 0.83		
Hymenoptera: Halictidae	0.11 ± 0.32	0.50 ± 0.95		
Hymenoptera: Megachilidae	0.05 ± 0.23	0		
Hymenoptera: Platygastridae	0.05 ± 0.23	0.05 ± 0.23		
Hymenoptera: Pompilidae	0.11 ± 0.32	0		
Hymenoptera: Scoliidae	5.47 ± 7.6	1.16 ± 2.02		
Hymenoptera: Sphecidae	0.16 ± 0.50	0.11 ± 0.31		
Hymenoptera: Thynnidae	0.68 ± 1.06	0.11 ± 0.51		
Hymenoptera: Tiphiidae	0.11 ± 0.46	0		
Hymenoptera: Vespidae	0.42 ± 0.61	0.16 ± 0.37		
Predators	0.89 ± 1.15	1.92 ± 2.56	3.14	0.0764
Araneae	0.32 ± 0.95	0.29 ± 0.69		
Diptera: Syrphidae	0.16 ± 0.37	0		
Diptera: Tachinidae	0	0.08 ± 0.36		
Coleoptera: Cantharidae	0.05 ± 0.23	0		
Coleoptera: Carabidae	0.05 ± 0.23	0.39 ± 0.95		
Coleoptera: Coccinellidae	0.11 ± 0.46	0		
Hemiptera: Anthocoridae	0.11 ± 0.46	0.08 ± 0.49		
Hemiptera: Geocoridae	0.11 ± 0.32	0.89 ± 1.89		
Hemiptera: Nabidae	0	0.03 ± 0.16		
Hemiptera: Reduviidae	0	0.16 ± 0.37		
Pests	3.53 ± 3.22a	12.34 ± 13.18b	14.752	0.0001
Coreidae and Pentatomidae	2.42 ± 2.61	2.34 ± 3.34	0.0058	0.9393
Hemiptera: Coreidae	0.05 ± 0.23	0.03±0.16		
Hemiptera: Pentatomidae	2.37 ± 2.59	2.32 ± 3.31		
Miridae				
Hemiptera: Miridae	0.47 ± 1.22a	9.08 ±12.06b	24.197	<0.0001
Auchenorrhyncha	0.63 ± 1.01	0.92 ± 1.28	0.875	0.3496
Hemiptera: Cercopidae	0	0.03 ± 0.16		
Hemiptera: Cicadellidae	0.32 ± 0.48	0.50 ± 1.11		
Hemiptera: Delphacidae	0	0.03 ± 0.16		
Hemiptera: Dictyopharidae	0.16 ± 0.69	0		
Hemiptera: Flatidae	0	0.05 ± 0.23		
Hemiptera: Fulgoridae	0	0.05 ± 0.23		
Hemiptera: Membracidae	0.16 ± 0.50	0.26 ± 0.50		
Not categorized[b]				
Blattodea: Blattellidae	0	0.03 ± 0.16		
Coleoptera: Anthicidae	0	0.16 ± 0.68		
Coleoptera: Cerambycidae	0	0.03 ± 0.16		
Coleoptera: Chrysomelidae	0.47 ± 1.02	0.18 ± 0.46		
Coleoptera: Corylophidae	0	0.05 ± 0.23		
Coleoptera: Curculionidae	0.05 ± 0.23	0.11 ± 0.39		
Coleoptera: Mordellidae	0	0.16 ± 0.37		
Coleoptera: Scarabaeidae	0.11 ± 0.32	0.11 ± 0.39		
Coleoptera: Staphylinidae	0	0.03 ± 0.16		
Diptera: Bibionidae	0.05 ± 0.23	1.50 ± 2.92		
Diptera: Calliphoridae	0	0.08 ± 0.27		
Diptera: Dolichopidae	0.11 ± 0.32	0.32 ± 0.77		

[a]Means in a row followed by different letters are significantly different ($P \leq 0.05$); X^2 analysis of deviance.
[b]Not categorized denotes taxonomic families not placed into a category/subcategory for analysis.
[c]Phoridae, Muscidae, and Tephritidae.
[d]Geometridae, Noctuidae, and Pyralidae.
[e]Coenagrionidae, Corduliidae, and Libellulidae.

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Table 1. (Continued) Mean number (± SD) of specimens in sweep samples taken at north Florida blueberry and vegetable farms in spring 2014 and 2015.

	Mean ± SD per sample[a]			
Taxon	Blueberry farm (*N* = 19)	Vegetable farm (*N* = 38)	Deviance	*P*
Diptera[c]	0.11 ± 0.32	0.26 ±1.31		
Hemiptera: Berytidae	0	0.21 ± 0.41		
Hemiptera: Blissidae	0	0.03 ± 0.16		
Hemiptera: Cydnidae	0.05 ± 0.23	0		
Hemiptera: Lygaeidae	0.26 ± 0.56	0.29 ± 0.73		
Hymenoptera: Formicidae	0.74 ± 1.37	0.11 ± 0.51		
Lepidoptera[d]	0.05 ± 0.22	0.16 ± 0.37		
Neuroptera: Ascalaphidae	0	0.03 ± 0.16		
Odonata[e]	0.16 ± 0.37	0.11 ± 0.39		
Orthoptera: Acrididae	1.21±1.58	0.76 ± 1.20		
Orthoptera: Gryllidae	0	0.05 ± 0.23		
Orthoptera: Tettigoniidae	0.26 ± 0.45	0.03 ± 0.16		
Orthoptera: Thysanoptera	0	0.05 ± 0.32		

[a]Means in a row followed by different letters are significantly different ($P \leq 0.05$); X^2 analysis of deviance.
[b]Not categorized denotes taxonomic families not placed into a category/subcategory for analysis.
[c]Phoridae, Muscidae, and Tephritidae.
[d]Geometridae, Noctuidae, and Pyralidae.
[e]Coenagrionidae, Corduliidae, and Libellulidae.

Cantharidae, Carabidae, and Coccinellidae; dipteran families Syrphidae and Tachinidae; and hemipteran families Anthocoridae, Geocoridae, Nabidae, and Reduviidae. The category for pests was restricted to the order Hemiptera and further divided into 3 subcategories: 1) Pentatomidae and Coreidae, 2) Miridae, and 3) Auchenorrhyncha. These 3 pest subcategories encompassed the major pests of concern to growers at both farms. Other taxa were listed as undetermined if their impact on the crops was not known or considered negligible. This group included potential pest families, such as Acrididae and several phytophagous hemipterans, as well as predators classified in Odonata and Neuroptera.

Statistical analysis of pest and beneficial arthropod abundance was performed using the R software package MASS (Venables & Ripley 2002). Abundance data for each category were fitted to a negative binomial generalized linear model selected on the following basis: a) non-normal count data, b) high frequency of zero-counts, and c) overdispersion (Sileshi 2006; O'Hara & Kotze 2010). Each pest or beneficial category and subcategory being tested was fitted to a separate model. The significance of farm type as the explanatory factor for each model was determined by chi-squared tests and analysis of deviance tables.

In total, 1,104 arthropods were collected and identified at least to taxonomic family, with 310 recovered from 19 samples taken at the blueberry farm and 794 from 38 samples collected at the vegetable farm (Table 1). The samples contained 63 insect families and the arachnid order Arenae (spiders), which was included in the analysis as a beneficial predator and treated the same as an insect family. The blueberry farm had an observed insect family richness of 39 and a predicted richness of 52.47. The vegetable farm had an observed richness of 53 families and a predicted richness of 62.96. Site similarity, based on family richness, was intermediate (Sørensen coefficient = 0.59), with 27 observed families shared at both sites. Sample coverage (completeness) was 88.59% for the blueberry farm and 94.45% for the vegetable farm. Standardizing sites on the basis of sampling coverage reduced bias caused by incomplete sampling and differing sample sizes (Chao & Jost 2012). Family richness and sample coverage at both farms had an overlap of 95% confidence intervals, suggesting that family-level richness did not differ significantly at the coverage level obtained by the sampling (Fig. 1).

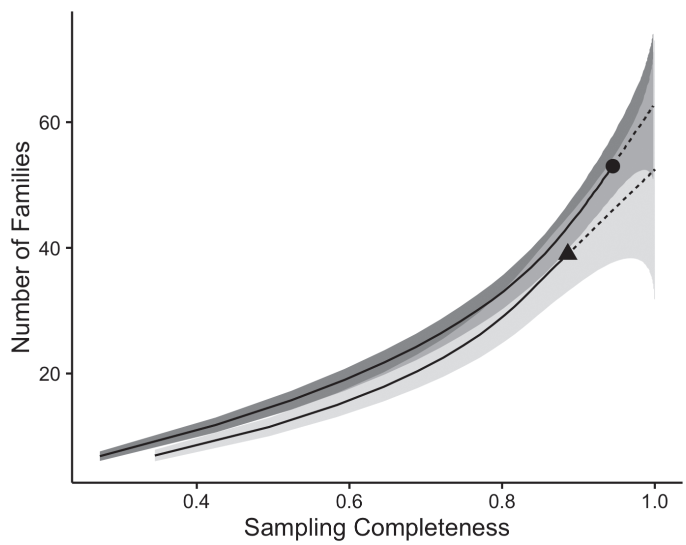

Fig. 1. Sample completeness curve for a vegetable farm (dark shaded area, 38 samples) and blueberry farm (light shaded area, 19 samples) in Suwannee County, Florida. The solid line is the interpolated insect family-level richness and the dashed line is the extrapolated richness. The shaded areas represent 95% confidence intervals. Sampling effort is standardized based on the sample completeness (the proportion of sampled families to predicted families) at each sampling level, with the circle representing final sampling completeness of 38 samples taken at the vegetable farm and the triangle representing final sampling completeness of 19 samples taken at the blueberry farm.

Based on the categories of arthropod families, there were significantly ($P \leq 0.05$) more beneficial arthropods per sample taken at the blueberry farm than the vegetable farm ($\bar{x}$ = 9.16 versus 4.39) and fewer pests ($\bar{x}$ = 3.53 versus 12.34) (Table 1). At the subcategory level, significantly more pooled beneficial hymenopteran families per sample were obtained at the blueberry farm ($P \leq 0.05$), whereas the non-hymenopteran predatory arthropod subcategory did not differ significantly between farms. The primary difference in pollinators was the family Scoliidae, which accounted for 104 of the 157 hymenopteran pollinators collected at the blueberry farm. Scoliid wasps were the

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most common non-*Apis* pollinators visiting buckwheat in north Florida (Campbell et al. 2016). There were more carabids and geocorids at the vegetable farm, mostly *Orius* spp. Both farms had a relatively high number of spiders (Araneae). Of the 3 pest subcategories (Pentatomidae + Coreidae, Miridae, and Auchenorrhyncha), only the Miridae differed between farms, with significantly greater numbers collected on the vegetable farm. The Miridae consisted almost entirely of the tarnished plant bug *Lygus lineolaris* (Palisot de Beauvois), which is attracted to buckwheat (Bugg & Ellis 1990) and feeds on tomato (Dixon & Fasulo 2015).

Growers at both farms were especially concerned about stink bugs (Hemiptera: Pentatomidae) and leaf-footed bugs (Hemiptera: Coreidae). The most numerous stink bug species was the redbanded stink bug, *Piezodorus guildinii* (Westwood), a species strongly associated with leguminous forage and cover crops, such as soybean, crimson clover, and *Indigofera* species (Fabaceae) (Panizzi & Slanksy 1985). Based on visual scouting, the most abundant leaf-footed bug was *Leptoglossus phyllopus* (L.). Additionally, Lygaeidae were abundant at both farms but Bibionidae, Calliphoridae, and certain other dipterans were prevalent only at the vegetable farm. Formicidae, Acrididae, and Tettigoniidae were captured more frequently at the blueberry than the vegetable farm.

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Summary

The occurrence of beneficial and pest arthropods collected from buckwheat companion plantings on a blueberry and a vegetable farm in north Florida was characterized. Similarity of arthropod diversity at the family level was intermediate (Sørensen index = 0.59). Significantly more pollinators and parasitoids but fewer pests were collected at the blueberry than the vegetable farm. The blueberry farm, therefore, achieved the goal of using companion plants to selectively enhance the impact of natural enemies. This goal was not accomplished at the vegetable farm because relatively large numbers of tarnished plant bugs and other pests attracted to the buckwheat were not controlled by the natural enemies.

Key Words: companion plant; natural enemy; *Fagopyrum esculentum*; integrated pest management; managed diversity

Sumario

Se caracterizó la presencia de artrópodos benéficos y plaga recolectados de las plantaciones conjuntas de alforfón, arándanos y hortalizas en una granja de en el norte de la Florida. La similitud de la diversidad de artrópodos a nivel familiar fue intermedia (*índice* de Sørensen = 0,59). Significativamente se recolectaron más polinizadores y parasitoides, pero menos plagas en el arándano que en la granja de hortalizas. El huerto de arándanos, por lo tanto, logró el objetivo de utilizar plantas de compañía para aumentar selectivamente el impacto de los enemigos naturales. Esta meta no se logró en la granja de hortalizas debido a que un número relativamente grande del chinche *Lygus lineolaris* y otras plagas atraídas por el alforfón no fuerton controladas por los enemigos naturales.

Palabras Clave: planta compañera; enemigo natural; *Fagopyrum esculentum*; manejo integrado de plagas; diversidad manejada

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