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Unlikely Guardians of Cropping Systems: Can Birds and Spiders Protect Broccoli from Caterpillar Pests?

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Summary
A field experiment was conducted to examine the impact of bird and spider predation on lepidopteran caterpillar densities and broccoli productivity. Densities of *Pieris rapae* and *Trichoplusia ni* large caterpillars and their post-caterpillar stages were reduced significantly by bird predation. The abundance of large caterpillars was also reduced on plants where spiders were allowed to forage freely. Further, plants foraged by birds, spiders, or birds plus spiders sustained less feeding damage attributable to leaf-chewing caterpillars than plants without birds or spiders (the check). Plants foraged by bird and/or spiders were also larger than check plants.

Introduction
On the island of O'ahu, birds and spiders have been casually observed preying on insect pests of *Brassica* plants. Their impact on insect pests, especially caterpillars, is potentially significant but had not been investigated in Hawai'i. Thus this study was designed to examine the impact of bird and spider predation on caterpillars commonly found feeding on *Brassica* crops and to determine whether their presence on broccoli, *Brassica oleracea* L., would result in reduced plant consumption by caterpillars and an associated increase in broccoli plant biomass.

Several studies have shown that birds that feed on insects, commonly called insectivorous birds, can significantly reduce insect population size (Bock et al. 1992, Greenberg et al. 2000) and the amount of plant damage they cause (Sanz 2001). These studies were mainly conducted in perennial plant communities such as temperate forests and grasslands where birds are likely the top predators of insect prey. However, insectivorous birds have a diverse diet and when feeding do not discriminate between pest and beneficial insects. Thus, it is not safe to assume that their presence within a cropping system will result in greater insect pest suppression.

Similar to insectivorous birds, spiders are not prey-specific and may fulfill their dietary needs by feeding on natural insect pest enemies such as parasitoids and predators. In some instances, this may cause an increase in insect pest numbers by reducing natural enemies that would normally keep their population in check. Further, spiders have a long generation time compared to most insect pests. As such, insects can produce offspring at a much faster pace than spiders. Thus, theoretically speaking, it is believe that spiders are not capable of reducing insect pests to noticeable levels in cropping systems. Nevertheless, we were interested in knowing the extent to which birds and spiders may influence the number of caterpillar pests on broccoli plants.

It was our belief that birds and spiders found on broccoli plants in Hawai'i are capable of reducing caterpillar pests to levels that will result in significantly less plant damage and an increase in plant size. As such, using a four-level system inclusive of birds, spiders, lepidopteran caterpillars, and broccoli plants, two questions were addressed: (1) Do bird and spider predation reduce lepidopteran caterpillar densities directly and subsequently increase plant productivity? and (2) Does an assemblage of birds and spiders reduce insect herbivore densities more than birds or spiders alone?

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Procedures

Study system

The insectivorous bird community within the study site consisted of the red-crested (Brazilian) cardinal, *Paroaria coronata*, and the northern cardinal, *Cardinalis cardinalis*. Four spider species frequently found on *Brassica* plants at the study site, in order of abundance, include (1) *Nesticodes (Theridion) rufipes* (Theridiidae), (2) *Oxyopes* sp. (Oxyopidae), (3) *Neoscona oaxacensis* (Araneidae), and (4) *Cheiracanthium mordax* (Clubionidae). The tangle web spider, *N. rufipes*, which spins a sparse web on the leaf surface, is the most abundant spider encountered on *Brassica* plants at the study site, consistently comprising 90 percent or more of the total spider fauna.

Brassica plants found at the study site are affected by a complex of caterpillar pests. Listed in order of importance, these are the imported cabbage worm, *Pieris rapae* =(*Artogeia rapae*) (Lepidoptera: Pieridae); the cabbage looper, *Trichoplusia ni* Hübner (Lepidoptera: Noctuidae); and the diamondback moth, *Plutella xylostella* L. (Lepidoptera: Plutellidae). The imported cabbage worm causes the greatest feeding damage. The adults are frequently seen searching for food or egg laying sites within agricultural fields or neighboring areas that contain flowering plants.

Experimental design

The experiment was conducted at the University of Hawai‘i at Mānoa’s Poamoho Research Station on O‘ahu during May 2002. Greenhouse-grown broccoli plants were transplanted and randomly assigned to four treatments: (1) bird-accessible plants (with daily spider removal); (2) both bird plus spiders present (no manipulation, plants accessible to birds and spiders); (3) spider-accessible plants (plants enclosed in a cage that allowed access to plants by spiders but not birds); (4) no birds or spiders (check plants enclosed in a cage that prevented access by birds with daily spider removal). Spiders were removed from the bird-accessible and check plants daily at ~ 3.5-h intervals beginning at 09:30 and completed everyday by 19:00 hour. After the final spider removal task of the day, a sleeve cage was placed over the bird and check treatment plants to prevent spiders from foraging them at night.

Sampling

For each treatment plant, all spiders, moth, and butterfly stages (e.g., eggs, caterpillars, pupae) were identified and counted to species. Insects and spiders were sampled at 5-day intervals initiating 10 days after planting (DAP). The caterpillar counts were divided into four size categories (bantam $\leq$ 0.5 cm, small >0.5 but $\leq$ 1.0 cm, medium > 1.0 but $\leq$1.5 cm, large > 1.5 cm). However, because overall counts of cabbage looper caterpillars were notably low, especially size categories medium and large, these latter size categories of cabbage loopers were pooled to one size group. Empty cocoons from which adult moth and butterflies had recently emerged were also counted and removed to provide an indication of the number of caterpillars that made it to the adult stage. Final counts of caterpillars were made during the harvest period by dissecting the broccoli crown and counting all caterpillars and cocoons present. Additionally, the remaining plant parts (e.g., leaves, stems, etc.) were surveyed from top to bottom, and all late-stage caterpillars and pupae were counted.

Statistical analysis

All insect and spider count data were analyzed by ANOVA (PROC GLM, SAS Institute, 1990). When the overall ANOVA was significant, differences among treatment categories were determined using Fisher’s protected least significant difference (LSD). Plant damage data were analyzed using 2 x 2 contingency tables (PROC FREQ). Treatments were considered significantly different at $P < 0.05$.

Results

Spider and insect density

On foliage during broccoli growth cycle. The composition of spiders found on broccoli plants during the study included *N. rufipes* (91%), *Oxyopes* sp. (7%), *N. oaxaencis* (1.5%), and *C. mordax* and an unidentified lyniphiid, which each made up approximately 0.7%. The abundance of spiders found on bird plus spider, and spider treatment plants were similar throughout the experiment (Fig. 1).

The abundance of bantam, small, and medium sized imported cabbage worm caterpillars were similar among treatments on most dates. However, beginning 20 DAP, the density of large caterpillars (> 1.5 cm) was greater on check plants than plants where birds were allowed to

Figure 1. Mean number of spiders per broccoli leaf in four experimental treatments. * indicates when birds were first observed foraging the study area (18 days after planting). Graph symbols within a period without letters indicate that the overall ANOVA is insignificant at *P* > 0.05; Fisher's protected LSD).

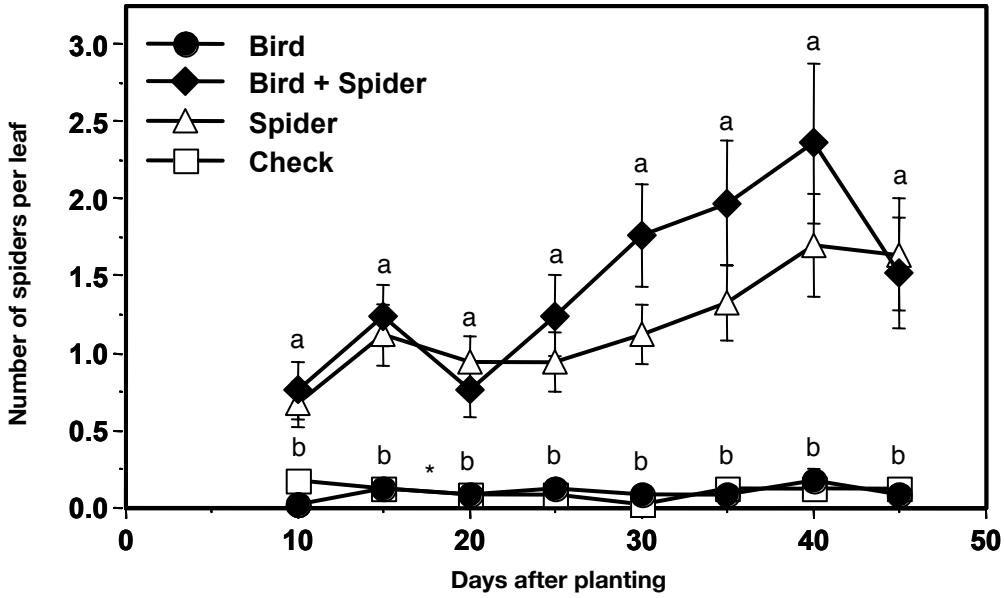
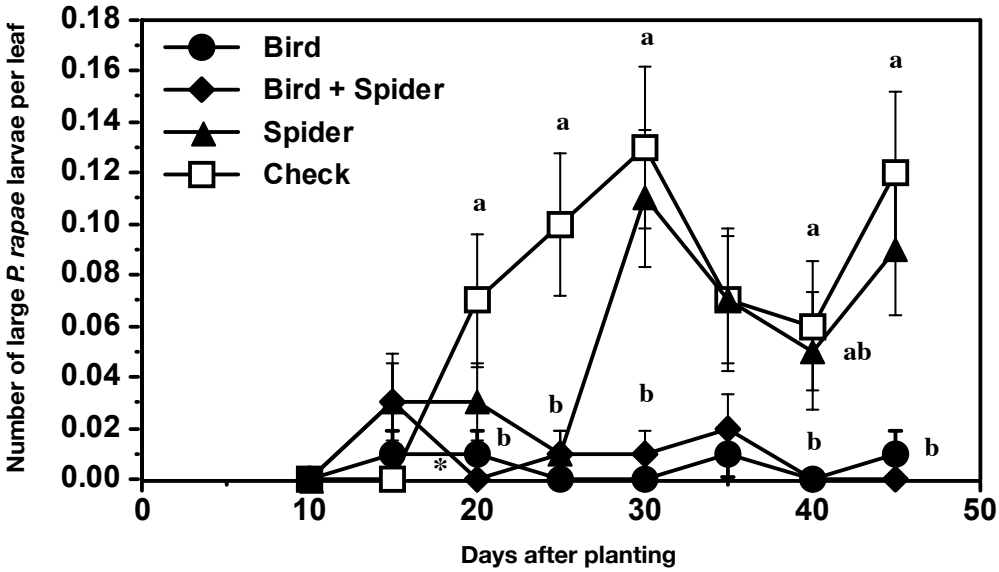


Figure 2. Mean number (± SE) of *Pieris rapae* large caterpillars (> 1.5 cm) per broccoli leaf in four experimental treatments. * indicates when birds were first observed foraging the study area (18 days after planting). Graph symbols within a period without letters indicate the overall ANOVA is insignificant at *P* > 0.05; Fisher's protected LSD).



freely forage, and beyond 25 DAP large caterpillar numbers were similar on check and spider treatment plants (Fig. 2). Additionally, a greater number of medium/large size category of cabbage looper caterpillars were found on spider compared to bird plus spider treatment plants (Fig. 3). The check and bird treatment plants were covered at night to prevent spiders from accessing these plants. However, cabbage looper moths mostly lay eggs at night. As such, their initial egg counts were lower on these plants compared to plants left uncovered at night.

Whole plant count at end of growth cycle. At harvest time, a significantly higher number of imported cabbage

Figure 3. Mean number (± SE) of *Trichoplusia ni* medium/large caterpillars (> 1.0 cm) per broccoli leaf in four experimental treatments. Bars with same letters are not significantly different (*P* > 0.05, Fisher's protected LSD).

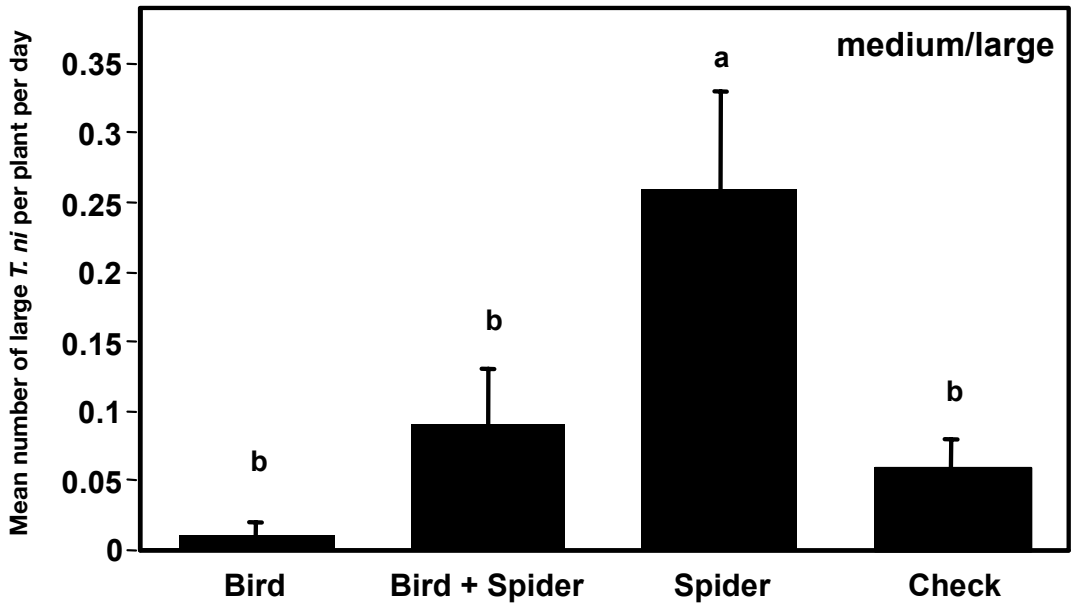


Figure 4. Proportion of broccoli plants displaying extensive chewing damage in four treatments. Numbers within and outside of bars indicate the proportion of plants showing greater than 50 to 75% of leaf area (four terminal leaves) consumed respectively, in each of four treatments. * indicates that no plants within that treatment sustained extensive defoliation. A significantly higher proportion of check treatment plants sustained extensive damage compared with other treatments on each date listed (*P* < 0.05, Fisher's exact test).

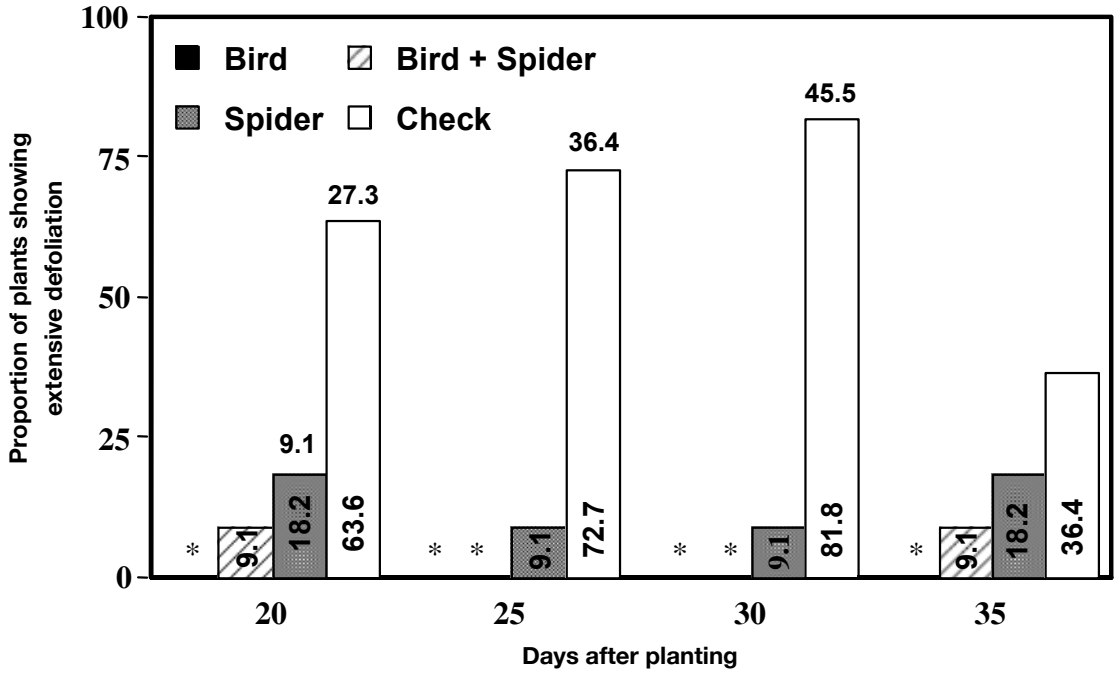


Table 1. Mean number of late-stage lepidopterans per brocolli whole plant at plant maturity (inflorescence fully developed) after exposure to four experimental treatments.

	Pieris rapae[1]			
Treatment[2]	Large caterpillar[3]	Pre-pupae	Pupae	Empty cocoon
Bird	0.18 + 0.18 b	0.09 + 0.09	0.0 b	0.0
Bird + spider	0.44 + 0.24 b	0.11 + 0.11	0.0 b	0.0
Spider	3.62 + 1.15 a	0.90 + 0.38	4.2 + 0.85 a	0.5 + 0.22 a
Check	4.70 + 0.46 a	0.50 + 0.22	5.0 + 0.22 a	0.9 + 0.28 a

[1]Same letter denotes no significant differences among treatments ($P > 0.05$), and means followed by columns with no letters indicates the overall ANOVA is insignificant (Fisher's Protected LSD).
[2]Bird = plants accessible by birds with daily spider removal; Bird + spider = no manipulation, plants accessible to birds and spiders; Spider = plants enclosed in a cage that allowed access to plants by spiders but not birds; Check = plants enclosed in a cage that prevented access by birds, with daily spider removal.
[3]large = >1.5 cm

worm caterpillars, pupae, and empty cocoons, respectively, were found on spider and check plants compared to those plants where birds or birds plus spiders were allowed to forage. Further, pupae and empty cocoons of the imported cabbage worm were only found on spider and check plants (Table 1).

Number in broccoli crown at maturity. At harvest, the imported cabbage worm was the most abundant caterpillar found in the broccoli crowns. The lowest numbers were found in the crowns of plants were both bird and spiders were allowed to forage. Large cabbage looper caterpillars were only found in the heads of spider treatment plants (Table 2).

Table 2. Mean numbers of *Pieris rapae* per broccoli crown exposed to four experimental treatments.

	Pieris rapae[1]			
Treatment	Large caterpillar[2]		Pre-pupae	Pupae
Bird	4.5 + 1.34	b	0.2 + 0.12	0.3 + 0.19
Bird + spider	1.7 + 0.53	c	0.0	0.1+ 0.11
Spider	8.2 + 1.69	a	0.3 + 0.15	0.5 + 0.27
Check	6.9 + 0.53	ab	0.1 + 0.10	0.8 + 0.51

[1]Same letter denotes no significant differences among treatments at the 5% level ($P > 0.05$), and means followed by columns with no letters indicates the overall ANOVA is insignificant (Fisher's Protected LSD).
[2]large = >1.5 cm

Plant damage

No plants in which birds were allowed to forage displayed significant insect chewing damage (50 percent or more of the leaf area missing) in the plants' terminal growth area throughout the experiment. The highest proportion of plants displaying extensive damage was observed among check plants. The amount of chewing damage sustained by the other treatments was similar throughout the experiment (Fig. 4).

Plant biomass

Broccoli head size was greatest on plants where birds were allowed to forage and smallest on check plants (Table 3). Significant differences were also found among treatment plants with respect to whole-plant biomass. Similar to head size, the smallest and largest plants by weight were check and bird plus spider plants, respectively.

Discussion

This field experiment used a natural colonization of moth and butterfly pests on broccoli plants to determine the direct effect of birds and spiders on caterpillar pest densities and their indirect impact on plant productivity. Both bird and spiders were found to suppress caterpillar

Table 3. Mean fresh head weight and dry whole-plant biomass of brocolli plants exposed to four experimental treatments.

Treatment	Weight (± SE)[1]			
	Head (kg)[2]		Whole plant (g)[3]	
Bird	0.182 + 0.01	a	153.5 + 6.7	ab
Bird + spider	0.161 + 0.01	ab	166.2 + 9.7	a
Spider	0.177 + 0.02	a	139.2 + 9.5	b
Check	0.112 + 0.02	b	91.2 + 7.7	c

[1]Same letter denotes no significant differences among treatments at the 5% level ($P > 0.05$; Fisher's Protected LSD).
[2]Multiply kg by 2.2 to obtain pounds and g by 0.035 to obtain ounces.
[3]Whole-plant biomass excludes the weight of the crown and plant parts below the soil surface.

numbers, thereby significantly reducing the level of plant damage. Additionally, plant productivity was greatest for plants where birds and/or spiders were allowed to freely forage; however, despite the negative effect of birds and spiders on caterpillar populations, the combination of birds and spiders did not suppress caterpillar densities on the broccoli foliage more significantly than either predator alone.

In conclusion, several studies have shown that bird predation can significantly reduce insect herbivore densities in forest ecosystems (Sipura 1999 and reference therein). The impact of bird predation on insect herbivores and their interaction with other natural enemies in agricultural systems is potentially great but has received limited attention (Greenberg et al. 2000). Clearly, insect pathogens, predators, and parasitoids and spiders may not be the only natural enemies inflicting mortality among insect pests in cropping systems. Therefore, more integrated research studies that evaluate the relationship arthropod natural enemies have with vertebrate predators such as birds are needed.

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