Establishing songbird nest boxes increased avian insectivores and reduced herbivorous arthropods in a Californian vineyard, USA

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SUMMARY

California winegrape growers interested in merging conservation with agricultural production have established nest boxes for songbirds in their vineyards. A common occupant, the native western bluebird *Sialia mexicana* consumes arthropods during the breeding season. We measured the effect of enhanced avian activity on arthropod pests and natural enemies by experimentally establishing songbird nest boxes in one section of a 50 ha vineyard. During avian brood production and shoot extension of the grapevines, we compared the composition of the arthropod community in the nest box area with that of a no-nest box control area. During peak nest box occupancy, the nest box area had significantly fewer herbivorous arthropods, including leafhopper pests, than the control area. There were also significantly fewer large, beneficial, predatory arthropods in the nest box treatment compared to the control area. After chicks hatched, small arthropods decreased in the nest box treatment area, while increasing in the control area. Therefore, although avian foraging near nest boxes reduced the abundance of beneficial arthropods, harmful herbivorous insects did not increase in the nest box treatment even when they increased in the control area. This indicates an overall positive effect of nest box provision on pest abundance in a large, commercial vineyard.

BACKGROUND

Since the 1950s, over one million acres of oak woodland has been converted to urban and agricultural lands in California (Merenlender & Crawford 1998, Heaton & Merenlender 2000). As a result, many cavity-nesting songbirds have lost nesting sites and populations have decreased (Partners in Flight 2002). In vineyard landscapes, some concerned owners are attempting to merge avian conservation with agricultural production by providing songbird nest boxes on their land. The California grape growing season overlaps with the migratory bird breeding season, which, due to the energetic demands of reproductive activities, can result in increased predatory pressure on arthropods (Holmes 1990). Thus, it is possible that breeding birds may offer growers ecosystem services in the form of insect pest control (Van Bael *et al*. 2008), or ecosystem disservices by consuming predatory insects important for pest regulation (Mooney *et al*. 2010).

Economically significant vineyard pests include leafhoppers and sharpshooters (Hemiptera: Cicadellidae). Some leafhopper and sharpshooter species such as the blue-green sharpshooter *Graphocephala atropunctata* transmit the bacterium *Xylella fastidiosa* that causes Pierce’s disease, which can kill grapevines if infected in April and May (Feil *et al*. 2003). Consequently, reducing leafhopper pests in early spring is beneficial to growers.

Western bluebirds *Sialia mexicana* are the principal nest box occupant in California vineyards (Heaton *et al*. 2008). They are generalist insectivores and foraging by bluebirds has been shown to significantly reduce sentinel pest larvae (Lepidoptera: Noctuidae) in vineyards with artificial nest boxes (Jedlicka *et al*. 2011). However it is unknown how bluebird foraging affects other vineyard arthropods, including pests and beneficial insects.

In this study we experimentally increased the abundance of avian insectivores (bluebirds) by establishing songbird nest boxes, and compared the type and abundance of arthropods present with those in a control area without nest boxes. We tested three questions: (1) do avian insectivores suppress herbivorous insects and specifically reduce leafhopper pest abundance near occupied nest boxes? (2) does avian foraging lower the abundance of beneficial insects? and (3) do avian insectivores target prey based on size?

ACTION

Study site: The 50 ha vineyard chosen for this experiment was adjacent to the Russian River in Mendocino County, CA, USA, near Ukiah (39°04'N, 123°09'W). Chardonnay grapevines were planted in 1988, grown on trellises forming rows, and certified organic since 1998. Tilling occurred in every other tractor row, alternating with cultivated cover crops.

Nest box treatment: The vineyard was divided into three sections. The 12 ha areas at each end were randomly assigned as the control and conservation (nest box) treatments. A 250 m wide middle section acted as a buffer between the treatment and control, and no sampling took place in this area (Jedlicka

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et al. 2011). Nest boxes were constructed from redwood following recommendations of the North American Bluebird Society (2008) (13.9 x 10.2 x 23.8 cm, with entrance hole opening of 3.8 cm diameter). In January 2008, 23 pairs of nest boxes were established in the conservation treatment area in a grid pattern of five rows. Each row consisted of three to six pairs of boxes on 3.1 m t-posts along grapevine trellises. All nest boxes were cleaned of previous reproductive materials in February 2009 and checked weekly for nesting activity during the 2009 bluebird reproductive season from March through July. Once nest boxes were found to contain eggs, Noel predator guards made of wire mesh hardware cloth (Toops 1994) were attached to the outside of the boxes to prevent predation by raccoons *Procyon lotor* and domestic cats *Felis catus*.

Arthropod Sampling: Arthropods were vacuum sampled from the cover crops growing between grapevine rows at five randomly selected points in the nest box treatment area (nest box area) and at five randomly selected points in the control area (control area). Arthropod sampling occurred during a two-week period before (5 May) and during (19 May) the peak avian foraging times of the 2009 breeding season. Vacuuming lasted 20 s per sample using a Stihl BG 85 hand-held machine. Contents were collected in an internal mesh bag (Osborne & Allen 1999), emptied into plastic bags containing cotton balls and ethyl acetate, and stored in a -20°C freezer until examined. Arthropods were identified to order, family, or as commonly known species. We measured the body length of each specimen to the nearest millimeter, unless there were more than 10 individuals in a family, in which case we measured the lengths of 10 representative individuals. We recorded the total number of individuals, functional guilds (predator, herbivore, parasitoid, or other), and representative lengths for each sample. Arthropods measuring over 5 mm were classified as large, under 2 mm were small, and between 2-5 mm were medium.

Data analysis: We conducted two-way ANOVAs (SAS Inc., V. 9.2) on arthropod guild, size categories, and selected insect families. Main effects were site (two levels: nest box and control areas), time (two levels: 5 May and 19 May), and time

Table 1. Average abundance (mean ± S.E.) of arthropod taxa and size classes per vacuum sample in a treatment area with nest boxes and a control area at two dates in May. Uncommon taxa are listed below the table.

Taxon	**Guild**	**Common Name**	**Average length (mm)**	**Nest box area**		**Control area**	
				5 May	**19 May**	**5 May**	**19 May**
Aphididae	herbivore	aphids	1.3	41.8 ± 10.1	7.4 ± 7.4	14 ± 3.3	19.8 ± 7.3
Chironomidae	herbivore	midges	1.5	0.4 ± 0.9	5.4 ± 3.7	1.4 ± 0.9	5.4 ± 2.7
Chrysomelidae	predator	clover flea beetles	2.2	18.6 ± 4.1	3.8 ± 1.2	5.6 ± 1.3	14 ± 6.3
Coccinelidae	predator	ladybird beetles	5.6	1.2 ± 0.4	0.4 ± 0.4	4.8 ± 1.0	11.8 ± 7.9
Curculionidae	herbivore	weevils	5.1	2.0 ± 0.7	0.4 ± 0.4	0.8 ± 0.4	1.4 ± 0.4
Drosophilidae	herbivore	fruit flies	1.9	10.8 ± 3.0	5.6 ± 5.1	8.0 ± 1.3	13.6 ± 6.4
Elateridae	herbivore	click beetles	5.2	1.8 ± 0.7	0	4.6 ± 2.7	0.6 ± 0.4
Lygaeidae	herbivore	false chinch bugs	4.2	0.4 ± 0.4	3.8 ± 3.3	0	3.0 ± 1.4
Aranidae	predator	orb-weaving spiders	4.4	1.2 ± 1.2	3.8 ± 3.6	0	1.2 ± 0.8
Carabidae	predator	ground beetles	3.7	1.0 ± 0.8	0	1.6 ± 1.0	1.6 ± 0.9
Formicidae	predator	ants	4.8	3.2 ± 0.7	1.6 ± 0.7	2.0 ± 0.9	6.6 ± 3.8
Isopoda	other	pill bugs	5.1	2.8 ± 1.9	1.2 ± 1.2	19 ± 6.5	0.2 ± 0.2
Ichneumonidae	parasitoid	Ichneumon wasps	3.9	3.2 ± 1.0	3.6 ± 1.2	2.0 ± 0.5	5.0 ± 1.5
		Small taxa	< 2	37 ± 4.3	13 ± 6.9	17 ± 2.3	36 ± 8.4
		Medium taxa	2 - 5	37 ± 9.0	18 ± 10	22 ± 1.9	40 ± 7.0
		Large taxa	> 5	10 ± 1.9	3.4 ± 1.4	32 ± 5.6	11 ± 2.0

Uncommon taxa in vacuum samples (< 6 individuals): Acari, Acrididae, Apidae, Berytidae, Chilopoda, Coreidae, Dermaptera, Diplopoda, Unknown Diptera, other Hemiptera, Lepidoptera, Lycosidae, Meloidae, Miridae, Mordellidea, Muscidae, Neuroptera, Pentatomidae, Psocodea (Psocoptera), Reduviidae, Salticidae, Sarcophagidae, Scarabaeidae, Siphonaptera, Tenthredinidae, Thomisidae, and Tipulidae.

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by treatment interaction. When variables were normally distributed we used raw arthropod abundances and when data Hto compare average lengths of arthropods within each foraging guild because homogeneity of variance assumptions were not met. Kruskal-Wallis tests were used to compare the size differences among all groups followed by Mann-Whitney U test for pairwise comparisons, with Bonferroni corrections for multiple tests (adjusted alpha-value at 0.017).

CONSEQUENCES

Insectivorous birds: During the breeding season, 23 active bluebird nests were found in the nest boxes established in the conservation treatment. On average, nests contained 4.2 nestlings (S.E. = 0.21, range two to six). The earliest hatchlings were found on 7 May with populations peaking on 21 May (n = 69 nestlings; Figure 1A). There was a clear decline of nestling abundance in late May when first broods fledged. Bluebirds are obligate cavity nesters and no bluebird nests were located in the control area of the vineyard.

Arthropod prey populations: A total of 3,252 arthropods were collected and showed a pattern of decreasing abundance with time as bluebird foraging increased to provision nestlings (mean ± S.E.: 108.2 ± 7.3 arthropods per sample on 5 May vs. 67.7 ± 13.0 on 19 May). This decrease in arthropod abundance occurred in the nest box treatment (from mean ± S.E. 84.4 ± 14.9 to 34.0 ± 18.5) but not in the control area (from mean ± S.E. 71.2 ± 4.9 to 86.6 ± 14.9; date by treatment interaction $F_{df=1}$ = 5.4, p = 0.034). Several pest and beneficial arthropod taxa increased in abundance with time in the control area, while simultaneously becoming scarcer in the section of the vineyard with bluebird nestlings (Table 1, Figures 1A-B).

Figure 1. Average (± S.E.) abundances of arthropods grouped as: A) leafhoppers, B) herbivorous arthropods, C) predaceous arthropods, and D) large arthropods (>5 mm in body length), captured in vacuum samples taken before (5 May) and after (19 May) peak brood hatch in the nest box area and control area of the vineyard. Line in Figure 1A shows total western bluebird nestling abundance in nest boxes in the conservation treatment area during the breeding season.

Figure 1A.

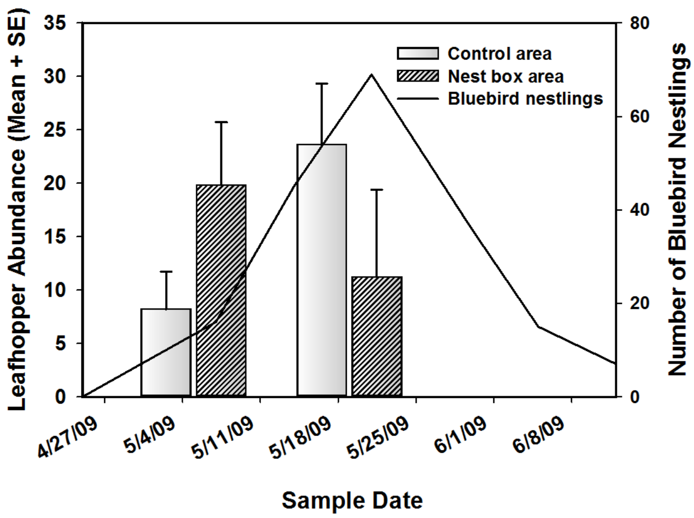


Figure 1B.

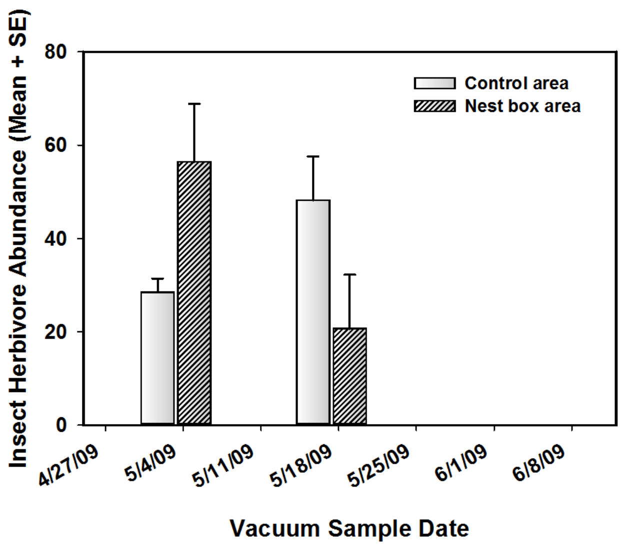


Figure 1C.

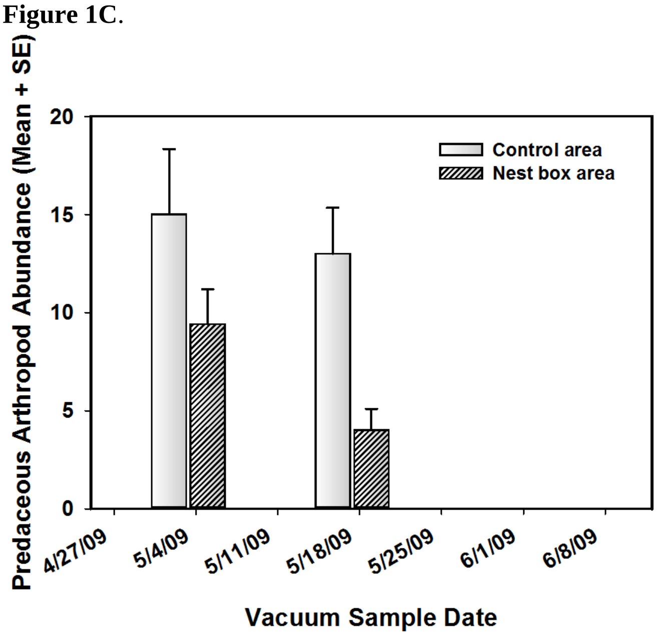
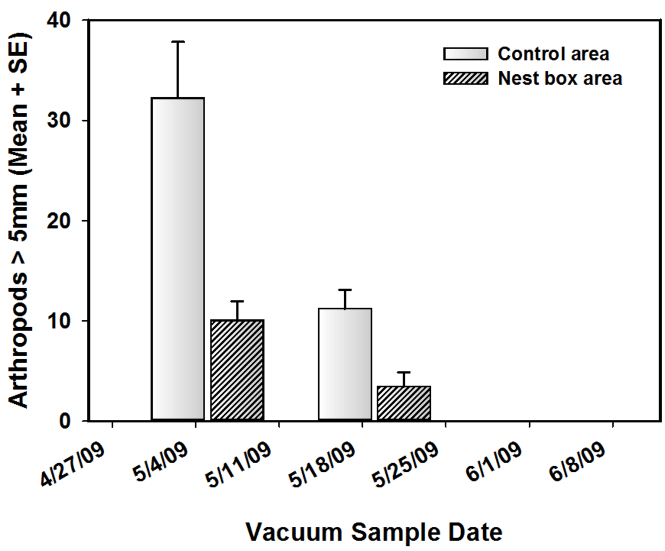


Figure 1D.



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Mean abundances of the less common taxa represented in vacuum samples, including herbivores, predators, ichneumon wasps, and isopods are shown with occasional captures listed below Table 1.

Herbivores in 18 families comprised the majority (70%) of the arthropods sampled (Table 1, Figure 1), including aphids (Aphidae), leafhoppers (including vineyard pests), and clover flea beetles (Chrysomelidae). By the time of peak nestling abundance in the nest box treatment (21 May) leafhopper abundance had decreased by over 50% on average, compared to a simultaneous threefold increase in the control area (Figure 1A), leading to a significant time by treatment interaction ($F_{df=1} = 5.8$, $p = 0.028$). Other herbivorous insects (e.g. chrysomelids and aphids) showed a similar pattern of abundance to leafhoppers (Figure 1B; Table 1), with significant time by treatment interactions ($F_{df=1} = 8.0$, $p = 0.012$)

Predaceous arthropods were half as abundant in the nest box treatment as in the control area (Figure 1C; mean ± S.E.: 17.6 ± 2.1 per sample vs. 9.3 ± 2.1 S.E., $F_{df=1} = 10.1$, $p = 0.006$, $p > 0.10$ for time and for the interaction term). Predatory ground beetles (carabidae) and ladybird beetles (Coccinelidae) (Table 1) showed this same pattern. Parasitoids, which were less abundant than other groups, were not significantly different between treatment and control areas (mean of approximately three individuals per sample in treatment and control during both time periods, $p > 0.05$ for treatment, time, and the interaction term).

Abundance of arthropods larger than 5 mm in length (large arthropods), regardless of guild, was significantly higher in the control area than the nest box treatment during both sampling periods (treatment effect $F_{df=1} = 32.3$, $p < 0.001$; Table 1). Large arthropod abundance significantly decreased by a factor of about three in both the control and nest box area over the two weeks in May (time effect $F_{df=1} = 23.7$, $p < 0.001$, Figure 1D). In early May the abundance of both small (those under 2mm) and medium (2-5mm) bodied arthropods increased in the control area while simultaneously decreasing in the nest box treatment ($F_{df=1} = 21.2$, $p < 0.001$). The average length of predators was significantly greater than the average size of herbivores (Mann-Whitney $U = 4010$, $Z = -8.5$, $p < 0.001$) although some herbivores such as cicadellids, curculionids, elaterids, and root feeders/detritivores were > 5 mm (Table 1).

DISCUSSION

Do avian insectivores suppress herbivorous insects and specifically reduce leafhopper pest abundance near occupied nest boxes? Variation in arthropod abundances indicated that the addition of nest boxes increased local foraging by bluebirds, reducing the number of arthropods that colonised vines during shoot extension and leaf expansion. Abundances of herbivorous arthropods, including leafhopper pests, declined significantly in areas with songbird nest boxes while numbers rose in areas without artificial nest boxes. By early June, leafhopper abundance in the control areas of the vineyard prompted the grower to spray a broad-spectrum pesticide. Leafhopper pests are known not to be controlled adequately by arthropod predators, parasitoids, or cover cropping practices, especially in the early spring (Costello & Daane 2003); thus it is promising that the provision of nest boxes reduced leafhopper populations during this critical period of vine leaf-out and shoot extension. Potential pests of cover crops (leaf beetles and aphids) also exhibited declines in abundance associated with the presence of nest boxes, suggesting that insectivorous birds feeding and raising young can provide additional benefits.

Does avian foraging lower the abundance of beneficial insects? We did not detect any impact of avian predation on abundances of adult parasitoids, which some growers use for biological control of pest insects. However, we found evidence that birds do lower the abundance of insect predators of herbivores. Two families of predatory arthropods (ladybird beetles and carabid ground beetles) declined in abundance near bird nest boxes. It is possible that avian foraging directly caused lower abundances of these families, but ladybird beetles are known to be unpalatable to many predators because they synthesize noxious chemicals in their body fluid (Glisan King & Meinwald 1996). Alternatively, ladybird beetles may have concentrated in control areas that offered more aphid prey (Triplehorn & Johnson 2005). Regardless, the reduction in predaceous arthropods was not observed to lead to an increase in herbivorous insect populations as a result of bluebirds occupying songbird nest boxes.

Do avian insectivores target prey based on size, reducing some size classes near nest boxes? Predaceous arthropods were more likely to be large bodied and avian foraging reduced the abundance of large arthropods, supporting the findings of other studies (Philpott *et al*. 2004). Optimal foraging theory predicts generalist birds are more likely to forage for larger, more energetically favorable prey (Pyke *et al*. 1977). However, our results show that during the peak intensity of the breeding season, avian predators can reduce the abundance of small and medium-bodied prey as well. It is notable that large arthropods were two-thirds less abundant in the nest box treatment than control area at the beginning of May, whilst abundances of smaller arthropods such as leafhoppers, flea beetles, and aphids were similar. These trends could be a result of early season foraging by insectivorous birds as they are defending territories, building nests, and laying eggs. There is a likely trade-off between prey abundance and size, such that when large taxa are not available, birds must forage for smaller, more abundant prey.

The costs and benefits of enhancing bird diversity by providing nest boxes will depend on site-specific factors such as target pest species and size of available arthropod prey. Nevertheless, our study shows that adding nest boxes to vineyards can encourage songbirds to nest in agricultural habitats and provide an ecosystem service in the form of pest control.

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