EFFECTS OF NATURAL HABITAT ON PEST CONTROL IN CALIFORNIA VINEYARDS

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ABSTRACT: Ecosystem services provided by wildlife can offer powerful incentives for conservation, particularly if species can be linked to natural habitat. We examined the hypothesis that natural habitats adjacent to vineyards provide a source of insectivorous birds by testing the prediction that predation rates should be higher close to oak woodland than in the interior of a vineyard. We simulated an insect outbreak in four small vineyards all adjacent to oak woodland. There was no evidence that predation was higher along edges of vineyards than in the interior. We did find that birds responded quickly to a simulated outbreak of insect larvae, with predation rates during the late summer reaching 90%. Motion-sensing cameras revealed that the most common predator of the larvae was the Western Bluebird (*Sialia mexicana*). These results suggest that vineyard managers may take advantage of biological pest control offered by songbirds and perhaps increase control by actively managing for the birds, a potentially beneficial scenario for both vineyard managers and bird conservation.

One of the major factors contributing to habitat loss is the expansion of agriculture (Tilman et al. 2001), and such habitat loss is currently one of the most pressing issues for wildlife (Johnson 2005). If wildlife can be shown to provide ecosystem services and those species can be linked to natural habitats, that connection may increase the incentive to conserve habitat. In California, songbirds can offer wine-grape growers pest-control services (Jedlicka et al. 2011), providing an economic incentive to preserve and expand the oak woodlands surrounding vineyards. Numerous studies have shown that birds can provide various levels of pest control in various agricultural settings (e.g., Mols and Visser 2002, Kellermann et al. 2008, Van Bael et al. 2008), but rapeseed and coffee are the only crops for which a decrease in pest damage has been quantified in relation to natural habitat (Thies and Tscharntke 1999, Chaplin-Kramer et al. 2011, Karp et al. 2013). More research is needed to clarify how avian predation of agricultural pests may be linked to habitats surrounding farms. Previous studies have shown that installation of nest boxes in vineyards can attract Western Bluebirds (*Sialia mexicana;* Fiehler et al. 2006) and enhance their control of pests (Jedlicka et al. 2011). Artificial provision of nesting sites, however, does not provide incentive for habitat conservation that may benefit other species as well.

In 2010, Sonoma County had 23,090 ha devoted to wine grapes, second only in area within California to San Joaquin County; Mendocino County supported 6977 ha, ranking ninth in the state (http://www.nass.usda.gov/Statistics_by_State/California/Publications/Grape_Acreage/index.asp). The continued conversion of oak woodland to vineyards contributes to habitat loss and displacement of wildlife in this region (Merenlander 2000). At least one study, however, has shown that the nest success of many native birds is higher in oak woodlands directly adjacent to vineyards, possibly because of a reduced diversity of nest predators exerting less predation pressure, suggesting that the oak woodland remaining within a matrix of vineyards may be of high value to breeding birds (Reynolds et al. 2006) and serve as sources of birds in a landscape dominated by agriculture. We examined the hypothesis that natural habitats adjacent to vineyards provide a source of insectivorous birds by testing the prediction that rates of predation on insects should be higher close to oak habitat than in the interior of a vineyard.

METHODS

Our study took place from 29 May to 15 July 2011 in four vineyards in northern California: Haywood Vineyards, Sonoma (38° 21′ N, 122° 26′ W, 36 ha), Bedrock Vineyard, Sonoma (38° 20′ N, 122° 30′ W, 49 ha; Figure 1), Old Hill Vineyard, Glen Ellen (38° 21′ N, 122° 30′ W, 12 ha), and Fetzer's Sundial Vineyard, Hopland (38° 59′ N, 123° 6′ W, 30 ha). Each vineyard was part of a matrix of natural habitat and land developed with homes, roads, and other man-made features, but adjacent to all was natural oak woodland dominated by Coast Live Oak (*Quercus agrifolia*), Bay Laurel (*Umbellularia californica*), Western Poison Oak (*Toxicodendron diversilobum*), and non-native annual grasses (Mayer and Laudenslayer 1988). Using aerial imagery in ArcMap (version 10.0, Environmental Systems Research Institute, Inc., Redlands, CA), we estimated the extent of natural habitat and vineyard or otherwise developed land in an area of 1 km^2 surrounding the center of each of our study sites. The extent of developed and natural habitat was, respectively, 24 and 43 ha at Haywood, 46 and 17 ha at Bedrock, 42 and 20 ha at Old Hill, and 34 and 25 ha at Sundial. The grape vines were all grown on trellises

Figure 1. Aerial image of the Bedrock Vineyard with study design illustrated, Sonoma County, California, 2011. White bars represent transects of 100 m.

and were between 1.3 and 3 m tall, in rows spaced 1 m apart. Grape varieties grown included red varietals, chardonnays, field blends, barbera, petite sirah, merlot, and cabernet franc; during the study all grapes were in the stages of flowering or green-bud growth.

We assessed predation of arthropods by birds in vineyards by using Mealworm Beetle (*Tenebrio molitor*) larvae to simulate an outbreak. We pinned the larvae to cardboard squares staked to the ground along transects (*sensu* Jedlicka et al. 2011). The mealworms represented caterpillars, as at least five species of Lepidoptera are major grapevine pests and four are minor pests (Flaherty et al. 1992). Recently the European Grapevine Moth (*Lobesia botrana*), a potentially devastating pest of grapevines, has been detected in parts of California (http://www.aphis.usda.gov/plant_health/plant_pest_info/eg_moth/index.shtml). These larvae hatch from eggs laid on the leaves and do damage to the plant from May through August (http://www.ipm.ucdavis.edu/EXOTIC/eurograpevinemoth.html#LIFE). Although mealworms are coleopteran larvae, they are similar in size and shape to lepidopteran larvae. They are also easily obtained, agriculturally benign, and hardy, making them ideal candidates for experiments with sentinel pests.

Our experiments and surveys at each vineyard took place on two consecutive days from May through July to correspond with birds' breeding season, the grape- growing season, and the larval stage of lepidopteran pests. We sampled all four farms between 29 May and 20 June, then again in July at two of the vineyards, Bedrock and Old Hill, 40 and 25 days after the first sample, respectively; time constraints prevented additional sampling at all four vineyards. At each farm we established four to six 100-m transects, depending on vineyard size ($\bar{x}$ = 15.3 ha), that were at least 30 m apart along vine rows perpendicular to oak habitat (see Figure 1). No transect was more than one half the total length of the vineyard, so at least 100 m of vineyard extended beyond the end of each transect. Oak patches were on average 60 m wide perpendicular to the edge of vineyard (range 29–119 m). From 07:00 to 07:30 on experiment days, we placed brown cardboard squares with five larvae each at 10-m intervals along each transect from 0 to 100 m. After 6 hours (13:00–13:30), we rechecked the squares and categorized each as depredated, if one or more larvae were missing, as not depredated if not. During the second sampling period we placed five motion-sensing cameras (Primos TruthCam 35) on random transects to document which species were consuming the larvae.

Prior to each experiment, we did an area survey (Ralph et al. 1993) to generate a rough index of relative abundance and composition of the bird population. These surveys began at 07:00 the day before an experiment, lasted 30 min, and covered the border between the oak habitat and the vineyard where the experiment was set up the following day. To prevent any confounding effects of the surveys on the experiment and vice versa, we recorded numbers of all species heard and seen each day preceding an experiment. On the basis of general diet and foraging behavior (Ehrlich et al. 1988), we identified which of the species observed is a potential predator of insect pests in vineyards, and we tallied the number of individuals of those species.

To avoid the possible confounding effects of pesticides, we restricted our experiment to vineyards where insecticides were not sprayed and no fungicides or herbicides had been sprayed in the 24 hours preceding the experiment. We avoided rainy days, and days when farm equipment or other people were working in the vineyards. All research was done with approval of Humboldt State University's Institutional Animal Care and Use Committee (HSU 10/11.W.69-A).

Statistical Analysis

In most cases (86% of 232) either all five or no mealworms were removed from a station, so we analyzed predation as a binary variable where 1 = predation and 0 = no predation. To examine the effect of distance to natural habitat on predation rate, we ran mixed-effects linear models with a binary response distribution (routine lme4 in program R 3.0.1) with transect number nested within vineyard (site) as a random effect and distance to oak-patch edge as the fixed effect. We used a chi-squared test to determine whether, at the vineyards sampled twice, predation rates in the two samples differed significantly, and ran the mixed-effects models separately for the first and second samples. We assessed significance by comparing the AIC_c scores of models with (hypothesized model) and without (null model) distance as a fixed effect.

RESULTS

The predation rates during the two periods of sampling differed ($\chi^2 = 17.0_1$, $P = 0.00004$), being 21% higher in the second period than in the first, reaching a maximum of 90% (Table 1), although species composition and abundance changed little. There was no evidence that distance to oak-patch edge contributed to the fit of the model predicting removal of larvae. In the first sampling period the null model (without distance) had an AIC_c score insignificantly lower (364.43) and model weight higher (0.65) than the model with distance (AIC_c = 365.67, weight = 0.35). Likewise, in the second period the null model had an AIC_c score insignificantly lower (206.13) and model weight higher (0.72) than the model with distance (AIC_c = 208.05; weight = 0.28). Coefficients for the Bedrock Vineyard were higher by 3.005 to 3.646 (standard error 0.644–0.670) than those for the other three sites, which were all nearly identical to each other, indicating that the probability of predation was higher at Bedrock than at the other three vineyards. The number of birds counted

Table 1 Prevalence of Predation of Mealworms Supplied in Four Vineyards in Sonoma and Mendocino Counties, California, 2011

Site	Date	Depredated	Not depredated	% Depredated
Haywood	29 May	17	27	39
Bedrock	2 June	53	3	95
Sundial	18 June	21	45	32
Old Hill	20 June	31	35	47
Bedrock	13 July	55	1	98
Old Hill	15 July	55	11	83
Total		232	122	66

during the area surveys and potential predators of the larvae varied from 14 to 46 per vineyard (Table 2). The cameras installed at Bedrock and Old Hill revealed the Western Bluebird (both sexes, adults and juveniles) to be the most frequent predator eating the larvae (Table 2), as well as one Dark-eyed Junco (*Junco hyemalis*) and two Western Scrub-Jays (*Aphelocoma californica*). In many cases the camera was too slow to reveal the animal responsible for predation (predator left the field of view before video recorded), but the speed at which the sensors worked (~2 sec) suggests that birds are the most likely candidate, though we cannot rule out the Western Fence Lizard (*Sceloporus occidentalis*), present in all of the vineyards, as were ants, wasps, and a variety of other predatory insects.

Table 2 Numbers of Potential Predators of Caterpillars Detected during Area Surveys along the Edges of Four Vineyards in Sonoma and Mendocino Counties, California, 2011

Species	Haywood (29 May)	Bedrock (2 June)	Sundial (18 June)	Old Hill (20 June)	Bedrock (13 July)	Old Hill (15 July)
California Quail *Callipepla californica*	1	1	7	12	0	0
Northern Flicker *Colaptes auratus*	0	0	3	0	0	0
Steller's Jay *Cyanocitta stelleri*	0	0	1	0	0	0
Western Scrub-Jay *Aphelocoma californica*	1	0	3	2	0	3
American Crow *Corvus brachyrhynchos*	0	3	0	0	1	1
Western Bluebird *Sialia mexicana*	1	0	5	3	0	3
American Robin *Turdus migratorius*	1	0	6	0	0	0
European Starling *Sturnus vulgaris*	0	0	5	0	1	0
Spotted Towhee *Pipilo maculatus*	0	2	0	2	1	4
California Towhee *Melozone crissalis*	10	4	3	0	1	0
Chipping Sparrow *Spizella passerina*	0	2	2	0	0	0
Song Sparrow *Melospiza melodia*	0	6	3	0	5	0
Dark-eyed Junco *Junco hyemalis*	15	1	0	2	3	2
Brown-headed Cowbird *Molothrus ater*	0	0	7	0	0	0
House Finch *Haemorhous mexicanus*	17	3	0	2	2	7
Total	46	22	45	23	14	20
Mean	3.1	1.5	3.0	1.5	0.9	1.3

DISCUSSION

We found no evidence that rates of predation were higher along edges of vineyards adjacent to natural habitat than farther from those edges. The vineyards we studied were small (mean 31.75 ha, range 12–49 ha), irregularly shaped, and embedded in heterogeneous landscapes, with maximum distances to adjacent habitat 30 to 300 m. It is possible that the effects of distance on predation would be evident at significantly larger distances in larger, more homogeneous, vineyards. It is possible that birds on the edges developed a search image for the mealworms or cardboard squares and followed the transects to the interior. Kellermann et al. (2008) demonstrated that birds reduce pest damage to coffee plants but were unable to confirm that natural habitat was correlated with the pest reduction, most likely because of birds' mobility and the patchiness of the plantations studied, a situation similar to the vineyards we studied. Baumgartner (1999) investigated birds' predation of codling moths (*Cydia pomonella*) in apple orchards and found it to be significant. They also found a higher diversity of birds in orchards near native habitat. Vineyards are essentially a shrub layer, and in our study area the natural surrounding habitats, being oak woodlands, are dominated by trees (Mayer and Laudenslayer 1988). Therefore, unlike orchards or shaded coffee plantations surrounded by forests, the use of vineyards by native birds may be limited by the local species' preferences for foraging in or under a canopy. Thus maintaining a heterogeneous landscape may promote a more diverse suite of species, which can provide agroecosystems with the resilience (Tscharntke et al. 2005) to recover from a pest outbreak.

We found that predation rates were significantly higher in mid-July than in May and June. In other California vineyards, Jedlicka et al. (2011) found that the abundance of birds more than doubled late in the breeding season, when fledglings are foraging alongside their parents. In our study the fledging of juveniles, which we video-documented foraging on larvae, may also explain the increased predation rates.

We found that the probability a mealworm would be taken was higher at Bedrock Vineyard than at the other three sites. The area surveys did not suggest a greater abundance of birds at Bedrock, suggesting bird density was not responsible for its high predation rate. Although the area surveys may not have reflected variation in abundance accurately, this vineyard maintained its vines at a height of 3 m rather than the standard 1.3 m, so it is possible that the different structure of the vines contributed to the difference in predation rate. Further investigation to identify specific characteristics of a vineyard and its surrounding habitat that enhance predation of pests would be valuable to vineyard managers. Reynolds et al. (2009) suggested that the natural heterogeneity of oak woodland may preadapt its native birds to certain levels of fragmentation. Quantifying threshold sizes of fragments within a matrix of vineyards may support a basis for preventing loss of important habitat patches that can support native bird communities, as well as for guidelines for restoring habitat useful to both birds and agriculture.

To make the service provided by wildlife into an incentive for conservation, one must be able to link those services to a direct human benefit. Further study could quantify the dollar value of pest removal to clarify for vineyard managers the financial benefit they would gain in crop yield saved from insect damage. Johnson et al. (2010) and Kellerman et al. (2008) estimated these savings to coffee growers, which in combination with outreach has resulted in farm-management recommendations that increase the quality of coffee farms for wildlife (Johnson pers. obs.).

Although we were not able to show that natural oak habitat provides a diversity of avian predators, we did corroborate that the Western Bluebird is an effective predator of arthropod larvae in vineyards. Jedlicka et al. (2011) found that providing nest boxes in vineyards increases the bluebird's numbers and that predation rates in vineyards with nest boxes are higher than in those without. The video cameras we deployed showed that the bluebird was the main predator of the larvae. The provision of nest boxes in vineyards increases the sizes of bluebirds' clutches, though it is unclear if there is a corresponding increase in fledging success or survival (Fiehler et al. 2006). Jedlicka et al. (2014) showed that the species composition of birds using nearby natural habitats was greater and significantly different from that found in vineyards, and the establishment of nest boxes within vineyards did not alter species composition.

Although our study examined the benefits of insect-eating songbirds, frugivorous songbirds can be pests in vineyards (Tracey and Saunders 2010). According to Taber and Martin (1998), the main bird species that do economic damage to grapes are the European Starling (*Sturnus vulgaris*) and House Finch (*Haemorhous mexicanus*), commonly excluded with netting during véraison. Thus, although the Western Bluebird may do some minor damage, it is not the species that concerns growers most. Kross et al. (2012) showed that in New Zealand the introduction of the New Zealand Falcon (*Falco novaeseelandiae*) can help reduce pest birds and limit crop damage. Future work should investigate the trade-off of raptors reducing frugivorous and insectivorous songbirds in vineyards. Although our study was short and its sample was relatively small, it suggests birds provide significant pest-control services that merit further investigation.

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