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Evaluation of damage by vertebrate pests in California vineyards and control of wild turkeys by bioacoustics

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Abstract: Complaints of agricultural damage by wild turkeys (*Meleagris gallopavo*), particularly from wine grape growers, have increased in California. We assessed damage by vertebrate pests in vineyards and tested a bioacoustic-aversion technique for turkeys as an alternative to other control techniques (e.g., reflective tape, trapping, bird netting). We selected 12 vineyards in the Napa Valley and Sierra Foothills American Viticultural Areas of California. We conducted damage surveys to assess percentages of missing or damaged grapes (i.e., grapes that had been stripped, pecked, and plucked) for every grape cluster on 20 randomly-selected vines before harvest in 2007 and on 40 vines in 2008. We assumed that all observed damage was caused by vertebrate pests and that most of this damage was caused by birds. Grape damage caused by wild turkeys was identified by contiguous sections of berries plucked from a cluster, which we referred to as stripped damage. We attributed pecked and plucked damage to passerines. In 2008, we randomly selected 3 vineyards in each area for treatment with broadcast calls (wild turkey alarm, domestic turkey alarm, crow distress). We used motion-activated video cameras to document evidence of damage caused by turkeys and other animals. Damage in the vineyard perimeter was greater than in the interior for all damage types in 2008, but only for plucked damage in 2007. In 2008, stripped, pecked, and plucked damage means for treated vineyards were 1.3%, 1.4%, and 1.5%, respectively; stripped, pecked, and plucked damage means for untreated vineyards were 1.3%, 0.7%, and 0.2%, respectively. There was no difference in mean stripped damage between treated and untreated vineyards in 2008, indicating that broadcast calls had no effect. Comparison between treated sites in 2008 with the same untreated sites in 2007 yielded similar results. Turkeys caused damage in several of the study vineyards, but the problem varied among vineyards and was inconsistent between years. Motion-activated video recordings suggested that raccoons (*Procyon lotor*), gray foxes (*Urocyon cinereoargenteus*), and other vertebrate pests were to blame for some of the stripped damage.

Key words: alarm call, bioacoustics, broadcast calls, California, damage survey, distress call, grapes, human–wildlife conflicts, *Meleagris gallopavo*, vineyards, wild turkey

The wild turkey (*Meleagris gallopavo*) is a nonnative bird in California, first released by ranchers on Santa Cruz Island in 1877. The California Department of Fish and Game (CDFG) released wild turkeys on the California mainland starting in 1908 with the intent of establishing a new species for hunting; the releases continued until 1999. Recent CDFG research estimated a wild turkey population of 242,000 (Gardner 2004), up significantly from an estimated 100,000 birds a decade earlier.

The growing wild turkey population and expanding range have resulted in conflict with human interests. Complaints include turkeys causing a nuisance in residential areas by damaging gardens and landscaping and by soiling yards and walkways with their excrement. These problems have grown from rare to common, especially in areas east and north of San Francisco Bay and in the Sierra Nevada Foothills (Gardner 2004). Complaints of agricultural damage have also increased, particularly from wine grape growers. Primarily in response to these complaints, the California state legislature in 2004 adopted changes to the Fish and Game Code (sections 4181 and 4188), which provided for the issuance of depredation permits to landowners.

Studies of damage by wild turkeys have focused on agronomic crops, such as corn, soybeans, alfalfa, and oats; each study concluded that turkeys caused less damage than growers perceived (Wright et al. 1989; Gabrey et al. 1993; Miller et al. 2000*a*, *b*; Tefft et al. 2005; MacGowan et al. 2006). The National Wild Turkey Federation studied damage to wine grapes from 2002 to 2003 at 9 vineyards in California (Mathis and Hughes 2005). Motion-sensing still cameras were used to identify the wildlife species eating grapes in vineyards. Cameras recorded 268 turkeys in the vineyards, 15 of which were photographed eating grapes. It was concluded that turkeys were not significant depredators of wine grapes. The authors also suggested that other species, including raccoons (*Procyon lotor*), mule deer (*Odocoileus hemionus*), and California ground squirrels (*Spermophilus beecheyi*), were more damaging, based on the percentage of photographs that showed these species feeding on grapes. In light of continued grower concerns in California, we decided to revisit the problem of damage by wild turkeys and conduct a quantitative assessment of grape damage.

Crop damage by wild turkeys is difficult to prevent. Many control techniques commonly used for deer (e.g., fencing) or passerines (e.g., reflective tape) in vineyards are considered ineffective for wild turkeys (Mathis and Hughes 2005). Growers have reported some success with bird netting, but this technique is expensive and labor intensive to install, so it is not used at many vineyards. There are no toxicants or repellents for wild turkeys. Some success has been reported with constant patrols on all-terrain vehicles and harassment by dogs (*Canis lupus familiaris*; Mathis and Hughes 2005). The National Wild Turkey Federation recommended spring hunting to keep wild turkeys away (Mathis and Hughes 2005), but hunting is not possible in many locations due to safety considerations.

Bioacoustics (the use of natural alarm or distress calls) has not previously been examined for control of wild turkeys. Our previous work with bioacoustic control of passerines in vineyards (Berge et al. 2007*a*), American crows (*Corvus brachyrhynchos*) in almond orchards (Delwiche et al. 2007), and cliff swallows (*Petrochelidon pyrrhonota*) nesting on highway structures (Conklin et al. 2009) has shown varying efficacy. Wild turkeys are a highly social and vocal species, with a vocabulary of 28 distinct calls (Williams 1984, Healy 1992), and we considered them to be possible candidates for control using bioacoustics.

Objectives

The overall goal of this research was to make an objective assessment of damage likely caused by wild turkeys and other vertebrate pests in vineyards and to develop an effective aversion technique for turkeys that could be used in vineyards and other agricultural areas and perhaps be adapted for nonagricultural settings. The specific objectives were to (1) determine the extent and significance of damage to wine grapes by wild turkeys and other vertebrate pests in California vineyards, (2) identify wild turkey alarm and distress calls and evaluate their effect on turkey foraging behavior, and (3) develop a field protocol for using broadcast alarm or distress calls in vineyards and measure the effect on damage levels.

Methods

Grower questionnaire

To get a preliminary idea of the extent of wild turkey depredation, we created an online questionnaire for wine grape growers in California. The questionnaire asked for information about vineyard size, location, grape varieties grown, wild turkey presence, perceived damage, and control measures. A link to the questionnaire was posted on a University of California Cooperative Extension (UCCE) viticulture website. The web address of the questionnaire was also disseminated with the assistance of UCCE viticulture farm advisors in each California county through regular newsletters and local wine-grape grower associations. The survey was not random because respondents knew of the survey topic before deciding whether to participate. Nevertheless, the information gathered provided us with insight on the subject. We compiled the questionnaire responses to determine the pervasiveness of turkey presence in vineyards and the perceived level of damage caused to grapes.

Call identification, selection, and testing

Three types of wild turkey calls were of most interest to us: the alarm putt, the predator alarm call, and the distress scream. The alarm putt is given by male and female turkeys of all age classes to indicate danger on the ground, usually from a predator, a human, or an unfamiliar object. Williams (1984) thought the alarm putt alerts the flock to danger, although when it is given by a lone turkey, it may serve to tell the predator that it has been detected. Healy (1992) stated that variations in the turkey alarm putt transmit information about the degree of alarm, i.e., the louder the putt, the greater the alarm. There is also a predator alarm call, which is not often heard, according to Williams (1984). It is given when an avian or ground predator approaches closely. The predator alarm call is most often made when a bird suddenly flies nearby and startles the turkey. The distress scream is given when a turkey is suddenly attacked by a predator (Williams 1984). Similar to the alarm calls of other bird species, the turkey alarm call is generally used in response to perceived danger, whereas a distress call is used when a bird is captured, restrained, or injured (Boudreau 1968).

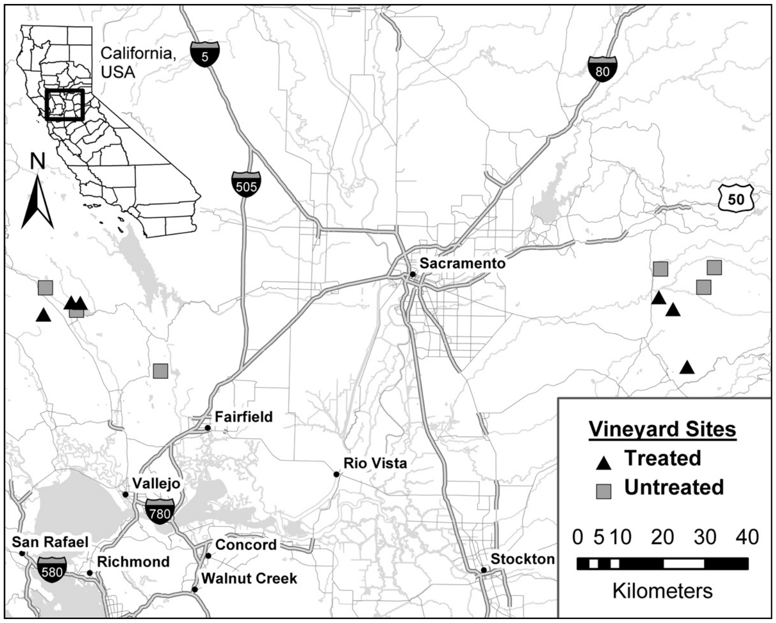

Figure 1. Location of 12 California vineyards used for wild turkey damage surveys during 2007 and 2008 and broadcast call treatments during 2008.

We searched academic, commercial, and Internet sources to obtain calls that might elicit favorable responses from turkeys to reduce damage in a vineyard. Favorable responses would be walking, running, or flying away after hearing the broadcast call. Wild turkey alarm putts were readily available from many sources, and we obtained several of them. We did not find recordings of predator alarm calls or distress calls described by Williams (1984). However, we spoke with turkey hunters regarding distress calls. Two hunters described an unusual call thought to be a distress call given by wounded turkeys in separate incidents (G. A. Giusti, UCCE, and J. E. Miller, Mississippi State University, personal communication). The call was described as sounding similar to the distress call of the American crow. With this in mind, we obtained adult and chick distress calls by American crows that we used in a previous study (Delwiche et al. 2007). We were also informed that domestic turkeys have a vocabulary similar to wild turkeys and are sometimes kept as pets by hunters in order to learn turkey calls (J. E. Miller, Mississippi State University, personal communication). We contacted a commercial turkey grower and recorded vocalizations of several poults while they were handled by the grower. To complete the collection of calls for testing, we obtained a barking dog call and call containing a mix of coyote (*Canis latrans*) barks and turkey calls. Altogether, we obtained 9 wild turkey calls, 6 domestic turkey calls, 1 turkey putt voice call by a human, 4 crow calls, and 2 calls with canine barks (Table 1).

We conducted field tests of the turkey calls during March to May 2007, September 2007, May 2008, and August 2008, by driving along country roads in lower elevation oak woodland and grassland habitats of Solano and Yolo counties, California. The test area included the interface between the croplands and grasslands of the Central Valley and the hills of the Coast Range, and extended from Vacaville in the south to Esparto in the north. When we observed turkeys, we stopped the vehicle and counted the number present. From the vehicle, we then broadcast a call for 10 to 20 seconds using a digital music player with an amplified trumpet speaker. If the response was not favorable after

Table 1. Sources and descriptions of calls tested for wild turkey response during March to May 2007, September 2007, and May and August 2008 in Solano and Yolo counties, California.

Call	Source[a]	Description
Wild turkey (*Meleagris gallopavo*)		
Wild-1	NWTF	Wild turkey putt—alarm call
Wild-2	BLB	Wild turkey—alarm call, adult female, #29390
Wild-3	BP	Wild turkey putt—alarm call
Wild-4	TTT	Wild turkey putt—alarm call
Wild-5	BLB	Wild turkey—alarm calls, adult females and juveniles, #30373
Wild-6	RT	Wild turkey putt—alarm call
Wild-7	BLB	Wild turkey—alarm call, juvenile female, #13261
Wild-8	RT	Wild turkey kee-kee
Wild-9	RT	Wild turkey kee-kee run
Domesticated turkey (*Meleagris* sp.)		
Domestic-1	Grower	Domesticated turkey poult (3–4 mon.) being held
Domestic-2	Grower	Domesticated turkey poult (3–4 mon.) being held
Domestic-3	Grower	Domesticated turkey poult (3–4 mon.) being held
Domestic-4	Grower	Domesticated turkey poult (3–4 mon.) being held
Domestic-5	Grower	Domesticated turkey poult (3–4 mon.) being held
Domestic-6	Grower	Domesticated turkey poult (1.5 mon.) being held
Domestic-7	Grower	Turkey putt mouth call by grower
American crow (*Corvus brachyrhnchos*)		
Crow-1	NWRC	Crow distress call after toxicant dosing, adult male
Crow-2	NWRC	Crow distress call after toxicant dosing, adult female
Crow-3	UCD	Crow chick being held—distress call
Crow-4	UCD	Crow chick being held—distress call
Other sounds		
Other-1	Entry Bell	Domestic dog (*Canis lupus familiaris*) barking
Other-2	Varmint Al	Mix of coyote (*Canis latrans*) and wild turkey calls

[a]NWTF = National Wild Turkey Federation, <*http://www.nwtf.org*>; BLB = Borror Laboratory of Bioacoustics, The Ohio State University, Columbus, Ohio; BP = Bragging Post, <*http://www.braggingpost.com*>; TTT = Tree Top Turkeys, <*http://www.treetopturkeys.com*>; RT = Real Turkeys VI (audio cd), Real Turkeys LLC, Cedar Key, Florida; Grower = Domesticated poultry grower (anonymous); NWRC = National Wildlife Research Center, Fort Collins, Colorado; UCD = University of California, Davis; EntryBell = <*http://www.entrybell.com*>; VarmintAl = <*http://www.varmintal.net/ahunt.htm*>.

the first broadcast, we repeated the broadcast another 1 or 2 times and recorded the number of birds and their responses to the call after the final broadcast. We recorded the following responses by turkeys: no reaction; alert, then approach; alert then stand or feed; walk slowly away; walk away at moderate pace; walk quickly away; and fly away. If a turkey responded to our presence before calls were played, the data were not included in the results.

Calls selected for bioacoustic treatments were cut and mixed with audio editing software (Goldwave, St. John's, Newfoundland, Canada) and stored as unsigned 8-bit, uncompressed pulse-code modulation, mono-waveform audio files. These were then converted to headerless binary files and loaded onto the broadcast unit flash memory chips (Berge et al. 2007*b*). Each call sequence was 26 seconds in duration.

Animal use and care in this project was approved by the Institutional Animal Care and Use Committee of the University of California, Davis, under protocol #12673.

Damage survey and bioacoustic treatments

We selected 12 vineyards in which the growers claimed to have had damage by turkeys in previous years. Half the vineyards were located in the Napa Valley American Viticultural Area (AVA) and half were in the Sierra Foothills AVA near Plymouth, California (Figure 1). The vineyards were located in areas with mixed oak and conifer woodlands interspersed with grasslands and other vineyards. Table 2 shows the size, training-trellis system, and grape variety for each vineyard. All vineyards had red grapes. Cordon and head-training heights were 0.8 to 0.9 m, vine spacings were 0.9 to 2.7 m, and row spacings were 1.5 to 3.7 m (Table 2). In all cases, clusters hung at heights reachable by turkeys.

We documented evidence of wild turkeys (i.e., sightings, feathers, tracks, droppings) at each site. Shortly before grape harvest at each site, we assessed grape damage at randomly-selected vines. We surveyed 20 vines in 2007 and 40 vines in 2008. We changed the sample size in 2008 to provide more data for the statistical analysis of treatment effects. We selected 50% of the vines from within a 2-vine perimeter subplot and 50% from the remaining interior subplot vines. The perimeter subplot contained the vines along the edges of the vineyard, i.e., the 4 outer rows (two on each side) and 2 vines on each end of every row. The interior subplot contained all vines not in the perimeter subplot. This sampling method was similar to our previous work (Berge et al. 2007*a*) and allowed us to test whether damage occurred primarily on the outside edges of the vineyard, which is common with damage by mammals and other

Table 2. Characteristics of vineyards used to study wild turkey damage in 2007 and 2008 and response to broadcast call treatments in 2008.

Site	Region	Treatment	Size (ha)	Training	Grape variety
1-NV-U	Napa Valley	Untreated	1.9	VSP[a]	Cabernet sauvignon
2-NV-T	Napa Valley	Treated	1.4	VSP	Cabernet sauvignon
3-NV-T	Napa Valley	Treated	0.6	Tee top	Cabernet sauvignon
4-NV-U	Napa Valley	Untreated	0.8	VSP, Wye	Merlot, petit verdot, cabernet sauvignon, syrah
5-NV-T	Napa Valley	Treated	1.6	VSP	Cabernet sauvignon
6-NV-U	Napa Valley	Untreated	5.3	VSP	Cabernet sauvignon
7-FH-T	Sierra Foothills	Ureated	1.4	Head trained	Zinfandel
8-FH-U	Sierra Foothills	Untreated	1.3	Head trained	Barbera
9-FH-T	Sierra Foothills	Treated	0.8	Simple curtain	Tinta cao, tinta amarela
10-FH-T	Sierra Foothills	Treated	1.2	Head trained	Zinfandel
11-FH-U	Sierra Foothills	Untreated	1.0	Head trained	Zinfandel
12-FH-U	Sierra Foothills	Untreated	3.2	Head trained	Zinfandel

[a]Vertical-shoot-positioned.

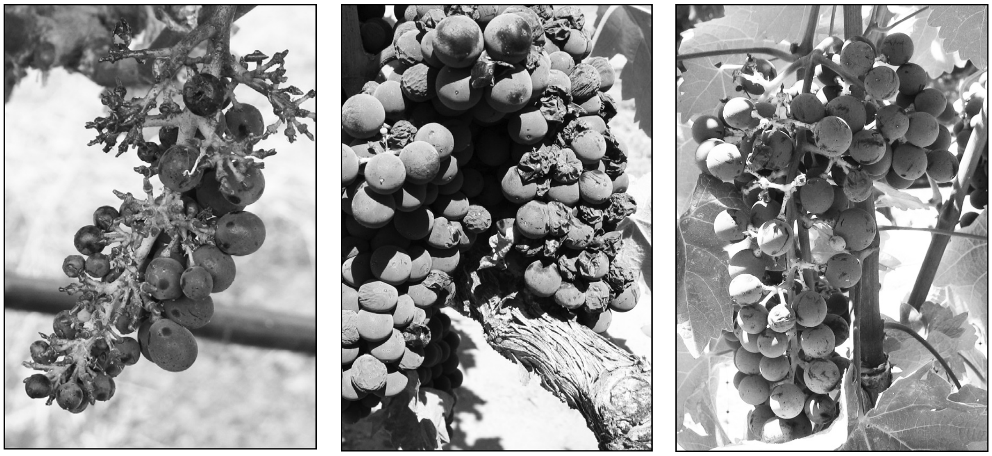

Figure 2. Grape clusters with (left to right) stripped damage, pecked damage, and plucked damage.

birds and has also been shown for turkeys in corn (Gabrey et al. 1993). For every cluster on a vine, we visually estimated the percentage of damage due to berries being stripped, pecked, and plucked (Figure 2). Pecked damage occurred when a bird pierced the skin of a berry. Removal of an entire berry was called plucked damage. A contiguous section of 5 or more plucked berries was stripped damage. In each vineyard, we first obtained a baseline for visual estimation of damage by counting the total number of berries (as if none were missing) on clusters of varying size. We then counted or visually estimated the number of missing or damaged berries for each damage type and estimated percentage of damage, accounting for cluster size. Damage was estimated to the nearest 1% if damage was <5%, and to the nearest 5% if damage was >5%. For example, we estimated that 1 pecked berry on a cluster with 50 berries had 2% pecked damage. One person was responsible for damage estimation throughout the entire study to reduce the effect of differences between investigators. We assumed that all observed damage was caused by vertebrate pests, and most of the damage was caused by birds. We assumed pecked damage was caused primarily by house finches (*Carpodacus mexicanus*), while we attributed plucked damage primarily to European starlings (*Sturnus vulgaris*) and American robins (*Turdus migratorius*; Berge et al. 2007*a*). Based

Table 3. Number and deployment dates of broadcast call (BC) units deployed, dates of damage surveys and harvest dates by year for 12 study areas in the Napa Valley and Sierra Foothills American Viticultural Areas of California.

	2007		2008			
Site	Surveyed	Harvested	BC units	BC installed	Surveyed	Harvested
1-NV-U	Sep 5	Oct 5			Sep 9	Sep 10
2-NV-T	Sep 5	Sep 6	2	Aug 28	Sep 5	Sep 10
3-NV-T	Sep 5	Sep 21	1	Aug 20	Sep 12	Sep 17
4-NV-U	Sep 27	Oct 5–15			Sep 9	Sep 12–Oct 31
5-NV-T	Sep 7	Sep 8	3	Aug 28	Sep 5	Sep 15
6-NV-U	Sep 27	Oct 16			Sep 17	Sep 22
7-FH-T	Sep 6	Sep 11	2	Aug 21	Sep 2	Sep 4
8-FH-U	Sep 6	Sep 7			Sep 3	Sep 21
9-FH-T	Sep 6	Sep 15	1	Aug 21	Sep 16	Sep 24
10-FH-T	Sep 11	Sep 12	2	Aug 29	Sep 10	Sep 11
11-FH-U	Sep 11	Sep 12			Sep 3	Sep 13
12-FH-U	Sep 11	Sep 12			Sep 10	Sep 13

on our own field observations and grower conversations, we determined that turkeys typically consume several berries from the same part of a cluster, so we assumed stripped damage was caused partially by turkeys. Damage by turkeys was further confirmed based on the presence of tracks, droppings, and feathers. We cannot say for certain what proportion of stripped damage was caused by turkeys for any given cluster; however, we would expect the amount of stripped damage to decrease if bioacoustic treatments were effective.

Identification of animal species causing damage was investigated by using motion-activated video cameras (DVREye, PixController Inc., Export, Pa.). We moved 4 cameras among vineyards during the growing season. We checked video later for evidence of animals eating grapes during the day and night.

To analyze broadcast call treatment effects, the untreated and treated sites had to be separated by enough distance to ensure independent observations; yet, they also had to be similar in spatial characteristics, such as animal abundance and surrounding habitat (Bomford and O'Brien 1990). In one approach, we could compare damage between untreated and treated sites in the same year, but the sites could not be adjacent because the broadcast calls would be heard in both sites and the turkeys could easily move to the untreated site. If selected sites were far enough apart to isolate the call sounds, some site characteristics might not be homogeneous (i.e., spatial effect). In another approach, we could compare damage between years by not treating a site 1 year and treating it during the next year. This provides homogeneity in site characteristics but introduces an effect of time due to differences in crop growth, weather, and animal abundance (i.e., temporal effect). We conducted experiments that allowed us to test treatment effects using both approaches.

In 2007, no treatments were used at the 12 vineyards. In 2008, 3 vineyards in each AVA were randomly-selected to receive treatment with broadcast call units. We installed the units when the first signs of apparent damage by turkeys appeared, or at least 2 weeks before projected grape harvest (Table 3). Treatments should ideally be deployed before the birds establish a pattern of damage; however, this increases the risk of habituation before harvest occurs. In practice, a better method would have been to apply these treatments just after the berries began to soften or change color, a stage in grape maturity growers call véraison (Weaver 1976). We visited treated and untreated sites weekly to check for evidence of damage by turkeys and other animals and to move the broadcast call units to a different location within the treatment site to reduce the likelihood of habituation. Broadcast call unit movement followed the protocol by Berge et al. (2007*a*). We completed damage surveys as near to harvest as possible (Table 3), but sometimes we completed surveys more than a few days before harvest, due to difficulty of obtaining information from growers, changes in harvest dates, and lack of time to complete a new survey closer to revised dates or multiple harvest dates for different varieties (site 4-NV-U).

We used analysis of variance (ANOVA) to evaluate the data for significant factor effects. We evaluated stripped, pecked, and plucked damage in independent statistical analyses. Because each vine had a different number of clusters, we had an unbalanced design (i.e., there were unequal numbers of clusters in both the perimeter and interior subplots). To simplify the analysis, we created a balanced data set by randomly selecting an equal number of clusters from each vine within each subplot. The number of clusters per sampled vine ranged from 1 to 28 for 2007 and from 1 to 58 for 2008. We eliminated vines with few clusters to maximize the total number of clusters in each subplot. This process resulted in balanced data sets with 6 vines and 11 clusters per vine in each subplot for 2007, and 10 vines with 15 clusters per vine in each subplot for 2008. For comparison of the same sites between years, we selected 6 vines with 11 clusters per vine in each subplot for 2008 to have a balanced data set between years. We calculated mean percentages of damage in both the perimeter and interior subplots from the balanced set of cluster-damage data. This produced 24-observation subplot data sets (i.e., 12 vineyards with 2 subplots each) for each type of damage and each year. To analyze region and treatment effects at the whole vineyard level, we calculated a weighted mean similar to Berge et al. (2007*a*). We multiplied mean damage in each subplot by a scaling factor equal to the number of vines in the subplot divided by the total number of vines in the vineyard. We summed these weighted subplot means to produce 12-observation weighted-total data sets for each type of damage and each year. We analyzed all data sets (i.e., combinations of subplot and weighted-total date for stripped, pecked, and plucked damage in years 2007 and 2008, as well as weighted-total data for same-site comparison between years) using SAS (SAS Institute, Cary, North Carolina).

Our first hypothesis was that sites treated with broadcast call units would have less stripped damage compared to untreated sites. We also tested whether there was a difference between pecked and plucked damage. We modeled the percentage of damage, Y_{ijk} as

$$Y_{ijk} = \mu + \rho_i + \alpha_j + (\rho\alpha)_{ij} + \varepsilon_{ijk}\,, \qquad (1)$$

where α was the weighted-total mean damage, ρ_i the region factor, α_j the treatment factor, $(\rho\alpha)_{ij}$ the interaction between region and treatment, and ε_{ijk} the error term. This is the model for a generalized randomized block design where ρ_i was a fixed-effect blocking factor having 3 experimental units (i.e., vineyards) per treatment within each block (i.e., region). Results using this model indicated there was no interaction between region and treatment, so we removed the interaction term to evaluate the main effects of region and treatment (Neter et al. 1996, p.837). The model became

$$Y_{ijk} = \mu + \rho_i + \alpha_j + \varepsilon_{ijk}\,, \qquad (2)$$

We analyzed the weighted-total data using regression model 2 separately for stripped, pecked, and plucked damage data. In 3 separate analyses, we compared sites treated in 2008 with sites untreated in 2008 (i.e., treatment confounded with spatial effect), sites treated in 2008 with the same sites untreated in 2007 (i.e., treatment confounded with temporal effect), and sites untreated in 2008 with the same sites untreated in 2007 (i.e., temporal effect). We used F-statistics to make inferences about the region and treatment effects.

Our second hypothesis was that the perimeter subplots would have more damage (of any type) than the interior subplots. A one-way ANOVA model described percentage of damage, Y_{ij}, as

$$Y_{ij} = \mu + \tau_i + \varepsilon_{ij}\,, \qquad (3)$$

where μ was the subplot mean damage, τ_i the subplot factor, and ε_{ij} the error term. We analyzed the subplot data using regression model 3 for pecked, plucked, and stripped damage data.

We assumed the error terms for each model were independent, normally distributed, and to have equal error-variances. However, for most data sets, this proved to be false due to substantial variability causing unequal error variances. Y for the subplot and weighted-total data sets for stripped, pecked, and plucked damage were each uniquely transformed to satisfy the model assumptions for the error terms. Transformations used the form

$$Y' = (Y + k)^{\lambda}\,, \qquad (4)$$

where Y' was the transformed dependent variable, λ was the exponent for transformation, and k was a constant added to account for instances of $Y = 0$ in the data. Optimum values of λ were selected by Box-Cox analysis (Neter et al. 1996) and minimizing the Hartley statistic for error variance

$$H = \frac{max(s_i^2)}{min(s_i^2)}\,, \qquad (5)$$

where $\max(s_i^2)$ is the largest sample variance and $\min(s_i^2)$ is the smallest sample variance in the data set. We performed optimizations with the best combinations of k equal to 0.05, 0.25, 0.5, and 1, and λ equal to -2 to 2 in increments of 0.5 (Table 4). We made an effort to use the same transformations when possible. With the transformed data, error terms did not violate the assumptions of normality or equal error variance.

Results

Grower questionnaire

We received 100 responses to the online questionnaire from growers in 19 counties. The size of the respondents' vineyards ranged from 0.1 to 1150 ha. Respondents indicated that wild

Table 4. Values of λ and k for data transformations to satisfy ANOVA model assumptions.

Data	Damage type	Year, Teatment	λ	k
Subplot	Pecked	2007	0	0.05
	Pecked	2008	0	0.05
	Plucked	2007	-0.5	0.05
	Plucked	2008	-0.5	0.05
	Stripped	2007	0	0.05
	Stripped	2008	0	0.05
Weighted-total	Pecked	2007	0	0.05
	Pecked	2008	None	None
	Plucked	2007	0	0.05
	Plucked	2008	0	0.05
	Stripped	2007	0	0.05
	Stripped	2008	0	0.05
Between years	Pecked	Treated	0	0.05
	Pecked	Untreated	0.5	0.05
	Plucked	Treated	0	0.05
	Plucked	Untreated	-1	0.05
	Stripped	Treated	0	0.25
	Stripped	Untreated	-0.5	0.25

turkeys were not present at 35 vineyards, were present on an irregular basis at 32 vineyards, and were present on a regular basis at 33 vineyards. Of the 65 respondents with turkeys present, twenty-eight (43%) thought turkeys caused damage, thirteen (20%) did not know or did not respond, and twenty-four (37%) thought turkeys caused no damage. Of the growers reporting damage, two (7%) indicated damage was high, ten (36%) described damage as moderate, and sixteen (57%) indicated that damage was low or did not respond. There did not appear to be any correlation between reported damage and vineyard size, trellis type, or region. Overall, respondents indicated that dogs and bird netting provided the most relief from damage by turkeys. In response to a question asking if the respondent was aware of depredation permits, forty-three were aware, twenty-eight were not, and twenty-nine did not respond. Only 3 respondents shot turkeys, and the effect of hunting as a deterrent was unclear. One respondent indicated that turkeys stayed away for >1 week after a turkey was shot, one indicated turkeys stayed away <1 week, and one indicated that turkeys did not stay away at all.

Call testing

The most common response to the broadcast calls was alert, stand, or feed (Table 5). In this response, a turkey stopped what it was doing, raised its head, looked toward the source of the call, and then either stood there or resumed feeding. Another response was to approach the source of the call. In some cases, the approach was rapid. The approach response was most frequently observed during spring with the Wild-7 call, a juvenile alarm call, which may have elicited a maternal response from the hens to seek and protect young poults. For the purpose of hazing turkeys in vineyards, alert, stand or feed, and approach would be undesirable responses. While these calls might be used to lure turkeys out of the vineyard, we decided that this was not feasible. Based on the frequency of desirable responses (i.e., moving away from the call source), we selected 3 wild turkey alarm putts, 2 crow chick distress calls, and portions of 5 calls from domestic

Table 5. Number of wild turkeys with listed response to broadcast calls during tests in March-May 2007, September 2007, May and August 2008 in Solano and Yolo counties, California.

Call	No reaction	Alert, approach	Alert, stand, or feed	Walk slowly away	Walk mod-erately away	Walk quickly away	Fly away	Total	Positive response[a] (%)
Wild-1	16	0	39	4	0	0	0	59	7
Wild-2	1	0	59	53	2	0	0	115	48
Wild-3	9	0	4	10	0	0	0	23	43
Wild-4	3	0	30	8	8	0	0	49	33
Wild-5	23	0	1	0	0	0	0	24	0
Wild-6	4	0	32	0	0	0	0	36	0
Wild-7	4	24	34	34	0	0	0	96	35
Wild-8	0	0	13	0	0	0	0	13	0
Wild-9	0	0	12	0	0	0	0	12	0
Domestic-1	0	0	0	0	0	0	0	0	-
Domestic-2	0	9	0	9	0	0	0	18	50
Domestic-3	0	10	0	0	0	0	0	10	0
Domestic-4	0	11	31	5	23	0	0	70	40
Domestic-5	0	1	14	0	0	0	0	15	0
Domestic-6	15	6	13	0	0	0	0	34	0
Domestic-7	0	6	19	0	0	0	0	25	0
Crow-1	1	0	2	0	0	0	0	3	0
Crow-2	0	0	4	0	0	0	0	4	0
Crow-3	0	0	1	5	5	0	0	11	91
Crow-4	4	0	1	4	16	15	0	40	88
Other-1	0	0	20	0	4	0	0	24	17
Other-2	5	0	1	0	0	0	0	6	0

[a] Positive response indicates turkey(s) moved away from source of sound.

turkeys to create 8 broadcast call sequences for vineyard treatment (Table 6). Though Wild-7 showed some evidence of deterring turkeys, we excluded it due to the frequent occurrence of approach responses. Domestic-1, -3, and -5 calls were included in spite of poor results because we could test only a few flocks with these calls before treatment deployment. These calls were similar to Domestic-2 and -4 calls, which had promising results, so we included them in several call sequences.

Damage survey and treatment effect

The data showed that damage of all 3 types was greater in the perimeter than in the interior of the vineyards (Figure 3). Statistical analysis of the transformed data showed that the means were different for stripped ($P = 0.005$), pecked ($P = 0.005$), and plucked ($P = 0.027$) damage types in 2008, and in 2007 it was different only for plucked damage ($P = 0.003$). The Sierra Foothills vineyards had greater damage than the Napa Valley vineyards for all damage types

Table 6. Call sequences used with broadcast call units in 2008 vineyard treatments.

Sequence	Calls used for sequence
1	Crow-3
2	Crow-4
3	Domestic-4, Domestic-5
4	Domestic-1, Domestic-2, Domestic-3
5	Domestic-4, Crow-4
6	Wild-2, Domestic-4
7	Wild-2, Crow-4

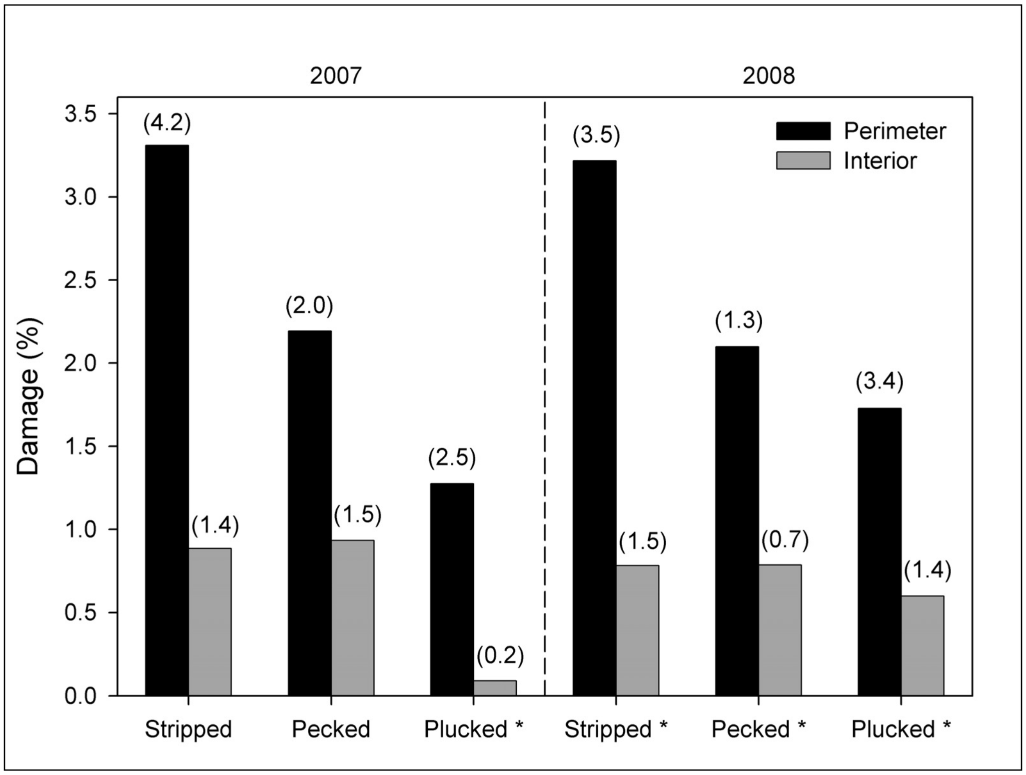

Figure 3. Subplot mean percentage damage (SD) for each damage type during 2007 and 2008. A significant difference between perimeter and interior means is denoted by an *.

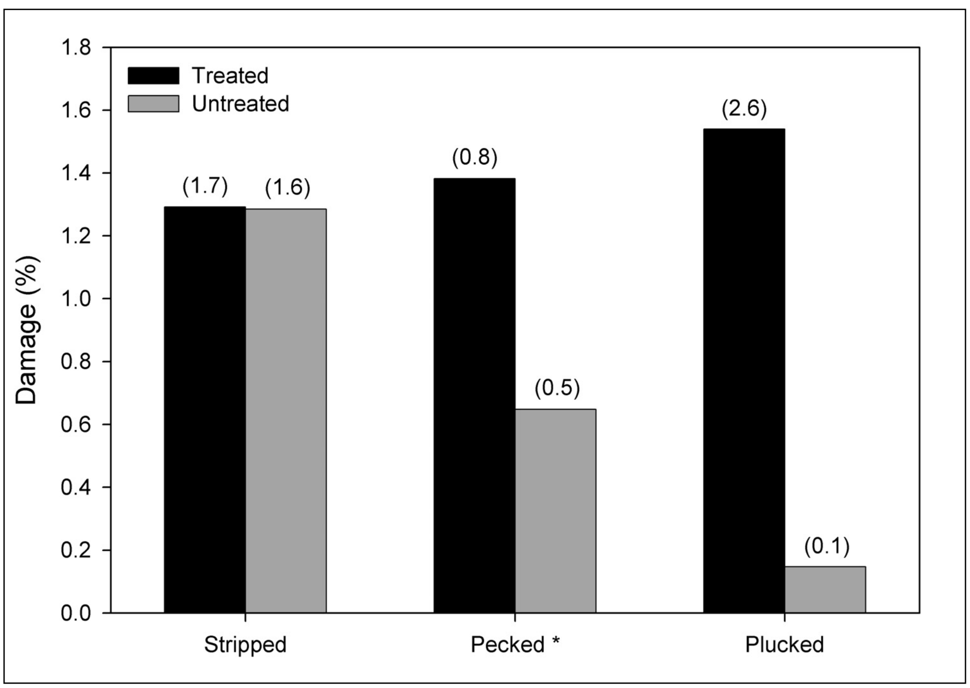

Figure 4. Treatment mean percentage damage (SD) for each damage type in 2008. A significant difference between treated and untreated means is denoted by an *.

in both years, except for stripped damage in 2007 (data not shown). The means differed only for pecked damage in both years (P = 0.0005 for 2007, P = 0.0001 for 2008).

Damage of all types for sites treated with broadcast calls in 2008 (Figure 4) was similar to or greater than damage for untreated sites in 2008. Damage means were small because there were typically many clusters with little or no damage on every vine. Stripped, pecked, and plucked damage means (and standard deviations) for treated vineyards were 1.3% (1.7%), 1.4% (0.8%), and 1.5% (2.6%), respectively. Stripped, pecked, and plucked damage means (and standard deviations) for untreated vineyards in 2008 were 1.3% (1.6%), 0.7% (0.5%), and 0.2% (0.1%), respectively. Only the pecked damage means differed (P = 0.002).

A comparison of damage for the same sites untreated in 2007 and treated in 2008 showed no differences in mean values. Stripped, pecked, and plucked damage means (and standard deviations) for treated vineyards in 2008 (balanced with 6 vines and 11 clusters per vine) were 1.8% (2.6%), 1.8% (1.3%), and 1.3% (2.1%), respectively. Stripped, pecked, and plucked damage means (and standard deviations) for untreated vineyards in 2007 were 1.8% (2.3%), 1.7% (1.9%), and 0.2% (0.2%), respectively. Similarly, a comparison of damage for the same sites that were untreated in both 2007 and 2008 showed no difference in mean values. Stripped, pecked, and plucked damage means (and standard deviations) for untreated vineyards in 2008 (balanced with 6 vines and 11 clusters per vine) were 1.7% (2.3%), 0.7% (0.6%), and 0.2% (0.1%), respectively. Stripped, pecked, and plucked damage means (and standard deviations) for untreated vineyards in 2007 were 0.8% (0.6%), 0.6% (0.7%), and 0.5% (0.8%), respectively.

Motion-activated video recordings showed a variety of animals present in the vineyards. Those specifically identified from video or during site visits included American robins, California quail (*Callipepla californica*), mule deer, European starlings, gray foxes (*Urocyon cinereoargenteus*), house finches, humans, pileated woodpeckers (*Dryocopus pileatus*), black-tailed jackrabbits (*Lepus canifornicus*), raccoons, and wild turkeys. Passerines, gray foxes, pileated woodpeckers, raccoons, and wild turkeys (Figure 5) were recorded eating grapes. Due to the limited number of cameras and frequent incidents of motion-triggering from blowing vines, we consider these results as anecdotal.

We converted stripped damage to monetary value to help understand its impact. The predominant varieties grown in the study sites were Cabernet Sauvignon in the Napa Valley vineyards and Zinfandel in the Sierra Foothills vineyards. The average price in 2008 for Cabernet Sauvignon in the Napa Valley was $5.27 per kg ($4,778 per ton) and for Zinfandel in the Sierra Foothills was $1.21 per kg ($1,100 per ton; USDA-NASS 2009). Weighted-total stripped damage during 2007 and 2008 in the Napa Valley vineyards ranged from 0 to 5.3% with a mean of 1.0%. In the Sierra Foothills, vineyards ranged from 0 to 4.5%, with a mean of 1.6%. Based on a typical yield of 6,725 kg per ha for Cabernet Sauvignon in the Napa Valley, stripped damage caused an average loss of $354 per ha. Based on a typical yield of 4,483 kg per ha for head-trained Zinfandel in the Sierra Foothills, stripped damage caused an average loss of $87 per ha.

Discussion

The grower questionnaire showed that about a third of the respondents believed wild turkeys caused damage in their vineyard. It is possible that growers with turkeys in their vineyard were more inclined to complete the online survey, so the results probably do not reflect the true proportion of California growers with turkey problems. However, the results still provide insight into grower perceptions and practices regarding wild turkeys in their vineyards. Respondents with turkeys rarely used hunting or killing turkeys under a depredation permit as a control tactic. It is possible, as was the case with several Napa Valley vineyards in this study, that hunting was not realistic due to the proximity to urban areas. It is also possible that many growers did not feel the level of damage was sufficient to warrant removal. Many respondents indicated that physical confrontation of turkeys with dogs and exclusion by netting was most effective.

In our study, damage was more concentrated in the perimeter vines of a vineyard. This raises the prospect of perimeter-focused control, such

Figure 5. Still-capture frame (from video) of a wild turkey eating grapes.

as perimeter-only bird netting. This may not be effective for passerines. But for wild turkeys, which typically walk through a vineyard, perimeter netting might reduce damage.

In spite of promising results from the call testing, broadcast calls which included turkey alarm putts, crow chick distress calls, and domestic turkey poult calls were not effective in reducing stripped damage in vineyards. There was no difference in stripped damage between treated and untreated sites in 2008 or between the treated sites in 2008 and the same sites (untreated) in 2007. There was no difference in untreated sites across years, suggesting that statistical comparison of treatment across years was reasonable. Differences in mean damage between factor levels were frequently not significant due to large variances. This was corroborated by our on-the-ground documentation of turkey presence, which showed that activity was highly irregular in several of the vineyards.

While our test of bioacoustic control for turkeys was ineffective, work with other bird species showed at least partial effectiveness, and we feel that the method warrants further investigation. Our search for wild turkey calls did not yield any that we considered to be true distress calls, and it was not possible for us to recreate the conditions necessary to elicit a distress call. Williams (1984) says the call is like the screaming of a bald eagle (*Haliaeetus leucocephalus*). It is unknown how wild turkeys would react upon hearing a distress call. We have received conflicting reports regarding the behavior of captured or injured wild turkeys, but, in light of positive results with other bird species, it would be worthwhile to test such a call.

Growers looking to reduce damage from wild turkeys should consider well-installed bird netting or traditional hazing techniques, such as roving patrols and dogs. Hunting has also been recommended in previous studies and may be considered when safe. Turkeys can habituate to the regular presence of people and animals. The most effective hazing techniques will be those that interrupt the regular routine of the birds.

Conclusions

Wild turkeys caused damage in California vineyards by stripping berries from the clusters. Many growers considered turkeys to be a problem, but video recordings indicated that other vertebrate pests, such as raccoons and foxes, were to blame for some of the stripped damage. Turkeys caused damage in several of the study vineyards, but the problem varied across vineyards and was inconsistent between years. Damage estimates in vineyards treated with broadcast calls were similar to untreated vineyards. Stripped damage was greater on perimeter vines, suggesting that netting on perimeter vines might reduce overall damage. In addition to netting, growers with damage from turkeys should consider dogs, roving patrols, or hunting.

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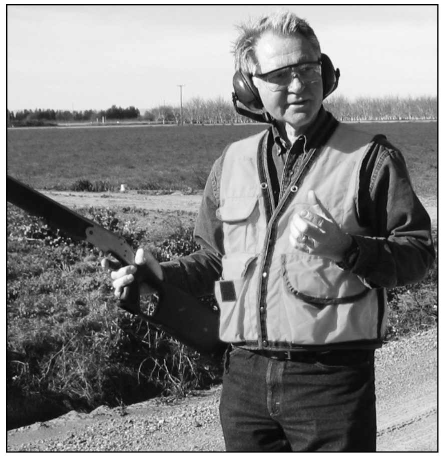

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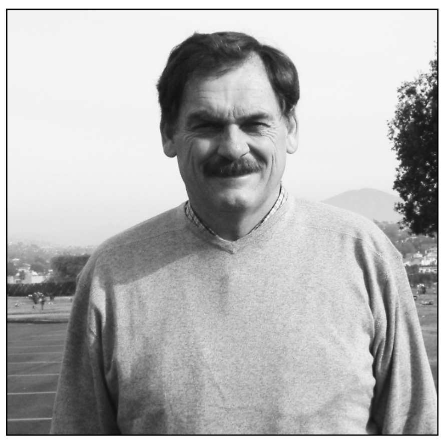

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