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Effects of Introducing Threatened Falcons into Vineyards on Abundance of Passeriformes and Bird Damage to Grapes

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Abstract: *Agricultural landscapes are becoming an important focus of animal conservation, although initiatives to conserve predators to date have rarely provided economic benefits to agricultural producers. We examined whether introduction to vineyards of the New Zealand Falcon* (Falco novaeseelandiae)*, a species listed as threatened by the New Zealand Department of Conservation, affected the abundance of 4 species of Passeriformes that are considered vineyard pests or affected the amount of economic loss due to grape* (Vitis vinifera) *damage. Three of the species were introduced and remove whole grapes from bunches (Blackbird* [Turdus merula]*, Song Thrush* [Turdus philomelos]*, and Starling* [Sturnus vulgaris]*), whereas the one native species (Silvereye* [Zosterops lateralis]*) pecks holes in grapes. The introduction of falcons to vineyards was associated with a significant decrease in the abundance of introduced passerines and with a 95% reduction in the number of grapes removed relative to vineyards without falcons. Falcon presence was not associated with a change in the number of Silvereyes, but there was a 55% reduction in the number of grapes pecked in vineyards with falcons. Our results indicate that, relative to damage in vineyards without falcons, the presence of a falcon could potentially result in savings of US$234/ha for the Sauvignon Blanc variety of grapes and $326/ha for Pinot Noir variety of grapes.*

Keywords: biological control, ecosystem service, IPM, pest management, raptors, threatened species

Efectos de la Introducción de Halcones Amenazados en Viñedos Sobre la Abundancia de Passeriformes y el Daño de Aves a Uvas

Resumen: *Los paisajes agrícolas se están convirtiendo en un objetivo importante para la conservación de animales, aunque a la fecha las iniciativas para conservar depredadores raramente proporcionan beneficios económicos a los productores agrícolas. Examinamos si la introducción en viñedos de* Falco novaeseelandiae, *una especie enlistada como amenazada por el Departamento de Conservación de Nueva Zelanda, afectó la abundancia de 4 especies de Passeriformes que son consideradas plagas en los viñedos o afectó la cantidad de pérdida económica debido a daños a la uva* (Vitis vinifera). *Tres de las especies son introducidas y remueven uvas enteras* (Turdus merula, Turdus philomelos *y* Sturnus vulgaris, *mientras que una especie nativa,* Zosterops lateralis, *picotea los frutos. La introducción de halcones en los viñedos se asoció con una disminución significativa de la abundancia de las especies introducidas y con una reducción de 95% en el número de uvas removidas en comparación con viñedos sin halcones. La presencia de halcones no se asoció con cambios en el número de* Zosterops lateralis, *pero en los viñedos con halcones hubo una reducción de 55% en el número de uvas picoteadas. Nuestros resultados indican que, en relación con el daño en viñedos sin halcones, que la presencia de un halcón potencialmente resulta en aborros de US$233/ha para la variedad de uvas Sauvignon Blanc y de $326/ha para la variedad Pinot Noir.*

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Palabras Clave: control biológico, especies amenazadas, manejo de plagas, MIP, rapaces, servicios del ecosistema

Introduction

Conservation has been viewed traditionally as an endeavor separate from agriculture (Green et al. 2005; Perrings et al. 2006). However, recently ecologists have examined whether biological control of pests may provide an incentive for the conservation of certain species within agricultural systems (Daily et al. 2000; Tilman et al. 2002). Conservation of predators can be a successful and sustainable approach for the control of many insects considered to be pests. Therefore, substantial research has focused on the management of habitats of predatory arthropods that reduce the abundance of arthropod pests (Chiverton & Sotherton 1991; Landis et al. 2000). Efforts to augment natural populations of predatory arthropods often represent additional costs to landowners because land is taken out of production or yields are reduced (Foley et al. 2005; Green et al. 2005), and these predators are seldom classified as threatened by conservation organizations. The ability of vertebrates to control arthropod agricultural pests has received much less attention, despite evidence that predators such as birds and lizards can effectively reduce damage to agricultural crops caused by their prey (Borkhataria et al. 2006; Kellermann et al. 2008). Moreover, when the agricultural pests themselves are vertebrates, control methods rarely focus on the preservation of natural predators because the predators of vertebrates tend to be large carnivorous species that are difficult to contain and rarely specialize on a single prey species (Hoddle 1999).

Vineyards are particularly vulnerable to predation by Passeriformes because ripening grapes (*Vitis vinifera*) represent an abundant food source for these birds in late summer and autumn (Somers & Morris 2002; Tracey & Saunders 2003; Saxton et al. 2004). For example, in Marlborough, New Zealand's largest wine-growing region, 3 species of introduced European birds remove whole grapes from bunches and 1 native species pecks holes in grapes to drink the juice from within, which exposes the grapes to fungal infection (Tracey & Saunders 2003; Saxton et al. 2004). The 3 introduced species are also known as dispersers of non-native, invasive, fruiting plants (Williams & Karl 1996).

To mitigate grape damage, viticulturalists use acoustic and physical bird deterrents and kill birds. However, commercial deterrents are often expensive, their efficacy may be exaggerated by advertisers (Fukuda et al. 2008), and some methods may even increase the amount of damage to grapes (Bomford & Sinclair 2002). Furthermore, even when physical or acoustic deterrents are used, birds can damage up to 83% of a vineyard's crop (Tracey & Saunders 2003).

Trained falcons are sometimes used to remove avian pests from areas such as airports and landfills (Baxter & Allan 2006; Soldatini et al. 2008), and artificial perches (Wolff et al. 1999) and nest boxes (Meyrom et al. 2009) have been used to attract wild birds of prey into some agricultural areas to reduce the abundance of rodents. These efforts demonstrate that captive or wild birds of prey can reduce pest abundance. Using the New Zealand Falcon (*Falco novaeseelandiae*) as a case study, we compared the abundance of birds considered to be pests and the levels of grape damage in vineyards with resident falcons (introduced for conservation) with vineyards without falcons.

Methods

Falcon Introduction

The New Zealand falcon is the country's only remaining endemic bird of prey. The population size and distribution of falcons decreased considerably after the arrival of human settlers (Fox 1977; Gaze & Hutzler 2004), and the species is now classified as threatened by the New Zealand Department of Conservation (Miskelly et al. 2008). The Falcons For Grapes project has been relocating wild New Zealand Falcon chicks from their nests in the mountains to the vineyards of Marlborough since 2005 (Fox 2005). No falcons, or other passerine-hunting raptors, occurred in this region prior to the relocations. Relocated falcons are provided with supplementary food and their nests are protected from mammalian predators. There are no a priori criteria for selection of vineyards into which falcons are introduced.

We selected 6 vineyards in which falcons had been introduced and 6 vineyards in which falcons had not been introduced (controls). Treated and control vineyards were interspersed spatially, and edges of vineyards were a minimum of 4 km apart (Supporting Information). All vineyards were managed using common commercial (not organic) methods for spatially extensive viticulture that were approved by Sustainable Winegrowing New Zealand. We trained workers in control vineyards in falcon identification and asked them to report any falcon sightings over the 2 years of the study.

Vineyard Characteristics

As of 2009, 23,600 ha were planted in wine grapes in the Marlborough region, with a mean vineyard size of 31 ha

(SE 7.35) (MAF 2009) and individual vineyards growing between 1 and 5 grape varieties in single-variety blocks. Sauvignon Blanc is the dominant variety of wine grape (mean = 21.5 ha/vineyard [SE 4.43]), and Pinot Noir is the second-most common (3.3 ha/vineyard [4.52]) (MAF 2009). The vineyards we studied had 49.3 ha (10.4) of Sauvignon Blanc grapes and 13.0 ha (4.8) of Pinot Noir grapes. There was no significant difference in the area of each grape variety grown in vineyards with falcons and control vineyards (Supporting Information).

Birds feed on grapes primarily at vineyard edges, nearest to vegetation or structures that provide passerines with shelter from potential predators. Feeding decreases toward the center of the vineyard (Somers & Morris 2002). However, Starlings in Europe and Australia have been observed to feed toward the center of agricultural fields, in areas farther away from shelter, because the open space may better accommodate their antipredator behavior (Whitehead et al. 1995; Tracey & Saunders 2003). Grapevines do not provide shelter for birds because the birds are known to flee from vineyards when approached by potential predators (Laiolo 2005). We therefore classified sampled vines as either edge or interior to account for differences in distance to vegetation (from long grasses to dense trees) in which passerines could take shelter from predators (bird shelter). We considered 50 m the threshold between interior and edge because in discussions with experienced vineyard managers before the onset of data collection we learned that the majority of damage in the previous 5 years occurred within 50 m of bird shelter. The mean percentage of edge compared with interior of the sampled area was 27.3% (SE 4.2) for Sauvignon Blanc and 33.0% (6.2) for Pinot Noir.

Abundance of Passeriformes

We established 1 edge and 1 interior transect within each of 4 vineyards with falcons (falcon vineyards) and 4 control vineyards. Transects were 500 m long and a minimum of 150 m away from center transect lines to avoid sampling the same individuals within both interior and edge transects. Because the edge transect ran alongside bird shelter, we used one-sided transect methods (Bibby et al. 2000). We walked each transect in one direction for 20 minutes and, using field binoculars (15 × 50 IS), identified all Passeriformes seen within 50 m of the transect line, including the 4 focus pest species (introduced Blackbirds [*Turdus merula*], Song Thrushes [*Turdus philomelos*], Starlings [*Sturnus vulgaris*], and the native Silvereye [*Zosterops lateralis*]) and 11 other common nonpest species. We ignored birds flying overhead. All transects ran along the edges of blocks, perpendicular to the rows of grapes. The number of individuals of each bird species observed during each survey of a transect was recorded; we refer to these counts as abundance data. We collected abundance data at 6 of the vineyards (3 falcon and 3 control) once a week starting the week of 23 November 2008 and at 2 of the vineyards (1 falcon and 1 control) once a week starting the week of 1 January 2009. We surveyed until the week of 18 March 2009. We analyzed each sample (transect survey) separately, but time (week) was included as a factor to control for temporal effects and vineyard was included to control for nonindependence of samples from multiple visits (see Analyses). We collected abundance data along transects between 06:00 and 10:00 and did not collect data when winds were high, temperatures were hot, or rain was moderate to heavy. If conditions precluded sampling, we sampled the transect during the same week under better conditions.

Grape Damage

In 2009 we measured grape damage in the 8 vineyards in which we conducted bird abundance surveys. In 2010 we again sampled 3 of the vineyards with falcons and 3 of the control vineyards from 2009, with the addition of 2 recently established falcon vineyards and 2 new control vineyards. One vineyard contained falcons in 2009 but not in 2010, so we treated it as a falcon vineyard in 2009 and as a control in 2010.

We sampled grape damage in the weeks of 18 March 2009 and 22 March 2010, which were immediately prior to the onset of harvest. Therefore, we used damage recorded during this period to estimate economic loss. We split vineyards into a grid of 50 × 50 m sampling plots and randomly selected a minimum of 10 edge and 10 interior plots for sampling in each vineyard (Supporting Information). Each plot contained only one variety of grapes. The few rows that were covered in bird-exclusion netting were not sampled. We sampled 1 grape bunch from each of 10 vines within each plot. We sampled 5 vines on each side of a row approximately midway along the plot at the edge nearest bird shelter. Sampling vines on both sides of the row controlled for differences in sunlight exposure.

We selected grape bunches for sampling with a method we adapted from Saxton (2006) that ensures a random selection of bunches from locations within and outside the vine canopy (Supporting Information). We estimated, to the nearest 5 grapes, the total number of grapes that had not been pecked or removed (undamaged grapes), the number of grapes that had been pecked, and the number of stems (pedicels) indicating grapes had been removed. We sampled 750 and 1490 bunches in control vineyards and 850 and 1050 bunches in vineyards with falcons in 2009 and 2010, respectively. We measured the cardinal direction each bunch faced and visually estimated the level of canopy cover for each bunch: 0, bunches with no canopy cover; 1, bunches with >0–50% canopy cover; 2, bunches with >50–100% canopy cover. From the edge of each plot, we measured the distance to the nearest bird shelter. If that bird shelter was located within 50 m of the sampled plot, we also characterized the type of shelter according to the presence or absence of grasses, shrubs, small trees (<3 m in height), large trees (≥3 m in height), buildings, and water. We used a scale from 0 to 5 to quantify the bird-scaring methods applied to each vineyard each year: 0, no bird-scaring methods; 1, only static nonacoustic methods (e.g., kites, balloons, ribbon); 2, static acoustic methods (gas cannons or avian alarm calls) set to go off every 5–10 minutes between dawn and dusk and rarely (1–2 times per week) deployed mobile acoustic methods (workers on 4-wheeled bikes or in vehicles honking horns or activating mobile gas cannons); 3, moderately deployed (once per day) mobile acoustic or lethal (workers with shotguns) methods; 4, often-deployed static nonacoustic methods and mobile acoustic and lethal methods (3–4 times daily); and 5, continuous mobile acoustic and lethal methods throughout daylight hours.

Analyses

Passeriformes abundance was the number of individuals of each focal species counted in each vineyard per week. We used generalized linear mixed models with a Poisson error, the most appropriate distribution for count data, and a log-link function to analyze the associations among abundance of focal species, weekly variability of focal species' presence, falcon presence, and location of the transect (interior vs. edge). We used the lme4 package (Bates et al. 2008) in R (version 2.7.2) for the generalized linear mixed models (R Core Development Team 2008). Mixed-effects models allow the inclusion of grouping (random) factors to account for nonindependence of data in nested and split-plot designs. We included vineyard as a random effect (so that multiple samples within one vineyard were not treated as independent) and week, falcon presence, and transect location as fixed factors, with interaction terms included among all 3 fixed factors in the maximal models. The generalized linear mixed models incorporated our hierarchical design and tested the effect of falcon presence over an error term, with degrees of freedom derived from the number of vineyards. For transect location (edge vs. interior) error degrees of freedom were derived from the number of transects (but blocked according to vineyards). We simplified the maximal models by removing interactions then main effects until no further reduction in residual deviance (measured using Akaike's information criterion) was obtained.

For the grape-damage data, we used a principal components analysis (PCA) to reduce the number of variables characterizing bird shelter to the 4 orthogonal axes that each explained more than 10% of the variance and cumulatively explained 86.7% of the variance in these variables (Supporting Information). We then used generalized linear mixed models with a binomial error and a logit link function to test whether falcon presence, canopy cover, grape variety, vineyard bird-scaring effort, distance from nearest bird shelter, cardinal direction the bunch faced, the 4 PCA axes, and plot location were significantly associated with the proportion of grapes per bunch (bunches being the unit of replication) that were damaged. We used separate models to test each of our damage categories: proportion of grapes per bunch removed but not pecked (removed) and proportion of grapes per bunch pecked but not removed (pecked). We included vineyard, plot, and year as random effects; plot nested within vineyard accounted for nonindependence of bunches within plots and of plots within vineyards and potential variation in damage across years. We initially included up to as many as 4 interaction terms between combinations of all available predictor variables and then reduced the maximal model to the minimum adequate model with the procedure outlined above. We tested all models for evidence of overdispersion (on the basis of the ratio of residual deviance to degrees of freedom) and reanalyzed overdispersed models with generalized linear mixed models fitted with penalized quasi-likelihood (the glmmPQL function) in the MASS package (Venables & Ripley 2002) in R (version 2.7.2). We used the parameter estimates from each model (after applying an appropriate inverse-link function) to estimate the actual abundance of birds or proportion of grapes removed or pecked. To compare the abundance of birds per vineyard with the amount of each type of damage, we used Spearman correlations (Supporting Information).

Economic Effect

We estimated the economic effect of falcon presence in vineyards by combining a model of overall grape damage (the sum of pecked and removed grapes) in vineyards with falcons and control vineyards (Supporting Information) with the average value of grapes harvested per hectare. In the overall grape-damage model, we used the same analysis methods as above for each damage class. In 2009, the average gross purchase price of grapes in Marlborough was US$13,790/ha (SE 430) for Sauvignon Blanc (assuming a conversion rate of 1NZ$ = US$0.718) and $13,951/ha (738) for Pinot Noir grapes (MAF 2009).

Results

Bird Abundance

Vineyard workers in vineyards without falcons reported no falcon sightings over the 2 years of our study. After controlling for differences through time, falcon presence in falcon vineyards was associated with a 78.4% reduction in the abundance of Song Thrushes ($Z = -3.17$, $p < 0.01$), an 82.5% reduction in the abundance of Blackbirds ($Z = -2.44$, $p = 0.02$), and a 79.2% (nonsignificant) reduction in the abundance of Starlings ($Z = -1.85$, $p = 0.06$) (Fig. 1) relative to control vineyards. Falcon presence did not explain significant variation in Silvereye abundance ($Z = -1.03$, $p = 0.30$) (Fig. 1), so we removed this variable from the Silvereye model; the lack of effect may have been due to low power.

Interior vines were associated with 70.5% fewer Song Thrushes ($Z = -7.66, p < 0.001$), 95.2% fewer Silvereyes ($Z = -10.71$, $p < 0.001$), and 44.4% fewer Blackbirds ($Z = -1.83, p = 0.07$) relative to edge vines. Conversely, interior vines were associated with a 57.7% increase in Starlings ($Z = 3.33, p = 0.001$) relative to edge vines.

Grape Damage

There was significantly less grape damage in vineyards with falcons than in control vineyards for edge and interior Sauvignon Blanc and Pinot Noir bunches (Fig. 2). Results of the generalized linear mixed models showed that in vineyards with falcons present there were significantly fewer grapes removed from bunches ($p < 0.001$) and fewer grapes pecked on bunches ($p < 0.01$) (Supporting Information). With all other variables held constant, the model intercept (inverse linked) indicated that in control vineyards an average of 0.6% of the edge Sauvignon Blanc grapes were removed and 2.3% were pecked (Table 1). In contrast, vineyards with falcons had an average of 0.03% of edge Sauvignon Blanc grapes removed and 1.0% pecked (Table 1).

Canopy cover was associated with observed damage to grapes. In control vineyards, bunches with >0–50% canopy cover had 43.3% fewer grapes removed ($p < 0.001$) than bunches with no canopy cover, whereas grape bunches with >50–100% cover had 89.4% fewer grapes removed and 47.0% fewer pecked grapes (both $p < 0.001$) (Supporting Information) than bunches with no canopy cover. However, in vineyards in which falcons were present, 32.5% more grapes were removed ($p < 0.001$) in bunches with >0–50% cover than in bunches with no canopy cover (Supporting Information).

Distance from bird shelter had a significant negative association with the number of grapes pecked (0.02% damage, $p = 0.04$), but this variable was taken out of the removed-damage model (Supporting Information). Bunches within the vineyard interior had significantly fewer grapes removed (0.03%, $p < 0.001$) and pecked grapes (1.0%, $p = 0.02$) than bunches at the edge of the vineyard (Supporting Information). Principal component axis 1, which was negatively correlated with the presence of natural features such as shrubs (variable loading = −0.54), small trees (−0.46), large trees (−0.43), and water (−0.44) (Supporting Information), had a significant negative association with both damage categories (both $p < 0.001$) (Supporting Information). Principal component axis 2 was positively correlated with the presence of buildings (0.95) (Supporting Information) and had a

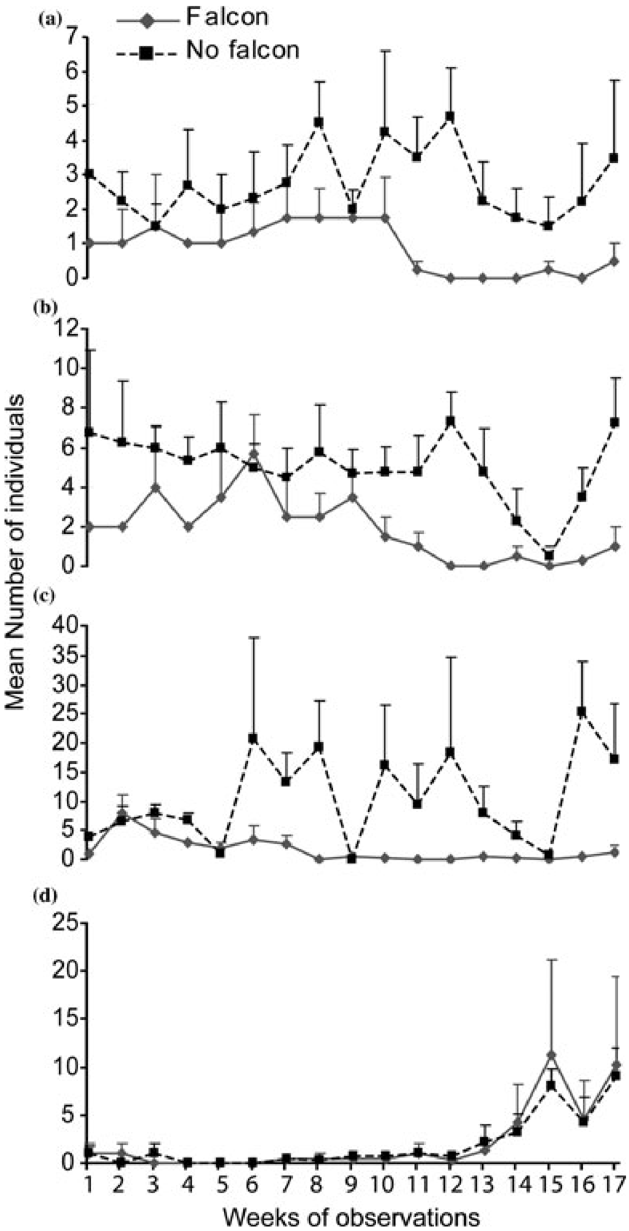

Figure 1. The effects of falcon presence on the abundance of (a) Song Thrushes (p < 0.01), (b) Blackbirds (p = 0.02), (c) Starlings (p = 0.06), and (d) Silvereyes (p = 0.30, removed from model). Lines graphs show the mean (SE) number of individuals observed in each of 17 weeks (beginning the week of 23 November 2008 and ending the week of 18 March 2009) along edge and interior transects combined at 4 vineyards with resident falcons present (Falcon) and 4 vineyards with falcons absent (No falcon). Grape ripening began at approximately week 12.

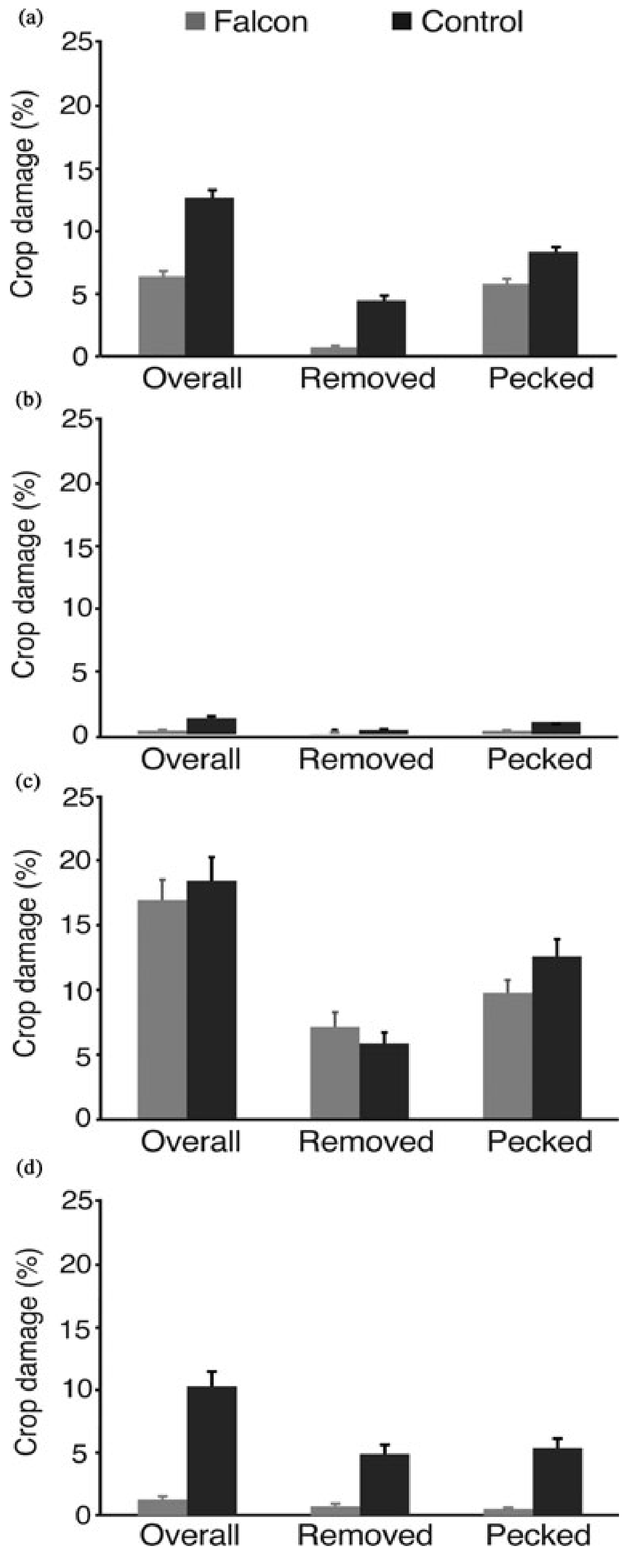

Figure 2. Mean (SE) percent overall damage to grapes (removed and pecked combined), grapes removed, and pecked grapes in falcon and control vineyards for (a) edge Sauvignon Blanc (b) interior Sauvignon Blanc, (c) edge Pinot Noir, and (d) interior Pinot Noir.

Table 1. Mean percent damage per bunch to vineyard grapes due to passerine foraging in control vineyards and in vineyards containing resident falcons, calculated from inverse-linked parameter estimates from generalized linear mixed models for removed and pecked grapes.

Damage, grape type, location[*]	*Control (% damage)*	*Falcon (% damage)*	*Relative change in damage with falcon presence (%)*
Grapes removed			
Sauvignon Blanc			
edge	0.62	0.03	−95.8
interior	0.03	0.00	−99.0
whole vine yard	0.19	0.01	−95.4
Pinot Noir			
edge	1.12	0.05	−95.8
interior	0.06	0.00	−95.8
whole vine yard	0.35	0.01	−95.8
Grapes pecked			
Sauvignon Blanc			
edge	2.26	1.00	−55.6
interior	1.05	0.46	−55.9
whole vine yard	1.38	0.61	−56.0
Pinot Noir			
edge	3.50	1.57	−55.3
interior	1.65	0.73	−55.8
whole vine-vyard	2.15	0.95	−55.6

Whole vineyard damage was calculated as the amount of edge damage multiplied by the proportion of control and treatment vineyards that consisted of edge vines (Sauvignon Blanc = 27%, Pinot Noir = 33%) plus the amount of interior damage multiplied by the proportion of our control and treatment vineyards that consisted of interior vines.

nonsignificant positive association with pecked damage ($p = 0.06$), but we took this variable out of the removed-damage model during simplification (Supporting Information). Principal component axis 3 was negatively correlated with the presence of water (−0.53, Supporting Information) and had a significant positive association with removed and pecked damage (both $p < 0.01$) (Supporting Information). We removed PCA 4 during simplification of both damage models.

We removed level of bird scaring in vineyards from the removed- and pecked-damage models during simplification. The cumulative number of Blackbirds, Song Thrushes, and Starlings in vineyards in the final 5 weeks of grape ripening was correlated with the number of grapes removed in vineyards (rho = 0.54, $p = 0.03$), whereas the number of grapes pecked was highly correlated with the cumulative number of Silvereyes (rho = 0.72, $p < 0.01$) (Supporting Information).

Economic Effect

For the combined average overall damage from both pecked and removed damage, 2.4% of the Sauvignon

Blanc crop and 3.4% of the Pinot Noir crop in control vineyards were damaged by birds (Supporting Information), equivalent to losses of $338/ha and $481/ha, respectively. A mean of 0.8% of the Sauvignon Blanc crop and 1.1% of the Pinot Noir crop was damaged in vineyards with falcons (Supporting Information), equivalent to losses of $104/ha and $155/ha, respectively.

Discussion

Our results show that relative to vineyards without falcons, vineyards with falcons were associated with significantly fewer non-native focal passerines and significantly fewer pecked and removed grapes. Relative to vineyards without falcons, falcon presence was associated with $234/ha less crop damage for Sauvignon Blanc and $326/ha less damage for Pinot Noir. Because these are rough calculations derived from model estimates, the values should not be treated as exact.

Relative to vineyards without falcons, the presence of falcons was associated with a lower abundance of non-native focal species and less grape damage associated with non-native and native focal species (Supporting Information). All 4 species are part of the diet of New Zealand Falcons (Fox 1977; Seaton et al. 2008). Our findings are likely a result of the combined effects of direct predation and increased predation risk. Direct predation reduces pest bird populations, whereas high predation risk increases antipredator behavior (e.g., avoidance and vigilance relative to time spent foraging) and may cause birds to forage in suboptimal locations that offer better protection from predators (Lima & Dill 1990; Fernández-Juricic & Tellería 2000; Devereux et al. 2006).

The relation between grape damage levels and the bird-scaring strategies employed by vineyards was not significant. Birds easily become habituated to common deterrent methods, especially if the same methods are used throughout the grape-ripening season (Bomford & Sinclair 2002; Fukuda et al. 2008). Understanding pest bird foraging behavior may allow better coordination of deterrent methods (Tracey & Saunders 2003). For example, knowing that fewer Starlings will forage at the vineyard interior if a falcon is present could encourage more efficient use of deterrent methods at the vineyard edge.

Our sample size was low because of the small numbers of falcons available for introduction into vineyards. Despite this low power, we found significant associations between falcon presence, passerine abundance, and grape damage. We do not think these correlations were spurious because falcons were introduced to these vineyards. In addition, a lower percentage of grapes in the vineyard in which falcons were present in 2009 and absent in 2010 were damaged in 2009 (mean [SE] damage = 2.0% [0.5]) than 2010 (5.2% [1.0]), whereas the remaining vineyards showed no significant between-year difference (Supporting Information). We believe that this finding means the falcon effects were not spurious. Nevertheless, we assumed that the effect of falcon presence was equal within and across the vineyards in which they were present, even though they may not visit all areas of a vineyard with the same frequency, and we did not include the few vines that were covered in bird-exclusion netting in our analyses. Thus, there may be some variation in falcon effectiveness within a given vineyard.

Mitigation of conflicts between humans and wildlife has become a key facet of predator conservation (Treves & Karanth 2003). Agriculture continues to intensify and to expand (Perrings et al. 2006) into areas inhabited by raptors, and when raptors hunt for valuable domestic or game species, they are sometimes killed by humans (Thirgood & Redpath 2008). Our results suggest that threatened falcons can reduce both the number of pest birds and the amount of damage that pest birds cause to wine grapes and that in this instance the goals of agriculture and predator conservation can converge.

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Supporting Information

Further information on the sampling design (Appendix S1), correlations between the original bird-shelter habitat variables and the first 4 axes from a PCA (Appendix S2), methods and results used to compare the abundance of focal species with the amount of each type of damage (Appendix S3), summary of overall damage-model results (Appendix S4), summary of the variables retained in our grape-damage models (Appendix S5), and a figure showing the changes in damage in a vineyard with falcons in 2009 and without falcons in 2010 (Appendix S6) are available online. The authors are solely responsible for the content and functionality of these materials. Queries (other than absence of material) should be directed to the corresponding author.

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