Evaluating the Use of Barn Owl Nest Boxes for Rodent Pest Control in Winegrape Vineyards in Napa Valley

Ashley Hansen and **Matthew Johnson**
Department of Wildlife, California State Polytechnic University, Humboldt, Arcata, California

ABSTRACT: Attracting natural enemies to farms to reduce pests has long been a part of integrated pest management for insects, but knowledge of the impact of raptors on rodent and other vertebrate pests is comparatively sparse. Using wooden nest boxes to attract rodent-eating barn owls (*Tyto alba* and *T. furcata*) to farms has been practiced in many regions for decades, but to date there have only been a handful of studies comparing rodent numbers in the presence and absence of barn owl nest boxes, and none done within the Western United States. In this study, we surveyed rodents on winegrape vineyards in Napa California with and without occupied barn owl nest boxes by live-trapping for rodents and using the open-hole method for gophers. We collected data before the owl breeding season, when hunting pressure should be light, and again when adult owls were hunting actively to feed their chicks. We found that gopher activity declined from before to peak hunting pressure on the vineyard with barn owl nest boxes, whereas it slightly increased on the vineyard without nest boxes. Live trapping revealed that the abundance of mice declined from before to peak hunting pressure, but this decline was not significantly affected by the presence of nest boxes. Results were inconclusive for voles because they not well-sampled by our live trapping method, even though analysis of owl pellets confirmed they are an important source of prey for barn owls.

KEY WORDS: barn owls, biological control, ecosystem services, gophers, integrated pest management, pest control, rodents, *Tyto furcata*, vineyard, wine

Proceedings, 30th Vertebrate Pest Conference (D. M. Woods, Ed.)
Paper No. 27. Published December 27, 2022. 9 pp.

INTRODUCTION

Through expansion and intensification, the growth of global agriculture poses one of largest threats to biodiversity (Green et al. 2005, McLaughlin 2011, Tscharntke et al. 2012). Rising population growth, per capita consumption, and the resulting conversion of uncultivated lands into agriculture continues to not only pose threats by degrading natural systems, but also through agrochemical inputs (Matson et al. 1997, Coeurdassier et al. 2014). As a result, environmentally friendly strategies such as utilizing natural predators as part of an integrated pest management (IPM) plan are becoming more common in agricultural settings (Green et al. 2005, Gómez-Baggethun et al. 2010, Paz et al. 2013, Sekercioglu et al. 2016).

Rodents are economically damaging pests in agriculture worldwide (Stenseth et al. 2003, Gebhardt et al. 2011). Rodents impact agriculture by directly consuming annual crops and reducing harvests by cutting roots or gnawing bark, which diminishes crop output or quality and in some cases kills adult crop plants (Baldwin et al. 2014). Though the economic impact can vary considerably across crop types and regions, damage caused by pests for California crops has been estimated to cost an average $95.9 million per year (Hueth et al. 1998). Winegrapes have been calculated to have the second greatest losses in the state, with an estimated 7.2% yield reduction per year (Gebhardt et al. 2011). Such results indicate that damage to winegrapes by vertebrates remains substantial despite the use of a variety of pest control methods. With such significant losses, a benefit is to be had by establishing and implementing more effective pest control methods.

The use of rodenticides is widely employed as the dominant rodent pest control measure (Tickes et al. 1982, Stenseth et al. 2003, Wood and Fee 2003), but killing rodents with rodenticide is costly, may have decreasing efficacy as rodents become resistant to certain compounds, can pose health risks to workers, and can have negative effects on the environment, such as secondary poisoning of non-target species (Erickson and Urban 2004, Berny 2007, Browning et al. 2016). Trapping is less damaging ecologically but is very laborious and costly. Consequently, more ecologically safe measures to control rodent pest populations, such as utilizing biological control agents as a form of IPM, are essential for future management (Johnson et al. 2018).

High-value crops such as winegrapes are experiencing an increase in public demand for sustainable agriculture and pest management solutions (Barber et al. 2010). The ongoing need to control rodent pest populations has led to the increased awareness of using IPM in agroecosystems (Evenden 1995, Kan et al. 2014, Kross et al. 2016, Labuschagne et al. 2016), including within vineyards in Napa Valley, California (Brodt et al. 2006). As a result, growers in California have been installing nest boxes to attract American barn owls (*Tyto furcata*) as a form of natural pest control (Kross and Baldwin 2016, Labuschagne et al. 2016). Through the installation of nest boxes, farmers can attract barn owls, which may be able to act as a natural predator and reduce populations of voles (*Microtus* spp.), mice (*Peromyscus* spp. and *Mus.* spp.), and pocket gophers (*Thomomys bottae*) – key pests in winegrape vineyards (Ross 2009, Tillmann 2012, Murray and DeFranesco 2016).

Given the economic importance of vineyards and the consequences of using rodenticides, there is incentive to research how effective barn owls are as an alternative to conventional rodent control practices. Theoretical modeling suggests barn owls could help control background levels of rodents, but even the highest barn owl densities

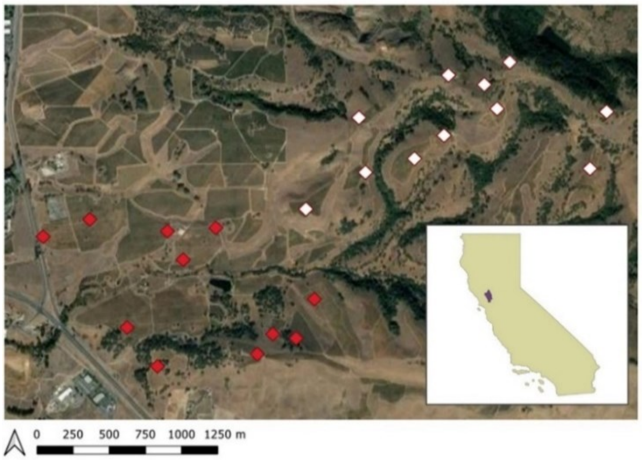

Figure 1. Map of study grids across two vineyards in Napa Valley, Soscol Vineyard (with barn owl nest boxes) and Cakebread Vineyard (without barn owl nest boxes).

may be unable to control abundant and quickly reproducing pocket gopher populations (Kross and Baldwin 2016, Hiroyasu et al. 2020). Recent empirical research on the use of barn owls in California has focused on patterns of nest box occupancy (Wendt and Johnson 2017), hunting habitat selection (Castañeda et al. 2021, Huysman and Johnson 2021), and prey removal rates (Johnson et al. 2018, Johnson and St. George 2020). Thus, while it is widely postulated that barn owls can benefit California farmers by hunting rodent pests, empirical data on the topic are very scarce.

This research aimed to advance our understanding of using barn owl nest boxes for rodent pest control and to help assess whether barn owls attracted to nest boxes in winegrape vineyards can meaningfully suppress the number of rodent pests. Specifically, this study assessed changes in rodent activity over time between two vineyards, one with and one without barn owl nest boxes. Rodent surveys were conducted at two sampling periods: before barn owl chicks hatched, and again during the nesting season when chicks were growing and adult prey delivery rates were among their highest. Such results can direct future research and application regarding rodent control in winegrape vineyards.

METHODS

Study System

The Napa Valley is a 50 km stretch of land located 100 km north of San Francisco, California that is characterized by a Mediterranean climate ideal for growing grapes and renowned for creating a wine industry valued at $3.7 billion annually (Stonebridge 2012). Surrounding habitats include mixed oak woodlands and oak savannas with more grasslands in the south and more mixed oak scrub and conifer forests in the north (Wendt and Johnson 2017).

Two large vineyard operations with similar row cropping, vine spacing and other farming practices that could affect rodent abundance were used as study sites, each with multiple fields near Soscol Creek south of the city of Napa (Figure 1). Cakebread Vineyard (approximately 250 ha) had no nest boxes at the time of study, and Soscol Vineyard (approximately 345 ha) had 13 operational nest boxes. Neither vineyard used rodenticides that would otherwise compromise rodent sampling. Additional details are available in Hansen (2022).

Sampling Design

To assess changes in rodent activity over time between the two vineyards, rodent surveys were conducted at two sampling periods: before barn owl chicks hatched (3 February - 13 March 2020) and again during the nesting season (4 May - 12 June 2020) when chicks were growing and adult prey delivery rates were among their highest. St. George and Johnson (2021) found peak prey delivery rates for chicks occurred at 4-7 weeks of age. A GoPro camera mounted on an extendable pole was used to non-invasively monitor occupied nest boxes (Wendt and Johnson 2017) to time the second sampling period accordingly.

Rodents were monitored on 22 sampling grids, 11 on Cakebread and 11 on Soscol vineyards. Grids on Soscol Vineyard were each positioned to be within 100 m of an owl nest box. For both vineyards, each grid was placed directly within vineyard rows (Figure 1). The minimum distance between a grid with a barn owl box and one without a barn owl box was 700 m and the maximum was 4090 m, so barn owl hunting and presence was assumed to be low on the vineyard without boxes (Cakebread) whereas it was higher on the vineyard with boxes (Soscol).

Live-trapping for Mice and Voles

At each sampling grid, Sherman traps were evenly dispersed in an 8 by 8 arrangement (n = 64) at ~8 × 6 m spacing (0.24 ha). Each grid was run for 4 trap nights at each sampling period, before and during peak hunting pressure. All captured animals were visually inspected for prior marking, and all unmarked animals were marked with a Monel ear tag (National Tag & Band model 1005-1) before release. The total number of animals captured on a grid over the 4-night sampling effort, excluding recaptures from the same sampling period, was used as a measure of rodent abundance for that sample grid and sample period and used to calculate changes in rodent abundance over time, which can be referred to as the minimum number alive (MNA) (Murano et al. 2019).

Open-hole Method for Gophers

The open-hole method is a validated method used for assessing the abundance of gophers (Engeman et al. 1993), which are notoriously difficult to live-trap. To reduce the chances of double-counting the activity of individual gophers, each grid was evenly subdivided into 64 8×6 m subplots. Within each subplot, if signs of gopher-caused soil disturbance were present, two holes into the tunnel systems were excavated, flagged, and inspected 48 hours later to determine if they were plugged by current gopher activity (Engeman et al. 1993). The proportion of all opened holes that were plugged was used as an index of gopher activity.

Owl Pellet Collection

To document the prey composition for owls nesting in boxes on the Soscol Vineyard (with barn owl boxes), fresh owl pellets were collected during the second sampling period, during peak hunting activity. Each night, adult owls

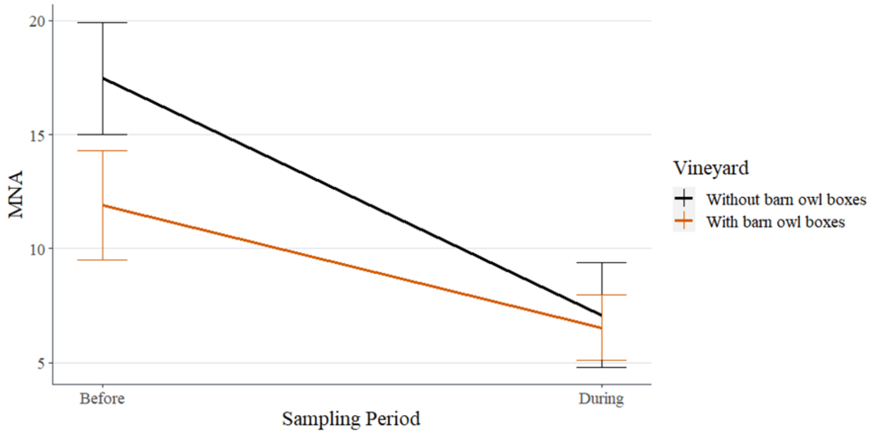

Figure 2. The minimum number alive (MNA) of mice caught across both vineyards and sampling periods (before and during peak owl hunting presence).

typically hunt for themselves before hunting and returning prey items to the nest for chicks, and the pellet from the prey consumed by adults is likely not deposited in the nest box (Roulin 2020). All pellets ejected by the young remain in the next box, except when the chicks are near fledging and begin to explore the exterior of the box. Therefore, the pellets collected from the box represent the vast majority of prey captured by adults. The proportion of each rodent genus in the pellets was used as a measure of prey composition during the breeding season. For descriptive purposes, the percent composition of voles, mice, and gophers in the pellets was calculated based on the estimated numbers of individual rodents and their corresponding biomass.

Live-trapping for Mice and Voles − Analysis

Generalized linear mixed effects models with a negative binomial distribution (GLMM, *glmr* from the *lme4* package in RStudio version 4.02 as described by Zuur et al. 2009) were used to test the prediction that the number of rodents captured declines more (from before to during peak hunting presence) on the vineyard with than without barn owl boxes. The response variable was "MNA," which represented the rodent population across both vineyards and sampling periods. The experimental variables were "Sampling Period" (before and during peak hunting presence) and "Vineyard" (with and without owl nest boxes). Since grids were spatially correlated and nested within each vineyard, grid was specified as a random effect (RE). A full interactive model was built and compared through ΔAICc, as well as simpler candidate models with additive effects, with each predictor variable singly, and a constant only model.

A second analysis was run similarly to test whether effects were different if the occupancy of nest boxes on the vineyard with boxes (Soscol) was recognized. Since not all barn owl boxes become occupied and because owls are central place foragers and hunt mainly near the nest box, rodents were effectively sampled on grids under three levels of spatial barn owl presence: on a vineyard without any nest boxes present (Cakebread, at least 700 m from on occupied box, low owl presence), on a vineyard with boxes but within 100 m of an unoccupied nest box (Soscol, intermediate owl presence), and on a vineyard with boxes and within 100 m of an occupied nest box (Soscol, high owl presence).

RESULTS

Live-trapping for Mice and Voles − Results

A total of 11,264 trap nights was recorded over the two sampling periods, yielding 203 animals captured on Soscol Vineyard and 270 on Cakebread Vineyard. No voles were caught on either vineyard, and the majority of captures were *Peromyscus* spp: deer mouse *Peromyscus maniculatus* (n = 400), brush mouse *Peromyscus boylii* (n = 58), pinyon mouse *Peromyscus truei* (n = 7), and house mouse *Mus musculus* (n = 8). Due to this, we were only able to analyze owl effects on the abundance of mice with trapping data.

Modeling results indicated that the number of mice declined from before to during peak hunting presence, but it did so fairly similarly on both vineyards, regardless of the presence of barn owl boxes (Figure 2). The top model included only an effect of sampling period on mouse abundance, carrying 62% of the model weight in the candidate set (Table 1). However, the model with a main effect of vineyard and sampling period was also competitive (ΔAICc = 1.72, wt = 0.26), with marginally higher mouse abundance on the vineyard without owl nest boxes. The interaction between sampling period and vineyard, which was predicted to be significant if MNA declined more rapidly on the vineyard with owl nest boxes, was not significant and this model was not competitive (ΔAICc = 3.61, wt = 0.10).

Owl Presence on the MNA Results

Of the 13 boxes on Soscol Vineyard, 8 were occupied and 5 were unoccupied. This resulted in 6 grids being classified as "high owl presence," 5 grids as "intermediate owl presence" and the 11 grids on Cakebread Vineyard as "low owl presence." The top model included additive effects of owl presence and sampling period, which carried 89% of the model weight in the candidate set (Table 2). The MNA of mice was lower on the grids classified as intermediate owl presence than on the other grids, and overall the MNA declined from before to peak hunting presence, but it did so fairly similarly on all three levels of owl presence (Figure 3).

Table 1. Candidate model set for predicting the minimum number alive (MNA) of mice in relation to the presence of occupied barn owl nest boxes across both sampling periods (SP). The model set was tested using generalized linear mixed effects models (GLMM). The top model (ΔAICc = 0) is bolded and significant coefficients (p-value < 0.05) for the top model (if any) are also indicated in bold.

Candidate Models	Intercept	Vineyard	Sampling Period (SP)	Vineyard*SP	k	AICc	ΔAICc	wAICc
MNA~vineyard*SP	2.79	-0.47	-1.02	0.42	6	299.41	3.61	0.10
MNA~vineyard+SP	2.71	-0.27	-0.80	–	5	297.52	1.72	0.26
MNA~vineyard	2.44	-0.32	–	–	4	306.51	10.71	0
MNA~SP	**2.58**	–	**-0.82**	–	4	295.80	0	0.62
MNA~intercept only	2.28	–	–	–	3	305.44	9.64	0.01

Table 2. Candidate model set for predicting the minimum number alive (MNA) of mice in relation to barn owl hunting presence across both sampling periods (SP). The model set was tested using generalized linear mixed effects models (GLMM). The top model (ΔAICc = 0) is bolded and significant coefficients (p-value < 0.05) for the top model are also indicated in bold.

Candidate Models	Intercept	Low Presence	Medium Presence	Sampling Period (SP)	Low Presence * SP	Intermediate Presence * SP	k	AICc	ΔAICc	wAICc
MNA~presence*SP	2.84	-0.05	-1.40	-0.61	-0.39	0.05	8	289.17	4.76	0.08
MNA~presence+SP	**2.94**	-0.22	**-1.37**	**-0.81**	-	-	6	284.41	0	0.89
MNA~presence	2.59	-0.16	-1.34	-	-	-	5	298.37	13.96	0
MNA~SP	2.53	-	-	-0.84	-	-	4	291.82	7.41	0.02
MNA~intercept only	2.20	-	-	-	-	-	3	307.56	23.15	0

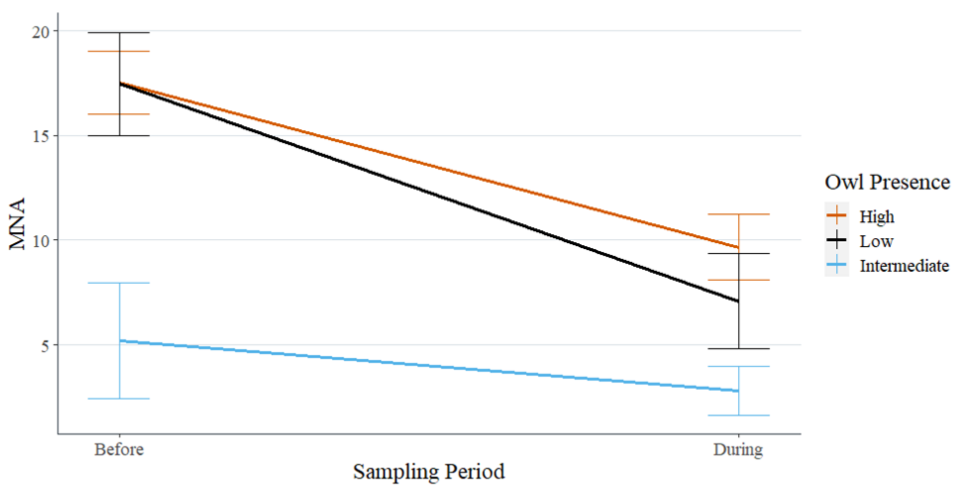

Figure 3. The minimum number alive (MNA) of mice caught across both vineyards and sampling periods (before and during peak owl hunting presence) with the associated classification of owl presence.

Open-hole for Gophers − Results

Gopher activity was widespread on the vineyards. Out of a total of 2,816 subplots examined for potential gopher activity, 868 holes were dug, of which 550 (63%) were plugged by gophers within 48 hrs, 289 on Soscol Vineyard and 261 on Cakebread Vineyard. Modeling results suggested that gopher activity declined on the vineyard with owl nest boxes (Soscol), whereas it increased slightly on the vineyard without (Cakebread; Figure 4). The top model for explaining gopher activity, the proportion of holes plugged, included the interaction between sampling period and vineyard, and no other model was competitive (Table 3).

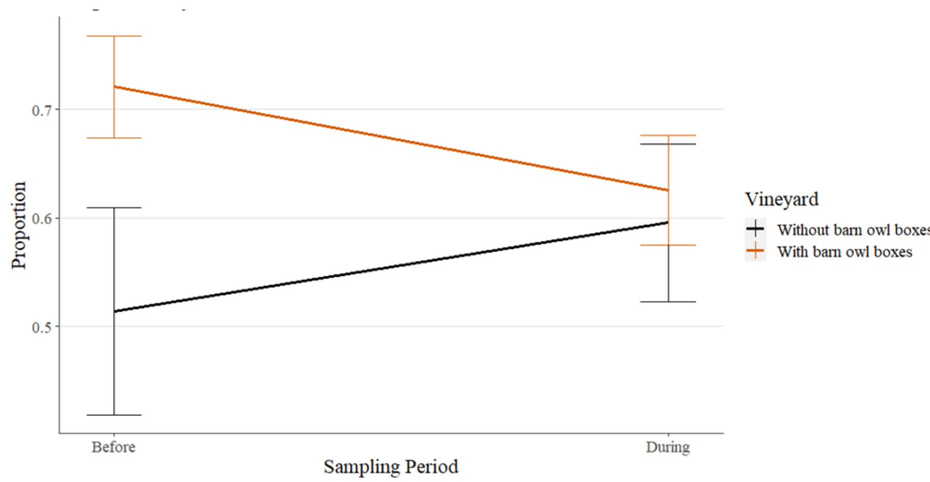

Figure 4. The proportion of gopher holes plugged to opened (an index of gopher activity) across both vineyards and sampling periods (before and during peak owl hunting presence).

Table 3. Model selection table for predicting pocket gopher activity based on the proportion of gopher holes plugged to open across both sampling periods (SP). The model set was tested using generalized linear mixed effects models (GLMM). The top model (ΔAICc = 0) is bolded and significant coefficients (p-value < 0.05) for the top model (if any) are also indicated in bold.

Candidate Models	Intercept	Vineyard	Sampling Period (SP)	Vineyard*SP	k	AICc	ΔAICc	wAICc
proportion~vineyard*SP	-0.39	**1.41**	**0.62**	**-0.96**	5	392.74	0	0.99
proportion~vineyard+SP	-0.14	0.92	0.11	-	4	415.49	22.75	0.00001
proportion~vineyard	-0.08	0.92	-	-	3	414.35	21.61	0.00002
proportion~SP	0.32	-	0.11	-	3	415.37	22.63	0.00001
proportion~intercept only	0.38	-	-	-	2	414.39	21.65	0.00001

Table 4. Candidate model set for predicting pocket gopher activity based on the proportion of gopher holes plugged to open in relation to barn owl hunting presence across both sampling periods (SP). The model set was tested using generalized linear mixed effects models (GLMM). The top model (ΔAICc = 0) is bolded and significant coefficients (p-value < 0.05) for the top model are also indicated in bold.

Candidate Models	Intercept	Low Presence	Medium Presence	Sampling Period (SP)	Low Presence * SP	Intermediate Presence * SP	k	AICc	ΔAICc	wAICc
proportion~presence*SP	**1.26**	**-1.65**	-0.54	**-0.44**	**1.06**	0.21	7	397.83	0	0.99
proportion~presence+SP	0.98	-1.11	-0.43	0.11	-	-	5	417.91	20.08	0.00004
proportion~presence	1.03	-1.11	-0.43	-	-	-	4	416.61	18.78	0.00008
proportion~SP	0.32	-	-	0.11	-	-	3	415.37	17.54	0.0002
proportion~intercept only	0.38	-	-	-	-	-	2	414.39	16.56	0.0002

Owl Presence on Gopher Activity

Like the results above, the top model for the effect of owl presence on gopher activity included owl presence and its interaction with sampling period. This model carried 99% of the weight in the candidate set, thus there was no other competitive model (Table 4). Grids classified as having "low owl presence" (the vineyard with no barn owl boxes, n = 11) experienced a significant increase in gopher activity across the two sampling periods, whereas the opposite was found for those classified as having "high owl presence" (Figure 5). Those classified as intermediate owl presence had a gopher response intermediate between high and low owl presence, with relatively stable gopher activity.

Owl Pellet Composition Results

A total of 67 pellets was collected across the Soscol Vineyard, with a total of 148 prey items identified (8.38 ± 7.87 of 18.5 ± 20.68 items per pellet). Prey items found

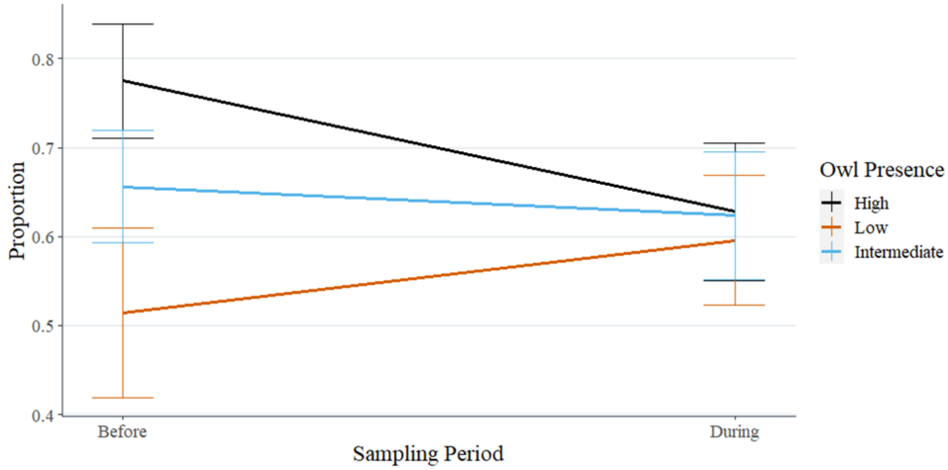

Figure 5. The proportion of gopher holes plugged to opened (an index of gopher activity) across both vineyards and sampling periods (before and during peak owl hunting presence) with the associated classification of owl presence.

included voles (n = 72), mice (n = 16), gophers (n = 38), and shrews (n = 1). There were 20 instances of invertebrates and two "other prey" (one shrew and one bird). Numerically, the vertebrate prey composition for Soscol Vineyard was therefore comprised primarily of voles (49%), followed by gophers (25%) and mice (10%). Using the biomass for gophers, mice, and voles, the prey composition for Soscol Vineyard was mostly gopher (57%), followed by voles (37%) and mice (6%).

DISCUSSION

Though the practice of installing owl nest boxes for rodent control has been widespread over the past 20 years, these results are among the first in the United States to confirm an effect of owl boxes on gopher activity in the field. These findings join other studies in other regions showing effects of barn owl on other prey species (Duckett and Karuppiah 1990, Hafidzi and Mohd 2003, Ojwang and Oguge 2003, Luna et al. 2020, Zainal Abidin et al. 2021), and support the hypothesis that pocket gopher abundance and activity is negatively associated with the presence of and hunting pressure by barn owls in Napa Valley vineyards. The vineyard with barn owl nest boxes experienced a decline in gopher activity from before to peak owl hunting presence, whereas the vineyard without owl nest boxes experienced an increase in gopher activity (Figure 4). Moreover, within the vineyard that had owl boxes, gopher activity declined more on grids near occupied than on grids near unoccupied nest boxes (Figure 5).

No voles were caught in this study, so whether barn owl nest boxes had any effect on their abundance cannot be determined. This is unfortunate because voles are a significant portion of the owls' diet, and other researchers using very similar field methods successfully trapped voles (Wolff et al. 1999, Murano et al. 2019). Although no voles were caught in this study, pellet analysis from our study area showed the barn owls hunted mainly gophers (57% by biomass) and voles (37%). Mice made up only 6% of the owl diet by biomass during the time of the study, which may help may explain why significant differences in mice populations over the two sampling periods and vineyards were not detected.

Other sampling methods may be useful for examining vole responses to barn owl hunting. For example, Luna et al. (2020) was able to show, using an index of vole activity, a significant reduction in the abundance of two vole species after raptor nest boxes were installed; they counted active common vole burrows (*Microtus arvalis*), which can be considered as a good estimator of vole abundance (Miñarro et al. 2012). Other methods to detect vole presence, aside from pellet analyses, include using track plates, chew blocks, and camera-trapping (Whisson et al. 2005, McCleery et al. 2014, Gracanin et al. 2018). Low vole densities can cause unsuccessful trapping of voles (Baldwin et al. 2015), suggesting that voles may have been rare in the vineyards and these owls may have been obtaining voles from surrounding habitats. Future research should consider alternative methods of detecting voles directly within vineyards if trapping proves to be unsuccessful.

Though we were not able to detect the effect of barn owl presence on voles in our two vineyards, the pellet analyses from this study and other diet composition work confirm that voles and gophers are a significant part of barn owl diets in California agriculture (Kross et al. 2016, St. George and Johnson 2021). This is good news for producers as these two rodent pests cause significant losses in agriculture. There is thus a benefit in researching ways to increase barn owl box occupancy, such as using north-facing wooden boxes that are positioned higher off the ground (Wendt and Johnson 2017, Carlino unpubl. data). Additionally, future research conducted in areas outside of Napa, with different crop types, and outside of the breeding season can provide significant insight into integrating raptors into more IPM approaches. Lastly, Cakebread Vineyard now has plans for installing nest boxes on their property; utilizing such opportunities to carry out before-after research could help us further monitor and detect the benefits of having barn owls in vineyards.

Trophic webs are composed of complex relationships, including negative impacts of predators on the abundance of prey ("top-down" effects) as well as predators responding functionally or numerically to spatial and/or temporal variation in prey availability ("bottom up" effects; Hunter and Price 1992, Power 1992). In this study, there is some evidence of both forces in operation between gophers and owls. While there was clear evidence that barn owl hunting diminished gopher activity over the course of the owls' breeding season (a top-down effect, Figure 4), it also appears that owls chose to occupy nest boxes with higher gopher activity at the start of the nesting season. On the vineyard with barn owl boxes, the unoccupied boxes had lower gopher activity at the beginning of the nesting season (intermediate owl presence) than did the unoccupied boxes (high owl presence, Figure 5). This connection may be a result of bottom-up forces that are influencing barn owl box occupancy (Van Veen and Sanders 2013). Long-term rodent monitoring coupled with barn owl occupancy data may provide us with more information regarding any bottom-up or top-down forces that may be at play within this system. A cascade involving barn owls, their rodent prey, and agricultural crops is theoretically possible (Strong 1992, Schmitz et al. 2000, Fortin et al. 2005, Labuschagne et al. 2016), but to date relatively few studies have examined this system empirically (Abramsky et al. 1996, Tillmann 2012, Kross et al. 2016). This could be fruitful area of future research, especially since owl numbers and distribution are relatively easily manipulated with nest boxes.

ACKNOWLEDGMENTS

We thank our funders for making this project possible, specifically the Humboldt Area Foundation, the Wright Refuge, and the California State University's Agricultural Research Institute. We would also like to thank the vineyards and vineyard managers who allowed us on their properties, particularly Keith Robbins from Soscol Creek and Roy Oneto and Lise Asimont from Cakebread Cellars. Thank you to our field assistants Jessica Barger, Camille Castro, Raquel Elander, and Jessica Sattler, and all the volunteers who helped us dissect owl pellets.

LITERATURE CITED

Abramsky, Z., E. Strauss, A. Subach, B. P. Kotler, and A. Riechman. 1996. The effect of barn owls (*Tyto alba*) on the activity and microhabitat selection of *Gerbillus allenbyi* and *G. pyramidum*. Oecologia 105:313-319.

Baldwin, R. A., R. Meinerz, H. E. Jantz, and G. W. Witmer. 2015. Impact of capture and transportation methods on survival of small rodents during relocation events. The Southwestern Naturalist 60:385-389. http://dx.doi.org/10.1894/0038-4909-60.4.385

Baldwin, R. A., T. P. Salmon, R. H. Schmidt, and R. M. Timm. 2014. Perceived damage and areas of needed research for wildlife pests of California agriculture. Integrative Zoology 9:265-279.

Barber, N., D. C. Taylor, and C. S. Deale. 2010. Wine tourism, environmental concerns, and purchase intention. Journal of Travel and Tourism Marketing 27:146-165.

Berny, P. 2007. Pesticides and the intoxication of wild animals. Journal of Veterinary Pharmacology and Therapeutics 30: 93-100.

Brodt, S., K. Klonsky, and L. Tourte. 2006. Farmer goals and management styles: implications for advancing biologically based agriculture. Agricultural Systems 89:90-105.

Browning, M., J. Cleckler, K. Knott, and M. Johnson. 2016. Prey consumption by a large aggregation of barn owls in an agricultural setting. Proceedings of Vertebrate Pest Conference 27:337-344.

Carlino, J. 2022. Measuring barn owl breeding habitat quality and predicting double brooding. Cal Poly Humboldt - Dept. of Wildlife. https://wildlife.humboldt.edu/graduate-students/jaime-carlino

Castañeda, X. A., A. E. Huysman, and M. D. Johnson. 2021. Barn owls select uncultivated habitats for hunting in a winegrape growing region of California. The Condor 123:1-15. https://dx.doi.org/10.1093/ornithapp/duaa058

Coeurdassier, M., R. Riols, A. Decors, A. Mionnet, F. David, T. Quintaine, D. Truchetet, R. Scheifler, and P. Giraudoux. 2014. Unintentional wildlife poisoning and proposals for sustainable management of rodents. Conservation Biology 28:315-321.

Duckett, J. E., and S. Karuppiah. 1990. A guide to the planter in utilizing barn owls (*Tyto alba*) as an effective biological control in mature oil palm plantations. Pages 357-372 *in* S. Jalani, Z. Z. Ziri, K. Paranjothy, D. Ariffin, N. Rajanaidu, S. C. Cheah, M. W. Basri, and I. Henson, editors. Proceedings of the 1989 International Palm Oil Development Conference-Agriculture. Palm Oil Research Institute of Malaysia, Kuala Lumpur, Malaysia.

Engeman, R. M., D. L. Campbell, and J. Evans. 1993. A comparison of 2 activity measures for northern pocket gophers. Wildlife Society Bulletin 21:70-73. https://www.jstor.org/stable/3783364

Erickson, W., and D. Urban. 2004. Potential risks of nine rodenticides to birds and nontarget mammals: a comparative approach. US Environmental Protection Agency, Office of Prevention, Pesticides and Toxic Substances. Washington, D.C.

Evenden, M. D. 1995. The laborers of nature: economic ornithology and the role of birds as agents of biological pest control in North American agriculture, ca. 1880-1930. Forest & Conservation History 39:172-183. https://doi.org/10.2307/3983958

Fortin, D., H. L. Beyer, M. S. Boyce, D. W. Smith, T. Duschesne, and J. S. Mao. 2005. Wolves influence elk movements: behavior shapes a trophic cascade in Yellowstone National Park. Ecology 86:1320-1330. https://www.jstor.org/stable/3450894

Gebhardt, K., A. M. Anderson, K. N. Kirkpatrick, and S. A. Shwiff. 2011. A review and synthesis of bird and rodent damage estimates to select California crops. Crop Protection 30:1109-1116.

Gómez-Baggethun, E., R. Groot, P. L. Lomas, and C. Montes. 2010. The history of ecosystem services in economic theory and practice: from early notions to markets and payment schemes. Ecological Economics 69:1209-1218. Elsevier B.V.

Gracanin, A., V. Gracanin, and K. M. Mikac. 2018. The selfie trap: a novel camera trap design for accurate small mammal identification. Ecological Management and Restoration 20: 156-158.

Green, R. E., S. J. Cornell, J. P. W. Scharlemann, and A. Balmford. 2005. Farming and the fate of wild nature. Science 307:550-555.

Hafidzi, M. N., and N. I. Mohd. 2003. The use of the barn owl, *Tyto alba*, to suppress rat damage in rice fields in Malaysia. Pages 274-276 *in* G. R. Singleton, L. A. Hinds, C. J. Krebs, and D. M Spratt, editors. Rats, mice and people: rodent biology and management. Australian Centre for International Agricultural Research, Canberra, Australia.

Hansen, A. 2022. Use of an avian predator as a biological control agent in agricultural systems: Do barn owls (*Tyto alba*) impact rodent abundance in a vineyard setting? Cal Poly Humboldt - Dept. of Wildlife. https://wildlife.humboldt.edu/graduate-students/ashley-hansen

Hiroyasu, E. H. T., S. M. Kross, R. A. Baldwin, and B. E. Kendall. 2020. Pest control by generalist predators depends on prey density and predator effectiveness. Proceedings of Vertebrate Pest Conference 29:126. https://escholarship.org/uc/item/8d5733vm

Hueth, B., D. Cohen, and D. Zilberman. 1998. Non-predator vertebrate pest damage in California agriculture: an assessment of economic impacts in selected crops. Proceedings of Vertebrate Pest Conference 18:371-377.

Hunter, M. D., and P. W. Price. 1992. Playing chutes and ladders: heterogeneity and the relative roles of bottom-up and top-down forces in natural communities. Ecology 73:724-732. http://www.jstor.org/stable/1940152

Huysman, A. E., and M. D. Johnson. 2021. Habitat selection by a predator of rodent pests is resilient to wildfire in a vineyard agroecosystem. Ecology and Evolution 11:18216-18228. https://dx.doi.org/10.1002/ece3.8416

Johnson, M. D., and D. St. George. 2020. Estimating the number of rodents removed by barn owls nesting in boxes on winegrape vineyards. Proceedings of Vertebrate Pest Conference 29:118-125.

Johnson, M. D., D. St. George, C. A. Wendt, A. E. Huysman, and X. A. Castañeda. 2018. Can barn owls help control rodents in winegrape vineyard landscapes? A review of key questions and suggested next steps. Proceedings of Vertebrate Pest Conference 28:180-187.

Kan, I., Y. Motro, N. Horvitz, A. Kimhi, Y. Leshem, Y. Yom-Tov, and R. Nathan. 2014. Agricultural rodent control using barn owls: Is it profitable. American Journal of Agricultural Economics 96:733-752.

Kross, S. M., and R. A. Baldwin. 2016. Gopherbusters? A review of the candidacy of barn owls as the ultimate natural pest control option. Proceedings of Vertebrate Pest Conference 27:345-352.

Kross, S. M., R. P. Bourbour, and B. L. Martinico. 2016. Agricultural land use, barn owl diet, and vertebrate pest control implications. Agriculture, Ecosystems and Environment 223:167-174. https://dx.doi.org/10.1016/j.agee.2016.03.002

Labuschagne, L., L. H. Swanepoel, P. John, R. Steven, and M. Keith. 2016. Are avian predators effective biological control agents for rodent pest management in agricultural systems? Biological Control 101:94-102.

Luna, A. P., H. Bintanel, J. Viñuela, and D. Villanúa. 2020. Next-boxes for raptors as a biological control system of vole pests: high local success with moderate negative consequences for non-target species. Biological Control 146:104267.

Matson, P. A., W. J. Parton, A. G. Power, and M. J. Swift. 1997. Agricultural intensification and ecosystem properties. Science 277:504-509.

McCleery, R. A., C. L. Zweig, M. A. Desa, R. Hunt, W. M. Kitchens, and H. F. Percival. 2014. A novel method for camera-trapping small mammals. Wildlife Society Bulletin 38:887-891.

McLaughlin, D. W. 2011. Land, food, and biodiversity. Conservation Biology 25:1117-1120.

Miñarro, M., E. Dapena, and C. Montiel. 2012. Vole pests in apple orchards: use of presence signs to estimate the abundance of *Arvicola terrestris cantabriae* and *Microtus lusitanicus*. Journal of Pest Science 85:477-488.

Murano, C., S. Kasahara, S. Kudo, A. Inada, S. Sato, K. Watanabe, and N. Azuma. 2019. Effectiveness of vole control by owls in apple orchards. Journal of Applied Ecology 56:677-687.

Murray, K., and J. DeFranesco. 2016. Pest Management Strategic Plan for Wine Grapes in Oregon. Oregon Wine Board. https://industry.oregonwine.org/news-and-media/pest-%0Amanagement-strategic-plan-wine-grapes-oregon/

Ojwang, D. O., and N. O. Oguge. 2003. Testing a biological control program for rodent management in a maize cropping system in Kenya. Pages 251-253 *in* G. R. Singleton, L. A. Hinds, C. J. Krebs, and D. M Spratt, editors. Rats, mice and people: rodent biology and management. Australian Centre for International Agricultural Research, Canberra, Australia.

Paz, A., D. Jareño, L. Arroyo, J. Viñuela, B. Arroyo, F. Mougeot, J. J. Luque-Larena, and J. A. Fargallo. 2013. Avian predators as a biological control system of common vole (*Microtus arvalis*) populations in north-western Spain: experimental set-up and preliminary results. Pest Management Science 69: 444-450.

Power, M. E. 1992. Top-down and bottom-up forces in food webs: do plants have primacy. Ecology 73:733-746. https://doi.org/10.2307/1940153

Ross, K. 2009. A pest management strategic plan for winegrape production in California. California Wine Grape Workgroup https://ipmdata.ipmcenters.org/documents/pmsps/cawinegrapes.pdf

Roulin, A. 2020. Barn owls: evolution and ecology. Cambridge University Press, Cambridge, U.K.

Schmitz, O. J., P. A. Hambäck, and A. P. Beckerman. 2000. Trophic cascades in terrestrial systems: a review of the effects of carnivore removals on plants. American Naturalist 155:141-153.

Sekercioglu, Ç. H., D. G. Wenny, C. J. Whelan, and C. H. Floyd. 2016. Why birds matter: bird ecosystem services promote biodiversity and support human well-being. Pages 341-364 *in* C. H. Sekercioglu, D. G. Wenny, and C. J. Whelan. editors. Why birds matter: avian ecological function and ecosystem services. University of Chicgo Press, Chicago, IL.

Stenseth, N. C., H. Leirs, A. Skonhoft, S. A. Davis, R. P. Pech, H. P. Andreassen, G. R. Singleton, M. Lima, R. S. Machang'u, R. H. Makundi, Z. Zhang, P. R. Brown, D. Shi, and X. Wan. 2003. Mice, rats, and people: The bio-economics of agricultural rodent pests. Frontiers in Ecology and the Environment 1:367-375.

St. George, D. A., and M. D. Johnson. 2021. Effects of habitat on prey delivery rate and prey species composition of breeding barn owls in winegrape vineyards. Agriculture, Ecosystems and Environment 312:107322. Elsevier B.V. https://doi.org/10.1016/j.agee.2021.107322

Stonebridge. 2012. The Economic Impact of Napa County's Wine and Grapes. Stonebridge Research Group, St. Helena, CA.

Strong, D. R. 1992. Are trophic cascades all wet? Differentiation and donor-dontrol in speciose ecosystems. Ecology 73:747-754.

Tickes, B. R., L. K. Cheathem, and J. L. Stair. 1982. A comparison of selected rodenticides for the control of the common valley pocket gopher (*Thomomys bottae*). Proceedings of Vertebrate Pest Conference 10:201-204.

Tillmann, H. 2012. Potential for barn owl as rodent biological control in central California vineyards. California Polytechnic State University, San Luis Obispo, CA. https://core.ac.uk /download/pdf/19153813.pdf

Tscharntke, T., Y. Clough, T. C. Wanger, L. Jackson, I. Motzke, I. Perfecto, J. Vandermeer, and A. Whitbread. 2012. Global food security, biodiversity conservation and the future of agricultural intensification. Biological Conservation 151:53-59.

Van Veen, F. J. F., and D. Sanders. 2013. Herbivore identity mediates the strength of trophic cascades on individual plants. Ecosphere 4:64.

Wendt, C. A., and M. D. Johnson. 2017. Multi-scale analysis of barn owl nest box selection on Napa Valley vineyards. Agriculture, Ecosystems and Environment 247:75-83. http:// dx.doi.org/10.1016/j.agee.2017.06.023

Whisson, D. A., R. M. Engeman, and K. Collins. 2005. Developing relative abundance techniques (RATs) for monitoring rodent populations. Wildlife Research 32:239-244.

Wolff, J. O., T. Fox, R. R. Skillen, and G. Wang. 1999. The effects of supplemental perch sites on avian predation and demography of vole populations. Canadian Journal of Zoology 77:535-541.

Wood, B. J., and C. G. Fee. 2003. A critical review of the development of rat control in Malaysian agriculture since the 1960s. Crop Protection 22:445-461.

Zainal Abidin, C. M. R., H. Mohd Noor, N. H. Hamid, S. Ravindran, C. L. Puan, A. Kasim, and H. Salim. 2021. Comparison of effectiveness of introduced barn owls, *Tyto javanica* javanica, and rodenticide treatments on rat control in oil palm plantations. Journal of Pest Science 99:1009-1022. Springer Berlin Heidelberg. https://doi.org/10.1007 /s10340-021-01423-x.

Zuur, A. F., E. N. Ieno, N. J. Walker, A. A. Saveliev, and G. M. Smith. 2009. Mixed effects models and extensions in ecology with R. Springer, New York, NY.