Title
Are Barn Owls a Cost-Effective Alternative to Lethal Trapping? Implications for Rodent Pest Management

Journal
Proceedings of the Vertebrate Pest Conference, 31(31)

ISSN
0507-6773

Authors
Larson, Katherine C.
Baldwin, Roger A.
Johnson, Matthew D.

Publication Date
2024

Are Barn Owls a Cost-Effective Alternative to Lethal Trapping? Implications for Rodent Pest Management

Katherine C. Larson
Department of Wildlife, California Polytechnic University-Humboldt, Arcata, California
Roger A. Baldwin
Department of Wildlife, Fish, and Conservation Biology, University of California-Davis, Davis, California
Matthew D. Johnson
Department of Wildlife, California Polytechnic University-Humboldt, Arcata, California

ABSTRACT: Pocket gophers (*Thomomys bottae)*, voles (*Microtus californicus*), and mice (*Mus musculus, Peromyscus* spp.) incur major costs to agriculture in California and worldwide. Introducing natural predators, such as American barn owls (*Tyto furcata*), shows promise as a solution to help manage rodent pests in a variety of crop systems, including winegrape vineyards. However, little work has evaluated the cost and efficacy of this pest removal service. To fill this gap, we simulate the cost and efficacy of using barn owl nest boxes and compare it to estimates for that of lethal trapping in California's winegrape vineyards. We found that it is cheaper to install barn owl boxes ($5.50 - $26.67 per acre per year) than to trap rodent pests ($72.57 - $227.52 per acre per year for gophers, and $237.57 - $552.67 per acre per year for voles and mice). However, the efficacy of using barn owls was only comparable to trapping if rodent densities were low, and even when nest boxes were deployed at their highest modeled density (1 per 5 acre), owl nest boxes could not achieve as high an efficacy as rodent trapping if intermediate and high rodent densities were present. Growers can use our assessments of efficacy for comparative purposes across treatment strategies, but because models in this study did not account for rodent reproduction nor immigration, growers should not directly relate costs to efficacies. For effective integrated pest management (IPM), we recommend that growers decrease rodent densities with targeted trapping and habitat modification, then use barn owls to help maintain lower rodent densities in most years, coupled with more intensive trapping when rodent numbers periodically spike.

KEY WORDS: American barn owl, cost analysis, ecosystem service, integrated pest management, rodent control, rodents, trapping, winegrape vineyards

Proceedings, 31st Vertebrate Pest Conference (R. M. Timm and D. M. Woods, Eds.)
Paper No. 39. Published December 20, 2024. 10 pp.

INTRODUCTION

Rodents are one of the foremost concerns for growers in nearly every agricultural system (Jacob and Buckle 2018). In California alone, rodents and birds incur >$168-$504 million annually in crop damage (Shwiff et al. 2009). Napa Valley, California, has the highest estimated job loss due to rodent and bird pest damage in California (619-1,858 jobs lost annually, Shwiff et al. 2009). In these winegrape vineyards, pocket gophers (*Thomomys bottae*), voles (*Microtus californicus*), and mice (*Mus musculus, Peromyscus* spp.) pose a particular challenge (Ross 2009, Baldwin et al. 2014). Pocket gophers gnaw on underground roots and girdle trunks belowground, chew through belowground irrigation systems, and create mounds and holes that make it difficult to run vineyard operations like mowing and disking (Baker at al. 2003). Meanwhile, voles gnaw on the base of vines, a particular concern for young vines (Ross 2009, Baldwin et al. 2014). Vole populations are cyclic, erupting every 3-5 years, and they have an extremely fast reproductive rate of 4-5 young per litter with up to 9 litters per year (Cudworth and Koprowski 2010).

Traditional methods for managing rodent pests include lethal trapping, which is costly and labor intensive (Engeman and Witmer 2000, Baldwin et al. 2014), and the application of rodenticide, which can be environmentally harmful when used improperly (Erickson and Urban 2004). However, barn owls are a promising alternative. Barn owls are non-territorial generalists (Tores et al. 2005) that are nearly cosmopolitan (Roulin 2020), have fast gut-passage times compared to similar sized raptors (Roulin 2020), hunt predominantly near their nests (Roulin 2020, Castañeda et al. 2021), and readily occupy human-made structures (Labuschagne et al. 2016), making them a nearly ideal candidate for agents of natural pest control. Furthermore, recent evidence in Napa Valley vineyards showed that barn owls reduced pocket gopher activity (Hansen and Johnson 2022), reduced mouse abundance (Larson et al.; unpubl), and increased mouse perceived predation risk (Larson et al.; unpubl).

To date, no work has investigated the cost of installing barn owl boxes and compared this to the cost of lethal trapping. This knowledge gap limits the information growers can use to make informed pest management decisions. To fill this gap, we estimate the expenses involved in installing and maintaining barn owl boxes, use empirical data to simulate their costs, and compared them to the costs of lethal trapping per rodent per year. We ran these simulations separately for gophers and for above-ground foraging rodents (voles and mice).

METHODS

Cost of Barn Owl Nest Boxes

We built a model to determine the cost of barn owl boxes expressed as $/acre/year (Figure 1a) and $/rodent /year

a)

$$\mathrm{D_b}\left(\frac{C_b}{I_b} + O\,\frac{C_c}{I_c}\right)$$

D_b = barn owl nest box density (1 per 5, 10, or 20 acres)
C_b = cost of barn owl nest box (box and installation); $425/box (from Napa Wildlife Rescue)
I_b = time interval for box replacement (10 years)
O = barn owl nest box occupancy (families per box; 0.25, 0.50, or 0.75)
C_c = cost of cleaning and maintenance occupied boxes; $100/occupied box/ year (from Napa Wildlife Rescue)
I_c = time interval for cleaning and maintenance (2 years)

b)

$$\frac{D_b\left(\frac{C_b}{I_b} + O\,\frac{C_c\mathrm{Cc}}{I_c\mathrm{Ic}}\right)}{Ko}$$

$$K_o = FE * O * V * D_b * \mathrm{P}$$

K_o = spatial kill rate for owls (number of rodents removed in vineyard per acre per year)
FE = individual owl family efficacy (3,466 rodents killed per family per year)
V = proportion of rodents killed that were removed from vineyard (1 rodent removed from vineyard/3 rodents killed)
P = proportion of rodents removed that are gophers or voles/ mice
  P_g = 17%
  P_v = 83%
See (a) for other variables.

Figure 1. Model for barn owl nest box annual costs per acre (a), and costs per rodent removed (b).

$$\frac{I-F}{I} \text{ or } \frac{K_o}{I}$$

$$F = I - K_o$$

$$K_o = FE * O * V * D_b * \mathrm{P}$$

I = Rodent density given no treatment (rodents per acre): low, medium, or high (15, 45, 75 and 50, 200, 450 rodents/acre for gophers and voles/mice respectively)
F= final rodent density (rodents per acre)
K_o = spatial kill rate for owls (number of rodents removed per acre per year)
FE = individual owl family efficacy (3466 owls killed/ family/ year)
O = barn owl nest box occupancy rate (0.25, 0.50, or 0.75)
V = proportion of rodents removed from a vineyard (1 rodent removed from vineyard/ 3 rodents killed)
D_b = barn owl nest box density (1 per 5, 10, or 20 acres)
P = proportion of barn owl diet with gophers (17%) or voles/mice (83%)

Figure 2. Model for barn owl nest box efficacy.

(Figure 1b). We then estimated the efficacy of using barn owls for gopher and for vole/mouse removal (Figure 2). We estimated separate efficacies for gophers than voles and mice because they comprise different proportions of the barn owl's diet (Kross et al. 2016). To estimate the number of rodents killed per acre, we multiplied the number of rodents killed per occupied box per year (3,466, St. George and Johnson 2021),by the proportion of hunting that occurs in a vineyard vs. other habitat types (0.33, Castañeda et al. 2021), and by the proportion of gophers and voles/mice in the barn owl's diet (0.17 and 0.83, respectively, St. George and Johnson 2021, Figure 2). We calculated a range of costs and efficacies for pest removal services as a function of owl box occupancy rate and densities. The cost increases as more nest boxes are installed and as the occupancy rate increases, due to the costs associated with cleaning occupied nest boxes. We used fixed values for the purchase of a box (Napa Wildlife Rescue) and

a)

$$\frac{C}{I} * D + (L * W * E) + (C * Tl * E)$$

C = Cost of trap (dollar per trap)
- C_g= \$7.92 per Gophinator trap
- C_v= \$0.55 per Victor trap

I = interval to replace traps (5 years)
D = trap density (traps/ acre)
- D_g = 107 traps per 16 acres
- D_v = 4000 traps per 16 acres

L = Labor (hours per trap day per 16 acres)
- L_g = 8 hours per trap day per 16 acres
- L_v = 56 hours per trap day per 16 acres

W = wage (dollars per hour; \$30/hour)
E = Effort (number of trap days per year)
- E_g = 1-14 trap days per year
- E_v = 1-5 trap days per year

Tl= trap loss (traps per day per 16 acres; 1 trap per day per 16 acres)

b)

$$\frac{\frac{C}{I} * D + (L * W * E) + (C * Tl * E)}{K_t}$$

$$K_t = TE * D * E$$

K_t = spatial kill rate per traps (number of rodents removed from a vineyard per year)
TE = Individual trap efficacy
- TE_g = 0.7, 0.8, 0.9
- TE_v = 0.1, 0.2, 0.3

D = trap density (traps/ acre)
- D_g = 71 trap sets per 16 acres (1.5 traps per trap set on average)
- D_v = 1200 traps per 16 acres

See (a) for other variables.

Figure 3. Model for rodent trapping costs per acre (a), and costs per rodent removed (b).

$$\frac{I-F}{I} \text{ or } \frac{Kt}{I}$$

$$F = I - K_t$$

$$K_t = TE * D * E$$

I = Rodent density given no treatment (rodents per acre): low, medium, or high (15, 45, 75 and 50, 200, 450 rodents/acre for gophers and voles/mice respectively)
F = final rodent density (per acre)
See Figure 3b for K_t

Figure 4. Model for rodent trapping efficacy.

cleaning and maintenance costs (Napa Wildlife Rescue). We also assume that the nest boxes are cleaned every 2 years and that a nest box lasts for ten years. To determine the efficacy of using barn owl boxes, we subtract the number of rodents removed per acre from a theoretical low, medium, or high rodent density given no treatment (15, 45, 75 and 50, 200, 450 rodents/acre, for gophers and voles /mice respectively, Figure 2). Note, this heuristic model assumes a closed rodent population (no immigration or emigration, no birth, and no death other than by owls and trapping). Thus, though our analyses do not express what would occur in wild rodent populations over time, they provide a baseline comparison of costs and efficacy of two non-chemical rodent management practices currently and widely available to farmers. We report imperial units for area (acres) and costs in US dollars to be consistent with

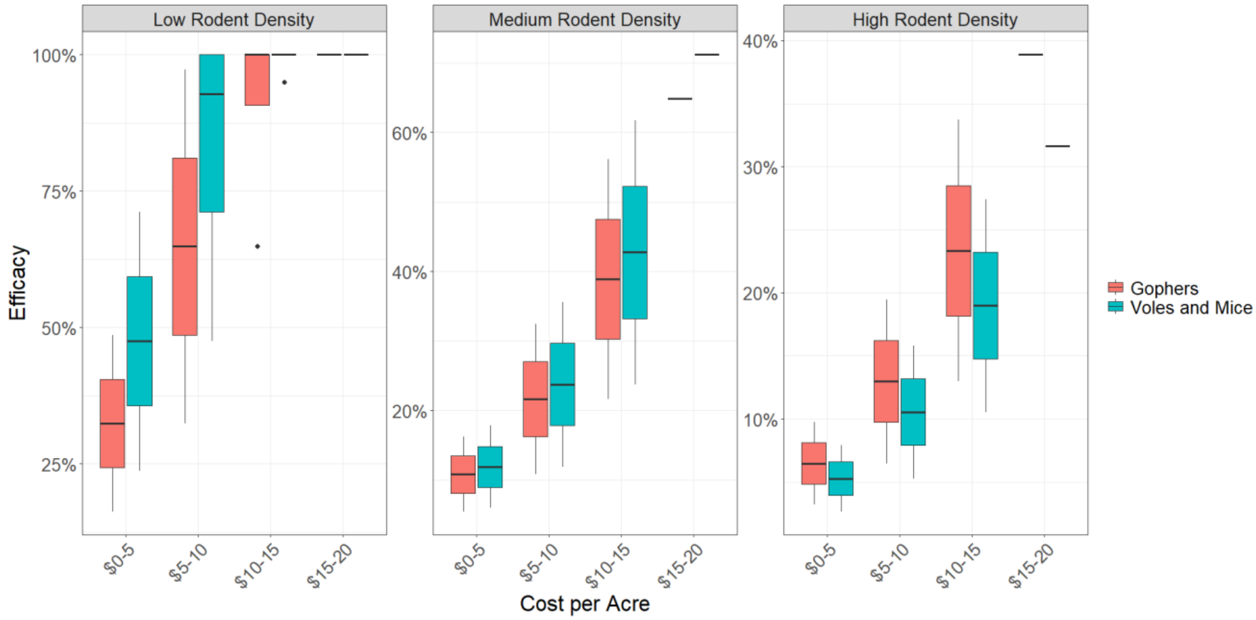

Figure 5. The efficacy (percent reduction from rodent density given no treatment) and cost per acre per year of using barn owl nest boxes given hypothetical low (15 gophers/acre and 50 voles and mice/acre), medium (45 gophers/acre and 200 voles and mice/ acre), and high (75 gophers/acre and 450 voles and mice/acre) initial rodent densities. Costs and efficacies vary due to the density and occupancy rate of barn owl boxes. Note, this heuristic model assumes a closed rodent population (no immigration or emigration, no birth, and no death other than by owls and trapping). Thus, though our analyses do not express what would occur in wild rodent populations over time, they provide a baseline comparison of costs and efficacy of two non-chemical rodent management practices currently and widely available to farmers.

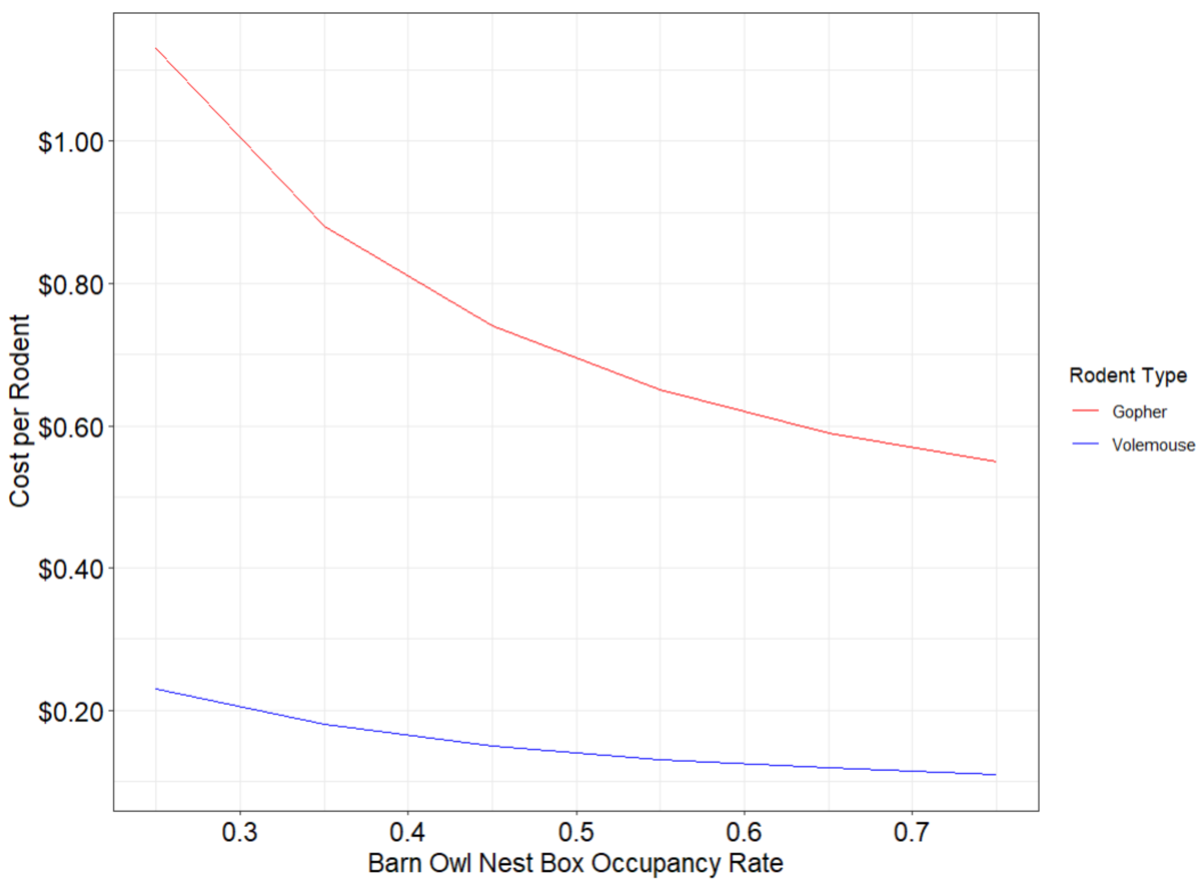

Figure 6. The cost per rodent removed per year of deploying barn owl nest boxes over a range of next box occupancy rates.

farmer applications in the USA; the relative relationships we report for trapping vs. owl nest boxes are identical if expressed in metric areal units (hectares).

Cost of Lethal Trapping

Similarly, we built a model to determine the cost of lethal trapping expressed as $/gopher/yr (Figure 3a) and $/vole or mouse/yr (Figure 3b) based on us achieving a minimum reduction of rodent abundance of 70%. We estimated separate costs for gophers and for above-ground foraging rodents (voles and mice) because trap costs and methods differ between the two rodent groups. We used fixed values for initial trap costs ($7.92 per Gophinator trap (Trapline Products, Redwood City, CA) and $0.55 per Victor trap (Victor, Lancaster, PA)), wage costs ($30/hr, going rate in Napa Valley), effort (1-14 trap days/yr), the number of traps deployed (107 for gophers, Baldwin et al. 2016; 4,000 for voles and mice, I. Jeramaz, Grgich Hills vineyard manager, pers. commun.), and labor hours per trap day (8 person-hours/day for gophers, Baldwin et al. 2016, and 56 person-hours/day for voles and mice, I. Jeramaz, Grgich Hills vineyard manager, pers. commun). We also assume that the trapping event covers 16 acres per day (Baldwin et al. 2016). Since traps are often lost due to terrestrial predators, we added an additional cost to replenish lost traps (1 trap per day). Since there is more than one Gophinator trap per trap set (about 1.5 traps per trap set on average; Baldwin et al. 2016), we multiply individual trap efficacy by the number of traps deployed divided 1.5 to determine the number of gophers removed and overall efficacy of the trapping treatment (Figure 5). Since trap success likely increases with rodent density, we calculated the number of rodents killed per year using a range of individual trap efficacies. We assume that individual trap efficacy is 0.9, 0.8, and 0.7 for high (75 gophers/acre), medium (45 gophers/acre), and low (15 gophers/acre) gopher densities, respectively (Figure 4). In addition, we assume that individual trap efficacy is 0.3, 0.2, and 0.1 for high (450 voles and mice/acre), medium (200 voles and mice/acre), and low (50 voles and mice/acre) vole and mouse densities, respectively (Figure 4). We multiply individual trap efficacy by the number of traps deployed to determine the number of voles and mice removed and overall efficacy of the trapping treatment (Figure 4). We modeled gopher trapping for up to 14 days and mouse and vole trapping for up to 5 days until greater than or equal to 70% of the rodent population was removed. We chose a 70% reduction in rodent numbers as our target goal given that this is the threshold required by U.S. EPA to consider a pesticide effective (Schneider 1982).

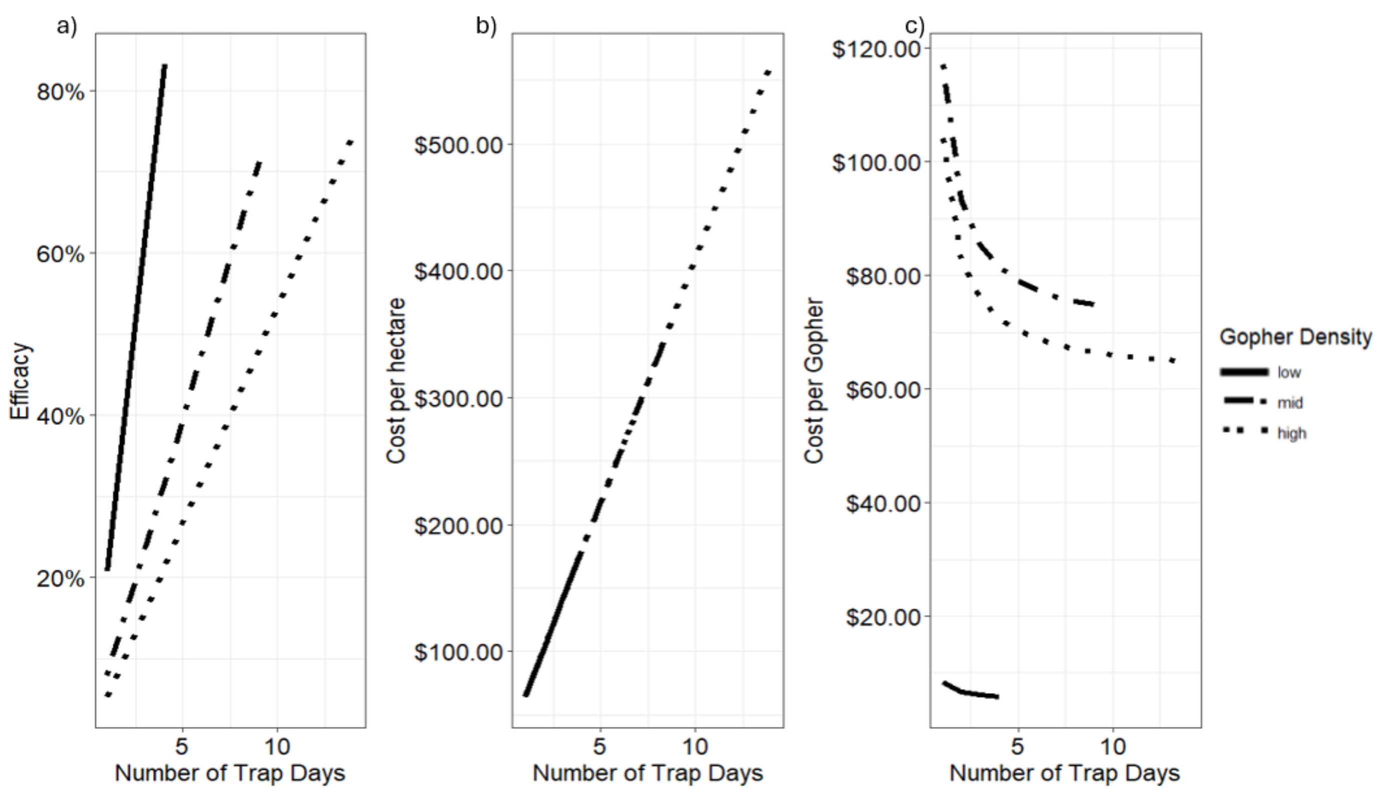

Figure 7. (a) The efficacy (percent reduction from initial rodent density), (b) cost per acre per year, (c) and cost per gopher per year of trapping across a range of trap days under hypothetical low (15 gophers/acre), medium (45 gophers/acre), and high (75 gophers/acre) initial gopher densities. Note that at low and medium gopher densities, the cost per acre plateaus where gopher numbers reach zero. This heuristic model assumes a closed rodent population (no immigration or emigration, no birth, and no death other than by owls and trapping). Thus, though our analyses do not express what would occur in wild rodent populations over time, they provide a baseline comparison of costs and efficacy of two non-chemical rodent management practices currently and widely available to farmers.

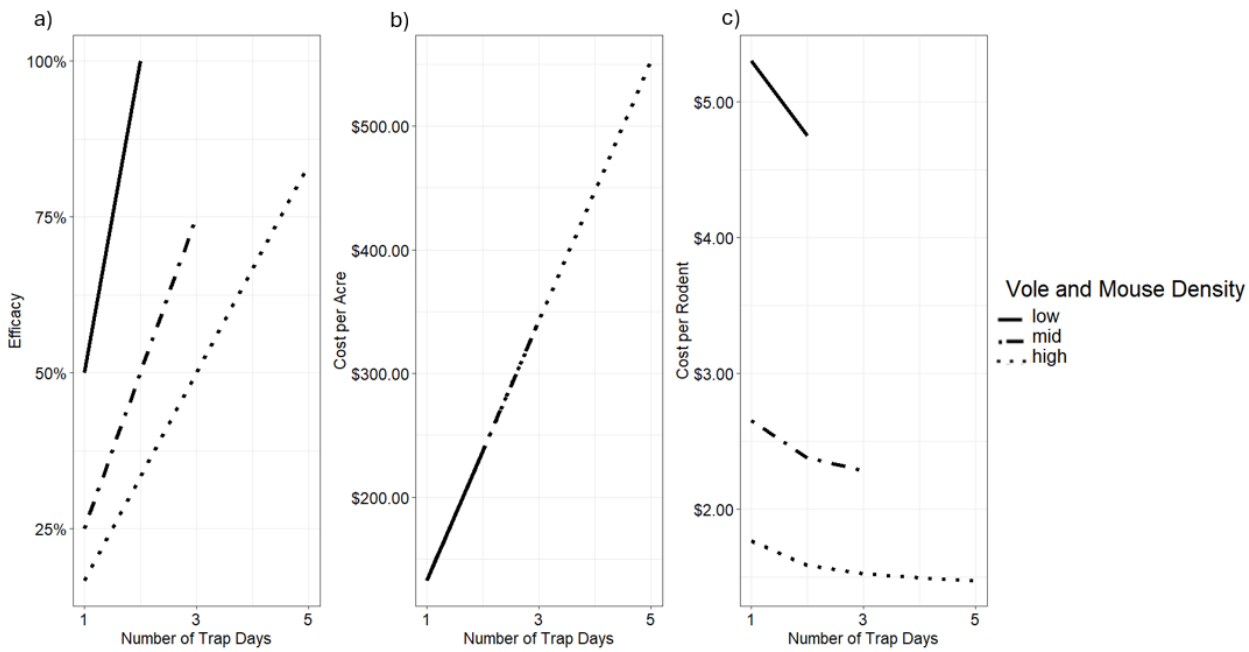

Figure 8. (a) efficacy (percent reduction from rodent density given no treatment), (b) cost per acre per year, and (c) cost per vole and mouse per year of trapping across a range of trap days under hypothetical low (50 voles and mice/acre), medium (200 voles and mice/acre), and high (450 voles and mice/acre) initial vole and mouse densities. Note that at low and medium vole and mouse densities, the cost per acre plateaus where vole and mouse numbers reach zero.

RESULTS

The cost of deploying barn owl boxes per acre per year ranged from $2.75 to $16.00, increasing with the density of nest boxes deployed (1 box per 5 to 20 acres) as well as the occupancy rate (25 to 75%; higher occupancy also prompts the need for additional nest box cleaning costs). The efficacy of barn owls increased as the cost per acre per year increased, and the efficacy decreased with higher initial rodent densities (Figure 5). The cost of deploying barn owl boxes per rodent per year ranged from $0.55 to $1.13 for gophers and $0.11 to $0.23 for voles and mice, decreasing with box occupancy rate (Figure 6). At low initial gopher densities, $7.00 per acre per year (1 nest box per 10 acres and 0.55 nest box occupancy rate) reduced gophers by 71.3% and voles/mice by 100%, while $14.00 per acre per year (1 nest box per 5 acres and 0.55 nest box occupancy rate) reduced gophers and voles/mice by 100% (Figures 5, 9, 10). At medium initial rodent densities, $7.00 per acre per year reduced gophers by 23.8% and voles /mice by 26.1%, while $14.00 per acre per year reduced gophers by 47.5% and voles/mice by 52.2% (Figure 5, 9,10). At high initial rodent densities, $7.00 per acre per year reduced gophers by 14.3% and voles/mice by 11.6%, while $14.00 per acre per year reduced gophers by 28.5% and voles/mice by 23.2% (Figure 5,9,10). It is important to note that the percent reduction is the efficacy associated with reducing the initial rodent densities, and it does not consider population replacement by reproduction and immigration. As such, these values should be used for comparative purposes rather than as documentation of the effectiveness of barn owls for reducing rodent densities in vineyards.

The cost of gopher trapping per acre per year ranged from $26.09 to $274.01, increasing with the number of trapping days (1 to 14, Figure 7b). The cost per gopher removed per year was much higher than that for owl nest boxes, ranging from $4.05 to $5.82, decreasing as the number of trapping days and initial gopher density increased (Figure 7c). The efficacy of gopher trapping increased with more trapping days (Figure 7a). After four days of trapping, we estimated an 83.2 % reduction in gopher abundance in low-density populations at a cost of $72.57 per acre and $93.06 per rodent (Figures 7, 9). For mid-range gopher densities, nine days of trapping cost $150.05 per acre and $74.82 per rodent, reducing abundance by 89% (Figures 7, 9). At high initial gopher densities, 14 days of trapping reduced gophers by 74.9% at a cost of $227.92 per acre and $64.83 per rodent (Figures 7, 9).

The cost per acre per year of vole and mouse trapping ranged from $132.53 to $552.67 per acre per year, increasing with the number of trapping days (1 to 5, Figure 8b). The cost per vole or mouse per year was much higher than that for barn owl nest boxes, ranging from $1.47 to $5.30, decreasing as the number of trap days and initial vole and mouse density increased (Figure 8c). The efficacy of vole and mouse trapping increased with more trapping days (Figure 8a). After two days of trapping, we estimated a 100% reduction in vole and mouse abundance in low-density populations at a cost of $237.57 per acre and $4.75 per rodent (Figures 8, 10). For mid-range vole and mouse densities, three days of trapping cost $342.60 per acre and $2.28 per rodent, reducing abundance by 75% (Figures 8, 10). At high initial vole and mouse densities, 5 days of trapping reduced vole and mouse abundance by 83.3% at a cost of $552.67 per acre and $1.47 per rodent (Figures 8, 10).

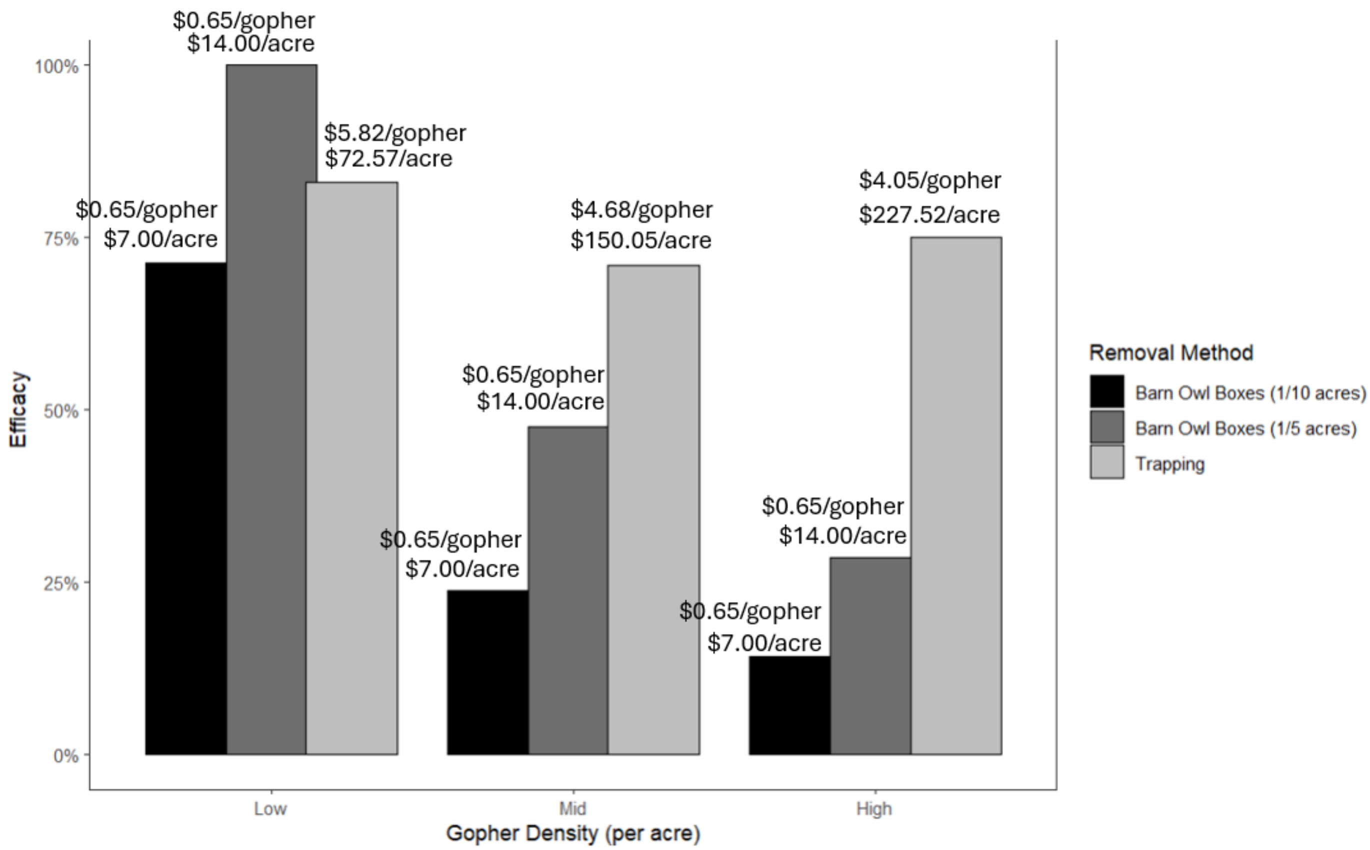

Figure 9. The efficacy (percent reduction from initial rodent density given no treatment) and associated costs of using barn owls and lethal trapping to reduce gopher populations. The cost values for trapping represent a threshold where efficacy ≥70% is met. Thus, the cost and efficacy values represent 4, 9, and 14 days of trapping for the hypothetical low (15 gophers/acre), medium (45 gophers/acre), and high (75 gophers/acre) initial gopher densities. The cost and efficacy of barn owl boxes represent 50% nest box occupancy rate and 1 box installed per 5 and 10 acres. Note, this heuristic model assumes a closed rodent population (no immigration or emigration, no birth, and no death other than by owls and trapping). Thus, though our analyses do not express what would occur in wild rodent populations over time, they provide a baseline comparison of costs and efficacy of two non-chemical rodent management practices currently and widely available to farmers.

DISCUSSION

We show that barn owls are a cheaper alternative to remove gophers and voles/mice compared to lethal trapping both in terms of cost per acre per year and cost per rodent removed per year (Figures 9, 10), and this is largely due to the labor costs associated with lethal trapping. However, the efficacy of using barn owls was only comparable to trapping if rodent densities were low, and even when nest boxes were deployed at highest model density (1 per 5 acre), owl nest boxes could not achieve as high an efficacy as rodent trapping if there were intermediate and high rodent densities (Figures 9, 10). Ultimately, the desired rodent removal method would depend on the desired efficacy of the treatment.

Models in this study did not account for rodent reproduction nor immigration, factors likely to decrease efficacy over the course of a year. Immigration and reproduction could decrease our results for barn owl efficacy more than for trapping, as trapping would result in a substantial population reduction over a short timeframe, whereas barn owl control would occur throughout the year. As such, assessments of efficacy should be used for comparative purposes across treatment strategies rather than for direct assessments of cost. For a more accurate assessment of barn owl efficacy, refer to the growing body of empirical field evidence for barn owl's capacity to meaningfully exert top-down effects in agriculture. For instance, barn owls (*Tyto furcata*) reduced mouse abundance (*Peromyscus sp*. and *Mus musculus*) by 38-52% on winegrape vineyards (Larson et al.; unpubl). Barn owls (*Tyto furcata* and *T. alba*) also reduced vole (*Microtus arvalis* and *Microtus. duodecimcostatus*) abundance in alfalfa fields (Luna et al. 2020), rat (*Ratttus tiomanicus*, *R. argentiventer*, and *R. exulans*) abundance in maize fields and palm oil plantations (Ojwang and Oguge 2003, Lenton 1984, Hafidzi and Na Im 2003), and gopher (*Thomomys bottae*) activity on winegrape vineyards (Hansen and Johnson 2022). Within their breeding territories, owls (*Strix uralensis*) reduced vole (*Microtus montebelli*) density in apple orchards by 63% (±*SE*: 53%-70%) compared with the predicted density without owls (Murano et al. 2019).

Owls not only affect rodent abundance but also their behavior. Barn owls (*Tyto furcata*) have been shown to increase perceived predation risk in mice (*Peromyscus sp.*)

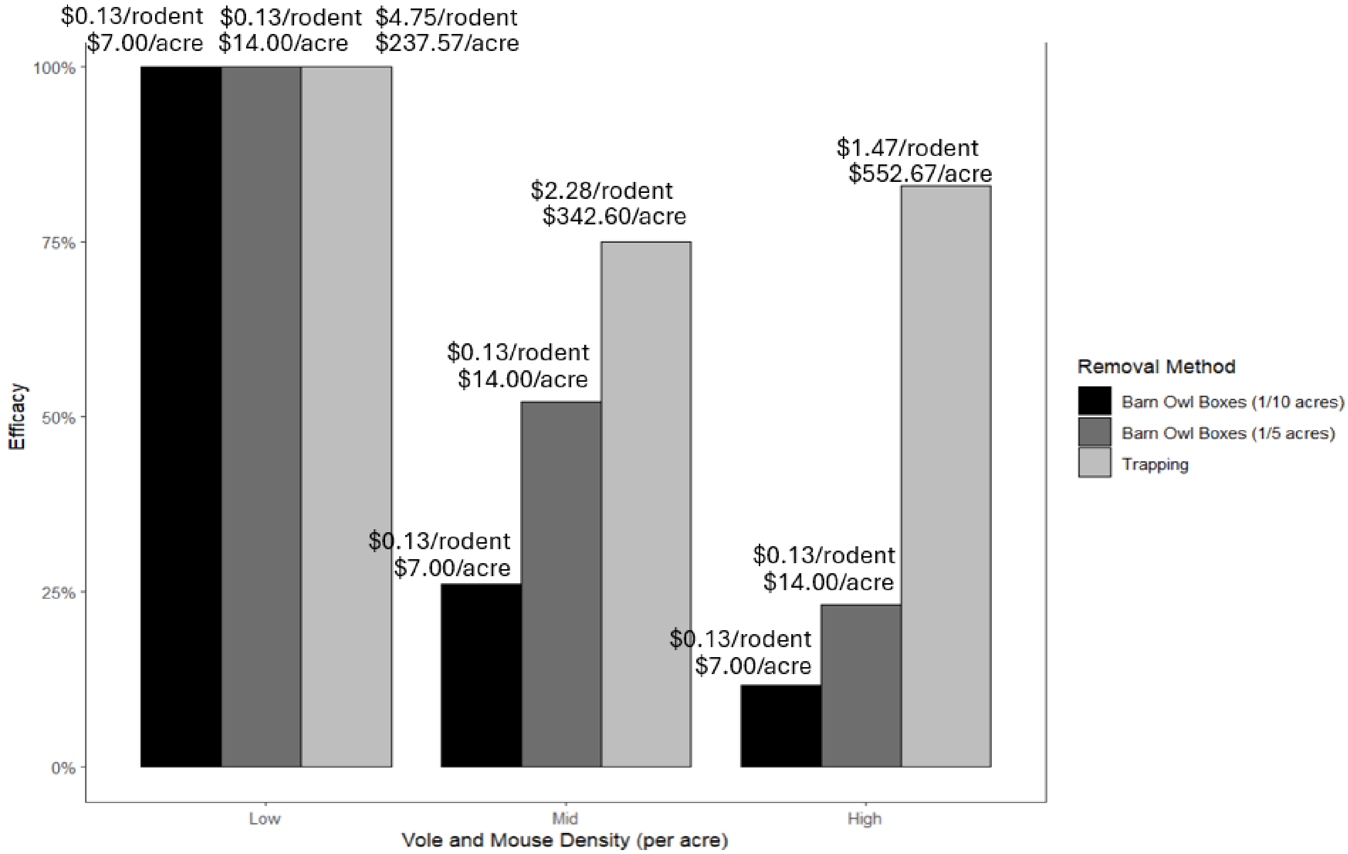

Figure 10. The efficacy (percent reduction from initial rodent density) and associated costs of using barn owls and lethal trapping to reduce vole and mouse populations. The cost values for trapping represent a threshold where efficacy ≥70% is met. Thus, the cost and efficacy values represent 2, 3, and 5 days of trapping for the hypothetical low (50 voles and mice/acre), medium (200 voles and mice/acre), and high (450 voles and mice/acre) initial vole and mouse densities. The cost and efficacy of barn owl boxes represent 50% nest box occupancy rate and 1 box installed per 5 and 10 acres. Note, this heuristic model assumes a closed rodent population (no immigration or emigration, no birth, and no death other than by owls and trapping). Thus, though our analyses do not express what would occur in wild rodent populations over time, they provide a baseline comparison of costs and efficacy of two non-chemical rodent management practices currently and widely available to farmers.

by 16-38% on winegrape vineyards (Larson et al.; unpubl), causing rodents to stop foraging earlier in experimental feed trays, which conceivably could translate to reduced crop damage. Perceived fear can also cause rodents to select suboptimal habitats, causing deleterious effects on rodent survival and reproduction (Lima and Dill 1990, Arthur et al. 2004).

We also show that the effectiveness (due to more hunting pressure) and cost (due to cleaning and maintenance fees) of using barn owls will increase with a higher probability of nest box occupancy (Figure 5). Wendt and Johnson (2017) showed that barn owls are more likely to occupy nest boxes surrounded by more acres of grassland, riparian, and mixed forest habitats in Napa Valley vineyards. Meanwhile, Chavez (2023) and Castañeda et al. (2021) showed that barn owls select areas for hunting that are near grasslands and oak savannahs, and that have landscapes with high edge density and low habitat aggregation. Therefore, the effectiveness of barn owl pest removal services will likely vary depending on the surrounding habitat.

Barn owl pest removal services depend on where barn owls prefer to hunt. Tracking data of barn owls in Napa Valley winegrape vineyards provide evidence that barn owls are central-place foragers, hunting predominantly near their box to provision their young; on average, 53% of hunting locations are found within 500 meters of the next box, though there is considerable variation among individual owls (Huysman and Johnson 2021). However, these same data also show that the entirety of the barn owl hunting radius is still quite large, hunting up to 2.86 km away from their nest box (Castañeda et al. 2021). This can be advantageous because it means this highly mobile predator can respond quickly to highly mobile prey. However, in heterogeneous landscapes, barn owls may be drawn to hunt in uncultivated habitats and field margins rather than in the vineyards themselves. Therefore, lethal trapping will be much more effective for targeting specific rodent species at specific places and times.

It bears noting that although rodenticides may have the ability to provide greater efficacy, the value of introducing barn owls to a vineyard extends beyond their pest removal services. Recent evidence indicates that consumers may be willing to pay higher prices for environmentally friendly wines (Mazzocchi et al. 2019, Ruggeri et al. 2020), and there is increasing public demand for sustainable agriculture and pest management solutions (Barber et al. 2010). Moreover, the non-target impacts of rodenticides, especially second-generation rodenticides, are widely recognized (Berny 2007, Browning et al. 2016), and environmental regulations are likely to increasingly restrict the use of chemical rodent control.

Though integrated pest management (IPM) allow for pesticides if needed, effective IPM should harness multiple non-chemical methods to control rodent species. Therefore, we recommend that farmers decrease rodent densities with alternative methods such as habitat modification and lethal trapping. These methods can be made more effective by initiating control efforts based on the rodent's reproductive biology (Krijger et al. 1999, Singleton et al. 1999, Lloyd and Baldwin 2021, Baldwin 2022), such as just before the young are recruited into the population or based on rodent's behavior and perceived predation risk (Larson et al.; unpubl., Krijger et al. 1999). Once rodent populations have been reduced to acceptable levels, vineyard managers could use barn owls to help maintain lower rodent densities in most years, coupled with more intensive trapping when rodent numbers periodically spike. We also recommend that farmers modify vegetation to favor the hunting strategy of barn owls (Larson et al.; unpubl).

LITERATURE CITED

Baker R. J., R. D. Bradley, and L. R. McAliley, Jr. 2003. Pocket gophers. Pages 277-287 *in* G. A. Feldhamer, B. C. Thompson, and J. A. Chapman, editors. Wild mammals of North America: biology, management, and conservation. Second edition. The Johns Hopkins University Press, Baltimore, MD.

Baldwin, R. A. 2022. Strategies for rodent management. Proceedings of the World Alfalfa Congress 28.

Baldwin, R. A., R. Meinerz, and S. B. Orloff. 2016. Burrow fumigation versus trapping for pocket gopher (*Thomomys* spp.) management: a comparison of efficacy and cost effectiveness. Wildlife Research 43:389-397.

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.

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

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.

Castañeda, X. A., A. E. Huysman, and M. D. Johnson. 2021. Barn owls select 18 uncultivated habitats for hunting in a winegrape growing region of California. Ornithological Applications 123:1-15.

Cudworth, N. L., and J. L. Koprowski. 2010. *Microtus californicus* (Rodentia: Cricetidae). Mammalian Species 42:230-243.

Engeman, R. M., and G. W. Witmer. 2000. Integrated management tactics for predicting and alleviating pocket gopher (*Thomomys* spp.) damage to conifer reforestation plantings. Integrated Pest Management Reviews 5:41-55.

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

Hafidzi, M. N., and M. Na Im. 2003. The use of the barn owl, *Tyto alba*, to suppress rat damage in rice fields in Malaysia. ACIAR Monograph Series 96:274-276.

Hansen, A, and M. Johnson. 2022. Evaluating the use of barn owl nest boxes for rodent pest control in winegrape vineyards in Napa Valley. Proceedings of Vertebrate Pest Conference 30: paper no. 27. https://escholarship.org/uc/item/99c7209s

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.

Jacob, J., and A. Buckle. 2018. Use of anticoagulant rodenticides in different applications around the world. Pages 11-43 *in* N. W. van den Brink, J. E. Elliott, R. F. Shore, and B. A. Rattner, editors. Anticoagulant rodenticides and wildlife. Springer International Publishing, Cham, Switzerland.

Krijger, I. M., S. R. Belmain, G. R. Singleton, P. W. Groot Koerkamp, and B. G. Meerburg. 2017. The need to implement the landscape of fear within rodent pest management strategies. Pest Management Science 73:2397-2402.

Kross, S. M., R. P. Bourbour, and B. L. Martinico. 2016. Agricultural land use, barn owl diet, and vertebrate pest control implications. Agriculture, Ecosystems & Environment. 223:167-174.

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.

Larson, K. L., R. A. Baldwin, and M. D. Johnson. Barn owls exert top-down effects on the behavior and abundance of rodent pests. Unpublished.

Lenton, G. M. 1984. The feeding and breeding ecology of barn owls *Tyto alba* in peninsular Malaysia. Ibis 126:551-575.

Lloyd, M. G., and R. A. Baldwin. 2021. Burrowing rodents: developing a management plan for organic agriculture in California. University of California, Division of Agriculture and Natural Resources, Publication 8688.

Luna, A. P., H. Bintanel, J. Viñuela, and D. Villanúa. 2020. Nest-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.

Mazzocchi, C., G. Ruggeri, and S. Corsi. 2019. Consumer's preferences for biodiversity in vineyards: a choice experiment on wine. Wine Economics and Policy 8:155-164.

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.

Napa Wildlife Rescue. Barn owl maintenance program. <https://napawildliferescue.org/barn-owl-maintenance>. Accessed 5 June 2024.

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, ACT, Australia.

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

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

Ruggeri, G., and C. Mazzocchi, and S. Corsi. 2020. Drinking biodiversity: a choice experiment on Franciacorta sparkling wines. British Food Journal 122:2531-2549.

Schneider, B. 1982. Pesticide assessment guidelines. Subdivision G Product Performance, U.S. Environmental Protection Agency, Office of Pesticide and Toxic Substances, Springfield, VA.

Shwiff, S. A., K. Gebhardt, and K. N. Kirkpatrick. 2009. The economic impact of bird and rodent damage to California crops: an economic evaluation of the losses caused by bird and rodent damage and selected benefits of pest control expenditures. USDA/APHIS/Wildlife Services, National Wildlife Research Center, Fort Collins, CO.

Singleton, G., L. Hinds, H. Leirs, and Z. Zhang. 1999. Ecologically-based management of rodent pests: re-evaluating our approach to an old problem. Pages 17-29 *in* G. Singleton, L. Hinds, H. Leirs, and Z. Zhang, editors. Ecologically-based rodent management. ACIAr Monograph No. 59.

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 & Environment 312:107322.

Trapline Products. Redwood City, CA. Design and manufacture of specialty traps for gophers and moles. <traplineproducts.com>. Accessed 25 August 2024.

Tores, M., Y. Motro, U. Motro, and Y. Yom-Tov. 2005. The barn owl - a selective opportunist predator. Israel Journal of Ecology and Evolution 54:349-360.

Victor. Lancaster, PA. <victorpest.com>. Accessed 2 September 2024.

Wendt, C. A., and M. D. Johnson. 2017. Multi-scale analysis of barn owl nest box selection on Napa Valley vineyards. Agriculture, Ecosystems & Environment 247:75-83.