Can Barn Owls Help Control Rodents in Winegrape Vineyard Landscapes? A Review of Key Questions and Suggested Next Steps

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ABSTRACT: Many winegrape farmers have installed nest boxes to attract barn owls to manage rodent pests, but this prospect has not been rigorously examined. We provide a brief history and context of the use of, and research on, barn owl nest boxes in California vineyards, and we suggest six key research questions necessary to better evaluate the capacity for barn owls to help control rodent pests: 1) How and where should boxes be placed to enhance barn owl occupancy? 2) How much are owls hunting in vineyards versus surrounding habitat? 3) How many rodents do they remove from vineyards? 4) Do they remove enough to meaningfully reduce rodent numbers and decrease crop damage? 5) What can farmers do to maximize hunting on their vineyards? and 6) What factors influence farmers' decisions to use or not use nest boxes? Some work has recently been aimed at questions 1-3, but additional work is needed to confirm and generalize those results, and questions 4-6 remain, to date, unanswered. We suggest a research agenda to help address those unmet needs and advance our understanding of the potential for and application of barn owl nest boxes for pest management in winegrape vineyards.

KEY WORDS: barn owl, biological control, ecosystem service, gopher, Napa, nest box, raptor, vineyard, vole, wine

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INTRODUCTION

Winegrapes are grown primarily in Mediterranean biomes, which are not only home to fertile soils and conditions for high quality winegrapes, but also high rates of biodiversity endemism and habitat loss (Viers et al. 2013). These regions have comparatively few formally protected areas, so the integration of biodiversity conservation on private lands is especially important (Underwood et al. 2009). Winegrape vineyard ecosystems can contribute to conservation in Mediterranean biomes if the farms themselves provide resources for native wildlife species while minimizing use of toxic inputs, and if practices and policies include mechanisms to conserve (or restore) patches of uncultivated habitats (Viers et al. 2013, Warner, 2007).

Managing pests is one of the premier challenges facing California's winegrape growers (McGourty et al. 2011). Pocket gophers (*Thomomys bottae*) are identified as important pests, capable of injuring roots, gnawing bark, and girdling vines several inches below the soil line. Moreover, their extensive burrows divert water, contribute to soil erosion, and produce an uneven vineyard floor, precluding efficient tractor operations (California Winegrape Work Group 2009). Voles (*Microtus californicus*) are also problematic as their herbivory can undermine survival of young vines (California Winegrape Work Group 2009). Controlling small mammal pests has been a challenge for farmers since the dawn of agriculture and is increasingly important in ensuring food security around the world (Witmer and Singleton 2010). Trapping to control rodents is labor intensive, expensive due to the high initial costs of purchasing traps and ongoing labor costs, is not practical on a large scale, and requires sustained effort to be effective. Chemical rodenticides can be highly effective (Baldwin et al. 2014) but also have high costs, may have decreasing efficacy as rodents become resistant to certain compounds (Salmon and Lawrence 2006), and some rodenticides can cause secondary poisoning to non-target wildlife species (Erickson and Urban 2004). In response, some vineyard managers have turned toward an alternative form of rodent pest control, by attracting rodent-eating barn owls (*Tyto alba*) to artificial nest boxes on their farms (Kross et al. 2016).

HISTORY AND BACKGROUND

Research on the capacity for birds to control agricultural pests has a long and storied history. Typically, biological pest control is often understood to be the use of insect predators in the control of insect or weed pests. This definition, however, ignores various other techniques that can help control economically damaging agricultural pests, including vertebrates as both pests and predators (Evenden 1995). The role of birds as agents of biological control was prominent in the late nineteenth and early twentieth centuries (McFarlane 1976). Systematic studies of the potential role of birds as pest control agents were first produced in the 1880s, embodied in the newly named field called "economic ornithology" (Evenden 1995).

From the late-nineteenth century to the 1930s, hundreds of studies on the role of birds in agriculture were published. By the late 1930s, however, depictions of birds as useful agents of pest control declined, and the field of economic ornithology all but disappeared (Whelan et al. 2015). The emerging dominance of chemical pesticides was clearly underlying this change, but economic ornithology also collapsed because it failed to offer practical methods for harnessing the role of birds as pest eaters and because scientists' debates over data analysis methods destabilized the claims of the field as a whole (Evenden 1995). This history illustrates the importance of close communication with farmers and producers to offer research that yields answers to practical implementation questions. More recently, the rise in recognition of ecosystem services (Gómez-Baggethun et al. 2010), heightened concern over impacts of chemical pesticides (Saba and Messina 2003), and the recognition of the importance of sustainable agriculture for both biological conservation and human well-being has renewed interest in the practical role of birds as agents of biological control in agriculture (Sekercioglu et al. 2016). The use of barn owls in integrated pest management programs provides an opportunity to advance this important line of research.

In the 1980s and 1990s, interest swelled in harnessing barn owl hunting for rodent pest control. Hundreds of farmers nationwide installed nest boxes to attract barn owls as part of their pest management strategies (Moore et al. 1998). Agricultural extension publications offered suggestions for erecting owl nest boxes (e.g., Heaton et al. 2008). Barn owls are an attractive method for pest control because their nest boxes are relatively inexpensive to install and maintain (Kross and Baldwin 2016), and several natural history attributes suggest they could help reduce rodents: adults are not very territorial and can sometimes reach high densities (Smith et al. 1974), they are efficient hunters and their broods demand many prey items (Durant and Handrich 1998, Taylor 1994), and in agricultural settings their diets are almost exclusively composed of rodent pests (Kross et al. 2016, Taylor 1994, Van Vuren et al. 1998).

However, very few studies have determined whether barn owls actually reduce rodent pest numbers and damage in U.S. agriculture, prompting skepticism that owls could provide meaningful control. For example, Ingels and Hoffman (in Heaton et al. 2008) asserted several ecological reasons why barn owls may not control rodents, including their tendency to switch prey (Heywood and Pavey 2002) and rodents' notoriously high reproductive rates. They also asserted that nest boxes may not increase owl density but simply shift owls from natural nesting sites, and even if they do nest on farms, the owls may hunt off farm boundaries. In a survey of 55 farmers who had installed barn owl nest boxes in California, only 23% reported that they were somewhat or very effective at controlling rodent pests, and the authors concluded that "With further research the approach might prove useful, but only when used in concert with other control approaches…" (Moore et al. 1998). Others were even more skeptical, with (Marsh 1998) arguing that "Without supporting facts, it is time to abandon this erroneous belief that native predators, such as barn owls, can provide meaningful control of pest rodent species such as pocket gophers or voles." (p. 415.)

Meanwhile, the use of barn owl boxes to control rodents was being practiced and researched more earnestly elsewhere in the world. In Malaysian oil palm plantations, crop damage from black rats (*Rattus rattus*) declined from 19.5% to 1.4% after the installation of barn owl nest boxes (Duckett and Karuppiah 1990). Similarly, nest boxes increased owl density and coincided with a reduction in damage from ricefield rats (*R. argentiventer*) from 12% to 2% (Hafidzi et al. 2003). In Kenya, rodent trap success rates dropped from 22% to 6% 12 months after installing nest boxes and raptor perches in maize fields (Ojwang and Oguge 2003). The use of barn owl boxes for agricultural pest control is probably most advanced in Israel, where there are over 1,500 boxes installed as part of a national program (Meyrom et al. 2008). Many studies have documented the diet (e.g., Charter et al. 2007, Tores and Yom-Tov 2003), demographics (e.g., Charter et al. 2012, Meyrom et al. 2009), and other aspects of the ecology of barn owls in Israeli agriculture. Moreover, several modeling studies suggest that barn owls can economically control rodent pests in Israel (Kan et al. 2014, Meyrom et al. 2009, Motro 2011).

More recently in California, there is renewed research interest in barn owls as pest control. At the 2016 Vertebrate Pest Control Conference in Newport Beach, Kross and Baldwin (2016) used empirical field data in a predictive model and suggested that a barn owl population density of one nest/10 ha may be able help control an average pocket gopher population, but even the highest barn owl densities would be unable to control abundant and quickly reproducing pocket gopher populations. At the same conference, Browning et al. (2016) reported that in Lodi, CA, mound surveys suggested that gophers declined on a vineyard with barn owl boxes relative to a control vineyard without barn owl boxes. Kross and her colleagues recently published initial work on barn owls in central California agriculture, including some work in vineyards (Kross et al. 2016, Wong and Kross 2018), and ongoing work is examining effects of rodenticides on barn owls in the area (Kross, pers. comm.). Meanwhile, Johnson and his students launched work on barn owls in Napa's winegrape vineyards (Wendt and Johnson 2017), which we review briefly below. Increased research interest on this topic in California is perhaps best evidenced by a recent international workshop on the potential for barn owls to contribute to an IPM plan, held at the University of California campus in Davis and attended by 25 scientists, students, and farmers from the United States, Israel, Canada, and Argentina.

Many farmers that erected nest boxes in the 1990s still maintain them today. Though they are relatively inexpensive, nest boxes are not free of costs or labor to deploy and maintain, and the retention of the practice over the decades suggests that farmers believe their benefits outweigh their costs. Benefits of nest boxes to farmers may extend beyond simple pest control, a point we return to later, but in a preliminary survey of 40 winegrape growers in Napa, over 80% of respondents agreed or strongly agreed that barn owl nest boxes offer legitimate value in an

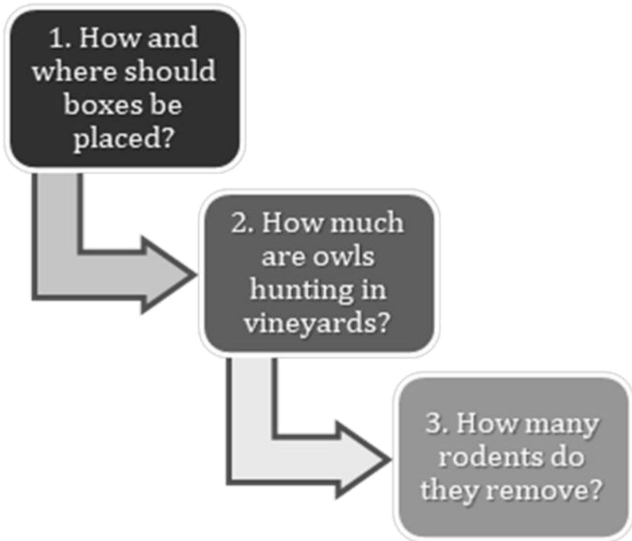

Figure 1. Three essential research questions, and their associated methods, that are currently under investigation in Napa County to advance our understanding whether barn owl nest boxes can attract barn owls and help control rodent pests in winegrape vineyards.

integrated pest management system (Wendt and Johnson 2017).

KEY RESEARCH QUESTIONS

Though newly initiated research is encouraging, here in the U.S. and in CA vineyards especially, we still know very little about the realistic potential for barn owl boxes to contribute to IPM, and much more work is needed. Based on research on barn owls in other countries as well as research on the delivery of ecosystem services by mobile organisms in agriculture more generally, we suggest six key research questions necessary to better evaluate the capacity for barn owls to help control rodent pests in winegrape vineyards. Three of these questions have recently been investigated in Napa winegrape vineyards (Figure 1), and three more remain unaddressed (Figure 2).

First, for the deployment of nest boxes to even have a chance to reduce rodent pests and crop damage, at least some of the boxes must be occupied by barn owls. Moreover, predator-prey theory suggest that for biological control to be sustained, the densities of owls should be enhanced on farms over background levels (Borer et al. 2005, Ehler 1998). The nesting habits of barn owls may make this possible. Naturally occurring nest sites for barn owls, such as cavities in large trees, rock crevices, etc., are often very rare in agricultural landscapes, and once common nesting sites in human structures (such as openings in old wooden barns) are also becoming more rare. The result is that the distribution and abundance of barn owls is often limited by the availability of nesting sites. Correspondingly, the use of artificial nest boxes may attract barn owls to areas where they may otherwise be uncommon, and may also locally elevate their populations, though this should be confirmed. But what type of nest box is best, and where should boxes be deployed to maximize their chances of becoming occupied? This important practical question has recently been examined in Napa County by Wendt and Johnson (2017), who used video cameras to monitor the contents of 297 nest boxes (Figures 3a and 3b). They found that the owls preferred boxes that were wooden, at least 2 m off the ground, facing East or North, and located in places with uncultivated habitats, especially grassland and riparian habitats, within 1 km of the nest box. The local habitat (within 75 m), and other box attributes (e.g., dimensions) had little effect on occupancy. Similar studies should occur in other winegrape growing regions to determine if these patterns are more widespread. For example, owls in areas with a different climate may show different preferences for nest box construction or nest hole orientation, and the effect of landscape composition may be different in areas with larger more homogenous farm blocks and fewer uncultivated habitats than in Napa.

Second, we must determine if and how much barn owls actually hunt in vineyards. Occupancy of nest boxes on farms delivers no meaningful pest control if the birds rarely hunt on the farms themselves. Barn owls can range widely when they hunt, up to 9 km though more commonly 1 to 3 km (Taylor 1994, Casteñeda 2018), and their nocturnal habits make direct observations difficult. Fortunately, recent advances in technology enable researchers to use lightweight and accurate telemetry tags fitted with global positioning system (GPS) technology, yielding high quality data on the birds' nocturnal locations and movements (Figures 3c and 3d). These data can reveal how often the birds hunt within vineyards, and preliminary analysis from birds in Napa County suggest they spend about one third of their hunting time in vineyards, and they actively select and use grassland and riparian habitats

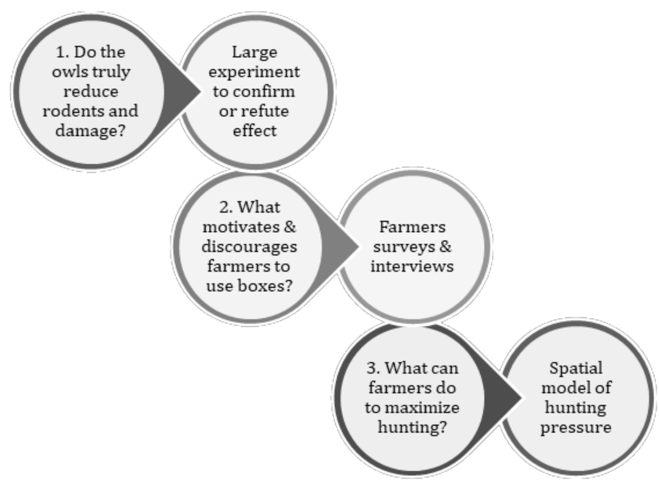

Figure 2. Three additional research questions, and their associated methods, that remain uninvestigated in winegrape vineyards and that could advance understanding of whether barn owl nest boxes can attract barn owls and help control rodent pests.

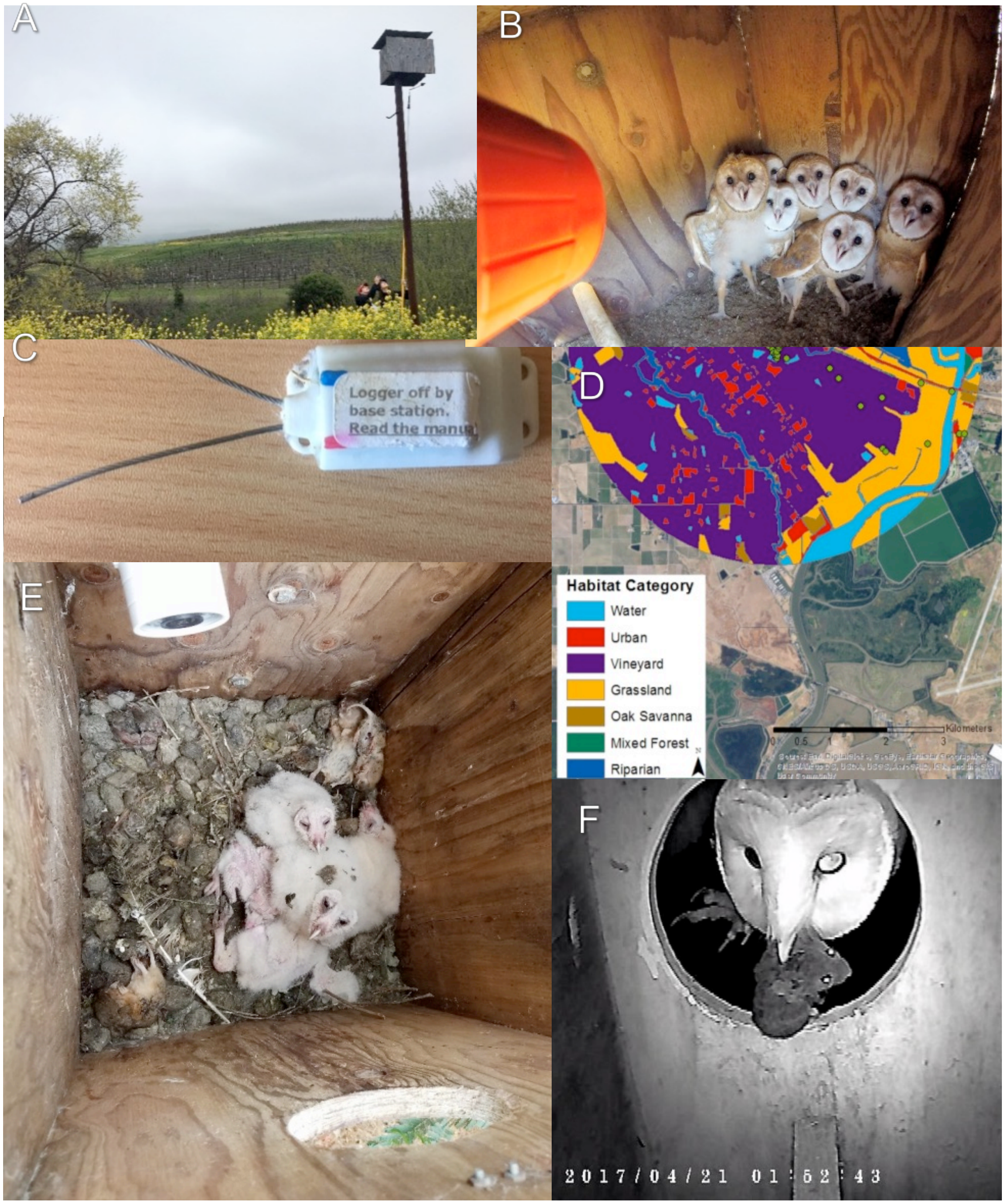

Figure 3. Images of methods currently used in Napa County to investigate three research questions on the capacity for barn owls to contribute to IPM in winegrape vineyards. Nest box occupancy can be efficiently monitored using a blue-tooth enabled video camera mounted on an extendable pole (A); which transmits images to the field worker's smart phone on the ground (B). New advances in GPS telemetry enable researchers to attach transmitters weighing as little as 13 g to barn owls (C), and data can be retrieved remotely or by re-capturing the bird, revealing detailed information about their movements and locations (D) useful in determining how often the owls are in vineyards. Inexpensive remote surveillance cameras can be mounted to the inside of nest boxes (E) and, when connected to a power source and video recorder, can document prey deliveries by adults to the nest box (F), which provides essential data for estimates of rodent removal from vineyards.

out of proportion to their availability in the landscape (Castañeda 2018). More work should be done in other areas with different landscape compositions, to determine how general these results are to other winegrape growing regions.

Third, while nest box occupancy and hunting in the vineyards are prerequisites for any possible rodent control by barn owls, prey removal is the cornerstone of biological pest control. Analyzing regurgitated pellets is a common method to quantify barn owl diets and approximate numbers of prey, though this method suffers from several limitations (Yom-Tov and Wool 1997). Videography at the nest site can better document prey removal by capturing each prey delivery to the nestlings. Here again, recent technological advances helped make this method affordable. Remote surveillance cameras fitted with power sources and video recorders can store video of prey deliveries (Figure 3e and 3f). Minimally, these data can be used to estimate the number of prey removed by a nesting pair of owls and their young, which Browning et al. (2016) estimated to be 938 rodents for a single box with two adults and 4 fledglings in Lodi, California. Ongoing work in Napa County will provide much larger sample size and estimates of variation (St. George, unpubl. data). If the videography is matched to fine-scale (in space and time) telemetry data described above, even more information about where and when the owls capture prey could be obtained.

Three more key vital questions remain unanswered (Figure 2), and should be prioritized as research objectives to advance our understanding of how to apply barn owl nest boxes as an IPM tool in winegrape vineyards. First, while evidence accumulates that barn owls nest and hunt in winegrape vineyards (Wendt and Johnson 2017), we still do not know if the owls remove enough rodents to meaningfully reduce rodent numbers and decrease crop damage. Ideally, a replicated before-after-control-impact (BACI) experiment will be conducted by assessing rodent numbers on multiple vineyards before and after installation and occupation of barn owl nest boxes on half of the vineyards. Clearly, such an experiment would be costly, and would require several years to complete. However, because rodent populations are notoriously dynamic in both space and time, experiments only controlled in space (control vs. impact) or time (before vs. after) are vulnerable to confounding effects that a true BACI design would overcome.

The methods required for the barn owl component of such an experiment are well established (e.g., Figure 3), but researchers should carefully consider how to best monitor rodent numbers. Techniques exist to measure occupancy (e.g., cameras, feeding blocks, Baldwin et al. 2014, Engeman et al. 2016), indices of abundance (e.g., minimum number alive from trapping or open-hole method for gophers, (Engeman et al. 1993, 2016), or true estimates of density (e.g., mark-recapture demographic modeling (Williams et al. 2002). In some cases it may be preferable for researchers to assess crop damage in addition to or perhaps instead of measuring rodents themselves. New technologies, such as the use of unmanned aerial vehicles (UAV or drones) coupled with high resolution imagery and remote sensing, may provide researchers and agriculturists with unprecedented ability to measure crop damage over fields efficiently (D. Malkinson, pers. comm.).

Second, farmers need to know how to best deploy barn owl nest boxes to use them in an IPM plan effectively. This includes an understanding of construction design and deployment details to maximize occupancy (Wendt and Johnson 2017), but additional understanding of the role of habitat and landscape composition is also vital. Barn owls are highly mobile predators with large home ranges (Taylor 1994), and they use a variety of habitats. It is therefore important to understand how the arrangement of habitats, including uncultivated habitats such as grasslands, oak woodlands, riparian strips, and hedgerows, affects the occupancy and hunting patterns of barn owls (Kremen et al. 2007, Lindell et al. 2018). Some of this information is emerging from recent research in Napa, but additional data are needed. Spatial modeling should be performed to generate predictive maps of occupancy and hunting, which could be manipulated to examine practical what-if scenarios that could reveal optimal placement of additional nest boxes (e.g., Kan et al. 2014) as well as the impact on the delivery of pest control services to vineyards with the loss or restoration of uncultivated habitats (Railsback and Johnson 2014). These analyses could clarify to farmers how their own management, by deploying boxes strategically and conserving key habitats on farm edges, could better harness the capacity for barn owls to help control rodents.

Third, if the use of barn owl nest boxes can deliver some meaningful pest control, then to advance the practice it will be imperative to understand what motivates and discourages farmers to use nest boxes. Conversely, if the practice demonstrably fails to control pests, it will be important to disseminate this information to farmers so they can turn their attention to other means of rodent control. Both of these require an understanding of how farmers get their information about nest boxes and their deployment. We also need to know what factors compel some farmers to invest in nest boxes, which could include reasons relating to economics, personal preference, environmental values, public perception, or some combination. For those who would like to install nest boxes but have not, what is holding them back? And for those who continue to use boxes even if they do not help control rodents, why? Answers to these questions demand collaboration with social scientists to design methods, such as surveys, semi-structured interviews, and mixed methods approaches (Bryman 2006). Kross and her colleagues (Kross et al. 2018) conducted a broad survey of bird services and disservices in agriculture, and they found that the majority of farmers believed raptors to be beneficial for vertebrate pest control. Importantly, they also documented that farmers' perceptions of wildlife were strongly correlated with actions to either attract or deter them, suggesting that outreach on the effects of wildlife could be influential in informing on-the-ground practices.

NEXT STEPS

Our review reveals three key questions that remain unanswered and should be prioritized for future funding requests and research (Figure 2). A before-after-control-impact experiment is clearly needed, and while ambitious, we believe that by collaborating with farmers installing new vines, researchers may be able to secure funding to conduct the experiment. Farmers could provide the nest boxes, which could serve as partial match for research funding to monitor rodents and owls. Ideally, this could be replicated on multiple vineyards, but even working on pairs in vineyards (control-impact) would be valuable, especially if replicated in a series of projects with funding over time. This type of "long view" may be necessary to realistically complete a meaningful experiment. Given the challenges of monitoring rodents, researchers should also explore alternatives such as use of UAVs to measure crop damage directly.

Spatial modeling to pursue examining how farmers could best deploy barn owl nest boxes for IPM is logistically far easier than a large field experiment. The minimum essential barn owl data already exist, at least in Napa (occupancy and hunting habitat selection via telemetry analyses), though these studies should be replicated. The appropriate remotely sensed data also already exist in Geographic Information Systems (GIS), so initial modeling could begin immediately. This modeling could reveal valuable practical information that should be immediately disseminated to farmers, such as optimal nest box distribution, and what-if scenarios that illuminate effects of uncultivated habitat distribution, loss, and restoration.

Spatial modeling could also advance our understanding of how ecosystem changes might affect the delivery of pest control services by barn owls to winegrape vineyards. Climate change is affecting winegrape vineyard ecosystems (Hannah et al. 2013), which could also affect the timing of barn owl nesting, or possibly their abundance and distribution (Jenouvrier 2013). In addition, one effect of climate change is an increased threat of wildfires (Westerling and Bryant 2008). Tragic wildfires occurred in Napa and Sonoma Counties in 2017, causing the loss of many homes and businesses. Also burned at various degrees of severity were uncultivated habitats surrounding vineyards, and in a few cases, vines and nest boxes themselves burned. All of these changes could affect the occupancy and hunting behaviors of barn owls in vineyard ecosystems, and research could make use of this catastrophe as a natural experiment to test hypotheses about owl responses to changes in habitat conditions. Habitat and climate models could be used to offer predictions useful in understanding the durability of owl-delivered pest control over time and with anticipated changes in habitat.

More social science work with farmers is urgently needed, not only to address the last key question identified above, but also to help us understand the more general role of social and economic forces shaping farmers' receptivity to environmental conservation and land-sharing agricultural strategies that could help protect the delivery of ecosystem services in agricultural landscapes. Traditionally, agricultural policies and programs have focused largely on the economic self-interest of producers, assuming economic factors to be the primary drivers behind any willingness to adopt environmentally friendly practices (Sheeder and Lynne 2011, Chouinard et al. 2016, Floress et al. 2017). However, these narrow models have proven insufficient to describe and predict conservation behaviors (Sheeder and Lynne 2011, Thompson et al. 2015), and many researchers have more recently turned to studying wildlife and environmental values orientations (Jacobson et al. 2006, Chase 2016). These take into account crucial psychosocial variables that acknowledge the complexity of human decision making. Moreover, since wine is an agricultural product more strongly associated with its growing location than many other crops, and because some vineyards also maintain tasting rooms and opportunities for consumers to view the farm, public perceptions of environmental practices play strong role in wine marketing. Several wineries have barn owl nest boxes installed near their tasting rooms, and some even have barn owl imagery incorporated into their labels. Wildlife researchers should collaborate with social scientists, marketing specialists, and economists to better understand the various forces at play in farmers' decisions to deploy barn owls nest boxes on their farms.

Lastly, while our review has focused on the benefit of owls to farmers, it is also imperative to better understand if and how deployment of nest boxes on winegrape vineyards affects barn owls. Demographic analyses should be conducted to determine whether barn owls attracted to vineyards are able to sustain local populations, or if these habitats may actually operate as "ecological traps" – habitats they are attracted to but unable to support themselves in without immigration from other more productive areas (Robertson and Hutto 2006, Martin 2009). This work must include additional research on lethal and sublethal effects of rodenticides on barn owls. Though not allowed to be applied to fields, anticoagulant rodenticides are often used in and around buildings and their effects can make their way into agricultural fields (Hindmarch and Elliot 2015). The documentation of secondary AR contamination of raptors through the consumption of poisoned prey has increased over the last three decades (e.g., see references in Hindmarch et al. 2017). Other approved rodenticides are used by some winegrape farmers who also use barn owl nest boxes (Wendt and Johnson 2017). To fully evaluate the capacity for barn owl nest boxes to be a "win-win scenario" (Rosenweig 2003) practice that benefits both owls and winegrape farmers, we must better understand the use and application of rodenticides, and whether they pose a threat to barn owls.

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