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# Gopherbusters? A Review of the Candidacy of Barn Owls as the Ultimate Natural Pest Control Option

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**ABSTRACT:** While many raptor species consume rodent pests, the behaviors and habits of barn owls make them particularly suitable candidates for consideration as a viable pest control strategy. As a cavity-nesting species, barn owls will readily nest in man-made structures including nest boxes. Barn owls are also less territorial than many other raptor species and will tolerate other pairs nesting nearby if prey is abundant. Barn owls preferentially consume rodents including voles (*Microtus* spp.) and pocket gophers (*Thomomys* spp.) in habitats where they occur, but will also switch to more abundant prey so they may be able to sustain populations even if preferred prey numbers fall. These life-history traits allow for people to inflate barn owl populations in target areas, and this has been a factor in the widespread popularity of encouraging barn owls to nest in agricultural areas to provide natural pest control of small nocturnal vertebrate pests. However, the ability of barn owls to control rodent pests has only been formally tested in Malaysian rice and palm oil agriculture, and whether barn owls are capable of controlling rodent pests to economically acceptable levels in areas such as California is as yet unknown. We extracted and combined data from field studies of barn owl nesting behavior and diet in California vineyards to predict that annually, a pair of nesting barn owls and their progeny will consume 97.85 kg of prey. We predicted that an average barn owl nest in a California vineyard will therefore consume 843 pocket gophers, 578 voles, and 1,540 other prey items, most of which are mice. At these values, a barn owl population density of one nest/10 ha may be able to offset the annual productivity of an average population of pocket gophers, but even the highest barn owl densities of one nest/2 ha would be unable to control pocket gopher populations at maximum densities and reproductive rates. While valuable for making initial predictions of the ability of owls to control small rodent pests, our prediction methods are crude, and accurately assessing the capability of barn owls to control rodent pests will require more field data and more sophisticated modeling techniques.

**KEY WORDS:** barn owl, biological control, *Microtus*, nest box, pest control, population modeling, raptors, rodent control, *Thomomys*, *Tyto alba*

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## INTRODUCTION

Controlling small mammal pests has been a challenge for farmers since the dawn of agriculture. These pests were traditionally controlled by natural predators, habitat management, and trapping. Chemical rodenticides developed in the last century replaced many traditional control methods and have become widespread and pervasive in some areas. However, rodenticides pose a challenge for farmers because they are expensive, may have decreasing efficacy if rodents become resistant to certain compounds (Salmon and Lawrence 2006, Horak et al. 2015), and may cause secondary poisoning in non-target animals (e.g., Christensen et al. 2012, Gabriel et al. 2012). Trapping requires high initial inputs (purchasing traps) as well as continued effort and associated staffing costs, but has been shown to be effective in the long term for pocket gopher management (Proulx 1997, Baldwin et al. 2016). Barn owls, historically lauded by farmers for their voracious appetites and cosmopolitan life histories, are again catching the eye of farmers in many regions around the world as a potential natural method for small mammal control. Barn owls are an appealing method for controlling small mammal pests because they are cheap to establish, have relatively low maintenance costs, are less territorial than most other predators, and are highly effective predators of certain rodents.

There are very few examples from agricultural production systems that document the control of a vertebrate pest by a vertebrate predator. In New Zealand, reintroducing New Zealand falcons (*Falco novaeseelandiae*) into a vineyard-dominated region reduced both the populations of, and damage caused by, introduced pest bird species (Kross et al. 2012). In Australia, erecting artificial perches for raptors in irrigated soybean fields led to an increase in raptor use of fields and a subsequent reduced population of mice (Kay et al. 1994). By clearing strips of vegetation and erecting raptor perches to give foxes (*Pseudalopex* spp.) and barn owls better access to prey, Munoz and Murua (1990) were able to demonstrate a decrease in the population of Bridges' degu (*Octodon bridgesi*), the main rodent pest, in Chilean *Pinus radiata* plantations.

Despite the multitude of studies documenting barn owl consumption of rodent pests (see Taylor 1994, Van Vuren et al. 1998, Kross et al. 2016), there have been relatively few field studies that have quantified the ability of barn owls to reduce or control populations of small rodents in agricultural regions, and this lack of data has prompted criticism of programs that claim that owls provide such services (Marsh 1998, Schmidt 2003). In Kenya, Ojwang and Oguge (2003) erected 400 raptor perches and 20 nest boxes in each of two 100-ha experimental grids in maize fields which were paired with control sites. Within 12 months, over 60% of owl boxes were occupied and rodent catch rates dropped from over 40% to ≤1% in the owl sites, compared to a drop from 22% to 6% in control sites (Ojwang and Oguge 2003). In Malaysia, Duckett and Karuppiah (1990) introduced barn owl populations to a palm oil plantation by constructing 200 nest boxes on 1,000 hectares and found that damage to palm was reduced from 19.5% to 1.4% over only two years, as owls moved into the area. Chia et al. (1995) monitored rats within three palm oil estates with low-density barn owl populations. Rodenticides were continued to be used at the sites, and rat damage was found to be above the economic thresholds with both owls and rodenticides in use, but the authors argued that these findings suggested that owls were neither able to control rat populations nor reduce the amount of rodenticides needed. Also in Malaysian palm oil plantations, Ho and Teh (1997) found that barn owl populations of one pair per every ten ha accomplished control of rat damage below the economic threshold of 5%. Similarly, in Malaysian rice fields, erecting barn owl boxes at densities as low as one box/10 ha or higher resulted in a <2% loss in production from rice-field rats (*Rattus argentiventer*), whereas areas without barn owl boxes had rat damage as high as 12% (Hafidzi and Mohd 2003).

When field data are available to populate them, computer models can be used to make predictions on the role of barn owls in controlling rodent pests. Computer models run by Chia et al. (1995) predicted that barn owls could only control rats in Malaysian palm oil plantations if rat populations were low and owl populations high. If rat populations were above a certain threshold, barn owls were unable to reduce the populations without the aid of an outside resource such as rodenticides. Smal et al. (1990) also ran computer models for the Malaysian palm oil plantations and incorporated the use of rodenticide applications and owl hunting efficiency as part of the model assumptions. Models predicted a 53-60% reduction in rodenticide costs in the presence of owl populations but did not take into account whether barn owl populations would crash in the face of low rat populations after rodenticide application. The Smal et al. (1990) models predicted that at low initial rat densities, one pair of owls per eight ha was needed to control rats if barn owls had high hunting efficiency. If barn owls had low hunting efficiency, densities of one pair per six ha was needed. At high initial rat densities (100/ha), owls densities would need to reach one pair per 3-4 ha in order to provide effective rat control, which was not considered biologically feasible in Malaysia. Similarly, the models predicted that if owl densities fell below one pair per seven ha and/or rat populations were raised above 80 per ha, a rodenticide treatment would be needed to get rat populations low enough to achieve adequate control. In some models, selective use of rodenticides to bring rat populations down to a threshold below 30-50 rats per ha would lead to sustainable control by barn owls. Similarly, in an economic model, Kan et al. (2014) predicted that utilizing barn owls for rodent control in alfalfa fields in Israel would be a profitable option, although their assessment did not account for the use of rodenticides as a potential management strategy.

Similar data on the efficacy of barn owls as predators of pest rodents in California are even more limited. Moore et al. (1998) conducted a survey-based study where they assessed occupancy rates and perceived efficacy of rodent pest control from those growers ($n$ = 55) who had installed barn owl nest boxes. The surveyed growers reported that 40% of boxes were occupied within six months of construction, but survey results on the efficacy of the owls was mixed: 66% and 79% of respondents did not respond or did not know if barn owls were effective control agents for pocket gophers or voles, respectively. While the authors of this study argued that these results did not provide evidence for barn owls acting as effective rodent control, the qualitative nature of surveys calls for more targeted field studies.

In California, the use of owl boxes is currently advocated by some as an effective component of an IPM program for managing damaging rodent species. Farmers throughout the state have constructed hundreds, if not thousands, of owl boxes; however, no data exists to support the notion that barn owls will control rodent pests in California farms. Field studies to assess barn owl diets in agricultural fields in California have revealed that owls primarily consume agricultural rodent pests (Van Vuren et al. 1998), with up to 99.5% of prey items in owl diets considered pest species (Kross et al. 2016). Available data also indicate that dense populations of barn owls can be achieved, and that these owls may be able to reduce the number of pocket gopher mounds in a California vineyard (Browning et al. 2016). However, no studies have thus far effectively linked barn owl diet, breeding parameters, and the potential for effective small rodent control. Here, we present a simple calculation using data from existing field studies to predict the annual food requirements of a pair of nesting barn owls and their progeny, and we compare those findings to field data on pocket gopher populations.

## METHODS

We used data from published literature on barn owl diet and breeding habits in California agriculture to predict the number of pocket gophers and voles consumed by the inhabitants of an average barn owl box in a vineyard habitat (Table 1). Where possible, we have preferentially selected data from studies conducted in California and/or from studies conducted in agricultural landscapes.

Because the biomass requirements for barn owls will differ depending on season and breeding status (Taylor 1994), we calculated weekly values wherever possible for our variables throughout the year. This is also an optimal strategy for comparing owl hunting needs with vole and pocket gopher population densities, since the populations of these rodents will fluctuate throughout the year depending on water and subsequent food availability. Because of a lack of field data, we made assumptions for select model parameters. First, we assumed that the population of barn owls in the area was limited to the nest boxes in that area, and that once juveniles left their parents' territories, they did not remain in the area to hunt. Second, we assumed that all boxes were occupied, and that any mortality of adult barn owls was offset by juveniles taking over any empty nest boxes. Only Browning et al. (2016) has reported on barn owl nesting success, including mean number of chicks and fledglings per nest, so we have used this data for our predictions.

**Table 1. Variables collected to predict the number of prey items consumed by an active barn owl nest per week.**

| Variable | Value/week | Reasoning |
|---|---|---|
| Adults/nest box | 2.094 Year-round | Pair of breeding adult owls, plus 0.094 non-breeding adults in area, calculated from the mean of 0.074, 0.084 (Taylor 1994) and 0.125 (Smal 1990). |
| Chicks/nest box | 4.33 | Means based on study in Lodi vineyard (Browning et al. 2016) |
| Fledglings/nest box | 3.93 | Means based on study in Lodi vineyard (Browning et al. 2016). |
| Hatching/fledging dates | Hatching: April 15<br>Fledging: June 11<br>Juveniles disperse 4.5 weeks after fledging | Medians based on study in Lodi vineyard (Browning et al. 2016). Here we are assuming a 'pulse' of breeding from all owls all at once. |
| Mean prey size | Gophers = 53-90 g (varies monthly)<br>Voles = 37.36 g<br>Other = 16.65 g | Gopher values from field study in Lodi over winter-summer (Van Vuren et al. 1998) extrapolated for fall. Vole values taken as mean from Yolo county study (Kross et al. 2016). Other values taken as mean for mouse species from field guides. |
| Biomass requirements (adults) | 90g/owl/day * 7 days | 1 female gopher or equivalent biomass/owl/day. Similar to Smal et al. (1990) models, and estimates from Browning et al. (2016). |
| Biomass requirements (chicks) | = # of chicks * prey delivery rates/day * 61.05g * 7 days | On average, a barn owl nest will have 4.33 chicks, each being delivered "x" prey items per day (varies by week, reported in Browning et al. 2016), and using the mean biomass of prey weighted based on prey ratios from Browning et al. (2016), and the mean weights of gophers (Van Vuren et al. 1998) and voles (Kross et al. 2016) from other California diet studies. |
| Biomass requirements (juveniles) | = # of juveniles * 90 g * 7 days | Assuming juveniles have the same biomass requirements as adults. |
| Proportion of prey items that are gophers | Varies by week: range = 0.246-0.703 | Taken from monthly reported values for winter-summer in Van Vuren et al. (1998). Fall values extrapolated based on winter-summer and on data from Loeb (1990) on proportion of gopher populations that are juveniles in each season and assuming that barn owls consume a greater proportion of gophers when juveniles are present. |
| Proportion of diet consisting of voles | Varies by week: range = 0.110-0.392 | Taken from monthly reported values for winter-summer in Van Vuren et al. (1998). Fall values extrapolated as mean between winter and spring values. |
| Proportion of diet consisting of other | = 1 – (proportion gophers + proportion voles) | Assuming that barn owls will make up any difference in biomass requirements by hunting for prey that are not gophers or voles. Based on Kross et al. (2016) the main other prey are likely to be mice. |
| Number of gophers/voles/mice consumed each week | = Nest biomass requirements * Proportion (prey type) in diet/Mean (prey type) biomass consumed | Values all vary by week and based on previous calculated values. Substitute values for gophers, voles, or mice into (prey type). |

While analyzing pellet contents gives accurate information about prey selection in raptors, the minimum number of individuals method (Marti et al. 2007) used is not a perfect measure of the frequency of occurrence of each prey item, which is better measured through direct methods such as video observations (Lewis et al. 2004). Browning et al. (2016) presents the first data from a video-monitored barn owl nest box, which provide information on prey delivery rates to chicks, and which we use for predicting the weekly food requirements for barn owl chicks (Table 1). However, because Browning et al. (2016) only observed the delivery of pocket gophers to the observed nest, we have calculated a weekly biomass requirement for the chicks based on the average mass of a pocket gopher each week. We also used data collected by Browning et al. (2016) for the average hatch dates, number of chicks per nest, fledging rates, and number of fledglings per nest.

Van Vuren et al. (1998) collected pellets from barn owl boxes in vineyards in the Lodi area at 5-week intervals between January and August 1996, allowing them to detail the seasonal changes in barn owl diet from winter to mid-summer (Table 1). We extrapolated from these data to assume that the relative importance of voles, pocket gophers, and mice in the prey of barn owls in fall would be equal to the mean spring and summer values, that the data collected in January were true for December, and that data collected in July were true for August. Similarly, we used the median body mass of pocket gophers reported in Table 2 of Van Vuren et al. (1998) which reported values from the same time periods as Table 1, so we used the same protocol as above to make assumptions about pocket gopher biomass for August-December. Van Vuren et al. (1998) found that, across all seasons, pocket gophers consumed by barn owls were an average of 61 g, which is similar to the 63.31 g average pocket gopher size found by Kross et al. (2016). Finally, we assumed that all prey items that were not pocket gophers or voles were mice [either Western harvest mouse (*Reithrodontomys megalotis*), deer mouse (*Permomyscus maniculatus*), or house mouse (*Mus musculus*)], because mice were the other main prey type in both Van Vuren et al. (1998) and Kross et al. (2016).

We calculated the number of pocket gophers, voles, and mice consumed by the inhabitants of an average barn owl box each week using the following formula:

$$(R / B_g) \times P_g$$

where R is the biomass requirements (in grams) of the barn owl nest, including adults, for the week; $B_g$ is the biomass of the average pocket gopher consumed by barn owls in that week; and $P_g$ is the proportion of barn owl diet consisting of pocket gophers in that week. The same formula was used for voles and mice, using the appropriate biomass and proportion data for those prey items for each week. Finally, to estimate the likely impact of a pest-control program installing different densities of barn owl boxes per hectare, we calculated the weekly rodent consumption by owls at three different densities: one pair per ten ha (Smal et al. 1990), one pair per five ha (Smal et al. 1990), and one pair per two ha (Browning et al. 2016).

## RESULTS

The weekly base requirement for adult owls was 630 g (equal to 1,319.22 g for a pair of breeding adults and 0.094 non-breeding adults per nest; see Table 1), chicks each required 448.72 g, and fledged juveniles each required 630 g of prey. The weekly biomass requirements for a barn owl nest containing 4.33 chicks and fledging 3.93 juveniles peaked at 3,795.12 g of rodent prey per week during the 4.5 weeks that juvenile barn owls remained near the nest to be fed by their parents (Figure 1). Annually, the average barn owl nest therefore consumed 97.85 kg of prey.

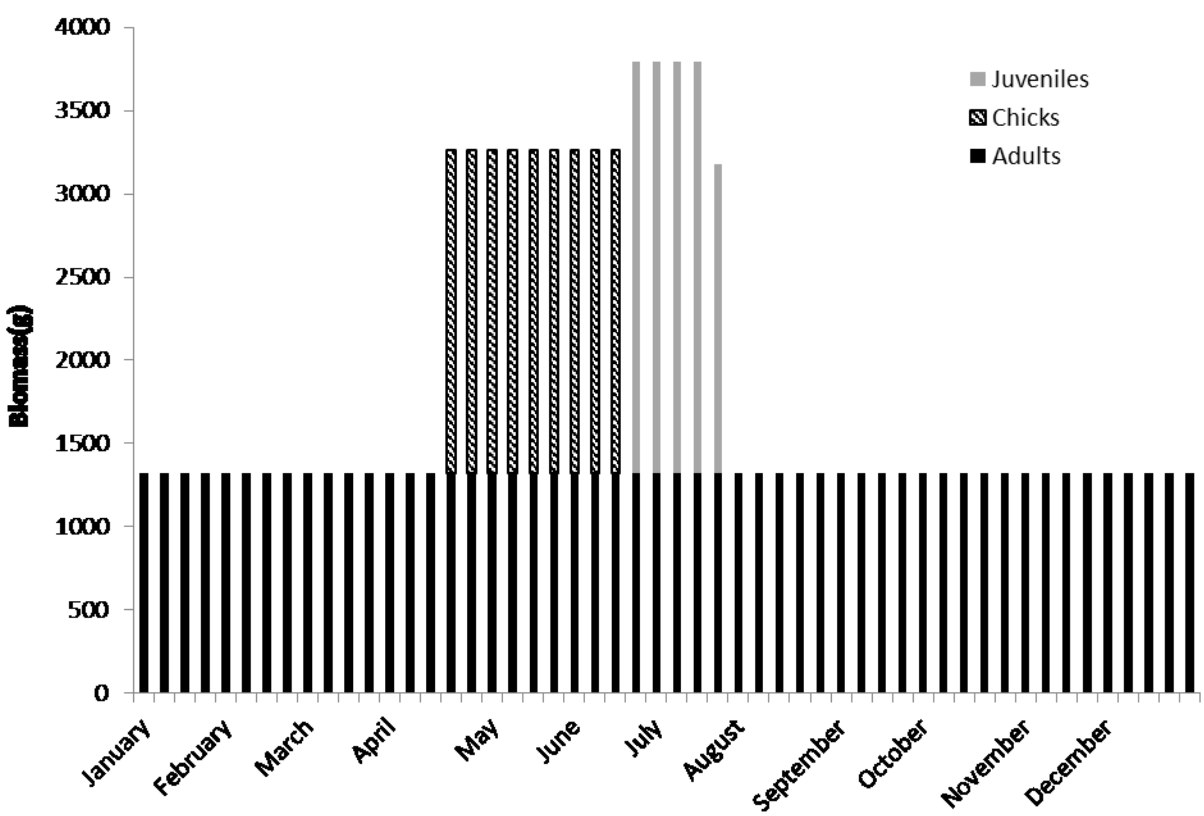


**Figure 1. Weekly biomass consumed by a pair of nesting barn owls, their chicks, and fledged juveniles in a California vineyard over the course of a year based on the data and assumptions outlined in Table 1.**

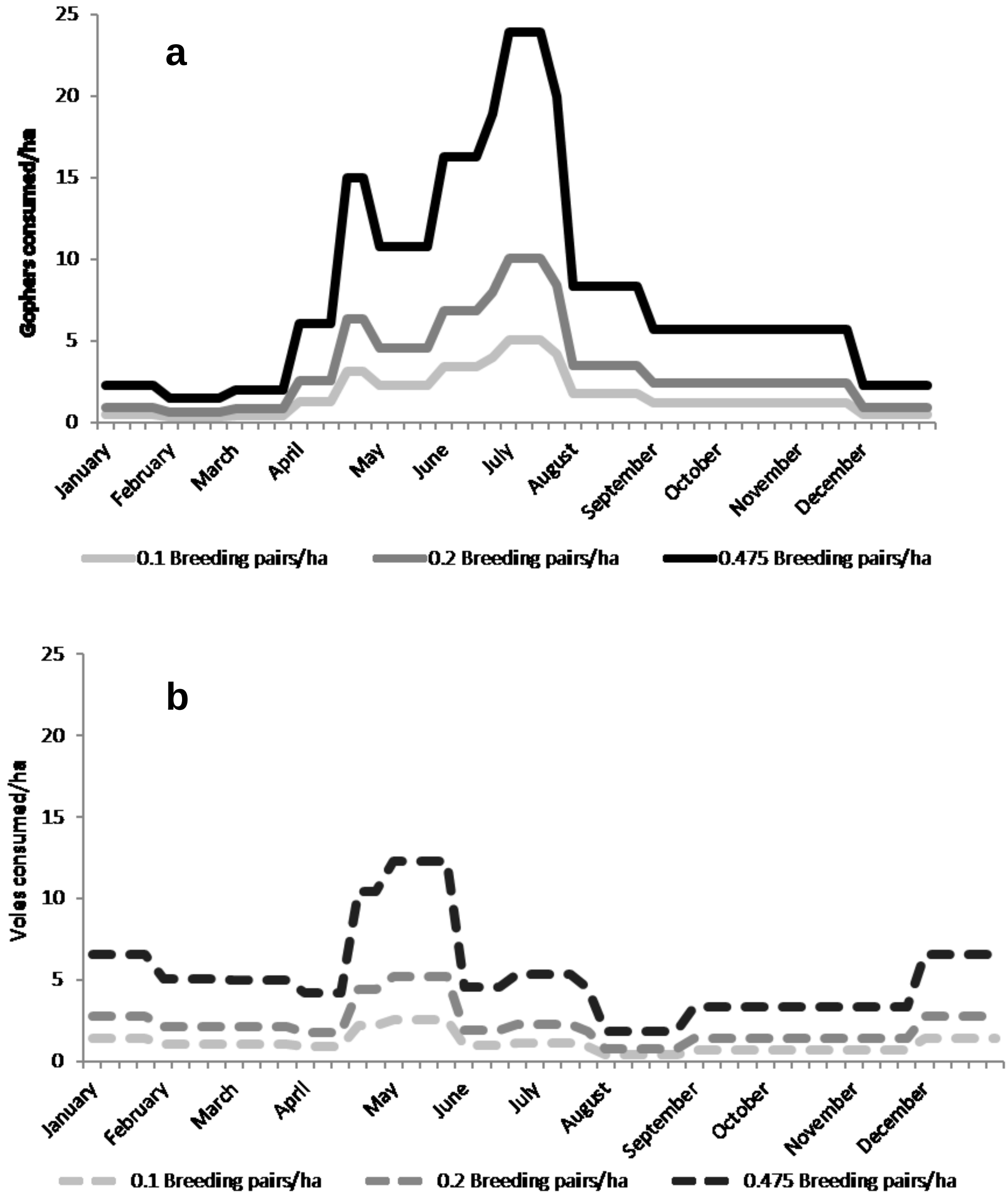


**Figure 2. Number of a) pocket gophers and b) voles per hectare consumed by different densities of barn owls over the course of a year.**

Annually, an average barn owl nest was calculated to consume 843 pocket gophers, 578 voles, and 1,540 other prey items, most of which were mice. At an owl density of one pair per two ha, consumption of pocket gophers peaked in the summer at a maximum of 24 pocket gophers per ha, while consumption of voles peaked in spring at a maximum of 13 voles per ha (Figure 2). At this very high owl density, we predict that owls will consume 401 pocket gophers per ha and 274 voles per ha annually (Figure 2). At lower owl densities, we expect owls to consume 85 pocket gophers and 58 voles (one pair of breeding owls per ten ha), and 169 pocket gophers and 116 voles (one pair per five ha).

## DISCUSSION

In their paper, Van Vuren et al. (1998) predicted that one pair of barn owls would consume an average of almost one pocket gopher per day, and they compared that to conservative pocket gopher density data of 15 females per ha (Howard and Childs 1959) at a reproductive rate of six young per female (Loeb 1990), resulting in an annual productivity of 90 pocket gophers per ha. Under their predictions, Van Vuren et al. (1998) therefore determined that, assuming owls are the only source of mortality, only owl densities of one pair per two ha would offset the annual productivity of pocket gophers. Here, we have used the data from multiple studies to predict that one pair of barn owls and their offspring are likely to consume 843 pocket gophers per year (over two per day), which far exceeds the annual productivity of pocket gophers at the conservative levels listed above. Based on our calculations, an owl density of one pair per ten ha would be just shy of offsetting annual pocket gopher productivity at the parameters outlined above. However, pocket gopher numbers can vary drastically from field to field depending on factors such as crop type and irrigation. For example, in irrigated alfalfa fields, pocket gopher density can reach 60 females per ha or more (Howard and Childs 1959) with an annual reproduction rate of 20 young per female (Loeb 1990), leading to an annual productivity of 1,200 juvenile pocket gophers per ha. Even at very high densities of one pair per two ha (Browning et al. 2016) we predict that owls will eat a maximum of 401 pocket gophers and therefore would not offset the annual production of juvenile pocket gophers.

The assumptions fed into models can severely limit the predictive power of those models, and the less biological data available, the more models must rely on assumptions based on related, but not exactly correct, biological data. Our annual predictions for barn owl consumption are more than double those of Van Vuren et al. (1998), which may be a result of extrapolating from prey delivery rates from a single video-monitored nest (Browning et al. 2016). While video is a more precise method for measuring prey consumption rates than pellets (Lewis et al. 2004), relying on video data from only a single nest has a high chance of producing misleading results. However, video monitoring has been shown to be a better measure of prey consumption at raptor nests than indirect methods such as analyzing prey remains and pellets (Redpath et al. 2001). The vineyard monitored by Browning et al. (2016) had a high initial pocket gopher population, so owls in that study may have been particularly successful in hunting for large prey items like pocket gophers. On the other hand, the barn owl population in the Browning et al. (2016) study was only established in the year prior to the data collection, so owls in the monitored box may have been relatively young and inexperienced and therefore may not have been as efficient hunters as older owls. We therefore strongly encourage future detailed studies of barn owl prey delivery rates in vineyards and other agricultural habitats.

According to Van Vuren et al. (1998), barn owls consumed pocket gophers of the median sizes reported for January-July, although sizes ranged from <40 to >230 g per individual prey item. We could use only the median pocket gopher size for each time period in our analyses, but these suggest that barn owls only eat juvenile pocket gophers in all seasons, which is unlikely since adults were occasionally taken (Van Vuren et al 1998). For example, Kross et al. (2016) found that during the breeding season, 13.73% of pocket gopher remains in owl pellets were from adults. Accounting more accurately for depredation on adult pocket gophers will lead to a lower estimate for total pocket gophers consumed per year, but will also have an effect on the impact of barn owls on pocket gopher populations, since consuming adults is likely to remove breeding individuals from the population. Furthermore, pocket gophers can range substantially in body mass depending on the region in which they are found. All of our model data come from similar regions in the California Central Valley, so these results may not be appropriate to extrapolate into other areas where larger or smaller pocket gophers are commonly found.

Despite their inclination for breeding in anthropogenic landscapes, barn owls are declining throughout much of North America (Colvin 1985, Taylor 1994). The reasons for this are poorly understood but may be a result of changes in land use, farm management practices that result in sudden loss of prey (e.g., harvesting; Martin et al. 2010), loss of natural and man-made cavities (such as barns), hazards such as traffic on roads (Martin et al. 2010, Hindmarch et al. 2012), and increasing use of chemical control for rodent populations, which may lead to loss of prey or secondary poisoning in the owls (e.g., Walker et al. 2008). Conversely, irrigated agricultural fields can offer relatively consistent prey availability when compared with non-irrigated sites (Marti 1988) which may provide an opportunity to bolster barn owl populations throughout much of their range.

Understanding how differences in land-use types affect barn owl breeding success, hunting rates, and prey selection are all important future research agendas to expand our knowledge of the role of owls in controlling pests in other agricultural habitats. For example, differences in habitat type may have a significant influence on clutch sizes and number of chicks fledged, although the literature from other regions suggests that local studies are needed to understand these relationships. For example, no significant correlations were found between barn owl breeding success and agricultural land use in England (Meek et al. 2009) or Switzerland (Frey et al. 2011), but in a UK-wide survey, Leech et al. (2009) found that barn owls breeding in semi-natural habitat and extensive grazing systems had higher breeding success compared to those nesting in arable fields. In a predominantly agricultural area in British Columbia, Hindmarch et al. (2014) found that barn owls with greater urban land cover near their nests successfully fledged fewer chicks despite laying the same number of eggs and having similar diets to barn owls with less urban land cover near their nests. Habitat can also have a major influence on diet; barn owls in California appear to consume more pocket gophers when they nest in areas with more vineyards and orchards, compared to areas with more row and forage crops (Kross et al. 2016). Furthermore, rodent populations can change drastically across different crop types and irrigation practices (e.g., Loeb 1990).

The results presented in this paper are limited in scope because they are based on only a small number of field studies from which assumptions and extrapolations were made. We also ignored potentially confounding factors such as density-dependent growth in pocket gophers and changes in the hunting success of owls under differing pocket gopher densities. Utilizing more sophisticated modeling methods will help to account for these likely demographic changes, but we suggest that to truly test whether a population of barn owls are capable of controlling rodent pest populations at "acceptable" levels, a large-scale field trial should be conducted. This project should install nest boxes in an area where barn owl boxes are not currently used and monitor rodent populations, owl populations, owl diet, and crop damage both before the installation of nest boxes and over 5-10 years following the establishment of owl populations. Measuring crop damage is as important as collecting information on the owls and their prey, since owl presence may change the foraging behavior of prey species (Abramsky et al. 1997, Embar et al. 2014). Finally, for any field study to measure the efficacy of owls for controlling pest rodents we must first have firm expectations of what constitutes effective control starting with tolerance thresholds for damage from specific pests and corresponding pest densities.

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