Prey Consumption by a Large Aggregation of Barn Owls in an Agricultural Setting

Mark Browning
Barn Owl Box Company, Pittsburgh, Pennsylvania
John Cleckler
CH2M HILL Inc., Sacramento, California
Kayla Knott
Sacramento, California
Matthew Johnson
Humboldt State University, Arcata, California

ABSTRACT: Barn owls produce large numbers of young, will nest in close proximity, are easily attracted to nest boxes, and occasionally form dense colonies. Their diet consists largely of various species of rodent pests. These characteristics suggest barn owls could contribute to pest control in agriculture. Studies have been conducted in Israel and Malaysia, but little quantitative research has documented their effectiveness. This study measured the effect of a population of barn owls on a rodent population in a 40-ha vineyard near Sacramento, California. In 2011, 11 of 20 boxes were occupied by breeding pairs, fledging 40 young. In 2012, 18 of 24 owl boxes were occupied, fledging 66 young; and in 2013, three of 24 boxes were occupied, fledging nine young. Nocturnal observations revealed the owls hunted the study area heavily. Monthly pocket gopher surveys using the mound-count method indicated that gophers declined on the vineyard with barn owl boxes relative to a control vineyard without barn owl boxes. Pellet analysis showed diet was composed mainly of Botta's pocket gophers (70.4%) and California voles (26.2%). An infrared camera recorded 316 deliveries to a nest with three chicks (105.3 per chick) over the first eight weeks. Using these figures, and adding conservative estimates of adult consumption over the 165-day breeding season, and adult and fledgling consumption prior to dispersal, the total number of prey taken over the three breeding seasons was estimated to be 30,020 rodents. Cost comparison analysis showed an average cost of $8.11 per pocket gopher trapped versus $ 0.34 per rodent taken by barn owls.

KEY WORDS: barn owl, *Microtus californicus*, nest box, pocket gopher, predation, rodent control, *Thomomys bottae*, *Tyto alba*, vineyard, vole

Proc. 27th Vertebr. Pest Conf. (R. M. Timm and R. A. Baldwin, Eds.)
Published at Univ. of Calif., Davis. 2016. Pp. 337-344.

INTRODUCTION

Barn owls (*Tyto alba*) exhibit a tolerance for their own kind that is unusual among raptors. When a large number of suitable nesting sites are available in a concentrated area, barn owls have been known to form dense populations. Thirty-five barn owls inhabited an abandoned steel mill in Utah (Smith et al. 1974); 25 barn owls were recorded in a 2.59-km^2 area in underground mines in New Mexico (Salter 1991); and densities of 18 pairs in 5-km^2 have been reported in south Florida (Martin 2009). In such cases they have often been termed "colonial" (Dixon and Bond 1937, Smith et al. 1974).

Although voles (*Microtus s*pp.) are often cited as a prey animal upon which barn owl numbers depend (Colvin and McLean 1986, Marti 1988), numerous studies have shown that barn owls will utilize other rodent species as their primary prey, including marsh rice rats (*Oryzomys palustris*; Jemison and Chabrek 1962), cotton rats (*Sigmodon hispidus*; Baumgartner and Baumgartner 1944), and palm rats (*Rattus tiomanicus* and *R. argiventer*; Smal 1988), all of which cause serious damage to various crops.

These characteristics have led to the idea that barn owls could contribute significantly to rodent control in various agricultural settings around the world. Nest box programs have been utilized in oil palm plantations (Lenton 1984, Smal 1988), rice fields in Malaysia (Hafidzi and Jamaluddin 2003), and in mixed agriculture in Israel (Meyrom et al. 2009). Nest boxes have also been used for decades in California vineyards and orchards (Moore et al. 1998).

Managing rodent pests is one of the premier challenges facing California's winegrape growers (McGourty et al. 2011). The California Winegrape Working Group has identified pocket gophers (*Thomomys bottae*) as "important pests, capable of significant injury by cutting roots or gnawing bark and rapidly girdling vines several inches below the soil line" (Roberts 2009). Pocket gopher mounds also interfere with harvest machinery and other operations (Salmon et al. 2013). Farmers routinely use trapping, which is labor intensive; strychnine, a powerful neurotoxin that can cause secondary poisoning in non-target species (Littrell 1990, Greek 1998); propane ignitor devices; and fumigants such as aluminum phosphide and carbon monoxide, which may kill other forms of wildlife living in rodent burrows (Littrell 1990).

Many farmers install nest boxes for barn owls as an alternative to trapping and poisons, but few studies have examined the effect of large numbers of barn owls on rodent populations. A study conducted in Malaysian oil palm plantations found that baiting levels could be reduced by 40% in the presence of barn owls (Smal 1988). A barn owl program in Malaysian rice fields was attributed to reducing crop loss up to 12% (Hafidzi et al. 1999). In Israel, barn owl predation was determined to have a statistically significant positive effect on alfalfa crop yield

(Motro 2011). However, none of these studies measured barn owl and rodent numbers contemporaneously. Martin (2009) increased barn owl populations by installing nest boxes in sugar cane in Florida, conducted barn owl and rodent surveys over a two-year period, and concluded that barn owls did not possess the ability to control resident populations of cotton rat and black rat (*R. rattus*) populations. However, the density of nest boxes in the study was extremely low: approximately one for every 40 ha, far below the recommended density in the Malaysian studies and only 1/25 of the density in our study.

The goals of this study were to determine if a dense population of barn owls could be established on a relatively small winegrape vineyard; measure the effect of a large population of barn owls on a resident rodent population; accurately record the numbers of rodents consumed by chicks during their development; estimate the numbers of rodents consumed by the entire population of owls over three breeding seasons; and compare costs and benefits with other methods. Poisoning and trapping were suspended on the study plot so barn owls would be the primary rodent pest remover.

METHODS

Study Area

The study area was a 40-ha vineyard of young vines located in the Central Valley of California, 32 km south of Sacramento. The site was chosen due to the high numbers of Botta's pocket gophers, indicated by the presence of many mounds characteristic of this species. The vineyard was bordered on the SE by a large reservoir, on the SW by a levy along the Cosumnes River, on the NE by an apple orchard and wheat field, and on the NW by woodland bisected by a stream.

Nest Box Density

In February 2011, 20 nest boxes were erected approximately 61 m apart along a service road surrounding the vineyard, with their entrances facing the study area. Six nest boxes faced NE; nine nest boxes faced NW, and five nest boxes faced SW. In June 2011, five more boxes were installed along the wooded creek, facing SE, making a total of 25 (i.e. one nest box for every 1.6 ha). Prior to the 2012 breeding season, one of these nest boxes containing a hen and one egg was damaged and rendered unusable. This nest box was not used in estimates of chick production or rodent removal.

These nest boxes were constructed of molded plastic with a white pigment highly reflective of radiant heat, and an inner box of dark plastic with a 2.5-cm gap of circulating air to keep the box close to ambient temperature in full sun (Browning 2008). The interior measured 64 cm deep by 43 cm wide by 43 cm tall. The floor of each box was covered with approximately eight cm of mulch. Each box was erected 2.44 m above the ground on a galvanized iron pole 2.54 cm in diameter.

Monitoring of Nest Boxes

Beginning in February 2011, nest boxes were checked at least once per month to count adults, eggs, and chicks. Nests were considered active when eggs were observed. When inspections coincided with the laying of a clutch, timing of the first egg was assessed by backdating two days for each egg present (Bunn et. al. 1982). When hatchlings were discovered, we backdated two days for each chick present, then factored in the 32-day incubation period. Young were determined to successfully fledge when they had survived long enough to develop pronounced facial disks and fully developed flight feathers, at around nine weeks.

Observations of Barn Owl Hunting Activity

Barn owl hunting activity was monitored through direct observation on a weekly basis during the breeding season in two ways: In the hour after sunset while residual light remained in the sky, a levee along the Cosumnes River provided a view of the entire study area and any barn owls present. Additionally, slow drives after dark by automobile around the perimeter of the vineyard were utilized to monitor barn owl activity on a weekly basis.

Determining Prey Ratios through Pellet Analysis

Over the course of the study, a sample of pellets (201 total) was collected from inside and below the next boxes and later dissected to determine prey ratios. Skulls were used to determine prey numbers consumed. Prey was measured numerically, not by volume. Prey species were determined by comparing skulls to skull samples of all possible rodent species in the area and to skull illustrations (Jameson and Peters 1988).

Prey Deliveries Recorded by Camera

In 2013, an infrared, motion sensor, SSC-113WX6 digital camera (Advance Security, Belleville, IL) was mounted inside one nest box that contained three eggs. These subsequently hatched and all three chicks successfully fledged. The camera captured every prey delivery to the nest box over the first eight weeks of development. The time of every arrival and departure of adult birds was recorded, as well as each delivery of prey.

Determining Length of Breeding Season

Although numerous barn owls were observed roosting and hunting on the study site year-round, we concerned ourselves with prey consumption only during the breeding season, defined as the onset of courtship through dispersal of young. Courtship has been cited to occur from four weeks (Marti 1992) up to eight weeks (Taylor 1994) before egg laying; incubation records range from 29 to 34 days (Bunn et al. 1982, Taylor 1994); fledging has been determined to occur 62 ± 4 days from hatching (Pickwell 1948, Reese 1972, Looman et al. 1996); and the period prior to dispersal from the natal area is variously cited as ranging from two to eight weeks (Seel et al. 1983) or up to seven to eight weeks (Smith et al. 1974). We used conservative figures of 35 days for courtship, 32 days incubation, 63 days of development, and 35 days presence of both adults and young prior to dispersal, comprising an adult breeding season lasting 165 days and a hatching-to-dispersal period for fledglings of 98 days.

Determining Numbers of Prey Harvested by Barn Owl Population

To determine total number of prey harvested per fledgling, we used the number recorded by camera over the eight-week developmental period, added in an estimate of consumption for the ninth week based on the seventh and eighth weeks, and added a conservative estimate of one prey item per night for the 35 days after fledging, prior to dispersal. Although other studies have indicated more than one prey item consumed per night, voles are usually the predominant prey in the research and weigh significantly less than pocket gophers. California voles (*Microtus californicus*) weigh 36 to 55 g (Verts and Carraway 1998), whereas Botta's pocket gophers weigh 89 to 172 g. (Vaughn 1967). Bunn et al. (1982) concluded that daily dietary intake ranged between 100 and 150 g, close to the median weight of adult pocket gophers, and in a California study where pocket gophers predominated, pellet analysis also indicated an average of approximately one pocket gopher per night (Van Vuren et al. 1998). For adults, we likewise estimated one prey item per night over the 165-day breeding season.

Pocket Gopher Surveys

We monitored pocket gopher activity on the vineyard with barn owl boxes (treatment site) and on a control site established in a similar vineyard approximately 6 km to the SW, where no boxes were installed. Like the treatment site, the control area contained plantings of young vines, and was heavily populated with pocket gophers. Pocket gopher activity was measured using the mound count method (Engeman et al. 1993) in which all mounds are flattened and, approximately 48 hours later, all new mounds are tabulated. While this method cannot reveal the absolute number of gophers, it provides a reliable index of relative gopher abundance useful for comparative analyses (Engeman et al. 1993). Mounds were counted within 30 randomly chosen quadrats measuring 9.14 × 9.14 m on each study vineyard. These quadrats were kept a minimum of 30.48 m apart, based on estimated home range size of pocket gophers (R. Baldwin, UC Davis, pers. comm.).

Over the duration of the study, we attempted to complete gopher surveys at two-month intervals. However, various factors caused some surveys to be cancelled: rainfall, which adversely affects short term pocket gopher activity (R. Baldwin, pers. comm.); lack of sufficient field workers; spraying of insecticides or fungicides; and flooding. A total of 16 pocket gopher mound surveys were successfully completed on the treatment site and 11 were completed on the control site.

Statistical Analyses

Barn owl preference for next box orientation was examined with a χ^2 test of independence. Comparisons of the index of gopher abundance were performed with a repeated measures ANOVA in which each quadrat was a subject, month of survey (using only the 11 monthly surveys completed on both treatment and control sites) was the within subject factor, and control vs. treatment vineyard was the between subject factor. We used correlation tests to examine the correspondence between numbers of barn owls and gopher mounds on the treatment site and to test for a linear trend in total number gopher mounds on the study sites, using all surveys available. Data used in parametric tests were normally distributed. All analyses were conducted with SPSS (IBM 2015) and an alpha level of 0.05 was set for statistical significance.

RESULTS

Barn Owl Population

In 2011, 11 of 20 nest boxes (55%) were occupied by breeding pairs between mid-February and late March. There was no significant trend in preference for nest box orientation ($\chi^2 = 3.48$, df = 2, $P = 0.18$). Ten (91%) of the active nests successfully fledged chicks. Egg laying occurred 28 February to 7 April; hatching occurred 25 March to 23 April; fledging occurred 26 May to 24 June. A total of 55 eggs were laid (average clutch size 5.5), resulting in 44 hatchlings (80% hatch rate; average 4.4 per nest); and 40 (93%) hatchlings successfully fledged (average 4.0 fledglings per nest). The egg-laying through fledging cycle took 121 days.

In 2012, 18 out of 24 nest boxes (75%) were occupied by breeding pairs, again in February and March. There was no significant trend in preference for orientation ($\chi^2 = 5.51$, df = 3, $P = 0.14$). Seventeen nests (94%) were successful. Egg laying occurred 28 Feb to 25 April; hatching occurred 20 March to 25 May; fledging occurred 30 May to 29 July. A total of 105 eggs were laid. However, this included a nineteenth clutch of five eggs that was a second effort laid to replace an infertile clutch of six (105/19 = average clutch size 5.5), resulting in 73 hatchings (69.5 % hatch rate; average 4.1 per nest), and 66 fledged young (90% successful fledge rate; average 3.7 per nest). The egg-laying to fledging cycle took 151 days. In 2013, 18 barn owls occasionally roosted in boxes, but only three boxes contained breeding pairs, with three chicks each. Timing was similar to that in 2012.

Barn Owl Hunting Behavior

Nocturnal observations revealed the resident population of owls hunted the vineyard heavily. Observations from the levee in the hour after sunset revealed numerus barn owls entering the study area from nest boxes and nearby groves of trees. Drives via automobile around the vineyard after dark revealed owls perched on nest boxes, trees, vine posts, and flying overhead. The owls mainly employed a strategy thought less common to barn owls: perching and pouncing (Taylor 1994). Perch hunting has also been reported as the main hunting method in oil palm plantations of Malaysia (Lenton 1984).

Prey Ratios based on Pellet Analysis

A sample of pellets collected over the course of the study showed pocket gophers were the dominant prey: 201 pellets yielded 362 skulls, composed of 255 pocket gophers (70.4%), 95 voles (26.2%), six *Peromyscus* spp. (1.7%), and six *Rattus* spp. (1.7%).

Numbers of Prey Delivered to Chicks based on Cam

A total of 316 deliveries (105.3 per chick) were recorded by the nest box camera over the first eight weeks of development. The ninth and final week's consumption before fledging was estimated based on the seventh and eighth weeks (35), resulting in 351 total (117 per chick) (Table 1). Deliveries recorded on the camera were made so rapidly that only brief glimpses of each prey item were observed, so species identifications was not possible; however, pellet analysis of the population of owls provided an estimate of the overall ratios of prey.

Predictably, deliveries in the first week started low at 22 (1.05 per night per chick), but climbed quickly to more than double at 52 (2.48 per night per chick) in weeks four and five. Deliveries tapered off dramatically to a mean of 35.5 in each of weeks six through nine, a decline of 30.7% from the fourth and fifth weeks. This decline in deliveries has been viewed as an adaption to bring the now overweight young down to active adult weight in preparation for fledging (Langford and Taylor 1992, Durant and Handrich 1998).

Timing of Prey Deliveries

Delivery of prey items occurred between 20:34 and 05:25 Pacific Daylight Time. Almost all first deliveries occurred at least one hour past sunset when the sky was dark. The highest number of deliveries occurred earlier in the evening and declined steadily through the rest of the night (Table 2).

Numbers of Prey Harvested by Barn Owl Population

Using 351 prey deliveries to chicks prior to fledging, and adding one prey item per night per chick in the 35 days before dispersing (351 + 105 = 456/3) resulted in 152 prey items consumed per fledgling. Using the same estimate of one prey item per night consumed by adults over the 165-day breeding season resulted in the total consumption shown (Table 3). Total number of prey items taken over the course of the three breeding seasons was 30,020. Based on prey ratios indicated by pellet analysis, this amounted to 21,134 pocket gophers, 7,865 voles, 510 *Peromyscus* spp., and 510 *Rattus* spp.

Pocket Gopher Activity: Study and Control Sites

There were statistically significant effects of treatment (treatment site vs. control site) and month on the number of gopher mounds counted in our surveys (Table 4). The number of gopher mounds varied temporally; 11 surveys over 24 months were completed in the same months on both sites and used in statistical analyses (July 2011 through June 2013), and unsurprisingly there tended to be more gopher mounds in the summer than winter months ($F_{10,\ 580} = 11.98$, $P < 0.001$, Figure 1). This temporal variation differed significantly between the study sites; there was a strong reduction in the number of gopher mounds on the vineyard with barn owl boxes compared to the control site ($F_{10,\ 580} = 10.86$, $P < 0.001$, Figure 1). The number of gopher mounds was most strongly reduced beginning in summer 2012, when their numbers increased on the control vineyard following the winter low, but remained low on the treatment site with barn owl boxes. This pattern continued in 2013. The correlation between owl numbers and total gopher mounds counted on the treatment site was negative, but not statistically significant (Pearson's $r = -0.063$, $P = 0.82$). Over all months of the study, there was a statistically significant decline in the number of gopher mounds counted on the treatment site (Pearson's $r = -0.61$, $P = 0.013$), whereas there was no significant trend on the control site (Pearson's $r = 0.355$, $P = 0.29$, Figure 1).

Table 1. Weekly consumption of prey by three barn owl chicks in a barn owl box placed on a winegrape vineyard near Sacramento, California, 2013.

Weeks	1	2	3	4	5	6	7	8	*9	Total
Deliveries	22	38	45	52	52	36	36	35	35	**351**
Average Per Chick	1.05	1.81	2.14	2.48	2.48	1.71	1.71	1.67	1.67	**1.86**

*estimated based on previous weeks

Table 2. Number and timing of prey deliveries by the hour to three barn owl chicks in a barn owl box placed on a winegrape vineyard near Sacramento, California, 2013.

Hour	2000 2100	2100 2200	2200 2300	2300 2400	0000 0100	0100 0200	0200 0300	0300 0400	0400 0500	0500 0600
Deliveries	11	89	53	31	35	33	27	17	14	6
%	3.5%	28.2%	16.8%	9.8%	11.1%	10.4%	8.5%	5.4%	4.4%	1.9%

Table 3. Estimated numbers of rodents harvested by barn owls 2011-2013.

Year	# of Adults	# Prey Per Adult	Prey Taken by Adults	# of Fledglings	# Prey Per Fledgling	Prey Taken by Fledglings	Total Prey Taken
2011	22	165	3,630	40	152	6,080	9,710
2012	36	165	5,940	66	152	10,032	1,5972
2013	18	165	2,970	9	152	1,368	4,338
Total	76	-	12,540	115	-	17,480	30,020

Table 4. Repeated measures ANOVA results for analysis of the number of gopher mounds between two study sites (control vs. treatment with barn owl boxes; between factor) over 11 survey periods (within subject factor) from July 2011 to June 2013 near Sacramento, California. In each survey period, 30 quadrats (subjects) at each study site were surveyed for mounds.

Source	df	Sum of Squares	Mean Square	F-ratio	*P* Value
Survey date	10	1526.06	152.61	11.98	<0.0001
Survey date × Site	10	1383.75	138.38	10.86	<0.0001
Error	580	7388.01	12.74		

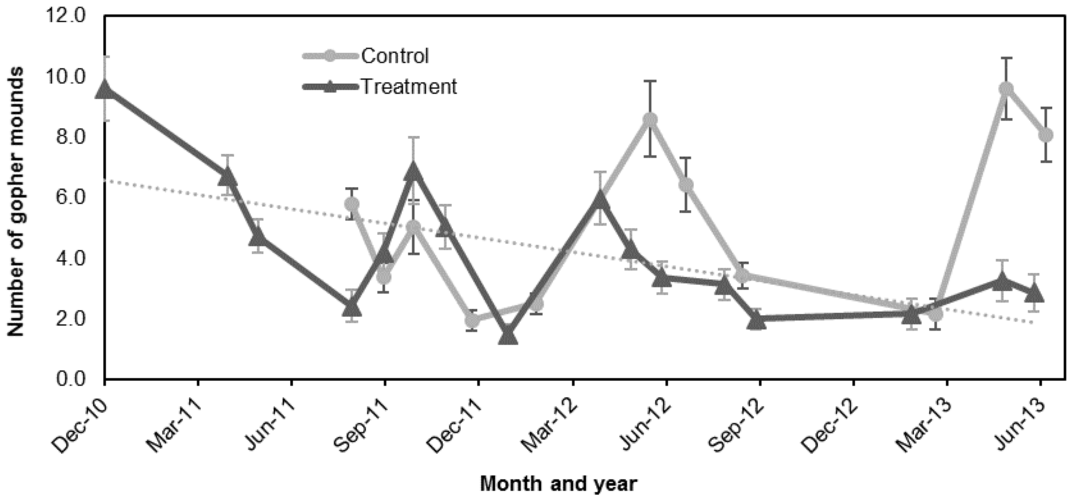

Figure 1. Mean (± 1 SE) number of gopher mounds per 83.5 m^2 quadrat (*n* = 30 per survey per study site; an index of gopher abundance) in vineyards with (treatment) and without (control) occupied barn owl boxes, July 2011 through June 2013, near Sacramento, California, USA. The dotted line shows the negative temporal trend in gopher mounds on the treatment site.

Costs Comparison

The cost of establishing and maintaining the barn owl colony was $6,025 for 25 nest boxes ($169 for each box, $69 for each pole, and $3 for mulch bedding). Labor was approximately two hours per nest box for installation, plus approximately half an hour per nest box per year for cleaning, for a total of $1,261, (3.5 hours per box over three years at $14.42 per hour), bringing the total cost for barn owl boxes to $7,286. Over the three-year study period, we estimated that 30,020 rodents were removed by barn owls on the treatment site. Pellet analysis ratios suggest 70.4% were pocket gophers, yielding 21,134 removed gophers, for a cost of $0.34 per pocket gopher. Since subsequent years will take no more than minimal maintenance of the boxes, the cost per rodent removed will decrease with time.

Analyses suggest that two common conventional gopher removal methods are more expensive than using barn owl boxes. For spring traps, Vino Farms indicated that they employ two workers that work nine months of the year (37 weeks), five days per week, with annual salaries of $30,000 ($14.42 per hour) paid exclusively to set traps, taking approximately 30 gophers per day. Thus, 5,550 gophers (30 × 37 × 5) are removed at a labor cost of $45,000 (9/12 months × $30,000 × 2), resulting in a cost of $8.11 per gopher trapped. Likewise, strychnine application is also comparatively expensive. Using a burrow building machine on a 40-ha plot is estimated to take $288.40 in labor (20 hours at $14.42 per hour), and with five pounds of poison per hectare ($5 per pound) the pesticide cost is $1,000. Running the tractor adds approximately $400, so the total for one application on a 40-ha plot equals $1,400. When applied only once per year, over a 10-year period the total equals approximately $14,000. This is over twice the amount required to establish an intensive barn owl program on the same acreage. Costs per gopher removed using strychnine are unknown, due to the fact that most pocket gophers killed with this method die below ground.

DISCUSSION

Barn Owl Population

The installation of 25 nest boxes resulted in rapid occupation by a large population of barn owls on a relatively small vineyard. With 62 barn owls established on the 40-ha (100-acre) vineyard in 2011, and 102 in 2012, this study demonstrated that dense populations of barn owls can be attracted rapidly to an area with suitable nesting sites and abundant prey. The estimated harvest of 9,710 rodents in 2011, 15,972 in 2012, and 4,338 in 2013 (Table 3) affected the local gopher population. This removal of gophers began in January when barn owl courtship began and the adults were taking approximately one rodent per night; climbed rapidly with the hatching of chicks; and peaked when the chicks were consuming 2.48 prey items per night in their fourth and fifth weeks of development (Table 1), amounting to the estimated harvest of nearly 200 prey items per night during these two weeks of peak consumption in 2012. Importantly, hunting pressure lasted January through August, nearly eight months. Notably, 2013 showed a marked decline in breeding pairs of barn owls, down from 18 in 2012 to three in 2013. Although numerous barn owls were observed roosting and hunting on and near the study site in 2013, most owls declined to breed. Rapid changes in barn owl breeding populations in response to changes in food supply have been noted in various studies (Schönfeld and Girbig 1975, Kaus 1977, Taylor et al. 1988). Although it is possible that the lower numbers of pocket gophers attracted fewer breeding owls, the degree of the owl decline might also be attributed in part to the extended drought which began in 2012 and continued through 2013 and beyond. The Audubon California Bird Conservation Program (Kuhne 2014) reported severe declines in nesting of many raptors, including barn owls, and attributed this to similar declines in insects and rodents. Nonetheless, continuing low pocket gopher activity on the study site in contrast to rising numbers on the control site suggested that the two years of heavy predation on the study site exerted a sustained effect on pocket gopher activity.

The Effect of the Barn Owl Population on the Pocket Gopher Population

Our results showed a strong negative effect of barn owl boxes on pocket gopher mound counts (Figure 1). Pocket gopher mound counts rose each year in late spring (e.g., May), but this increase, which coincides with hatchling and nestling periods for barn owls, was far less pronounced on the vineyard with barn owl boxes than on the control vineyard in both 2012 and 2013. This pattern suggests that the greatest level of impact on the rodents occurred when chick dietary demands were at their peak. At the end of our study (June 2013), mound counts were holding relatively steady on the site with barn owl boxes, at fewer than four mounds per quadrant, a figure more than 70% lower than on the control site.

Caveats in Estimate of Numbers of Prey Harvested

Several caveats should be noted in assessing our estimates of the numbers of prey consumed. First, our nestling consumption figures represent the deliveries to only one nest, with three chicks, over 56 days. Although estimates of prey consumption exist, including based on captive bird consumption (Durant and Handrich 1998) and pellet analysis (Van Vuren et al. 1998), our data provide the first count of deliveries to developing barn owls in the wild. One study of European barn owls used infra-red sensors to record visits to barn owl nests; however the equipment utilized could not distinguish between visits with or without prey (Langford and Taylor 1992). Overall, there were no indications that the delivery of prey to the chicks was atypical. The bell curve of deliveries reported in other studies (Langford and Taylor 1992, Durant and Handrich 1998) was similar in our nestlings, no birds died, and each of the three fledged at around the 63 day period, suggesting a characteristic flow of prey (Pickwell 1948, Ricklefs 1968). However, it is important to note that our data more accurately apply to deliveries made in environments with similar prey abundance and make-up (i.e. a predominance of pocket gophers, with a secondary population of voles). If voles, which are smaller, were the primary prey, we suggest the numbers of prey taken would be greater. Future research should increase the sample of camera-monitored nests to confirm or refute if our estimates are representative.

Second, presence of adults at the study site was observed year-round, but estimates of their consumption of prey outside the breeding season were not included in our calculations. Pairing may have occurred much earlier than assigned since barn owls have been observed roosting at the breeding site as early as 60 or more days prior to egg laying (Marti 1992). Consumption by both adults and fledged young may be higher than the one daily prey item assigned, especially since the fledglings were consuming 1.67 rodents (approximately 1.18 pocket gophers and 0.44 voles based on pellet analysis) per night on average in their eighth week. Chicks that died in the nest prior to fledging (four in 2011 and seven in 2012) still consumed unknown numbers of prey before succumbing and were not included in our figures. Also, possible mortality of young after fledging, in the estimated 35 days prior to dispersal, was not taken into account. However, overall, by using conservative figures to determine length of breeding season and the number of prey taken daily by adults and fledglings, we believe our estimated number of prey taken remains a conservative estimate.

Third, we are assuming the captured rodents were removed from the study area (winegrape vineyard), which is supported by both our direct observations of owls hunting over the study site and the reduction in gopher mounds during the course of the study. However, future work should establish to what degree barn owls nesting in boxes erected on vineyards hunt and take prey from vineyards versus surrounding habitats.

Barn Owls as a Non-toxic Alternative for Rodent Control

Our analyses suggest the use of barn owl boxes can be an economically effective non-toxic way to control gophers in our study system. Costs per gopher removed were far less for barn owl boxes ($0.34 per gopher) than for spring traps ($8.11 per gopher). Removal costs per gopher for strychnine are currently unknown, but could be higher over time because it requires annual reapplication of the poison, whereas barn owl boxes require an initial investment but very little maintenance costs. We did not compare the costs of anticoagulant rodenticides (ARs) because they were not used in our system, but they are sometimes used in winegrape vineyards.

Common methods of rodent control on farms include anticoagulant rodenticides, strychnine, and fumigants, all of which have been shown to affect non-target wildlife. Anticoagulant rodenticides such as chlorophacinone and diphacinone, used to control pocket gophers, could pose a risk to nontarget species, although this risk is not well defined.

Although studies have shown that strychnine, when used properly, does not pose much risk to non-target wildlife (Hegdal and Gatz 1976, Arjo et al. 2006), the strychnine-related deaths of non-target predators of various species suggest that strychnine, as with many other poisons, still finds its way into the food chain (Proulx 2010).

Fumigants, such as aluminum phosphide, usually kill any inhabitants of the burrows in which they are used (Fagerstone 1997). Vaughn (1961) found 22 species of vertebrates inhabiting pocket gopher burrows in Colorado. In California, this includes such protected species as the tiger salamander (*Amystoma tigrinum*), San Francisco garter snake (*Thamnophis sirtalis tetrataenia*), and Alameda whip snake (*Masticophis lateralis euryxanthus*), as well as a host of other vertebrates and invertebrates.

Although the overall effect on non-target species is unknown, the successful harvest of a high number of rodent pests by the population of barn owls in this study suggest that the use of barn owls in adequate numbers can reduce or eliminate such risks to non-target species.

CONCLUSION

Barn owls' ability to be attracted in high numbers to an agricultural setting, their production of many young, and their adaptation to various species of prey lend this raptor to use in pest management programs. This study showed that a large population of barn owls can be established quickly in an area with ample number of prey. The estimated number of rodents harvested over the three breeding seasons (30,020) revealed the high level of predation that a dense barn owl colony can exact on a resident rodent population. Our study suggests that a high population of barn owls can be attracted to a site with ample prey, and it may be able to suppress the local gopher population. Once rodent numbers have declined, a lower population of barn owls may able to maintain a gopher population at lower sustained numbers.

Our figures of 165 rodents taken by each adult and 152 rodents taken by each fledgling during a breeding cycle provide farmers with useful numbers to gauge the numbers of prey taken by barn owl populations and the economic value of nest box programs in comparison to other methods. The cost comparison of $8.11 per gopher taken through trapping versus $0.34 per gopher taken by barn owls demonstrates high cost-effectiveness in utilizing barn owls for removal of rodent pests. Such programs have wide applicability, because the barn owl habit of preying on the most prevalent rodent species in any given environment allows them to be used in a wide variety of crops. This approach carries the added benefit of reducing if not eliminating other methods commonly used to control pocket gophers, such as anticoagulants, strychnine, and fumigants, all of which can affect non-target species.

ACKNOWLEDGEMENTS

Thanks to numerous students from the University of California, Davis, and Cosumnes River College who conducted field surveys, Vino Farms who agreed to have the study conducted on their property, Pacific Gas and Electric for their donation of nest boxes and poles, the Lodi Winegrape Commission for their grant to purchase two camera systems, Roger Baldwin from the University of California for advice on rodent census design, and Chris Storm of Vino Farms for organizational and advisory support.

LITERATURE CITED

Arjo, W. M., K. K. Wagner, D. L. Nolte, R. S. Stahl, and J. J. Johnston. 2006. Potential non-target risks from strychnine-containing rodent carcasses. Crop Protect. 25:182-187.

Baumgartner, A. M., and F. M. Baumgartner. 1944. Hawks and owls in Oklahoma 1939-1942: food habits and population changes. Wilson Bull. 56:209-215.

Browning, M. 2008. The barn owl box pole model. Website. Barn Owl Box Company, Pittsburgh, PA. http://www.barnowlbox.com.

Bunn, D. S., A. B. Warburton, and R. D. S. Wilson. 1982. The Barn Owl. Buteo Books, Vermilion, SD. 264 pp.

Colvin, B. A., and E. B. McLean. 1986. Food habits and prey specificity of the common barn owl in Ohio. Ohio J. Sci. 86:76-80.

Dixon, J. F., and R. M. Bond. 1937. Raptorial birds in the cliff areas of Lava Beds National Monument, California. Condor 39:97-102.

Durant, J. M., and Y. Handrich. 1998. Growth and food requirement flexibility in captive chicks of the European barn owl (*Tyto alba*). J. Zoology Lond. 245:137-145.

Engeman, R. M., D. L. Campbell, and J. Evans. 1993. Comparison of two activity measures for northern pocket gophers. Wildl. Soc. Bull. 21:70-73.

Fagerstone, K. A. 1997. Overview of controls: why they work and how they function: toxicants. Pp. 17-24 *in*: D. L. Nolte and K. K. Wagner (Eds.), Wildlife Damage Management for Natural Resource Managers, Oct. 1-2, 1996, Olympia, WA. Western Forestry and Conservation Association, Portland, OR.

Greek, R. 1998. Controlling pocket gophers for the home gardener. Dept. of Agriculture/Weights and Measures, San Luis Obispo County, San Luis Obispo, CA. 4 pp.

Hafidzi, M. N., and M. L. Jamaluddin. 2003. Ranging behavior of *Tyto alba* in rice fields from radio telemetry studies. J. Malaysian Appl. Biol. 32(1):47-51.

Hafidzi, M. N., A. Zulkifli, and A. A. Kamarudin. 1999. Barn owls as a biological control agent of rats in paddy fields. Biological control in the tropics: towards efficient biodiversity and bioresource management for effective biological control. Pp. 85-88 *in*: Proc., Symposium on Biological Control in the Tropics. MARDI Training Centre, Serdang, Malaysia.

Hegdal, P. L., and A. Gatz. 1976. Hazards to wildlife associated with underground strychnine baiting for pocket gophers. Proc. Vertebr. Pest Conf. 7:258-266.

IBM. 2015. IBM SPSS Statistics for Windows, v23.0. IBM Corp., Armonk, NY.

Jameson, E. W., and H. J. Peeters. 1988. California Mammals. Univ. of California Press, Berkeley, CA. 403 pp.

Jemison, E. S., and R. H. Chabrek. 1962. Winter barn owl foods in a Louisiana coastal marsh. Wilson Bull. 74:95-96.

Kaus, D. 1977. Zur populationsdynamik, okologie, und Brutbiologie der Schleiereule in Franken. Anzeiger der Ornithololigischen Gellsellschaft in Bayern 16:18-44.

Kuhne, M. 2014. California drought 'emaciates' hawks and owls, forces a lost generation. Website. Accuweather Inc.

http://www.accuweather.com/en/weather-news/california-drought-emaciates-r/28057557.

Langford, I. K., and I. R. Taylor. 1992. Rates of prey delivery to the nest and chick growth patterns of barn owls *Tyto alba*. Pp. 100-103 *in*: C. A. Galbraith, I. R. Taylor, and S. M. Percival (Eds.), The Ecology and Conservation of European Owls. Joint Nature Conservation Committee, Peterborough, UK.

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

Littrell, E. E. 1990. Effects of field vertebrate control on nontarget wildlife. Proc. Vertebr. Pest Conf. 14:59-61.

Looman, S. J., D. L. Shirley, and C. M. White. 1996. Productivity, food habits, and associated variables of barn owls utilizing nest boxes in north central Utah. Gt. Basin Nat. 56(1):73-84.

Marti, C. D. 1988. A long term study of food-niche dynamics in the common barn owl: comparisons within and between populations. Can. J. Zool. 66:1803-1812.

Marti, C. D. 1992. The Barn Owl. *In*: A. Poole (Ed.), The Birds of North America Online database. Cornell Laboratory of Ornithology, Ithaca, NY. http://bna.birds.cornell.edu/

Martin, J. M. 2009. Are barn owls biological controllers of rodents in the Everglades agricultural area? M.S.thesis., Univ. of Florida, Gainesville, FL. 77 pp.

McGourty, G. T., J. Ohmart, and D. Chaney. 2011. Organic Winegrowing Manual. UC-ANR Publ. 3511, University of California, Oakland, CA. 192 pp.

Meyrom, K.Y., Y. Motro, Y. Leshem, S. Aviel, I. Izhaki, F. Argyle, and M. Charter. 2009. Nest-box use by the barn owl *Tyto alba* in a biological pest control program in the Beit She'an valley, Israel. Ardea 97(4):463-467.

Moore, T. D., D. Van Vuren, and C. Ingels. 1998. Are barn owls a biological control for gophers? Evaluating effectiveness in vineyards and orchards. Proc. Vertebr. Pest Conf. 18:394-396.

Motro, Y. 2011. Economic evaluation of biological rodent control using barn owls *Tyto alba* in alfalfa. Pp. 79-80 *in*: 8th European Vertebr. Pest Manage. Conf., Julius-Kuhn Archiv. 432, 2011. doi: 10.5073/jka.2011.432.040

Pickwell, G. 1948. Barn owl growth and behaviorisms. Auk 65:329-373.

Proulx, G. 2010. Field evidence of non-target and secondary poisoning by strychnine and chlorophacinone used to control Richardson's ground squirrels in southwest Saskatchewan. Pp.128-134 *in*: Proc. 9th Prairie Conservation and Endangered Species Conf., February 2010, Winnipeg, Manitoba, Canada.

Reese, J. G. 1972. A Chesapeake barn owl population. Auk 89:106-114.

Ricklefs, R. E. 1968. Patterns of growth in birds. Ibis 110(4):419-451.

Roberts, J. 2009. A pest management strategic plan for winegrape production in California. California Winegrape Work Group. 95 pp. http://www.ipmcenters.org/pmsp/pdf/cawinegrapes.pdf

Salmon, T. P., R. E. Marsh, and T. J. Bettiga. 2013. Vertebates. Pp. 473-496 *in*: L. J. Bettiga, (Tech. Ed.), Grape Pest Management, 3rd Ed. UC-ANR Publ. 3343, Univ. of California, Oakland, CA.

Salter, R. 1991. Aggregations of barn owls in abandoned desert mines. American Birds 45:56-57.

Schönfeld, M., and G. Girbig. 1975. Beiträge zur Brutbiologie der Schleiereule, *Tyto alba*, besonders unter Berucksichtgung der Feldmausdichte. Hereynia 12:257-319.

Seel, D. C., A. G. Thomson, and J. C. E. Turner. 1983. Distribution and breeding of the barn owl *Tyto alba* on Anglesey, North Wales. Bangor Occasional Paper No.16, Institute of Terrestrial Ecology, Bangor University, Bangor, Gwynedd, UK.

Smal, C. M. 1988. Barn owls *Tyto alba* for the control of rats in agricultural crops in the tropics. Pp. 255-276 *in*: S. B. P. Sosromarsono, R. C. Gabriel, S. S. Titrojosomo, and M. Thohari (Eds.), Biological Control of Pests in Tropical Agricultural Ecosystems. Special Publ. 36, SEAMEO-BIOTROP, Bogor, Indonesia.

Smith, D. G., C. R. Wilson, and H. H. Frost. 1974. History and ecology of a colony of barn owls in Utah. Condor. 76:131-136.

Taylor, I. 1994. Barn Owls: Predator-Prey Relationships and Conservation. Cambridge Univ. Press, Cambridge, UK. 304 pp.

Taylor, I. R., A. Dowell, T. Irving, I. K. Langford, and G. Shaw. 1988. The distribution and abundance of the barn owl *Tyto alba* in southwest Scotland. Scottish Birds 15:40-43.

Van Vuren, D., T. G. Moore, and C. A. Ingels. 1998. Prey selection by barn owls using artificial nest boxes. Calif. Fish Game 84(3):127-132.

Vaughan, T. A. 1961. Vertebrates inhabiting pocket gopher burrows in Colorado. J. Mammal. 42(2):171-174.

Vaughan, T. A. 1967. Two parapatric species of pocket gophers. Evolution 21(1):148-158.

Verts, B. J., and L. N. Carraway. 1998. Land Mammals of Oregon. Univ. of California Press, Berkeley, CA. 800 pp.