

# UC Agriculture & Natural Resources

## Proceedings of the Vertebrate Pest Conference

### Title

Effects of American Kestrel Nest Boxes on Small Mammal Prey in Cherry Orchards

### Permalink

<https://escholarship.org/uc/item/29n67629>

### Journal

Proceedings of the Vertebrate Pest Conference, 28(28)

### ISSN

0507-6773

### Authors

Shave, Megan  
Lundrigan, Barbara  
Lindell, Catherine

### Publication Date

2018

### DOI

10.5070/V42811041

# Effects of American Kestrel Nest Boxes on Small Mammal Prey in Cherry Orchards

Megan Shave, Barbara Lundrigan, and Catherine Lindell

Integrative Biology Department, Michigan State University, East Lansing, Michigan

**ABSTRACT:** In order to potentially reduce use of environmentally damaging rodenticides, integrated Pest Management (IPM) for rodents, or Ecologically Based Rodent Management (EBRM), proposes a more sustainable management approach using strategies informed by an increased understanding of rodent population and community ecology, including interactions with important predators, such as raptors. Nest boxes and perches can encourage raptor presence in agricultural areas and potentially enhance the regulatory ecosystem services provided by raptor predation of agricultural pests. To assess this idea, we studied American kestrels (widespread, generalist predators that readily use nest boxes) in a fruit-growing region of northwestern Michigan. The most common mammal prey in the diets of these kestrels from 2013 through 2016 were voles, which are considered the most important rodent pests in temperate fruit orchards. We utilized live trapping to measure small mammal abundances and activity during the summer at sites with and without active kestrel nest boxes; furthermore, we utilized camera trapping to measure small mammal presence during the winter, when damage to trees is most likely. As predicted, small mammal abundance and activity was lower at orchards with active kestrel boxes and at orchards that had been more recently mowed; however, these differences did not carry over as differences in winter presence in orchards. Our sampling demonstrated that voles were absent from orchards during both summer and winter, which suggests that orchards offer insufficient cover except under certain conditions, such as sustained snow cover. Instead, mice were the most abundant small mammals in most orchards during the summer and were also present during the winter. More evidence is therefore needed to determine the extent of orchard damage attributable to *Peromyscus* spp. and whether indirect effects of kestrels on *Peromyscus* spp. may reduce damage. We provide recommendations for future research on the effects of raptor predation in orchards.

**KEY WORDS:** American kestrel, biological control, *Falco sparverius*, integrated pest management, meadow vole, *Microtus pennsylvanicus*, nest box, orchard, *Peromyscus*, predator, rodent

Proc. 28<sup>th</sup> Vertebr. Pest Conf. (D. M. Woods, Ed.)  
Published at Univ. of Calif., Davis. 2018. Pp. 224-230.

## INTRODUCTION

Small mammals, particularly rodents, are worldwide agricultural pests with widespread distributions and high adaptive and reproductive potentials (Leirs 2003). Anticoagulant and zinc phosphide rodenticides are commonly used as effective rodent control agents (Stone et al. 1999, Proudfoot 2009); however, these chemicals can cause secondary poisoning of predators (e.g. Brakes and Smith 2005, Hughes et al. 2013) and pollute soil and ground-water (Arias-Estevés et al. 2008). Integrated Pest Management (IPM) for rodents and Ecologically Based Rodent Management (EBRM; Singleton et al. 1999) propose a more environmentally sustainable rodent pest control approach using strategies informed by an increased understanding of rodent population and community ecology, including interactions with important predators, such as raptors.

Previous research has investigated the use of artificial perches and nest boxes to attract raptors to agricultural areas and encourage predation on rodents. The majority of studies have focused on the barn owl (*Tyto alba*), a specialist predator that uses nest boxes (Labuschagne et al. 2016). However, generalist predators may also be important rodent predators; generalists can show a functional response to peak densities of rodents with cyclical population dynamics such as voles by increasing the proportion of rodents in their diet, and thus may stabilize and dampen rodent population cycles (Andersson

and Erlinge 1977, Korpimäki and Krebs 1996). Perches can increase hunting activity of a variety of raptor species, which reduces growth of rodent populations and limits maximum rodent densities (e.g. Kay et al. 1994, Sheffield et al. 2001). Thus, encouraging raptor presence in agricultural areas can enhance the regulatory ecosystem services provided by predation on agricultural pests.

American kestrels (*Falco sparverius*; hereafter “kestrel”) are widespread generalist raptors that include a variety of small mammal species in their diet. In the fruit-growing region of northwestern Michigan, mammals were the second most common prey type in the diet of nestling kestrels, comprising 13% of 7,778 deliveries made over a total of 179 days to nestlings by breeding kestrels using 15 cherry orchard nest boxes (Shave 2017). Voles, particularly *Microtus pennsylvanicus* in northern North America, are the most important rodent pests in temperate fruit orchards (Wood and Singleton 2015). Voles can damage and even kill young trees by girdling the bark and roots (Tritten 2014, Wood and Singleton 2015). *M. pennsylvanicus* was the most common mammal prey of kestrels using the orchard nest boxes (57% of mammal deliveries; Shave 2017). Kestrels may be able to reduce peak vole abundances, which would benefit orchards if vole densities are kept below the threshold for tree damage (Tritten 2014).

A previous study of kestrel nest boxes in apple orchards did not find a significant effect of boxes on rodent activity (Askham 1990); however, the nest box occupancy rates in that study were much lower than those observed in northwestern Michigan (Shave and Lindell 2017). Our objective was therefore to investigate the effects of active kestrel nest boxes on small mammals, especially voles, in cherry orchards. We utilized live-trapping to measure small mammal abundances and activity during the summer at sites with and without active kestrel nest boxes. We predicted that small mammal abundance and activity would be lower in orchards with active kestrel boxes and in orchards that had been recently mowed because mowing exposes small mammals to greater predation risk (Tritten 2013), and hunting kestrels will cue in on recently mowed or plowed areas (Rudolph 1982, Toland 1987).

We used camera trapping to measure small mammal presence during the winter, when damage to trees is most likely. Although the kestrels in our study region are migratory and not present during the winter (Brewer et al. 1991), we predicted that the probabilities of small mammal presence would be lower at trapping sites in orchards that had active kestrel boxes during the summer because kestrel predation, combined with rodenticide application, would reduce small mammal populations below the threshold for winter presence in the orchard. We also predicted that winter trapping sites in orchards with perches would have lower probabilities of small mammal presence because breeding kestrels and their offspring used the perches in young orchards (Shave 2017) which should facilitate hunting (Sheffield et al. 2001), potentially further reducing small mammal density. Additionally, we predicted higher small mammal presence at orchard edges because small mammals from adjacent woodlots, drainage ditches, and other agricultural fields may move into orchards after exhausting available resources (e.g. residual crop in corn and soybean fields; Irish-Brown 2016). Finally, we predicted that small mammal presence would be more likely in orchards with snow because small mammals, particularly voles, use snow cover as protection from predators (Hansson and Hettonen 1985, Tritten 2014).

## METHODS

### Summer Surveys of Small Mammal Abundance and Activity

#### *Live Trapping in Orchards*

We conducted small mammal live trapping in cherry orchards between late June and early Aug during the 2014 kestrel breeding season in Leelanau County, MI (45.0751°N–44.8365°N, 85.5032°W–85.7758°W). Orchards consisted of blocks of sweet and/or tart cherries of varying ages. Rodent management in these orchards included mowing the grass lanes between the tree rows during summer and applying rodenticides to young (three years old or younger) blocks in the fall. We trapped in six orchards with an active kestrel box and three orchards that were at least 800 m from the nearest active kestrel box. At orchards with active kestrel boxes, we trapped in the block closest to the nest box. We considered orchards 800 m from the nearest active box to have significantly less

exposure to hunting kestrels based on the average kestrel territory diameter of 500 m (Rohrbaugh and Yahner 1997). At each orchard site, we set up a grid of 100 small mammal traps (2 × 2.5 × 9" aluminum Sherman traps) arranged across five orchard rows with 20 traps per row (with the exception of one 10 by 10 trap arrangement due to orchard shape). We spaced traps approximately 12 m apart in the orchard rows, and faced the trap openings towards the grass lanes in between rows. We baited traps with rolled oats (Barnett and Dutton 1995). We opened traps at 21:00 EST at each orchard and then checked traps three times per day (06:00–07:00, 14:00–15:00, and 21:00) for three days. We identified each captured small mammal to species, weighed it, and measured tail length when possible; for *Peromyscus* spp., we also measured ear length to help distinguish between *P. maniculatus bairdii* and *P. leucopus* (Jones and Birney 1988). In order to identify mammals as new versus recaptured individuals, we cut away a small patch of the outer coat to expose the contrasting color of the underfur (Barnett and Dutton 1995). We released all small mammals following processing.

#### *Vegetative Cover in Orchards*

To estimate vegetative cover in orchards, we measured vegetation height in the lanes between rows, sampling four lanes within the trapping grid at each orchard. We used the step-point method of vegetation sampling in which we started at a random point within a lane and measured the height of vegetation touching a flag stake stuck into the ground every 10 steps (Evans and Love 1957). We collected 25 measurements per lane and calculated the mean vegetation height for each orchard. We found that mean heights were either <100 mm or >150 mm. We therefore created two vegetation height categories: recently mowed (mean height <100 mm) or not recently mowed (mean height >150 mm).

#### *Statistical Analysis*

Because our trapping protocol was consistent across orchards, we used the number of new small mammal captures as an index of relative abundance (Hopkins and Kennedy 2004). Similarly, we also used total number of small mammal captures as an index of relative activity. We built Poisson regression models to explain the variation in small mammal abundance and activity between orchards. We included the following variables as fixed effects: whether the orchard had an active kestrel box (box) and whether the grass lanes in the orchard had been recently mowed (mow). We ranked models using Akaike's Information Criterion (Akaike 1974) corrected for small sample size (AICc; Hurvich and Tsai 1989, Zuur et al. 2009). We built all models using package "lme4" in program R (3.1.0). We calculated model-averaged parameter estimates based on the 95% confidence set of models (Buckland et al. 1997).

#### *Winter Surveys of Small Mammal Presence Camera Trapping in Orchards*

We surveyed small mammal presence in orchards during winter using camera traps. Camera trap surveys allow for species identification without the added monitoring effort and trap myopathy risk associated with

traditional live trapping methods (McCleery et al. 2014). We therefore considered camera trapping the appropriate choice for surveying small mammals during winter fieldwork, when time constraints made regular trap checks unfeasible. Camera trap stations consisted of a modified Hunt trap, designed to prevent disturbance by larger non-target animals (McCleery et al. 2014), containing a weatherproof security camera connected to a portable video recording system (Shave and Lindell 2017). We baited camera traps with peanut butter and oats.

We conducted surveys between Nov 2015 and Mar 2016, following fall rodenticide application, in nine orchards with blocks of trees that were three years old or younger: three orchards had active kestrel boxes during the summer, three orchards had active boxes and 5.5 m-tall supplemental perches (Hall et al. 1981) installed during the summer of 2015, and three orchards had no active box within 1.63 km and no supplemental perches. Five of these orchards were included in the summer of 2014 surveys. We conducted surveys in one or two blocks per orchard. In orchards with more than two young blocks, we conducted surveys in two randomly chosen blocks. We set up three camera trap stations in each block: one in a randomly chosen spot in an interior tree row, and two in randomly chosen edge rows that had continuous non-orchard edge habitat. Each camera trap station served as a trapping site ( $n = 51$ ). We placed the camera traps in the orchard rows, and during surveys with snow on the

ground, we dug out spaces for the traps so that the entrances opened into the subnivean space. We left the camera traps at each site for 24 h. We conducted one to three surveys per trapping site over three survey rounds (Nov, Dec, Mar surveys).

### Occupancy Modeling

We recorded small mammal presence or absence during 15 min intervals (events) within the 24 h surveys (Rendall et al. 2014). We then built a dynamic occupancy model of small mammal presence under a Bayesian framework (Kéry and Schaub 2012). Small mammal populations in seasonal northern environments experience population declines during the winter (Fairbairn 1978, Hansen et al. 1999); furthermore, summer territories break down as dispersal occurs in the fall (Fairbairn 1978), so we considered populations open between surveys.

We modeled trapping site occupancy ( $\psi_{i,t}$ ), colonization ( $\gamma_{i,t}$ ), and persistence ( $\phi_{i,t}$ ) probabilities as follows:

$$\text{logit}(\psi_{i,t}) = \alpha_0 + \alpha_1(\text{box}_{i,t}) + \alpha_2(\text{perch}_{i,t}) + \alpha_3(\text{edge}_{i,t}) + \alpha_4(\text{snow}_{i,t})$$

$$\text{logit}(\gamma_{i,t}) = \alpha_5 + \alpha_6(\text{box}_{i,t}) + \alpha_7(\text{perch}_{i,t}) + \alpha_8(\text{edge}_{i,t}) + \alpha_9(\text{snow}_{i,t})$$

$$\text{logit}(\phi_{i,t}) = \alpha_{10} + \alpha_{11}(\text{box}_{i,t}) + \alpha_{12}(\text{perch}_{i,t}) + \alpha_{13}(\text{edge}_{i,t}) + \alpha_{14}(\text{snow}_{i,t})$$

where  $\alpha_{1-4,6-9,11-14}$  represented the logit-linear coefficients for model covariates (Saracco et al. 2011): whether the

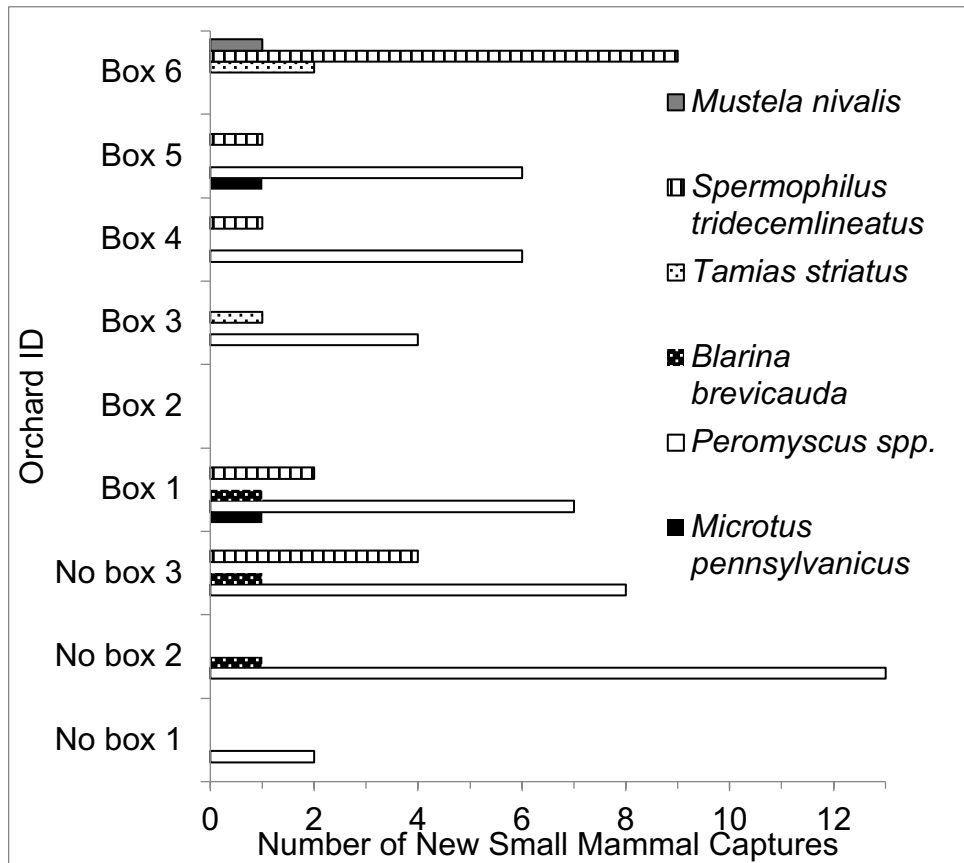


Figure 1. Number of new small mammal captures in each orchard by species during the summer of 2014. Orchards identified as either “Box” or “No box” based on presence of an active kestrel box. *Peromyscus* spp. includes *Peromyscus maniculatus (bairdii)* and *P. leucopus*.

**Table 1. Akaike's Information Criterion corrected for small sample size (AICc) table for Poisson models of summer small mammal abundance. Bold indicates the 95% confidence set of models used for parameter estimation via model averaging.**

Model	AICc	$\Delta$ AICc	Weight
<b>Mow</b>	<b>56.4</b>	<b>0.0</b>	<b>0.681</b>
<b>Box + Mow</b>	<b>58.7</b>	<b>2.4</b>	<b>0.209</b>
<b>Intercept only</b>	<b>60.9</b>	<b>4.6</b>	<b>0.0688</b>
Box	62.1	5.8	0.0381
Box * Mow	67.7	11.4	0.0023

trapping site  $i$  was in an orchard with an active kestrel box during the summer (*box*), whether the trapping site  $i$  was in an orchard with perches (*perch*), whether the trapping site  $i$  was at an orchard edge (*edge*), and whether the trapping site  $i$  was in an orchard with > 10 cm of snow cover on the ground during survey  $t$  (*snow*).

We modeled the detection probability,  $p_{i,k,t}$ , as follows:

$$\text{logit}(p_{i,k,t}) = \beta_0 + \beta_1(\text{night}_{i,k,t}) + \beta_2(\text{lag}_{i,k,t})$$

where  $\beta_{1,2}$  represented the logit-linear coefficients for model covariates: whether event  $k$  at site  $i$  occurred during daylight hours or night (*night*), and whether we detected a small mammal at trapping site  $i$  during the previous event (*lag*). We predicted that detection probabilities would be higher at night due to the nocturnal behavior of most small mammal species (Jones and Birney 1988). We included the *lag* variable to account for the potential spatial dependence between consecutive events within a 24-h survey.

We estimated model parameters using Markov Chain Monte Carlo (MCMC) methods. For each model, we used uninformative priors and ran two chains for 30,000 iterations, discarding the first 20,000 runs as burn-in and thinning by two. We ran all models using package "R2jags" in Program R (3.3.1). We assessed convergence by visually inspecting model trace plots and confirming that values for the potential scale reduction factor were <1.1 for all model parameters (Gelman et al. 2003). We identified a covariate effect as important if the 95% credible interval (CRI) for the posterior mean of the parameter coefficient did not overlap zero (Kéry and Schaub 2012). We also generated estimates for two derived parameters: the estimated number of occupied sites during each round of surveys and the occupancy-based population growth rate  $\lambda$  between survey rounds (Kéry and Schaub 2012).

## RESULTS

### Summer Surveys of Small Mammal Abundance and Activity

We had a total of 122 small mammal captures, including 52 new captures (Figure 1). The captures represented six genera, including one capture of the mustelid *M. nivalis*. Hereafter, we group *P. maniculatus bairdii* and *P. leucopus* as *Peromyscus* spp. because the species identity of some captures was ambiguous based on tail and ear length. We also removed the Box 6 orchard from our statistical analyses because we expected the presence of *M.*

*nivalis*, a specialist predator of rodents, to potentially confound the effect of kestrel predation on small mammals.

According to the model-averaged parameter estimates based on the 95% confidence set of models for small mammal abundance ( $\beta_0 = 1.60$ ; Table 1), new small mammal captures were greater in orchards without active kestrel boxes than in those with boxes ( $\beta_1 = 0.10$ ), and new small mammal captures were greater in orchards that had not been recently mowed than in those recently mowed ( $\beta_2 = 0.69$ ; Figure 2).

According to the model-averaged parameter estimates based on the 95% confidence set of models for small mammal activity ( $\beta_0 = 1.90$ ; Table 2), total small mammal captures were greater in orchards without active kestrel boxes than in those with boxes ( $\beta_1 = 0.36$ ), and total small mammal captures were greater in orchards that had not been recently mowed than in those recently mowed ( $\beta_2 = 0.66$ ; Figure 3).

### Winter Surveys of Small Mammal Presence

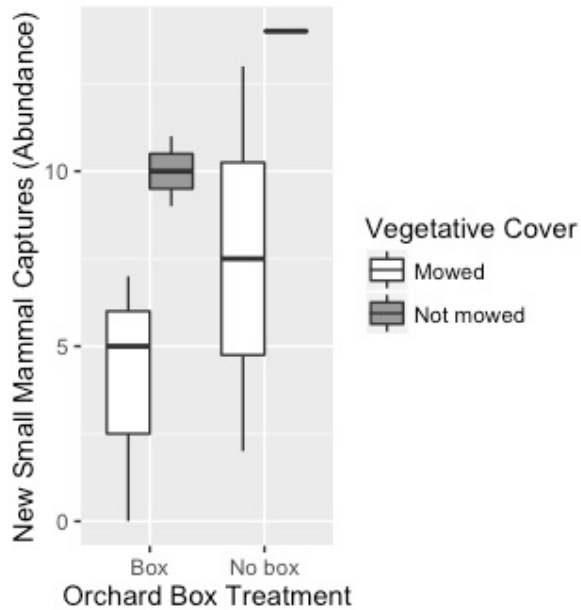
We detected small mammals at 17 of the 51 trapping sites and during 19 of 135 surveys across all trapping sites during the three trapping rounds. We identified all detections as *Peromyscus* spp. based on relative tail, ear, and eye sizes; we hereafter refer to the occupancy model as a model of *Peromyscus* spp. presence (Table 3). *Edge* had an important positive effect on the colonization probability; *Peromyscus* spp. were more likely to colonize trapping sites in edge rows. *Night* and *lag* had a positive effect on detections: we were more likely to detect a mouse during an event at night and if we had detected a mouse during the preceding event. The estimated number of occupied sites decreased between the Nov and Mar survey rounds; furthermore, the occupancy-based population growth rates were less than 1.0, which indicates that *Peromyscus* spp. presence decreased as the winter progressed.

## DISCUSSION

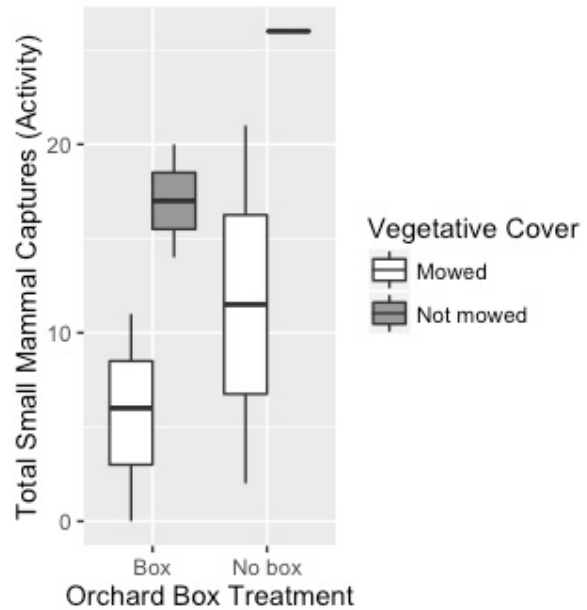
As predicted, summer small mammal abundance and activity was lower in orchards with active kestrel boxes and in orchards that had been more recently mowed. These results suggest that kestrel boxes enhance the regulatory ecosystem services provided by kestrel predation and should therefore be further considered as a potential tool for biological control of orchard-damaging rodents. Our

**Table 2. Akaike's Information Criterion corrected for small sample size (AICc) table for Poisson models of summer small mammal activity. Bold indicates the 95% confidence set of models used for parameter estimation via model averaging.**

Model	AICc	$\Delta$ AICc	Weight
<b>Box + Mow</b>	<b>77.0</b>	<b>0.0</b>	<b>0.672</b>
<b>Mow</b>	<b>78.4</b>	<b>1.5</b>	<b>0.320</b>
Box * Mow	85.8	8.9	0.008
Box	93.7	16.7	<0.001
Intercept only	95.4	18.5	<0.001



**Figure 2. New small mammal captures (abundance) in recently and not recently mowed orchards with and without active kestrel boxes. Boxplots show medians and interquartile ranges (IQRs); boxplot whiskers extend 1.5 IQRs.**



**Figure 3. Total small mammal captures (activity) in recently and not recently mowed orchards with and without active kestrel boxes. Boxplots show medians and interquartile ranges (IQRs); boxplot whiskers extend 1.5 IQRs.**

results also indicate that mowing the lanes between orchard rows is effective for rodent reduction.

However, differences between orchards in summer rodent abundance and activity did not translate into differences in winter presence in orchards. One explanation is that rodenticides reduced small mammal populations to low enough levels that any additional effects of kestrel predation could not be detected by our survey method.

Another unexpected result was the detection of voles on only two occasions total during summer and winter small mammal surveys. We expected to capture voles regularly because they were the most common small mammal prey in the kestrel diet (Shave 2017), and they are the most well-documented rodent pest in orchards (Wood and Singleton 2015). One explanation for our results is that voles are typically absent from orchards during the summer because of the general lack of sufficient ground cover and are only present in the winter during periods of sustained snow cover. We were unable to adequately investigate the latter relationship because of the lack of sustained snow cover during the winter of 2015-2016: snow cover >10 cm was only present in two orchards during one survey visit, and that cover was likely not present long enough prior to our surveys for voles to have moved into those orchards. Furthermore, a lack of sufficient snow fall during the winter of 2016-2017 again prevented us from investigating the effect of snow cover on vole presence.

Unlike voles, *Peromyscus* spp. mice were present in the orchards during the summer and winter, which suggests that their requirements for cover are lower. Thus, *Peromyscus* spp. are apparently less deterred by removal of ground cover in orchards or by years of limited snow

fall. *Peromyscus* spp. damage in orchards may therefore be more difficult to control than vole damage. Our occupancy model of winter presence further indicates that *Peromyscus* spp. are more likely to move into edge rows, which supports the conclusion that orchard edges may be particularly vulnerable to damage (Tritten 2013). The question remains of whether *Peromyscus* spp. are as important an orchard pest as voles. Many farmers refer to “mice and voles” when discussing orchard damage (e.g., Tritten 2013, 2014; Irish-Brown 2016), but there is little evidence in the literature that *Peromyscus* spp. in particular are responsible for the same tree girdling damage usually attributed to voles (Irish-Brown 2016). *Peromyscus* spp. are associated with consumption of seeds and newly-emerged seedlings in agricultural fields and forest regeneration sites (Witmer and Moulton 2012). Research has also identified *Peromyscus* spp. as a “lesser known” consumer of crop in almond orchards (Pearson et al. 2000), which raises the question of whether *Peromyscus* spp. may damage cherries and other tree fruit. *Peromyscus leucopus* in particular readily climb trees (Kaufman et al. 1985); we observed a few individuals climbing cherry trees upon release during the summer live-trapping surveys. Thus, more evidence is needed to determine the extent of damage attributable to *Peromyscus* spp. in orchards.

Overall, our results prompt us to propose three recommendations for future research on the effects of raptor predation in orchards. First, we recommend utilizing a consistent surveying protocol across seasons if possible in order to facilitate seasonal comparisons and detect potential carry-over effects of predation by migratory predators. Next, we suggest conducting surveys in or-

**Table 3. Posterior summaries for parameter coefficients and derived parameters from the model of *Peromyscus* spp. presence at a trapping site (n = 51) in orchards in winter. Important covariate effects are indicated in bold (95% CRI does not overlap zero; Kéry and Schaub 2012).**

Parameter		Mean	SD	95% CRI	
				2.5%	97.5%
$\psi$ (first survey occupancy)	$\alpha_0$ (intercept)	-2.12	1.71	-4.64	1.46
	$\alpha_1$ ( <i>box</i> )	0.01	0.49	-0.96	0.95
	$\alpha_2$ ( <i>perch</i> )	0.18	0.46	-0.71	1.11
	$\alpha_3$ ( <i>edge</i> )	-0.19	0.38	-0.93	0.56
	$\alpha_4$ ( <i>snow</i> )	-2.31	5.37	-9.68	8.98
$\gamma$ (colonization)	$\alpha_5$ (intercept)	-7.76	1.61	-9.91	-4.17
	$\alpha_6$ ( <i>box</i> )	-3.00	2.32	-7.84	0.64
	$\alpha_7$ ( <i>perch</i> )	4.31	2.23	-0.93	9.01
	<b><math>\alpha_8</math> (<i>edge</i>)</b>	<b>4.12</b>	<b>2.27</b>	<b>0.57</b>	<b>5.74</b>
	$\alpha_9$ ( <i>snow</i> )	-2.48	2.80	-9.19	0.25
$\phi$ (persistence)	$\alpha_{10}$ (intercept)	-6.42	2.38	-9.83	-1.13
	$\alpha_{11}$ ( <i>box</i> )	0.58	4.49	-7.53	9.12
	$\alpha_{12}$ ( <i>perch</i> )	4.25	2.70	-0.11	9.51
	$\alpha_{13}$ ( <i>edge</i> )	-0.21	0.98	-2.10	1.72
	$\alpha_{14}$ ( <i>snow</i> )	3.29	4.75	-8.16	9.68
$\rho$ (detection)	$\beta_0$ (intercept)	-7.47	1.43	-9.85	-4.17
	<b><math>\beta_1</math> (<i>night</i>)</b>	<b>5.37</b>	<b>1.61</b>	<b>2.32</b>	<b>8.05</b>
	<b><math>\beta_2</math> (<i>lag</i>)</b>	<b>0.24</b>	<b>0.02</b>	<b>0.22</b>	<b>0.28</b>
Number of occupied sites	Nov survey round (1)	11.44	1.70	10	16
	Dec survey round (2)	6.61	0.59	6	8
	Mar survey round (3)	3.19	1.04	2	5
$\lambda$ (occupancy-based growth rate)	Survey 1 to 2	0.59	0.09	0.40	0.73
	Survey 2 to 3	0.48	0.16	0.29	0.83

chards without rodenticide use in order to detect effects of predation that were potentially masked in the present study by the reductions of small mammal populations following rodenticide application. Finally, we recommend combining small mammal surveys with fruit and tree damage assessments in order to identify which species are responsible for damage throughout the year and under different conditions (e.g., variation in snowfall).

#### LITERATURE CITED

- Andersson, M., and S. Erlinge. 1977. Influence of predation on rodent populations. *Oikos* 3:591-597.
- Arias-Estévez, M., E. López-Periago, E. Martínez-Carballo, J. Simal-Gándara, J. C. Mejuto, and L. García-Río. 2008. The mobility and degradation of pesticides in soils and the pollution of groundwater resources. *Agriculture, Ecosystems and Environment* 123:247-260.
- Askham, L. R. 1990. Effect of artificial perches and nests in attracting raptors to orchards. *Proceedings of the Vertebrate Pest Conference* 14:144-148.
- Brakes, C. R., and R. H. Smith. 2005. Exposure of non-target small mammals to rodenticides: short-term effects, recovery and implications for secondary poisoning. *Journal of Applied Ecology* 42:118-128.
- Brewer, T., G. A. McPeck, and R. J. Adams Jr. 1991. The atlas of breeding birds of Michigan. Michigan State University Press, East Lansing, MI.
- Buckland, S. T., K. P. Burnham, and N. H. Augustin. 1997. Model selection: an integral part of inference. *Biometrics* 53:603-618.
- Evans, R. A., and R. M. Love. 1957. The step-point method of sampling: a practical tool in range management. *Journal of Range Research* 10:208-212.
- Fairbairn, D. J. 1978. Dispersal of deer mice, *Peromyscus maniculatus*. *Oecologia* 32:171-193.
- Gelman, A., J. B. Carlin, H. S. Stern, and D. B. Rubin. 2003. Bayesian data analysis, second edition. Chapman & Hall, Boca Raton, FL.
- Hall, T. R., W. E. Howard, and R. E. Marsh. 1981. Raptor use of artificial perches. *Wildlife Society Bulletin* 9:296-298.
- Hansen, T. F., N. C. Stenseth, and H. Henttonen. 1999. Multi-annual vole cycles and population regulation during long

- winters: an analysis of seasonal density dependence. *American Naturalist* 154:129-139.
- Hansson, L., and H. Henttonen. 1985. Gradients in density variations of small rodents: the importance of latitude and snow cover. *Oecologia* 67:394-402.
- Hopkins, H. L., and M. L. Kennedy. 2004. An assessment of indices of relative and absolute abundance for monitoring populations of small mammals. *Wildlife Society Bulletin* 32:1289-1296.
- Hughes, J., E. Sharp, M. J. Taylor, L. Melton, and G. Hartley. 2013. Monitoring agricultural rodenticide use and secondary exposure of raptors in Scotland. *Ecotoxicology* 22:974-984.
- Irish-Brown, A. 2016. Rodent management in commercial apple orchards requires an integrated approach. Article, Michigan State University Extension website, published Oct. 21, 2016. Accessed 10 Mar 2017.
- Jones Jr., J. K., and E. C. Birney. 1988. *Handbook of mammals of the north-central states*. University of Minnesota Press, Minneapolis.
- Kaufman, D. W., M. E. Peak, and G. A. Kaufman. 1985. *Peromyscus leucopus* in riparian woodlands: use of trees and shrubs. *Journal of Mammalogy* 66:139-143.
- Kay, B. J., L. E. Twigg, T. J. Korn, and H. I. Nicol. 1994. The use of artificial perches to increase predation on house mice (*Mus domesticus*) by raptors. *Wildlife Research* 21:95-106.
- Kéry, M., and M. Schaub. 2012. Bayesian population analysis using WinBUGS. Elsevier, New York, NY.
- Korpimäki, E., and C. J. Krebs. 1996. Predation and population cycles of small mammals: a reassessment of the predation hypothesis. *Bioscience* 46:754-764.
- Labuschagne, L., L. H. Swanepoel, P. J. Taylor, S. R. Belmain, and M. Keith. 2016. Are avian predators effective biological control agents for rodent pest management in agricultural systems? *Biological Control* 101:94-102.
- Leirs, H. 2003. Management of rodents in crops: the pied piper and his orchestra. Pages 180-190 in G. Singleton, L. A. Hinds, C. J. Krebs, and D. M. Spratt, editors. *Rats, mice and people: rodent biology and management*. ACIAR Monograph No. 96. Australian Centre for International Agricultural Research, Canberra, ACT, Australia.
- McCleery, R. A., C. Zweig, M. A. Desa, R. Hunt, W. M. Kitchens, and H. F. Percival. 2014. A novel method for camera-trapping small mammals. *Wildlife Society Bulletin* 38:887-891.
- Pearson, A. B., W. P. Gorenzel, and T. P. Salmon. 2000. Lesser-known vertebrate pests of almonds in California. *Proceedings of the Vertebrate Pest Conference* 19:365-376.
- Proudfoot, A. T. 2009. Aluminum and zinc phosphide poisoning. *Clinical Toxicology* 47:89-100.
- Rendall, A. R., D. R. Sutherland, R. Cooke, and J. White. 2014. Camera trapping: a contemporary approach to monitoring invasive rodents in high conservation priority ecosystems. *PLoS ONE* 9:e86592.
- Rudolph, S. G. 1982. Foraging strategies of American kestrels during breeding. *Ecology* 63:1268-1276.
- Saracco, J. F., R. B. Siegel, and R. L. Wilkerson. 2011. Occupancy modeling of black-backed woodpeckers on burned Sierra Nevada forests. *Ecosphere* 2:art31.
- Shave, M. E. 2017. Evaluating the conservation and agricultural applications of orchard nest boxes for a declining raptor. Dissertation, Michigan State University, East Lansing, MI.
- Shave, M. E., and C. A. Lindell. 2017. American kestrels occupying cherry orchard nest boxes show high reproductive rates and tolerance of monitoring. *Journal of Raptor Research* 51:50-60.
- Sheffield, L. M., J. R. Crait, W. D. Edge, and G. Wang. 2001. Response of American kestrels and gray-tailed voles to vegetation height and supplemental perches. *Canadian Journal of Zoology* 79:380-385.
- Singleton, G. R., H. Leirs, L. A. Hinds, and Z. Zhang. 1999. Ecologically-based management of rodent pests: re-evaluating our approach to an old problem. Pages 17-30 in G. R. Singleton, H. Leirs, L. A. Hinds, and Z. Zhang, editors. *Ecologically-based management of rodent pests*. ACIAR Monograph No. 59. Australian Centre for International Agricultural Research, Canberra, ACT, Australia.
- Stone, W. B., J. C. Okoniewski, and J. R. Stedelin. 1999. Poisoning of wildlife with anticoagulant rodenticides in New York. *Journal of Wildlife Disease* 35:187-193.
- Toland, B. R. 1987. The effect of vegetative cover on foraging strategies, hunting success and nesting distribution of American kestrels in central Missouri. *Journal of Raptor Research* 21:14-20.
- Tritten, B. 2013. Fall mice and vole control is critical to reduce potential damage in orchards. Article, Michigan State University Extension website, published Nov. 27, 2013.
- Tritten, B. 2014. Mice and vole populations are building in many orchards. Article, Michigan State University Extension website, published Feb. 14, 2014.
- Witmer, G. W. and R. S. Moulton. 2012. Deer mice (*Peromyscus* spp.) biology, damage and management: a review. *Proceedings of the Vertebrate Pest Conference* 25:213-219.
- Wood, B. J., and G. R. Singleton. 2015. Rodents in agriculture and forestry. Pages 33-80 in A. Buckle and R. Smith, editors. *Rodent pests and their control*. CAB International, UK.